# Economy of Nature

A Genealogy of the Concepts 'Growth' and 'Equilibrium' as Artefacts of Metaphorical Exchange between the Natural and the Social Sciences

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Jeremy Walker

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## Abstract

Presently, the more or less global political consensus is that the primary task of government is to perpetually maximise a quantity called 'economic growth'. Given the decline of 'socialist' models of industrialisation, the economic consensus is that economic growth is best achieved through the deregulation of markets, industry and trade, as free markets are self-regulating institutions that automatically and efficiently optimise growth through their tendency to reach 'equilibrium.' Another word for this consensus might be 'neoliberalism'.

This cosy situation, however, is increasingly under challenge from the recent transformation of global warming from a deniable proposition to a clear and present danger. As ecologists and earth scientists have long argued, global warming (an unforeseen side effect of what was called the 'energy crisis' in the 1970s) is just one of many aspects of a generalised global ecological crisis. The biosphere, environmentalists tell us, is radically 'out of balance'. Given this impasse, it appears that the science of social systems (economics) and the science of living systems (ecology) are incommensurable.

This incommensurability is the starting point of the thesis, which seeks to provide a genealogy of the concepts of equilibrium and growth as they appear in the claims of both disciplines to represent 'hard' science. Drawing from debates in the philosophy of science, studies in the history of ideas, the anthropology of technology, and political economy, the thesis charts the mutual exchange of metaphors and analogies between the natural and the social sciences, and traces a surprisingly parallel trajectory in the separate histories of economics and ecology. Beginning with early historicist and organicist conceptual frameworks, both sciences embraced 'mechanism' in their bid to attain the mantle of Science.

For both sciences, the attainment of this status was associated with the incorporation of the language of energetics and an insistent identification of 'equilibrium' with the central scientific object of inquiry, 'the market' and 'the ecosystem' respectively. What is ironic in these claims is that the acceptance of the machine metaphor effectively screened out the study of actual machinery from the pure states of nature called 'the market' or 'the economy.' This history is taken up to the climactic moment of the early 1970s, when, it is argued, the ontological foundations of ecology and economics collided. This is the moment from which the political dIscourses of neoliberal globalisation and global environmental crisis both date, and since then we see the rise of hybrid discourses that attempt to address and overcome the deep contradictions of disciplinary specialisation.

The thesis concludes with a brief discussion of the implications of this conceptual legacy, and in analysing the interactions of the 'new ecology' and the 'new economy', offers suggestions as to why what appeared in 1971 as a fundamental and obvious contradiction between 'growth' and 'equilibrium', no longer attracts debate.

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It is to the angel Marlene that this thesis is dedicated, may your future be one of abundant life.

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## PART I: INTRODUCTION

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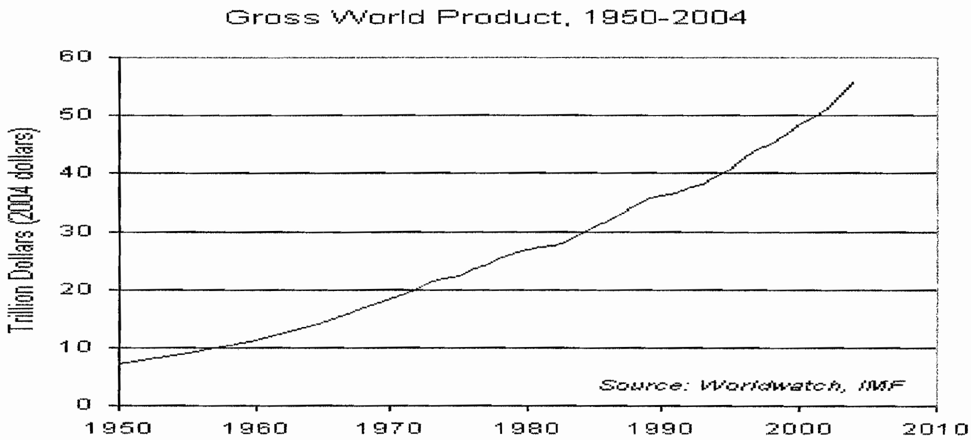


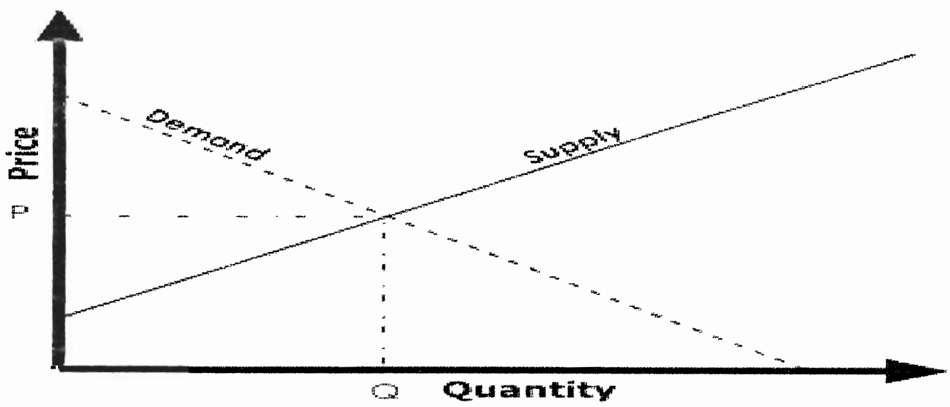


## Theoretical, Methodological and Historical Propositions

*The true rationalism must always transcend itself by recurrence to the concrete in search of inspiration. A self-satisfied rationalism is in effect a form of anti-rationalism. It means an arbitrary halt at a particular set of abstractions.*

- Alfred North Whitehead [1]

**Prologue**

Generally speaking, the politics of environmental concern are no longer novel or radical in the way they once were. 'The environment' is everywhere acknowledged as a normative domain. Where once radicals spoke of an apocalyptic global ecological crisis awaiting in the future, most now accept, to use the euphemistic phrase, that we live in a world already and irreversibly undergoing 'global environmental change'. Australian Prime Minister John Howard, a socially conservative liberal and a new right economic radical, has on a number of occasions insisted that "we are all environmentalists now", in one memorable instance upon defending his rejection of Australia's involvement in the Kyoto treaty on climate change, even after Australia's negotiators had achieved the right to increase carbon emissions.[2] If environmental concern is as universal as Howard claims, some versions of this concern are surely more genuine than others. Even if our immersion in environmental crisis is generally acknowledged, the degree of degradation, its causes, the effects of pollution, extinctions and resource depletion upon societies are hotly disputed. Knowing that a problem exists is very different from knowing what to do about it. If we are all environmentalists now, opinion on the nature of the relationship between global ecology and global economy remains radically differentiated.

In October 2003, US President George W. Bush addressed a joint sitting of Australia's Federal Parliament, in order to thank Howard for Australian support of a war which has since been systematically deprived of all its initial rationalisations. Breaking the general bipartisan consensus on the value of Australia's commitment to the economic and military objectives of the United States, Australian Green Senators Kerry Nettle and Bob Brown interrupted his speech, and were subsequently expelled from the chamber. Their later attempts to present the US president with a petition were dramatically obstructed by Liberal senators, who gallantly put their bodies on the line to defend Bush from this attack from dangerously zealous extremists. As I go to press on this thesis, an Australian government official has finally let slip what Iraqis and environmentalists have known all along, that we need to continue the war to secure access to Iraq's underdeveloped oil reserves, perhaps the last great energy prize ever.

George W. Bush has argued that "the great divide in our time" is "not between religions or cultures", but between "civilisation and barbarism."[3] The divide between the rich and the poor was not mentioned. As Mitropolous and Nielsen have noted, under these conditions, the defence of the public sphere requires a certain prior agreement on what constitutes the fundamental consensus, as it is the exclusion of genuine, open conflict (war as such) that guarantees the politeness and civility of exchange and keeps the barbarians at the gate of the 'gentlemen's club.[4] To criticise the liberal consensus in a time of war is to invite polemical attack and expulsion from the ranks of those who are entitled to free speech.

Liberal Senator George Brandis was so incensed by the Greens' lack of due deference to President Bush, the uncivilised breach of Bush's right to speak on behalf of civilisation, that in a subsequent session he made a long speech of denunciation. Warning the Australian people of a covert anti-democratic agenda being pursued by the environmental movement, Brandis drew sinister analogies between the rise to power of the National Socialist German Workers Party in the 1930s and the contemporary political tactics and ideologies of the Australian Greens. Where most Australians had tended to divide individual Greens into the categories of either "well meaning oddballs" or "scruffy ratbags", Brandis saw the true urgency of the *Weltanschuang*. Organised around a "hatred of industrialisation" and "the manipulation of bodgie science in order to maintain political conclusions" the hidden agenda of the Greens involved the cynical use of democratic institutions to engineer an eco- fascist takeover of Australian society, according to a "fundamentalist view of nature in which the integrity of the human person comes second to the whole of the natural system."[5]

Internet debaters have formulated a rule of discourse called 'Godwin's Law', which states that the first participant to introduce Hitler to the discussion signifies the end of the debates rationality and thus cedes victory to her opponent. Of course both the analogies Brandis used to discredit the Greens, and his alarming paranoia regarding contemporary Australian political conditions were immediately and obviously spurious to most observers. Feral hippies engaging in non-violent direct actions (scruffy ratbags) or Anglican doctors like Bob Brown (well meaning oddballs) are surely unlikely to don paramilitary uniforms and begin openly murdering their opponents in the street. One web journal noted a few ironies in the Governments' attack, given its willingness to abandon small 'l' liberal issues such as *habeus corpus* and human rights norms in pursuit of hardline nationalist border control, and its drive to transform the structure of Australian society according to the models of the 'driest' of economic sciences:

> "What might a future under the Greens mean for Australians? Thousands held indefinitely behind razor wire in camps in the desert? Millions more forced into menial repetitive employment in the name of a grand, global project of improvement? Individual will eroded in accordance with a closed set of familiar numerical indicators – much-quoted abstractions that supposedly reflect natural forces in the physical world?"[6]

The Howard governments' attempts to claim the sensible, centrist position on environmental matters and to marginalise self-described environmentalists may simply reflect the routine political practice: if you sling enough mud some of it will stick. This attack was one moment in broader context of the 'culture wars', which were accompanied by the emergence of a highly organised anti-environmentalism from right-wing 'think tanks', whose mastery of marketing, lobbying and media techniques over the last twenty years successfully painted environmental activists, scientists and reformers as eco-Stalinists, eco-fascists, irrational nature worshippers, and pathological anti-humanists obsessed with a fictitious impending apocalypse.[7] As is this parable suggests, what locates environmentalists beyond the pale of civility in these deeply conservative times might be their refusal to accept *as science* the basic categories of economic discourse upon which the neoliberal consensus on questions of environmental degradation and social progress rests. Simplified, this is the view that perpetual economic growth is ultimately good for the environment, that the rich countries of the North are exemplary models of post-industrialisation and ecological modernisation completely innocent of environmental degradation and immiseration in the global South, and that global 'market forces' uncontrolled by government intervention are the natural and ideal vectors of social justice, 'poverty reduction' and even 'sustainable growth.' As Ulrich Beck has observed, one of the consequences of the rise of ecological risk is the erosion of the scientific consensus supposedly underlying the rationality of modernity and its consequent politicisation, involving the pitting of science against science in bitter public disputes.[8] This thesis is an attempt to unpack and historicise some of these conflicts, and to do so we must return to the 1970s, when both the global ecological crisis and the neoliberal revolution first emerged.

## 1971 Redux: The Origins of Neoliberalism and Environmentalism in the Crisis of Fordism

The post-millennial epoch in which we all now dwell, characterised by a certain set of seemingly inescapable political, financial and economic arrangements on a global scale, and by a deepening global ecological crisis that has been uneasily normalised within our every day life, came into existence in the crisis of American power and political life between 1970 and 1973.

Of course all metanarrative claims and stage theories of history, discredited as they are for scholars, involve subjective and elective designations of what counts for meaningful key events. Nevertheless, in making this rather bold claim, I want to argue that fundamental changes were underway in the self-conception of modern society in the years 1970 – 1973, with numerous portents of significance to this narrative appearing particularly in 1971. While I have no belief in Hegelian dialectics, any argument must be couched in a narrative, and since Hayden Whites' *Metahistory*, few believe in the possibility of understanding 'history as a whole' objectively.[9] That this document of the loss of faith in historical narrative was itself published in 1973, may or may not be of significance to this narrative. Georg W. F. Hegel taught that history as a whole was driven by dialectic of ideological struggle, with periods of complacency punctuated by the irruption of struggle between proponents of antithetical ideologies, with each party driven to distraction by the existence of alternative ideologies whose very existence contradicted their own universalising ontologies. This occurred both at the micro-level of local political and religious discussion, and was manifest as the wars between states – what Hegel referred to as the 'slaughter bench of history'. Through this struggle, in which ideas engaged with contradicting ideas, there was a process of exchange in which a concept or its realisation passed over into and was preserved and fulfilled by its opposite. Thus the 'world soul' came to realization of its own rationality, a rationality reflected in the order of the cosmos, and social evolution occurred.[10] 'Dialectics' according to the Merriam-Webster dictionary, refers to

> "[...] any systematic reasoning, exposition, or argument that juxtaposes opposed or contradictory ideas and usually seeks to resolve their conflict [...] the dialectical tension or opposition between two interacting forces or elements."[11]

Hegel's dialectical philosophy of history thus gave contradiction between opposites in moments of profound epistemological crisis a central role in the realisation of Progress. During the crisis of the 1970s, both systems ecology and neoclassical economics became increasingly embedded in the American state, reflecting the simultaneous rise to power of environmentalism and neoliberalism. This thesis will attempt to unearth the deep contradictions that each science held for the other within itself as a source of political ideology. Ecology looks to the future and reveals Apocalypse, economics looks to the future and sees the New Heaven and the New Earth.

This thesis is polemical in relation to Progress ideology, especially the Hegelian idealist tradition of state and right, which sees the realisation of Ideas as causally above the material conditions of life. Here my understanding of 'contradiction' is closer to that of Karl Marx. As is well known, Marx 'put Hegel back on his feet', offering a materialist philosophy of history, and arguing that it was the moments of crisis generated by insurmountable class contradictions in the organisation of production relations that drove history into new stages of economic organization. What was specific to the capitalist stage, he argued, was the subordination of society to abstract exchange value, which strives to incorporate all social phenomena and transcend the reality that human existence is restricted by time and space and the specificity of the material:

> "[A]s representative of the general form of wealth – money – capital is the endless and limitless drive to go beyond its limiting barrier. Every boundary is and has to be a boundary for it."[12]

I will argue provisionally that a 'crisis of contradictions' in the way that Westerners perceived relationships between Nature and Society emerged in sharp relief in the early 1970s – between the natural and the social sciences, between the roles of capital and the state in relation to science, between the symbolic realm of abstract exchange value (money) and the biophysical realm of production and waste (matter/energy), between organisms and machines. Put simply, the announcement of ecological crisis, the revelatory claim that unceasing production was threatened looming destruction, represented an epistemological crisis for the dominant worldview, already pressured by social and economic crisis.

These reconfigurations were played out in the simultaneous origins of two political movements of great importance to the present: neoliberalism and environmentalism.[13] As modern political ideologies do, both drew their truth claims from science, in the former by resurrecting the largely defunct neoclassical economic science of the late 19th century, and the latter by politicising a new scientific consensus in systems ecology, a branch of biology that had only recently made the shift from being thought of as the province of butterfly-catchers and woodsy natural historians, to that of a basic science, by claiming to have finally 'grounded' its models and methods in physics and the most up to date computational techniques. Through 'systematic reasoning, exposition and argument' this thesis will attempt to unearth the origins of the 'dialectical tension' between these two 'interacting forces or elements', although it will make no attempt to resolve this increasingly heated conflict, hopes merely to shed light upon it.

Like all epochal shifts and moments of crisis, this one brought to a head certain subterranean contradictions and ambiguities that had deep historical provenance. Although few were aware of this when ecology and economics were brought briefly into stark contrast in the 1970s (or are still), there was once a time when there was no distinction made between them. In the 16th century, the study of the complexity and order of society and the study of the complexity and order of living nature were as yet not divorced by the Cartesian dualism, and were united under the theological term 'economy of nature'. Despite this apparent three hundred year separation, in which separate and distinct paths were taken following the opposing poles of Nature and Society, the historical development of the two disciplines followed a surprisingly mirrored journey. Indeed, as we will discover, this mirroring reflects a contingent history of indirect influence between ecology and economics. On another level, which remains unexplored by most participants in contemporary debates, the crisis of the 1970s brought into view certain questions left unsettled since the revolutionary developments in physics that occurred in the mid-19th century. Derived from the analysis of industrial machines, the discovery of energy and the elaboration of the first and then the second laws of thermodynamics were to profoundly alter Western understandings of nature and society in ways which, while they are largely forgotten, normalised in our ordinary perceptions, and taken for granted are nevertheless still contradictory, profoundly unsettled and productive of new worlds of discourse. The claims of ecology and economics (and thus ultimately of environmentalism and neoliberalism) to be genuinely 'scientific' can both be traced to their foundational relation to energy physics. However, these claims were made in different ways, at different times and for different purposes. The elaboration of the first law in 1847, the Law of the Conservation of Energy, posited a universal invariance underlying all phenomena, and led to a profound confidence in the timeless order and rationality of nature, thus vindicating the new industrial society and its technical and scientific achievements. By contrast, the 1865 discovery of the second law – the Entropy Law – implied unceasing change, waste, disorder and chaos, and as it exfoliated into wider social discourse in the late 19th century, complicated the earlier optimistic confidence with *fin-de-siecle* pessimism and declinist fatigue. These apparent paradoxes regarding the fundamental nature of nature were not resolved when economics it made its bid to be an exact science on par with physics in the 1870s. When ecology sought to become a 'hard' science in the mid-20$^{th}$ century, it similarly strove to bring biology into coherence with energy physics although quite different uses and interpretations were made of it, and physics itself had moved into new worlds.

It was not until the 1970s however, that ecology and economics were brought into direct ontological conflict, although most players were unaware – and most remain so – of the historical origins of the theoretical contradiction between the ecologists' view of the world and that of the economist.

Originally the intention of the thesis was to briefly review the parallel history of theory change outlined above as a starting point for the analysis of the discourses of the 'new economy', announced as the turn of the millennium approached in the late 1990s. The 'new economists', heady with the long stock-market bubble centered on information technology ventures, proposed the becoming-virtual of the 21$^{st}$ century capitalist economy. The hyper-efficiency of frictionless digitized real time financial markets embedded in the Internet, so it was said, had lead to the dematerialisation, deterritorialisation and deindustrialisation of the US economy, now centered on services, relentless scientific innovation, and the global management of information, 'brands' and intellectual property rights. I was intrigued by the assertion of 'postindustrial' growth in the advanced 'markets' despite the increasing consumption of manufactured goods (now imported from East Asian export-processing zones). Of particular interest were claims of 'weightless' economies despite increasing demand for energy to power the warehouses full of servers, routers, processors and air-conditioners that housed the internet, not to mention the continued denial of the warming caused by the 26.5 billion metric tones of anthropogenic carbon dioxide estimated to have been added to the atmosphere in the millennial year 2000.[14] Amid assertions that energy crises were a relic of the 1970s – the anti-environmentalist Cato Institute for example published a long monograph on 'The Increasing Sustainability of Conventional Energy' which argued for "virtually infinite" supplies of oil, coal and gas [15] – the years after 2001 saw the emergence of a new energy imperialism in Central and West Asia. President Bush unofficially enacted the Carter Doctrine of 1980 (in which the US promised to invade the Middle East were 'its' energy supply threatened) to keep the proliferating black hulks of the Chevrolet Suburban SUV on the road to the post-historical utopia of the shopping mall. Elsewhere, according to the Food and Agriculture Organisation of the United Nations, 850 million people were undernourished in the year 2000, people unable to acquire enough 'food energy' to maintain their own personal metabolism.

The working title of this earlier version of the thesis was going to be 'New Economy of Postnature', reflecting the synchronous publication of Bill McKibben's ominous meditation on global warming, *The End of Nature*, and the hyper-optimism of Francis Fukuyama's *The End of History and the Last Man.*[16] What I wanted to discuss were the ways in which the neoliberal activists of the 1990s had established that there was no fixed limit to growth, and that there was no ecological crisis unrepairable by the existing institutions of the liberal state. Environmental activists were portrayed by the new right as delusional millenarians addicted to announcing apocalypse, and unwilling to accept that the millennium of post-scarcity had arrived. For environmentalists like McKibben, the 'end of nature' was the end of any part of the biosphere being unpolluted wilderness separate from society, which was fatal to the meaning of Nature in Western thought. For the libertarian promoters of the biotech industry, 'the end of nature' was to be celebrated in the termination of the geologically slow process of biological evolution through trial-and-error, and it's coming under direct human control. This optimistic version of post-nature posited a new era of 'smart growth' beyond industrialism, through information-based biotechnology and its convergence with nanotechnology. In order to delve into the transcendence of nature by the new economy, I thought it necessary to begin the thesis by clarifying the origins of ecology and economics as sciences. However the history of the intellectual formation of 'the economy' and 'the ecosystem' as objects of positive science – as pure realms of nature devoid of social relations – was of such interest, so pregnant with paradoxes and (I hope to convince the reader) of such importance for contemporary skirmishes on the borderlands of ecology and economics, that what was meant to be the background of the thesis has come to the foreground. Thus the historical remit of the thesis now terminates its narrative in the early seventies, at the beginning of the modern discourse of global environmental crisis, thus the only slightly less over-ambitious title 'Economy of Nature.' Without giving the plot away at the beginning, it is enough perhaps to suggest that ecology and economics have a lot more in common than one might think: whether this is part of the problem or grounds for hope, it is as yet too early to tell.

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Amid the revolutionary social, political and economic upheavals of the early 1970s, a new social movement emerged from the counter-cultural margins of Western societies. Then called the 'ecology movement', this new movement was novel in that it connected some of the then abundant radical critiques of post-war industrial capitalist culture and society with the concepts, models and metaphors of ecology, a previously obscure branch of the life sciences. In its orientation to the future, this movement painted a vision of the logic of modernisation that radically reversed the growth-oriented technological optimism of the post-war period, which had witnessed, at least in the United States and its sphere, the longest period of stable, widely shared increases in material consumption in known memory.

At the time, both Soviet and American futurists outbid each other in millennial visions of the complete triumph of modern technology and their preferred theory of social organisation over a nature rendered the malleable servant of modern science. The prophecies of a post-industrial era beyond scarcity and the class conflicts of Fordist industrialism published by the conservative theorists Daniel Bell, Herman Kahn and Anthony Wiener, and in popular form by Alvin Toffler, did much to define the image of the postindustrial, flexible, high-technology, service-oriented economy that is said to have arrived with the 'new economy' of the 1990s, right on time for the fateful year 2000.[17] With his more populist rival Alvin Toffler, Bell imaginatively described the emergence of a qualitatively new society from the revolutionary instability that characterised his historical milieu, distinguished by the increasing importance of science and technology or knowledge and information, by what have come to be termed 'post-Fordist' or 'flexible' forms of production, and by the de-massification of political life and a drift toward individualization. Bell's term 'postindustrial' is now a commonplace of academic sociology and public discourse. Everyone worth their mobile phone or internet-ready refrigerator knows that we (well some of us) now live in the Information Economy, and that the trillions of digitised packets of immaterial 'knowledge' circulating the globe at the speed of light and bouncing about the ether are the currency and product of our time. In the lead up to the new millennium, the 'new economy' associated with the globalisation of deregulated venture capital and the ubiquitous penetration of information technology represented by the World Wide Web, convinced many pundits of the dawning of a new historical stage where labouring bodies and kinetic machines would no longer be central to the economic process. Prophets are not always so fortunate, as history favours the victors. While scornful of 'bourgeois futurology' – the Soviet academicians Modhrizinska, Stephanyan and Kosolopav produced a promised land that was if anything, even more fundamentally committed to untroubled technological progress and the omnicompetence of science. By the turn of the millennium, according to the Soviet scientists, humanity would control *unlimited* flows of nuclear energy, which would unlock the door of nature's treasure house, yielding infinite supplies of natural resources. Because of this plenitude of energy, hunger would be abolished: the world's deserts would be converted to gardens, food would be harvested from the sea, synthetic food would be produced on an industrial scale, and the climate would be subjected to something approaching push-button control. All repetitive work in the Soviet bloc would be automated by 1990, and by 2000 the citizens of socialism would all live to be one hundred because of genomic control of the aging process. Abundant leisure time would be absorbed by trips to the moon, which would have an extensive network of railways by 2030. In addition, all this would be achieved with new technology that would not degrade the biosphere but actively restore "ecological equilibrium."[18]

This last piece of promissory rhetoric explicitly recognised the profound influence of one of the then most ambitious attempts to model the future of the world, the 1972 report to the Club of Rome.[19] (Indeed, after 1972, Bell, Toffler, Kahn and other conservative writers actively conceived the postindustrial vision against this document.) Commissioned by a club of industrialists, a team of systems theorists and computer programmers at the prestigious Massachussetts Institute of Technology developed a model of the exponential growth trajectory of the global economy, attempting to program into it with 200 equations the complexity of positive and negative feedbacks between industrial expansion and the biosphere. While the authors never claimed to be able to predict the future with any precision, no matter how many simulations were run on the model, the conclusions were clear: exponential growth in population and industrialisation could not continue forever without running up against some combination of the inherent limits of arable land, of mineral resources including fossil energy, and of the biosphere's capacity to absorb pollution. The report also warned of the possible dangers to the stability of the climate of what was then called 'thermal pollution', associated with the noted increase in atmospheric carbon dioxide and the waste heat released by energy conversion in cities and power plants.[20] Unless political agreement was met on the necessity of shifting from an exponentially growth oriented economy to some form of steady-state, the 'limits to growth' would be met within a hundred years. Such predictions, though of necessity imprecise, were testament to what Meadows et al. described as the "simple fact [...] that the earth is finite."[21] The industrial economy needed to be regulated within the fixed limits set by the logic of geochemical depletion and the reproductive limits maintaining the fragile equilibria of the global ecosystem, or both the economy and the biosphere would ultimately face 'overshoot' and ongoing collapse. While devoid of prescriptions for avoiding the apocalypse of unregulated expansion, the report urged the need for a "general strategy" for achieving "global equilibrium", a situation in which "population and capital are essentially stable, with the forces tending to increase or decrease them kept in a tightly controlled balance."[22] Needless to say, this vague notion of a politically derived end to growth followed by a synchronisation of economic and ecological equilibrium is a historical relic as far as contemporary debate is concerned. Nevertheless the idea that there exists a 'balance of nature' upon which all life depends, that this was being rendered unstable, and that this equilibrium needed to be restored, arguably remains the essential ontological claim of environmentalism.

The much less publicized second Report to the Club of Rome, authored by Mihajlo Mesarovic and Eduard Pestel, *Mankind at the Turning Point*, attempted to include even more variables in its computerised world model.[23] Unlike *Limits*, it emphasised political factors – global institutions, wars and revolutions – and importantly, North- South relationships and global income distribution. Widening disparities between rich and poor countries were viewed as major sources of geopolitical instability. Given the proliferation of atomic weapons, this meant that a more "balanced and equitable" share of global resource consumption had become "a question of the survival of the world as such." Unless the polarisation of wealth and poverty were reversed, eventually "there will be a thousand desperadoes terrorising those who are now rich and eventually nuclear blackmail and terror will paralyse completely orderly development."[24] This prophetic claim has a contemporary ring to it. And again we see an appeal for the restoration of 'equilibrium', this time in the normative sense of political and economic justice.

*Limits to Growth* has been criticised extensively for any number of reasons. The main critique is that it made specific predictions of an imminent decline of basic mineral resources, followed by sharp price spikes that have not happened. This critique, which reflects the alarmist reception of its pessimistic findings, is misplaced, if only because Meadows et al. wisely allowed a century for their prophecies to come true. Rather, the detailed tables on mineral resource consumption showed that where previous accounting had projected linear expansion of demand, recent figures suggested exponential increases, and thus *known* reserves of some key minerals faced exhaustion within decades. (Another table in the report showed the massively disproportionate share relative to population of the world's mineral resources consumed by US industry, which was meant to show its dependence on foreign sources.) Economists countered by arguing that as rich mines faced exhaustion, prices would rise, which would make previously difficult mines profitable: rising prices would also attract entrepreneurs to invest in more efficient or radically new technologies, and the net effect would be that prices would tend equilibrate supply and demand, which would in turn stabilise prices. The 'price mechanism' would always restore its own economic 'equilibrium'.

Eric Schumacher gave voice to a second and more perceptive critique. "It would have been better", he wrote, "if the MIT team had concentrated its analysis on the one material factor the availability of which is the precondition of all others and *which cannot be recycled* – energy." [his italics][25] As the petroleum geologist M. King Hubbert once said, "there is a different and more fundamental cost that is independent of the monetary price. That is the energy cost of exploration and production. So long as oil is used as a source of energy, when the energy cost of recovering a barrel of oil becomes greater than the energy content of the oil, production will cease no matter what the monetary price may be."[26] Hubbert predicted as early as 1956 that U.S. oil production would peak in about 1970 and decline thereafter.[27] While he was a laughing stock at the time, his analysis has since shown to be remarkably accurate. Around 1970, the US ceased to be a net exporter of oil and become increasingly dependent upon imported energy. The 'oil shocks' of the Arab oil embargoes of 1973 and 1978 brought home the risks of depletion to American strategists. In 1979, the Iranian revolution and the Soviet invasion of Afghanistan intensified these anxieties and in January 1980, President Carter announced that the US would invade and occupy the Middle East in the event of hostile cartelisation or the encroachment of a foreign power.

A third major critique of *Limits* was that the output of the computer model merely reflected the assumptions that were built into its operations. This was true, although to some extent this must be true of all models – one does not begin to build a model of a Sopwith Camel and then end up with an aircraft carrier. As we will discuss later and at length, this critique, which was mobilised by the supporters of the standard Solow-Stiglitz growth model, could equally be applied to their own preferred model, leaving us with a choice between incommensurable assumptions and pre-analytic visions, or as Kuhn would say 'paradigms'. The Club of Rome assumed that 'the economy' was a quantitative material process, that the earth was finite, and implied that American wealth was predicated upon a monopoly share of the earth's resources. By contrast, Solow and other upholders of orthodoxy assumed that the economy was a circular flow of intersectoral payments and investments, with the reinvestment of profits in technology leading to ever higher levels of output (increasing returns to scale). Natural resources were completely substitutable for capital and labour, and therefore economic growth was more or less independent of biological and geochemical limits. Economic growth was thus in principle unlimited and was presented in the new field of 'development economics' as universally available to any nation with the correct modernisation policies.

The bases for these two very different assumptions, and the polarising contradiction between finite and infinite growth are, I think, of profound relevance for our continuing struggle to conceptualise the relationship between ecology and economics, between industrial society and the biosphere. This thesis might be read as a historical unearthing of the contradiction between finite and infinite accounts of 'growth', and an attempt to reconstruct the deep intellectual currents that lead to this impasse. Surprisingly enough, both of these assumptions have their origins in alternative appropriations by ecology and economics of energy physics, which leads into another theme of the thesis: the question of the relation between the value of money and the 'real value' of energy as nature's 'currency', hinted at above by Hubbert. This impasse is one of the main stories to be explored in the thesis.

While not deriving directly from ecological science or the counter-culture, the systematic analyses of the Club of Rome report crystallised and made mainstream the modern environmental movement's vision of looming future ecological apocalypse driven by unregulated industrial depletion and pollution. This movement made such rapid inroads into public consciousness after the 1962 publication of Rachel Carson's *Silent Spring*, [28] that by September 1970, Milton Friedman of the Chicago University school of economics felt compelled to warn that any firm spending more on pollution controls than the absolute minimum required by law "in order to contribute to the social objective of improving the environment", was practising "pure and unadulterated socialism."[29] In December 1970, President Nixon established the Environmental Protection Agency which was followed by a series of other environmental statutes, at a time when most 1st world democracies were enacting similar legislation and thereby institutionalising recognition of environmental crisis within the state. (It would be a mistake to think of Nixon as an environmentalist, his motive was to poach a decisively popular policy from his rival Edmund Muskie in order to win upcoming elections.[30]) In 1971, the usually conservative magazine *Newsweek* announced that the "Age of Ecology" was at hand. Massive sales of Eugene Odum's 3rd edition of *Fundamentals of Ecology*, printed in 1971, established the 'ecosystem' as a single unifying concept among divergent schools of ecological science, while it simultaneously established 'ecology' for the first time as an indispensable term of public discourse, and a new source of metaphors. [31]

This sense of impending crisis was not confined to conservation biologists, oil geologists or futurists studying the ecological and economic linkages of the global system. The publicity accorded such documents as the report to the Club of Rome – with its implicit call for strict regulation and an end to growth – was disquieting to figures of the business, political and judicial establishment in the United States, who felt themselves under siege from civil rights, anti-war, and ecological protest movements, as well as declining returns from the Fordist corporate model of standardised, fossil-fuel based mass production and Green revolution chemical agriculture. Corporate profitability was threatened by numerous rebellions at home and abroad, and the national economy by the rising inflation *and* unemployment of the stagflation crisis. Public calls for increased regulation of certain industries were mounting. Just prior to quitting the board of Phillip Morris and accepting an appointment from President Nixon to the US Supreme Court in 1971, Lewis Powell, in a confidential document prepared for the United States Chamber of Commerce, passed on an alarming call to arms to big business, beginning with a message from Milton Friedman:

> "It its crystal clear that the foundations of our free society are under wide ranging and powerful attack – not by Communists or any conspiracy but by misguided individuals parroting one another and unwittingly serving ends they would never intentionally promote." [32]

Appealing to business executives to mobilise themselves into a counter-movement to preserve and promote the American system, Powell outlined the field of battle and a strategy for victory:

> "Although the origins, sources, and causes are complex and interrelated and difficult to identify without careful qualification, there is reason to believe that the campus is the single most dynamic source. The social science faculties usually include members who are unsympathetic to the free enterprise system."[33]

In the memorandum, Powell advocated "constant surveillance" of textbook content, and a purge of 'left-wing' faculty members. Businesses ought to stridently pursue the goal of funding scholarship both within the universities and without that supported the system. Here we follow Ravenscroft and Willams in arguing that this document represents the origin of the neoliberal 'revolution from above', which from its very inception has sought the subordination of universities to the interests of commerce, and to the business model of institutional organisation. In 1972, business responded to the threat with the formation of the Business Roundtable, a powerful federal lobby group of the CEOs of the 200 largest US firms. Corporate donors established the Heritage Foundation, the first of many corporate-funded neoliberal 'think-tanks' such as the Cato Institute, the American Enterprise Institute, and the Hudson Institute.. Unlike previous think-tanks such as the RAND Corporation, which drew experts from numerous branches of academia and elsewhere to develop interdisciplinary approaches to problems of public importance and national security (however defined), the 'adjunct scholars' deployed by these think-tanks were not subject to peer-review and existed entirely to propagate respectable looking corporate-friendly ideology. This pressure applied within the universities, as well as the construction of a network of think-tanks whose prodigious media-friendly output rivalled academic social science in its formation of public opinion, was crucial to the rise of the new right in the 1980s. In a return to the classical liberalism of the era before the welfare state, the new right called for the radical restriction of the state's role in the management of the economy. The undivided centre of neoliberalism as a political and moral system, argues Paul Treanor, is the reduction of politics to economics and economics to 'the market':

> "Neoliberalism is a philosophy in which the existence and operation of a market are valued in themselves, separately from any previous relationship with the production of goods and services, and without any attempt to justify them in terms of their effect of the production of goods and services; and where the operation of a market or a market like structure is seen as an ethic in itself, capable of acting as a guide for all human action, and substituting for all previously existing ethical beliefs." [34]

At the basis of the neoliberal revolution has been the transformation of political discourse by the hegemonic appeal of neoliberal policy makers to the 'scientific foundations' provided by neoclassical economics; which provides a highly formalised mathematical system, a closed universe impenetrable to all but the adept, that 'proves' the "naturalness of societies that rely on markets to distil the actions of free, solipsistic self-interested beings into what is optimal for all of them."[35] Since then, the neoclassical programme has been busy brushing aside all other schools claim to the title of economics. By the 1990s, the neoliberal 'revolution' had elevated neoclassical economics to unchallenged dominance in academic economics and business studies and provided the bipartisan framing discourse not only for US politics, but for the commanding heights of the global economy occupied by the IMF and its related institutions. In addition, it was also imposing its form of analysis on other genres, as the vast literature generated by the metaphor 'human capital' shows. Writing presciently in 1930, R. W. Souter proposed that:

> "The salvation of Economic Science in the 20th century lies in an enlightened and democratic 'economic imperialism' which invades the territories of its neighbours, not to enslave them or swallow them up, but to aid and enrich them and promote their autonomous growth in the very process of aiding and enriching itself."[36]

Souter was speaking metaphorically of course, proposing the insinuation of economic analysis (on the basis of rational utility, maximisation and equilibrium) into sociology, political science, anthropology, and demography, which Ben Fine notes has all but come to pass, or at least in the North American academy.[37] This passage could be taken almost as an axiom of neoliberal globalisation, reminiscent of the benevolent rhetoric of 'structural adjustment programmes' of advancing democracy and economic growth through the privatisation of public wealth, the downsizing of public service, the deregulation of 'labour markets' and exposure of developing nations to the rigorous 'laws of economics' manifest in markets. As it turned out, Souter's prophecy had to wait until the 1970s to bear fruit. Between the catastrophe of 1929 and the crisis of the 1970s, the neoclassical approach was an intellectual outcast, relegated to the margins of applied economics as Keynesian approaches dominated in the West.[38] Since the 1970s, the intellectual imperialism of the neoclassical approach in the academy has been matched by the global institutionalisation of the applied form of market fundamentalism.

The 1970s was clearly a revolutionary moment in the transformations of late capitalism, leading to a geographical and financial re-structure of world scale capital accumulation. Fordist national industry governed by the Bretton Woods system of fixed exchange rates and protected by trade quotas and tariffs gave to way to what we now call globalisation, with transnational corporations engaged in 'flexible production' across national borders. The revival of neoclassical theory began among the students of Friedrich von Hayek and Milton Friedman at Chicago University and was first applied under General Pinochet's Chile in 1973. With elected governments, unions, and civil society safely 'cleansed' from the political landscape, the Chicago school was offered its first laboratory experiment in 'shock therapy' and 'structural adjustment.' With the 'success' of this project, the neoclassical revival was imported to Thatcher's Britain and Reagan's America in the early 1980s and then to the world in the post-Cold War period through the 'Washington consensus', an accommodation forged between Wall Street, the Federal Reserve, the International Monetary Fund and the World Bank. With the Bretton Woods institutions captured by neoliberal ideology, the international financial and economic system were profoundly restructured, but especially the internal economies of developing nations whose 'development loans', denominated in dollars, had massively expanded during the oil shocks, inviting the imposition by the IMF of unpopular 'austerity measures' (later repackaged as 'structural adjustment programmes') and pressure to liberalise finance and labour markets. The Keynesian macro-economic policies that had empowered nation-states to pursue goals such as full-employment and social welfare came under siege as corporations became increasingly mobile across transnational boundaries, able to relocate to more accommodating parts of the world system, with lower wages and less regulation. Indebted countries were required to raise interest rates, 'balance' their budgets by shrinking public expenditures, allow 'the market' to lower the value of their currencies to the 'equilibrium' price, sell off publicly owned assets to transnational corporations, and export their way out of indebtedness with labour intensive commodity production, agricultural commodities and the national patrimony of 'natural capital'. Market fundamentalism, according to currency speculator George Soros, is the ideology now driving the global capitalist system, and he defines it as an "extreme belief in the theory of perfect competition", in which "markets tend toward equilibrium and the equilibrium position represents the most efficient allocation of resources".[39]

In tandem with the rise since 1971 of what Fine calls the 'economics imperialism' of neoclassical intellectual hegemony, came a novel form of financial imperialism. The question of debt was on the agenda in the US in the early 1970s. The spiralling budget blowouts of the war on Vietnam and

Cambodia had began to put serious downward pressure on the US dollar, and in 1971 President Nixon finally refused to exchange dollars for the gold that had backed the US dollar under the agreements of the Bretton Woods treaty of 1944. The economist Michael Hudson has shown that since then, the US has transformed the US Treasury Bill, a security through which the government raises debt for fiscal expenditures, into the international monetary standard.[40] The gold standard had in theory placed a limit on the balance of payments deficits US government could run, because foreign creditors could always discipline the speculative expenditures and wars of Congress and the Treasury by demanding gold for the surplus dollars accumulating in their central banks. With no physical referent to the paper US dollar as world currency, and with American diplomats warning in 1972 that foreign attempts to buy out American firms with excess dollars would be read as an act of war, central banks had no choice but to buy US debt with their dollars in the form of promissory notes. Over time, US Treasury bills have paid ever-lower interest, and what this means is that the world's central banks are essentially providing a continuous and indefinite loan to the US government, a loan so fundamentally built into the structure of the global economy that it will be "rolled over indefinitely" and "will not have to be repaid."[41] Indeed, the US is far and away the world's greatest debtor, with its external debt standing at $3 trillion as of 2005, with George Bush's tax cuts to the investor class and the 'military Keynesianism' of the War on Terror estimated to drive this debt up to $7 trillion by the time he leaves office. By contrast, the accumulated debt of all developing countries was estimated at $2.6 trillion by the World Bank in 2004.[42] Indeed much of the US T-bill debt is held by East Asian developing countries 'structurally adjusted' according to American economic theory on the basis that the US, as the major investor of the World Bank and the International Monetary Fund has always held the deciding vote on their policies. Holders of US debt are quite unable to impose the Washington Consensus on Washington and demand that the government 'balance' its books with lower wages, currency devaluation and bulk exports of cheap manufactures and natural resources. The nations of the world are in the position of exchanging real goods and services for what might be called American 'nation state futures' in that they must accept, anticipate and ensure the promised dominance of the US as the 'motor of growth' for the world's economy through investing in US debt. This is hardly the smooth 'global equilibrium' of economic theory; it rather resembles, as Larry Summers has said, a "delicate balance of financial terror."[43] That this comment paraphrases the title of a 1959 article by Alfred Wohlstetter, which established the strategic objective of the Cold War nuclear arms race as 'mutually assured destruction' (MAD) might give us pause for thought.[44]

Here the banal yet incredibly dense metaphor 'motor of growth' reveals some uncanny paradoxes: the biological metaphor 'growth' is ordinarily applied to industrial production in terms of continuous increases in output, yet in a situation where the average US family has 13 credit cards and spends $1.22 for every dollar it earns, American debt has been miraculously transformed into an income generating asset, with the entropic sink of American consumption-led growth driving the export-dependent growth of much poorer countries. While growth is a biological metaphor, the 'motor' metaphor implies that 'growth' involves not only the irreversible thermodynamic conversion of fuels into heat and work, but also the abundant reproduction of machines by machines. The continuous economic growth of the post-war period has been and remains irrevocably tied to cheap and abundant oil. Even oil executives now believe that global supplies of oil will reach their peak production levels within the next decade or two, if they have not already. Nevertheless this compounding sum of money capital owed by both nations of wealthy consumers and poor producers to the future presupposes and is entirely dependent on a future of continuous exponential economic growth, which is still, I would insist, not at all disconnected from the material and geographical expansion of 'capital' infrastructure and industrial 'technomass'. In this sense the deliriously optimistic promise of infinite growth is driving all economies into a future which, at least until oil is miraculously replaced as the energy input for motors and for industrial agriculture, is surely impossible.

The question of energy depletion aside, ecological risks to human societies and to the integrity of the biosphere as a whole are increasing, both in scope and complexity. Ecologists, who suffer the professional ignominy of documenting the disappearance of their research object, are appalled by this state of affairs, with some vowing not to rest until humanity commits to restore the 'sacred balance' between human and non-human communities.[45] Many environmentalists and scientists concur that human impacts on the biosphere are already 'beyond the limits' of any definition of sustainability, and yet the notion of infinite growth remains central to economic governance. Back in 1986, when there were one billion less human beings on the surface of the earth, Vitousek and his fellow ecologists estimated that organic material equivalent to about 40% of the present 'net primary production' (the GDP of nature's economy) in terrestrial ecosystems is being co-opted by human beings each year.[46] From geographical data, Matthias Wackernaegal et. al calculate that universal per capita natural resource consumption on the scale of North America would literally require 'three to four additional earths.'[47] In biological terms, 'primary production' refers to the capture of solar energy and its conversion into plant biomass by photosynthesis, the biochemical process at the basis of nearly all life. This means that the remaining millions of land-based species, the 'communities' that provide the unpaid 'ecosystem services' that economists are beginning to discover, must compete for the remaining 'net primary production'. Indeed the 'ecological footprint' methodology developed by Wackernaegal and his colleagues indicates that the land required to underwrite the resource consumption of Northern citizens is far in excess of the national territory governed by their parliaments. What this implies is that liberalised trade between North and South has increasingly deprived Southerners of access to their own 'bioproductive' land. Yet despite all this talk of limitation and crisis, the millennial vision of endless economic growth – the secular utopia of industrial modernity – seems to have survived the basic argument of the Club of Rome that 'the earth is finite'.

Indeed, environmental crisis is so normalised, that it no longer alarms us into questioning business as usual. Rather than being the source of crisis, 'sustained growth' is now the precondition for the 'sustainability' of the biosphere itself. "Growth is indispensable", asserts the World Bank in a recent publication entitled *Responsible Growth for the New Millennium*.[48] In it, the Bank acknowledges massive global inequality and the deepening risks of environmental degradation. Although the authors admit that by 2055 'the global economy' may well be up to four times as large as it presently is, they are confident that the only possible solution to entrenched poverty and radically unequal resource consumption is not redistribution and conservation in some kind of 'steady state', but more growth, which is "essential for development." That the developed countries consume by far the majority of the world's resources does not count as 'over-consumption' or 'mal-development': the rich world is the norm, and poverty deviant. Although the Bank suspects all this growth might have 'deleterious' consequences on the environment (implying that growth tends to delete the environment?), the bank believes that by "integrating society, ecology and the economy," the realisation of the New Millennium – an end to global poverty *and* ecological crisis – can and will be achieved, through growth. But through growth of a new kind: 'responsible', 'sustainable' growth, presumably not the old irresponsible, unsustainable growth associated with free-market capitalism and the Bank's own history of neoliberal governance. The Bank projects that the world economy will be four times larger by 2055: how this is to be achieved while increasing 'sustainability' and "integrating society, ecology and the economy," is anybody's guess. It should also be mentioned that the report does not recommend that 2055 is the date when growth will or should cease: growth is thus presented as infinite

It is surprising how very few are the economists that have explicitly and continuously defended the concept of infinite growth. Perhaps this is because of the ubiquity of the ideology within the confines of expertise, or because of the short-term fascination with the next financial boom or crash, or (most likely for my money) because the consequences of seriously meditating on the question would simply be too disturbing to contemplate. Julian Simon, resident anti-environmentalist 'doomslayer' and 'adjunct scholar' at the Cato Institute was one of these few brave souls, who once asserted that:

> "Technology exists now to produce in virtually inexhaustible quantities just about all the products made by nature - foodstuffs, oil, even pearls and diamonds . . .We have in our hands now - actually in our libraries - the technology to feed, clothe and supply energy to an ever-growing population for the next 7 billion years . . . Even if no new knowledge were ever gained . . . we would be able to go on increasing our population forever."[49]

While this statement hardly deserves critique (why is everyone not already a billionaire?), it is worth noting that Garrett Hardin has calculated that at the recent rate of population growth of 1 percent annually, the time it would take for the human population to equal all the atoms in the universe is just 17,000 years.[50] Nevertheless, Simon's deliriously optimistic position is essentially indistinguishable from the normal operating assumptions of modern political economy. To conclude on this question of the relation of growth and crisis, society and physics, ecology and economics I would like to introduce two crucial texts, both published in 1971. As they are final points of reference for subsequent chapters of the thesis, we shall not summarise or discuss them in detail here, but mention them merely to indicate the importance of the synchronicities and 'elective affinities' that I have attributed to the original, contradictory and prophetic dialectical moment of 1971.

In this year the mathematical economist Nicholas Georgescu-Roegen published *The Entropy Law and the Economic Process,* a comprehensive and devastating critique of the scientific claims of neoclassical economics. Attempting to reveal the substantive and biophysical 'nature of the economy', his essay completely undermined the orthodox account of value theory, of 'economic equilibrium' and of production, by exposing these concepts to the rigorous limits imposed by the foundational principle of energy physics: the second law of thermodynamics. From this analysis, Georgescu-Roegen concluded that Fordist industrial growth was ultimately dependent on the diminishing returns of mining and agriculture, and argued that what was presented as 'production' *ex nihilo* by the standard models of economic growth, was actually the transformation of low entropy to high entropy, which was inseparable from the generation of 'irrevocable waste.' It is sadly ironic that the rise of the orthodox economic science to global pre-eminence also dates from the same year, given that Georgescu-Roegen, a perennial candidate for a Nobel prize, remains thoroughly ignored by the economics profession. To date, none of the major exponents of the discipline that he targeted as a highly qualified insider have attempted to answer his profound critique, much less to systematically refute it. To further compound the irony, this work is considered the foundation stone of the nascent discipline of 'ecological economics', even though it contains not a single reference to 'ecology' or 'ecosystems'.

Coming at similar problems from the flip side of the 'economy of nature', the systems ecologist Howard Odum extended his original and groundbreaking method of ecosystem analysis to the question of international political economy in his *Environment, Power and Society,* also published in 1971. Like the World Bank report cited above, Odum set out with the goal to 'integrate society, ecology and the economy' by re-visioning all social and natural phenomena according to the principles of energetics, as irreversible transformations of matter/energy ultimately driven by the photosynthetic capture of solar energy. Where the conventional model of growth sees economic activity as the 'production of resources', and argues that perpetual growth is the only way to redeem the biosphere, Odum argued exactly the opposite. Now confined to the margins of historical curiosity, this idiosyncratic work nevertheless provides us with a thorough attempt to explicate the order of ecosystems and the order of socio-economic systems within the same energetic principles. Odum is motivated by the urgent requirement for modern societies to ward off the catastrophe of depletion and biosystem collapse, to re-engineer the relationship of nature to society so that it might achieve a state of 'ecological equilibrium', the only solution later offered by the Club of Rome to the impending crisis of limits. This work attempted nothing less than to subsume and entirely replace economics with systems ecology as the basis for measuring and re-organising the world economy in accordance with a genuinely sustainable 'equilibrium' steady-state beyond growth. Regardless of the validity of this ambition, Odum's approach to the unification of science and society was thoroughly technocratic and reductionist. One can read almost the entirety of Odum's explication of his rival energy theory of economic value without gaining the impression that he the legacy of the humanities and the social sciences had anything at all to contribute to conceptualising and resolving the coming crisis.

Given the obvious parallels between ecology and economics as the study of complexity, growth, and equilibrium under the constraint of scarcity at the level of the total system, these striking omissions in coterminous works treating essentially the same questions (neither Georgescu-Roegen nor Odum feel the need to mention the discipline that their work was attempting to entirely incorporate and subsume) is puzzling. On the one hand, it is plainly indicative of the deep academic estrangement of the twin 'economies of nature' across the Natural and Social divide, which if anything has intensified since, despite the mirroring of key metaphors, concepts and terms throughout the history of the two disciplines. On the other hand, it may indicate that for serious thinkers aware of the constraints of thermodynamics, economies and ecosystems followed the same unitary principles and thus there was no essential difference between them. One thing that Odum and Georgescu-Roegen shared in common was the aim to ground transcendent, isolated and abstract economic discourse in the biological and physical sciences. Respectively, these works represent very ambitious attempts on the part a social scientist and a biophysicist to extend the core insights of their fields beyond their traditional disciplinary confines into the broader crisis of growth and limits facing industrial modernity that was everywhere apparent in the early 1970s.

At this time, the notion of crisis resolved entirely around the incompatibility of exponential 'economic growth' with 'ecological equilibrium'. In our own time, despite the fact that global ecological crisis is no longer a future possibility but acknowledged by everyone as the dwelling place of modern society, this simple relationship is thoroughly complicated and almost impossible to argue for an any respectable Western institution. Why is this so? Apart from some appeal to the universal short-termism of entirely self-interested of maximising economic actors, which would cede victory to 'economics imperialism' from the start, there are I think, three main reasons:

The first is that, as has already been hinted at, from the beginning of the modern grass-roots environmental movement there has arisen a virulent anti-environmentalist movement mobilised by the

Reaganite new right and diffused by corporate-sponsored think tanks, who have circulated reams of 'counter-science' to debunk every new revelation of environmental risk emerging from legitimate scientific institutions in order to stave off social regulation of corporate activity. This 'brownlash' movement of crisis denial has been part of neoliberalism from the beginning, as I have already suggested, and thus neoliberalism is not merely a political and economic philosophy, but has as one of its foundational rationales the propagation of its own unique ontology of nature.

A second reason for this might be that these works represent the swansong of an industrial conception of society (and thus nature) that was becoming untenable in the new era characterised by the rapid evolution of information technology and the communications industry, the emergence of networked global markets, and the momentous developments in molecular biotechnology that also can be traced to the early 1970s. The emergence and popularisation of a whole new theoretical lexicon of concepts and metaphors associated with far-from-equilibrium thermodynamics, complexity theory and chaos theory, which has profoundly reconfigured the relation between biology, economics and physics. This has led to the decline of the ancient metaphor of 'the balance of nature' in numerous fields. This led in turn to the articulation of a 'new ecology' in the mid-1990s, which "rejects the traditional notion of nature resting in harmonious equilibrium and offers instead a vision of a restive nature – in perpetual flux, disturbance and renewal."[51]

While acknowledging the importance of these two possible reasons for the current non-contradictory status of 'equilibrium' and 'growth' in hegemonic discourse, this thesis will advance a third explanation. This is that ecology and economics may have always shared the same constitutional metaphors, and despite their radically divergent prophecies, they are like the two faces of an old coin, speaking against one another from different sides of the grandest of all metaphors: the 'economy of nature.'

As I will argue in the first half of the thesis (Nature of Economy) the development of economics as a 'pure science' rather than as a form of social philosophy is inseparable from the rise of the energetics movement that accompanied the development of heat engines in the 19th century. As Philip Mirowski has shown, neoclassical economics is a form of social physics. What Georgescu-Roegen was doing was pointing out the fatal anachronism of a sterile physical metaphor of pristine motion for a science of economics in an age when the biological and ecological limits of the earth were being pressed by fossil-fuelled industrialisation. The history of ecology retold in the second half of the thesis (Economy of Nature) culminates with Odum, who was completing a long held aspiration of ecology to provide a comprehensive understanding of the totality of biological interaction. Odum's career demonstrates that ecology's drive for totalisation did not occur in a political vacuum of pure intellectual interest, but in accommodation to the state's interest in increasing the control over its interactions with nature and defining the optimal economic strategies to maximise productivity and secure the life of the population.

Ecology had always been to some extent a form of 'sociobiology,' Odum exemplifies the aspiration of ecology to become a social physics with superior holistic realism than economics, which after all was blinkered by its focus on money. By subjecting the circulation of abstract exchange value to the hard realities of unidirectional energy flow through systems of organisms and systems of machines in his economy of nature, Odum hoped to unify the sciences and bring the chaos of looming economic and ecological crisis under control. This would require a conscious and controlled transition to a low-energy, post- growth society.

What is intriguing about Odum's move to develop an objective energy theory of value, as the ecologist Richard Levins was later to provocatively suggest, is that abstract capital is not as conceptually remote from energetics as one might think:

> "[...] the notion of energy as the fundamental thing to look at as the universal medium of exchange is clearly brought into biology by analogy with economic exchange...There was a hope...that we could ignore all the complexity of interacting species, the heterogeneity of populations, the complexities of competition and symbiosis, of mutation and predation, and reduce everything to a single medium of ecological exchange, which was designated as 'energy'."[52]

Our task is unearth and polish this metaphorical coinage before putting it back into circulation, in the belief that current debates are in urgent need of it.

## Thesis Overview

In his fascinating history of neoclassical economics, Philip Mirowski begins by quoting the great essayist and satirist Jorge Louis Borges, who once wrote: "It may be that universal history is the history of a handful of metaphors." [53] Working from this surprisingly productive premise, this thesis will attempt to sketch out the career of a couple of metaphors, and their role in the recent history of the fearful sphere of the Earth in the age of the global economy. Mirowski's own works have turned this line from Borges into a comprehensive approach to historical methodology, and used it very profitably in discussing the history of economics. In this thesis, a similar approach will be employed to explore the relationship between ecology and economics by looking at the history of shared terms such as 'growth' and 'equilibrium', as well as appeals to 'laws of nature'. As disciplines, ecology and economics have overlapping intellectual roots and shared histories of conceptual exchange. Both have had a tendency to construct a pure nature external to social relations, and to assert the objectivity of this nature in the face of the intense politicisation of the respective disciplines' subject matter.

This study has been prompted by the observation that in spite of its basic incompatibility with the life sciences, with other social sciences, and indeed with physics, neoclassical economics in its many guises has managed to maintain most of the core features of the research programme as it emerged in the 'marginalist revolution' in the 1870s. Thus the first task of the essay is to investigate the scientific authority claimed by economics, 'the queen of the social sciences', a claim that is part and parcel of its rise to political hegemony at all levels of governance. Its claim to be the only social science verifiable according to natural scientific standards of evidence and theory formation, ecologists would argue, is most grievously countered by its de facto predictions of infinite growth contrasted against the proliferating reams of empirical evidence documenting the increasing degradation and destabilisation of the biosphere. Despite the fact that this development in human-environment relations has been discussed in the mainstream since the crisis of limits in the 1970s, despite unprecedented rates of species extinction and radical social inequality, the theoretical core of economics has remained essentially stable since its formalisation. The second task is to investigate the history of ecology up until the early 1970s when the two sciences came into open conflict. Playing David to the Goliath of economics for space in the political arena, and a century late to approach the discursive heights of mathematisation on the model of energy physics, the momentary claim of ecology for superior scientific legitimacy over economics deserves a second look and some serious analysis. What history recalls of the 'subversive' science should raise our eyebrows. As a general theory of life, its initial trajectory of scientisation not only parallels the ascent trajectory of economics, but also reveals that ecology has also systematically borrowed directly from the social sciences, and of none more than political economy. Archaeological exertions far greater than we have time for are required to fully flesh out the relation to economics and the metaphors and concepts that they implicitly share. Ecology has historically been in a subsidiary position to economics; it is and always has been a 'bioeconomics' as 'economy of nature', as the pre-modern name of the study tells us. Questions of power/knowledge aside, among the reasons that the issue of 'sustainability' provokes such friction and outright contradiction, is that our current view of the world draws largely on a set of scientific theories - sociology, psychology, evolutionary theory, ecology, economics, thermodynamics and physics – whose roots are tightly bound together in a complex cross-fertilisation of ideas dating back several centuries. The pollinating agents of this universal history, we will argue, are as Borges ironically suggests: 'the different intonations given a handful of metaphors.'

Both sciences are (holding aside for the moment the efforts of post-modernists) committed to the elaboration of a realm of nature which has general validity. As any layman knows the difference between science and ideology is that true science is devoid of grand, anthropomorphic and aggrandizing historical narratives, there is no poetry, metaphor, mythology or unmoved movers in real science. With the displacement of theology by scientific materialism in modernity, the scientist (especially the physicist) has become the towering epistemological authority. Truth has come to be located in the observation of nature rather than in divine revelation. Likewise, science has been placed outside the realm of politics; it is only truly science if its practitioners are sufficiently insulated from the arbitrary decisionism of sovereign power. Despite this, modern history shows numerous of examples where political ideologies lay claims to science as their criterion of truth. Both ecology and economics have attempted to establish a realm of nature devoid of social relations, and this process of objectification is in itself an important part of the establishment of the disciplinary boundaries of a research program, or after Kuhn, a 'normal science'. But as Judy Wacjman has put it, "Science is not disembodied truth, it is social knowledge, a form of life and a material-semiotic practice using similar narrative forms similar to those other social knowledges."[54] To survive in the 'marketplace of ideas', normal sciences thrive on a good income stream and an organisational field, whether it be in the pay of the nation-state, or in the R & D department of a large firm. This is not to say that knowledge thus gained is tainted, but that it needs to be useful to society for some reason or other. As we shall discover, ecology itself only became socially useful when modern economies in their material form as 'integrated technomass' were perceived to be threatening to undermine the regenerative capacity of the biosphere through exhaustion and various forms of pollution, especially radiation.

This thesis is divided into three main parts. Part I is introductory and methodological. Part II explores the origins of the core concepts of neoclassical economics, setting it in the wider history of the rise of modern physical sciences, the emergence of the social sciences and the rise of industrial capitalism. As we shall see, this is also the career of a particular set of machine metaphors – biology was excluded from the neoclassical synthesis of the late 19th century. Part III subjects ecology to the same treatment. Here we focus on its place in the rise of modern biology, and emphasise its relationships with other sciences, particularly political economy. This connection leads us into the 20th century, and ecology's increasing relationship to physics, cybernetics, neoclassical economics and the 'military-academic complex' of the Cold War nation state. The thesis will be concluded by a small epilogue which demonstrates the contemporary relevance of the history revisited here, and indicates how the methodology of the thesis might also be extended into present debates. The following paragraphs will outline the general narrative and conceptual structure of the thesis.

The introductory remarks made so far in Part I have laid out up some of the historical and theoretical terrain of our problematic. The section that follows this overview provides a discussion of the methodological positions that we shall engage with. Here we discuss certain debates in philosophy of science and the analysis of interactions between the natural and the social sciences. While there are numerous histories that discuss moments of 'paradigm formation' in economics, there are few that do so for ecology. The novelty of this thesis is in its attempt at a parallel demonstration of the emergence of these incommensurable versions of nature. But this is not all there is to the story: as I will attempt to show, this incommensurability, evident in the contradictory use of terms like 'growth' and 'equilibrium', has arisen through a long history of exchange, borrowing, and mirroring of key concepts, approaches and methodologies every since modern economics and modern ecology emerged from the *prima materia* of their mutual ancestor – an ill-defined area of pre-modern theology called 'economy of nature'. Bernard Cohen, the eminent historian of the interactions between the natural and the social sciences, has noted that despite the frequent claims of economics and sociology to be real sciences, there was a general paucity of research on cross-disciplinary influences when he began to take interest in the question of interactions.

> "There was precious little literature, if any, that took account of the ways in which social scientists of the past three centuries had interacted with their fellow natural scientists, or had attempted to use concepts, principles, theories, or methods of the natural sciences at large. Additionally, the reverse interaction – the influence of social sciences on the development of the natural sciences, was completely ignored and in some cases denied."[55]

Our concern is to track some of these interactions. While a good deal of sophisticated science history has since been written, the absence of a comprehensive shared history of conceptual symbiosis and predation between ecology and economics is curious, given the grave contradictions between their representation of the nature of equilibrium and the future of economic growth. Such a history would also be useful given that medium-term health of the biosphere seems dependant upon the success of such social artefacts as 'carbon trading'. A research effort in this direction would have much to offer in the analysis of bioengineered crop species such as Monsanto's Terminator technology, developed in partnership with the US government and pushed as the saviour of developing world agriculture. These organisms have their biological makeup restructured to ensure reproductive sterility, and an ontogenetic 'program' suited to monopolistic contracts and the enforcement of intellectual property rights. Perhaps one reason that such research is reasonably rare is that technical artefacts – being both natural and cultural – would keep undermining the vital division between nature and society. In sum, a comprehensive and critical analysis of the history of disciplinary interactions between ecology and economics has yet to be written. This thesis is intended to provide a sketch of what thematic questions might occupy such a formidable research effort.

The method of this thesis, as has been hinted at, is to trace certain key theoretical analogies and metaphors to moments of 'paradigm shift', build up some of the social and political context of that moment, and then attempt to provide a sociological account for why a particular metaphor was selected. To aid us in this, in bridging some of the historical gaps between ecology and economics, we draw upon a particular approach to the sociology of knowledge that might be called the 'anthropology of classificatory schemes'. Associated with Emile Durkheim, Marcel Mauss and Mary Douglas, this approach from structural anthropology detects a pattern in the way numerous cultures – be they totemic, animist or monotheistic – organise their account of the internal order of society and their narrative of the order of nature. As it turns out, the natural order tends to be organised along the same lines as the social order, which of course sits at the centre of the human cosmos. Nature reflects back the projection onto nature of social hierarchies, categories and structures. Natural images are also built reciprocally into the social order, bringing the cosmos into the meanings of society and ensuring the naturalness of existing social relations. Thus the basic cognitive relationship between nature and society is metaphor. When pollution our 'matter out of place' defies classification, apocalypse looms, as the stable reproduction of the social order through historical time is dependent on the reproductive stability of the natural order.

Turning to the philosophy of modern science, and the methodological writings of Thomas Kuhn, Pierre Duhem, Willard Quine and Mary Hesse, we introduce a taxonomy of positions on the role of metaphor in science: from logical positivism, which believes the operation of the 'laws of nature' have nothing whatsoever to do with metaphor, to Nietzsche, who alerts us to the ubiquity of metaphor and the difficulty of knowing anything that is not in some way linked to metaphor. Here we take interest because the basic metaphor of industrial society is of course the industrial machine: for many, it is self-evident that to 'seek the mechanism' is identical to doing science. The machine metaphor is, it turns out, is so integral to modern thought that it might be termed a 'world hypotheses'. The metaphor of the machine was thoroughly embedded in the ascent of economics and then ecology to 'hard science' status, and yet neither economics nor ecology pay much attention to industrial machines as such. Economists are interested in the interaction of prices, ecologists in the interactions of species. And yet it is industrial machines that are at the heart of our material interactions with nature, our knowledge of its fundamental laws, and our ecological crisis. Therefore the similar metaphors that organise both fields of knowledge, especially those concerned with 'equilibrium', 'growth', and the 'laws of nature', will attract our attention.

We are now in a position to discuss Part II of the thesis: 'Nature of Economy', which will present an archaeological history of the formation of 'the economy' as a natural object with its own science. Our chief interest is what would appear to be a profound internal contradiction: the core of the theory is about 'general equilibrium', the mathematical theorisation of Adam Smith's metaphor of the 'invisible hand'. Yet the core application of economics as a policy science is in the practice of enabling permanent exponential growth. I want to argue that the origins of economics are not in some branch of the natural sciences, but ultimately in theology. The narrative begins by suggesting that the social sciences have arisen within a dialectical tension existing between two poles of attraction: a view of history as Progress, and a view of nature as timeless, harmonious, self-governed and invariant with respect to equilibrium. The former I refer to as 'secular millennialism', and the latter as 'social physics'. The unprecedented 'advance of the productive forces' embedded materially within industrialising societies infused the historicist tendencies in the social sciences, and the 'world hypothesis' of the machine metaphor internalised in the founding documents of modern science inspired the reductionist path. Modern economics can thus be considered the vehicle for the realisation of the 'industrial millennium.'

The first section of Part II will briefly examine the origins of Progress ideology, and will argue that rather than modernity replacing Christian eschatology with a rational science of history, its political ideologies have tended rather to 'secularise the millennium' by positing science as the salvation of humanity, a process aided by the profound social change associated with the rise of modern science and technology, nation-states and industrial capitalism. However, what is often left out of the story of Progress ideology is the opening to the West of two vast resource frontiers: the first through the colonial capture of the vast territories and populations of the New World, and the second through the sudden access to a hundred million years worth of fossilised solar energy, suddenly made available through new techniques in the mining, refining and harnessing of coal and oil. By ignoring the geographies of resource appropriation, the industrial machine was abstracted from the social relations that reproduced it, and was fetishised into appearing as productive and generative in their own right. Both of these factors have been left out of standard accounts of the origins of modern capitalism, which sees the origins of Britains 19$^{th}$ century wealth in ingenious technology and the discovery and liberal institutionalisation of the 'laws of supply and demand'. The consequence of this restrictive focus is to present the combination of industrial machinery and lassez-faire economics as if both were intrinsically productive, obscuring the global exploitation of resources and colonial labour out of the picture. In contemporary economic discourse, secular millennialism takes the banal and abstract form of perpetually increasing dollar values for the national accounts (GNP), the metric at the base of development theory and arguably all modern governance. The ideology of perpetually rising GNP (or if you prefer, stock market capitalisation) is a form of millennialism in that institutionalises the expectation of perpetual growth in the historical consciousness of the global system of nation-state political economy.

The general equilibrium theory of pure market exchange is the most important result of another tendency in the social sciences – the drive to produce a 'social physics' – a topic taken up in the following section. By social physics we mean the quest among the early founders of the social sciences, and indeed among the important 19$^{th}$ century philosophers and systematisers of science such as Auguste Comte, to develop 'physique sociale' as a master science of society which would unify all the other sciences and place the prediction of social and political events on the same level as that of (say) the natural laws of celestial mechanics. As the example of Comte shows, one can be a secular millennialist and a social physicist at the same time. The founder of Positivism as a movement to bring government under the control of social physics, Comte believed he was living on the cusp of the Third Age of human social evolution, which would arrive when scientists had brought all social phenomena into coherence with the laws of nature and established a utopia upon the firm ground of positive science.

Having established these two unusual terms, our attention then turns to the role of the machine metaphor in the rise of modern physical science. This projection of the machine into the hidden structure of a despiritualised nature by the followers of Descartes was then reprojected back into society in early political theories of the newly emerging modern state. This discussion then leads us to the discovery of 'the economy' as a distinct realm of social existence. Here we encounter the ambiguous use of the machine metaphor in the agronomic Physiocracy of Quesnay, where it was used in combination with a vitalist notion of value and an absolute monarchical state.

Noting the shift in political mechanism from an authoritarian conception of the state modelled on clockwork to a liberal account of the self-regulating economy modelled on the Watt steam governor, we turn our attention to the defining moment of classical political economy: the conversion of Adam Smith's provocative and deistic metaphor of the 'invisible hand' to a science of the inexorable 'laws of supply and demand'. Here we delve deeply into the golden age of British lassez-faire in the 19th century, and discuss the elevation of the market to the status of both a natural law *and* a moral law, which conception is at the core of neoliberal politics. Here we argue that this confluence did not arise directly from the political economy of Smith and Ricardo, but from the rise of the middle-class Evangelical movement, which has parallels in the recent rise of Protestant fundamentalism in Australia and the United States in tandem with socially conservative market-fundamentalist governments. The British Empire in the 19th century was the first to institutionalise the idea of 'the economy' as equivalent to 'the market', which was portrayed as a stable natural order that would only 'fail' as a result of 'exogenous' shocks such as political interference or natural disasters. Here we take up as a case study the response of British administrators to different 'ecological' disasters falling under their jurisdiction, the Irish potato famine of the 1840s, and the even more severe famines in India under the British Raj, when the monsoon failed in the late 1870s and again in the mid 1890s. Europe's colonies have been memorably described by the historian Ann Laura Stoler as "laboratories of modernity", where legal regimes enforcing racial identity and sexual hierarchies were first developed and then exported back to Europe to form the moral order of the emerging bourgeois metropolis and the legal order of the new 'biopolitical' state.[56] We extend this concept here to argue that Ireland and India were the experimental laboratories of political economy, and to highlight the paradoxical necessity of the need for an iron fist of colonial authority to uphold the 'invisible hand' as a universal principle of human nature and moral order. Entire populations of colonial subjects were sacrificed in order to stabilise the free-trade faith, which as we can see in the words of the Manchester industrialist Richard Cobden, easily combined a version of secular millennialism with the dream of a social physics:

> "I see in the Free Trade principle that which will act on the moral world as the principle of gravitation in the universe - drawing men together, thrusting aside the antagonisms of race, and creeds and language, and uniting us in the bonds of eternal peace."[57]

By the late 19th century, however, the messianic civilisational claims of Western political economy were under increasing pressure from anti-colonial nationalisms abroad and an increasingly organised, militant and self-conscious working class movement at home, both of which saw political economy as the basic science with which powerful commercial interests were able to engineer exploitative political machines designed to concentrate wealth in their hands. This is perhaps one of many reasons that prompted the drive among several intellectuals in the 1870s to drop all the political, historical and moral content of political economy and to develop a 'pure' economics devoid of rhetoric and on par with the 'exact' sciences. In order to achieve this, the narrative and historicist elements of political economy were thoroughly purged and the program became entirely dedicated to the full mathematical elaboration of economics as a 'social physics.'

From here we move on to the most difficult and the most intriguing section of Part II, which recalls the social and scientific milieu attending the inauguration of neoclassical economics as a 'genuinely scientific' social science. The current hostility of economics to historical method extends to the history of its own origins, and in this section we primarily follow the historian of economics Philip Mirowski who, acting on inspiration provided by earlier economists Thorstein Veblen and Nicholas Georgescu-Roegen, has thoroughly explicated a largely forgotten aspect of the history of the 'marginalist revolution'.[58] Rather than some discovery or breakthrough in empirical research that led *a posteriori* to a novel mathematical technique that could independently explain observed social phenomena, the claim to 'scientific' status involved nothing more than the wholesale appropriation of the mathematics used in rational mechanics and 'proto-energetics.' Here we will focus specifically on the breakthroughs of William Stanley Jevons, who developed the neoclassical theory of price, and Leon Walras, the acknowledged founder of the discipline with his theory of general equilibrium. This appropriation was entirely metaphorical: it was not the case for example, that traders were found to behave in a fashion so identical to atoms that they could be predictively modelled as such. Indeed the motive for this move was arguably more sociological than scientific: the emulation of physics had the effect of surgically removing the political from political economy by presenting the social phenomena of commodity exchange as a pure realm of nature, universally valid and invariant with respect to culture or history, and thus external to social relations and political power. Simultaneously, the economist was able to bask in the glorious epistemological regard with which physicists were held.

At the heart of the metaphor was the marginalist transformation of value theory, which collapsed all prior ontological distinctions between land, labour and 'capital' (which stands for both machinery and money) into a single category – 'utility'. Utility was then subjected to extensive mathematisation with an analogy to 'energy'; or rather energy as it was presented in the nascent years of the development of modern thermodynamics and the popular elaboration of the social implications of the principle of the conservation of energy. This transformative moment in physical theory paralleled the radical technological progress in the construction of fossil-fuelled heat engines. Here we have recourse to the work of Anson Rabinbach, who has documented the vast array of late 19th century social theories and political ideologies generated by another particularly fecund metaphor: the 'human motor'.[59] Our concern is not only to set the aspiration of economics to become a social physics within this wider history of the scientific culture of industrial modernity, but also to argue that the most important fact of industrial economic history was not a great leap forward in social science methodology or of technical competence in engineering. What has been largely absent until recently in economic history is recognition of the central importance of the switch of the energetic 'metabolism' of capitalism from reliance on limited, though 'renewable' flows of what is ultimately solar energy – wood, wind, water, whale oil, crops, and human labour – to non-renewable stocks of mineralised solar energy that at the time appeared more or less infinite. To cut to the chase, the essence of this critique of the crowning moment of neoclassical hagiography, the presentation of a 'general equilibrium model' of the exchange economy by Leon Walras, is that the appropriation of energy physics was bungled, inept and never approved by senior physicists. Its gravest defect was its ignorance of the most consequential development of late 19th century scientific materialism, the discovery and elaboration of the second law of thermodynamics (otherwise known as the entropy law) with its implications of irreversibility, depletion, waste and disorder. The neoclassical economists were quite unaware that they had violated their own metaphor, and later inheritors of the discipline forgot that the metaphor ever existed, treating the conservation of utility in market exchange, and the natural movement toward the 'equilibrium price level' as if it were a fact accomplished entirely within a fully independent theory of Society. This presentation of the neoclassical economy of nature leads is into contemporary questions regarding to the role of economics imperialism in the recent history of neoliberal globalisation. My argument here centres on the paradoxes implicit in modelling the laws of supply and demand upon 'laws of nature'. This metaphor hides the fact that ultimately, the smooth function of 'the invisible hand' as a 'law of force' is ultimately ensured by the sovereign violence of the 'force of law' – by the sovereign administrative, juridical, political and coercive capacities of nation states. The smooth exchanges of equivalent values at the core of the model clearly do not fit with the stratified relations of uneven development and unequal exchange evident in the 21st century global economy.

Having established the history of the constitutional machine metaphors of economics, we turn in the final section of Part II to the consequences of the neoclassical model of economy for our current socio-ecological crisis. This section of Part II deals with what is a generally ignored yet profound contradiction within orthodox model. This contradiction arises from the incommensurability between the stasis of equilibrium theory and the applied post-war economics of rapid and continuous economic growth. The development of GNP statistical accounting in the United States was part of a centralised drive to maximise the output of industrial machinery for the battle of attrition of total industrialised war. 'Growth' is of course a biological metaphor, which does not at all fit with the static model of inert and balanced 'material' forces at the core of economic theory. In this section we argue that the neoclassical theory of 'production' and economic growth derives from an implicit ontology of nature that extends the foundational errors of the Walrasian equilibrium to nature in general. In accordance with Douglas-Durkheim-Mauss-Mirowski thesis, the outdated proto-energetics that was pressed into service to naturalise highly unrealistic ideals of a 'market' subject to 'perfect competition', was then re-imposed upon Nature in development economics. In line with the implications of the proto-energetics metaphor, neoclassical growth theory views nature as composed of a completely uniform and malleable matter/energy that merely requires the application of 'science' to open an unlimited horizon of perpetually expanding commodity production.

Derived from a vast network of machine metaphors, the abstract neoclassical economy of nature obscures the concrete properties of real industrial machines in transforming the surface of the living earth and approaching the regenerative limits of the biosphere itself. Despite conforming to the second law of thermodynamics, biological life bears little functional resemblance to the iron steam engines which led to the discovery of that fundamental law. In appropriating the form of physics, economics was able to transcend all reference to the physical realities of labour, land and machinery and constitute abstract capital as 'energy' or 'force' itself, representing 'the economy' as if it were a perpetual motion machine. The biological metaphor of 'growth', while opening the possibility of viewing 'the economy' as a potentially mortal 'industrial organism' dependant on its environment for 'food' and the absorption of its wastes, is similarly violated by the wholly unnatural assumption of infinite and perpetual growth. Rather, the entire discourse of industrialisation and development as 'growth' reinforces the idea that it is the machines themselves that are productive, rather than the energy consumed in their operations, the social relations of the global division of labour, the unique qualities of specific natural resource inputs, or the reproductive powers of biological life harnessed by agriculture.

In the remainder of the thesis we consider something perhaps more serious than the disintegration of social norms, a situation that as we have already suggested, is associated with the apocalyptic genre. Here we consider the scientific announcement of the continuing disintegration of the biosphere – the aggregate of all ecosystems – by the science whose reason for being is the study of ecosystems. Through developing this narrative, we will also consider the theme of what ecology means for 'philosophy of history', by which I mean discourses about the totality, meaning and direction of human history 'as a whole': the carbonisation of the atmosphere and the threat of runaway global warming provides only the latest and perhaps most serious example of the way in which Nature and Society are increasingly impossible to separate, and the consequence that the sciences that once sought to speak for either side of the dichotomy are now thoroughly politicised.

Part III of the thesis presents a history of the origins ecological science and rise of the concept of the 'ecosystem', the scientific object at the heart of modern ecology. It explores the origins of ecology as a science of the biological 'Economy of Nature' in theological discourse and early modern science, its links to political economy in the 19th century, its vitalist period in relation to organicist ideologies of national progress during the 1930s, and most importantly its subsequent formal integration with thermodynamics in the mid-twentieth century. The consolidation of ecology as a 'hard' science was largely achieved as a result of the inter-disciplinary development of cybernetic systems theory within the American military-academic complex, and ecosystems ecology came into its own through direct sponsorship by the military and the Atomic Energy Commission. The irony here is that research during this period formed the basis of ecology's ongoing biophysical challenge as 'the subversive science' to the reigning 'economy of nature', the orthodox economics of market equilibrium and perpetual growth. The atomic arms race of the Cold War was the apocalyptic context of ecology's energetic overdetermination: ecologists were the first to publicise the systemic hazards associated with the global diffusion of radiation and the ecological meltdown that would accompany a nuclear war and the subsequent nuclear winter. A new role was thus conferred upon the ecologist as the moral voice of science in a technological society, and by the early 1970s, this led politically active ecologists to the rejection of the entire post-war political-economic consensus on the standard model of economic growth. Of key interests here is the different intonations given the metaphors of 'growth' and 'equilibrium' in economics and ecology, and the parallel with economic science – the machine metaphor was imported into the 'tangled bank' of biodiversity in order that ecology could gain respect as a genuine science. Part III is introduced with a discussion of the announcement of ecological crisis in the late 1960s and the early 1970s as an apocalyptic rupture to the narratives of industrial millennialism. Environmentalists claimed that only solution to the deepening industrial apocalypse was an end to economic growth and the inauguration of an 'age of ecology' characterised by the redemptive restoration of 'ecological equilibrium' on a global scale.

The narrative has several major themes, which are dealt with sequentially. In the first section of our history of ecology, we discuss the tangled roots of ecology in pre-modern Western knowledge systems, suggesting that it has a much longer-term relationship with the grand historical themes of the West than its recent rise to importance belies. Of particular interest are the deep origins of the 'natural law tradition' and the antiquity of the notion of the balance of nature. The formulation of a modern disciplinary research program under the name ecology only dates back a century and a half, but the study of the 'economy of nature' is ancient. The complex of ideas contained within the phrase 'the balance of nature' is perhaps as old as written philosophy itself, appearing explicitly in the writings of Herodotus. Of particular interest here is the provenance of the term *oeconomia,* originally a theological term used to describe the 'dispensations' of God toward Man and Creation through successive ages or covenants. By the 17th century the term was frequently used by theistic naturalists to describe the order of Creation, and it is only in the 18th century, characterised by humanist tendencies of the Enlightenment, that a bifurcation in the term occurs along the lines of the Cartesian dualism, and the 'economy' emerges primarily as a term to describe the order of Society. In this period the order of nature is conceived within the deist natural law tradition, which held that nature and society are governed by an autonomous natural law, which is both harmonious and rational, in a way coherent with the rationality of the human mind because of the unity of purpose inherent in the works of Divine Providence. The greater order of species life and non-human organisms remained a neglected topic, and given the paucity of systematic taxonomical data, languished as an obscure and speculative branch of natural history. Linnaeus, who invented a universally accepted system of binomial classification fundamental to the study of biology, also wrote the first 'properly ecological' text in 1749, telling entitled *Oeconomy of Nature*. Prior to the discovery of deep time in the nineteenth century, natural history was not separable from human history, and thus was bound up in the eschatological narrative of Christianity, with its Creation and Apocalypse.

Second, we look at the relations between ecology and other sciences in the late 19th century – especially political economy – and look at the consistent blurring of the lines between Nature and Society as the context in which ecology staked out its claims to describe the natural order and attempted to discover general 'laws of nature' As theology gave way to science as the privileged lodestone of truth and source of metaphors in the mid- late 19th century, millennialism was to some extent displaced by the ideology of progress and secularized in the philosophies of scientific materialism, as knowledge is organised into the increasingly specific discourse communities under the broad heading of Natural or Social sciences that we recognise today. 'Ecology' was coined as a term by the German scientist Haeckel, which posited a break from the older study, 'economy of nature', and established ecology as a research programme connected to the elaboration of "the study of all the complex relationships referred to by Darwin as the conditions of the struggle for existence." [60] Here we look at the complex exchange of metaphors between political economy and the life sciences in this period, particularly between Malthus, Darwin, Spencer and Marx. We note the simultaneous elaboration of evolution as a 'struggle for existence', and the arguments of lassez-faire economists around the 'naturalness' of 'the market' as the ordering logic of the emerging industrial society.

In the third section we discuss the rise of ecology as a distinct science, looking at the Western frontier of the United States. As we will see with the history of Samuel Clements, whose work did much to raise the profile of ecology as a science in the early 20th, ecologists needed to be of use, and this for Clements this meant making a contribution to national economic development. Just as neoclassical economics allowed the liberal state to develop an 'objective' language for its fiscal, trade, and industrial policies, so ecology was proposed as an objective tool for managing the social conflicts and boom-and-bust cycles of frontier of agricultural expansion in the early 20th century in the United States. We discuss the communitarian metaphors favoured by early figures such as Warning and Clements, who formulated the study as the search for the 'laws of succession' leading to the 'climax superorganism.' We note the resemblance to then contemporary historicist stage theories of social progress, especially the post-1929 organicist critiques of the speculation-driven stock market economy. These social philosophies called for increasing 'cooperation' in the 'social organism' and hoped increasing scientific control would rationalise the chaotic and inefficient processes of production and distribution of the market.

In the fourth section we look at the drift of ecology away from vitalism and historicism and into energetics and mechanism. At this point we trace the complex intellectual pathways linking evolution, energetics and systems theory to ecology, through the interdisciplinary polymath Alfred Lotka. Lotka's attempt to derive the 'struggle for existence' axiomatically from thermodynamics later inspired both game theory and concerted efforts to make ecology a 'hard science'. Lotka's entire approach to the mathematisation of biology was inspired by the key figures attending the birth of neoclassical economics: Jevons, Pareto and members of the 'social energetics' movement such as Solvay. In the process, the communitarian focus on species and organisms was downplayed as the 'ecosystem' was reconfigured in discourse as an economy of natural machines competitively transforming energy and maximising production consumption within the constraints of energy budgets. In a strikingly paradoxical parallel to the neoclassical synthesis of the 1870s, energy was treated in ecosystems ecology as a 'universal medium of exchange' regulating the general equilibrium of the economy of nature. Given the influence of Lotka on the second reconfiguration of neoclassical economics around cyborg themes and especially game theory, I believe a novelty of this thesis to point out that Lotka has produced intellectual ancestors adapting aspects of his bioenergetic approach to theories that both support the idea of infinite economic growth and categorically reject it.

In the fifth section of Part III, we discuss the road to the mechanistic formalisation of ecology as the theory of ecosystems, and its not entirely subversive coming of age as the 'subversive science' in the 1960s and 70s. We discuss the rise of the 'cyborg sciences' in the atomic age, a result of the United States' cold war investment in the military-academic complex, the intellectual and funding milieu nurturing both the reconfiguration of orthodox American economics and Odum's 'subversive' ecosystems ecology. Cybernetics, the study of control mechanisms in organisms and machines, seemed to the optimists of the era as promising to unify the sciences, bringing social theory and biology at last into unity with the predictive physical sciences. Systems modelling with the newly minted digital computers – despite their puny computational powers by contemporary standards – were thought to offer the extension of technocratic control over the phenomena studied and even the possibility of the engineering of entire systems, including the weather. In the work of H. T. Odum, we see this impulse brought to the fore as ecology is claimed as a master science for the total quality management of 'the system of Man and Nature', uniting ecology with the physical sciences in one direction and the social sciences in the other.

It is at this point that ecology becomes subversive, and in becoming a biologically informed 'social physics' collides headlong with economics. The epistemological crash took place within the energetic metaphor that secured the legitimacy of the respective claims of each to be a 'hard' science, and exfoliated into the ontologically contradictory analogies of 'growth' and 'equilibrium', which meant entirely different things depending on which side of the Economy of Nature one was committed to. The final section of Part III compares Odum's idiosyncratic *Environment, Power and Society* (1971) with a book published in the same year, Georgescu-Roegen's *The Entropy Law and the Economic Process.*

Both books critique the neoclassical theory of production and the enthusiasm for infinite 'growth' as an increasingly disastrous contravention of the laws of nature. Claiming systems ecology as the necessary unified science to ward off the gathering apocalypse of system wide collapse, Odum tries to reverse engineer economics, political science, ethics and even religion within a single epistemological framework, producing a diagrammatic energy theory of value capable of gearing economic activity down toward a steady state compatible with the biosphere. Brilliantly critiquing mathematical economics from within in a rigorous analysis according to biological consequences of the entropy law, Georgescu-Roegen establishes a bioeconomics of fundamental limits that secures his place as the father of contemporary ecological economics. While providing few predictions and no solutions, he ends with a comprehensive denunciation of arithomorphism, behaviourism, positivism, mechanism and all other determinisms, and a plea for the irreducible and untranslatable value of cultural experience, the ultimate goal of the economic process.

To finish the thesis by bringing it up to date, the Conclusion will briefly discuss the continuing interactions of ecology and economics in the contemporary period. This section is not intended to be comprehensive, but to indicate the abiding relevance of the history accounted for in the thesis, as well as the usefulness of the method it has employed (the combination of metaphorical analysis, the DMD thesis, and social, historical and political contextualisation) in deciphering the continuing imposition of metaphors upon the social discourse about nature by those with the ideological power to do so.

Here we examine the interplay between 'the new ecology', which essentially denies the existence of 'the balance of nature', and the 'the new economy' of the 1990s, which some pundits claimed had severed the connection of economic growth to the material world by opening an unlimited 'bioelectronic frontier' where 'growth' had become purely informational. The associated celebration of globalisation in mainstream discourse was noticeably divorced from the discourse of global ecological crisis. At issue here is the popular synthesis of the far-from-equilibrium thermodynamics of Ilya Prigogine, the new theories of complexity and chaos, which claimed to have thoroughly integrated biological evolution and the second law, and the promissory rhetoric of the biotechnology industry that has flourished since the advent of the first 'life patent' in 1971 and the technical 'recombination' of molecular DNA achieved in 1973. What was remarkable about the new dispensation within the life sciences is how easily it lent itself to the new economy's market fundamentalism and exuberant 'postindustrial millennialism'. Prigogine and Stengers' seminal work *Order out of Chaos,* which explicated a new biochemical theory of emergence to wide audience, contained a foreword written by the 1970s futurist Alvin Toffler, who proposed a metascientific paradigm shift from Newtonianism to Prigoginianism in line with his theory of radical post-industrialisation.[61] This and other key documents of complexity theory fed into a new post-Newtonian 'social physics' which celebrated disequilibrium and raised it to the status of a law of nature from which no polity had a right to exempt itself. This Prigoginian social physics perfectly met the needs of neoliberal deregulation and the brand of anarcho-libertarian capitalism pushed by the corporate think tanks. Businesses, corporations, markets, products, brands and national economies were all equated metaphorically with 'organisms' or 'species' in the business management literature at some stage or other, slugging it out in the pristine and perfectly competitive neo-Darwinian rainforest where any attempt to engineer 'equilibrium' –a fallacious concept for the neoliberal avant-garde – in the form of social protections or institutional regulation would only ruin the productive chaos from which the spontaneous order of the NASDAQ bubble had arisen. What was particular pernicious about this metaphor was that it obscured ecological crisis by conflating 'business' with life itself. A popular 'new economy' text, Michael Rothschild's' *Bionomics: Economy As Ecosystem* (1995), insisted on the need to move beyond industrial age language and thinking:

> "The economy is not an engine, it's an ecosystem. And machines don't grow, ecosystems do. Economic policy should not be about 'fine-tuning' our economic machine or, even worse, dividing up slices of a fixed economic pie. Rather, it should be about cultivating growth. If capitalism is a jungle, socialism is a zoo." [62]

It is hard to see how handing out fair slices of pie is a policy error resulting from the 'old economy' machine metaphor, but the implications are clear. Lassez-faire was the 'natural policy', although this time not because it led to a neoclassical equilibrium which married efficiency with social justice and Paretian 'welfare' but precisely because all of these goals were undesirable obstacles to rapid 'growth'. The metaphorical appropriation by the 'business revolution' of the new ecology effectively acted to naturalise the catastrophism and chaos of speculative capital, the supernormal paycheques of star CEOs, and the increasingly precarious condition of ordinary workers on short term-contracts and faced with declining real-wages and continuous cuts in quality public services. The ecosystem metaphor led not only to stringent calls to dismantle the New Deal and sell off and privatise what was left of the welfare state: as one enthusiastic reviewer of Rothschild's put it:

> "Thinking of them [economies] as evolutionary/biological systems might remind us that cultures, economies and institutions influence and control us just as much as we hope to influence and control them. Better yet, it might trigger the same scepticism that we apply to those who'd massively intervene in rain forests and oceans. I buy it. He's right."[63]

Here what is meant by 'massive intervention' is unclear: does it mean the rapid, irresponsible industrial clearcutting of forests by transnational corporations using bulldozers and chainsaws? Or does 'massive intervention' refer to regulation and the risk management of the precautionary environmental state? Either way, the great and monstrous irony of the <economy is an ecosystem> metaphor was that its strident opposition to democratic regulatory institutions further undermined actually existing ecosystems. Calls for nature conservation, endangered species protection, family planning, precaution in biotechnology development, mandated emissions standards, carbon taxes, subsidies for photovoltaic technology development, quotas on fisheries, the labelling of genetically modified food or any other policy designed to maintain the integrity of the biosphere and restore the 'balance of nature', could be tarred as an unnatural intervention in the miraculous powers of 'the market' to bring 'order out of chaos'. Whatever actual biologists may have thought about the neoliberal appropriation of their science, in rejecting the notion of 'ecological equilibrium', the new ecology was easily bent into providing support not only for the deregulation and privatisation of the atmospheric, terrestrial, oceanic and biogenetic commons, but also into upholding the millennial doctrine of infinite economic growth.

## Methodology: on Metaphor, Scientific Knowledge and the Social

The declining years of the 20th century ushered fully into public consciousness the notion that our era is characterised by global environmental degradation. This has had profound implications for popular concepts of nature, and has at once extended the influence of scientific institutions and politicized their assessments of technology and economic policy. In addition to this politicization of the sciences, which is driven by the increased sensitivity of populations to ecological risk and the attempt by corporations to ward off the 'sovereign risk' presented by new regulative restraints on their activities, the most basic metaphors that underscore research on nature in physical and biological sciences have increasingly been challenged by theorists across the spectrum of disciplines, with important potential implications for the way concepts of 'nature' are operationalised back into policy. Nature is not what it used to be, and neither is science.

I would like to make it clear from the outset that this thesis, critical as it is of a simple reading of economics or ecological science, is not intended as an act of demolition. The ultimate justification of scientific inquiry is not, in my view, knowledge for its own sake, but to provide correct information to solve practical problems and to improve the general human condition. That this was the goal of the political economists such as Adam Smith, John Stuart Mill, Karl Marx and John Maynard Keynes, who were also moral philosophers, I am convinced. Likewise, notions of social justice were at the heart of Leon Walras' efforts to create a social science on par with physics. Similarly, ecologists such as Samuel Clements and H.T. Odum, despite the critiques that can be directed at them, were not bird-watching escapists from the social problems of their day but actively sought to produce ecological knowledge that was timely and relevant to the long term sustainability of society – although whose societies and whose conditions are an altogether different question. The 'improvement of the human condition' need not be interpreted in a strictly instrumental or productivist way, according to the mechanical values of efficiency or the supply of $x$ kilocalories per citizen per day. Values such as justice, fairness and trust can never be replaced by scientific theories, science can describe the limits of technical feasibility, but can ultimately only serve the values that the decision-makers hold. Finally, the sublime beauty of the living world, the pleasure of immersion in clean river waters, and the sense of astonishment one experiences on encountering a rare moth or epiphyte in a deep corner of the forest are, I think, essential to the quality of human life.

At the time of writing, it seems plain that the theoretical aporia represented by the incommensurability of ecology and economics epitomises the fragmentation of nature produced by the specialisation of academic disciplines, and this comes into sharp relief where they intersect with policy. This problem of ill communication requires us to take a brief look at the philosophy of science. With his 1962 work, *The Structure of Scientific Revolutions*, the philosopher of science Thomas Kuhn made popular the notion that alternate scientific paradigms can be incommensurable. Two theories are said to be incommensurable if there is no common theoretical language that can be used to compare them.

> "[..] the early developmental stages of most sciences have been characterised by continual competition between a number of distinct views of nature, each partly derived from, and roughly compatible with, the dictates of scientific observation and method. What differentiated these various schools was not one or another failure of method – they were all 'scientific' – but what we shall come to call their incommensurable ways of seeing the world and practicing science in it." [64]

The interest of this thesis is to reconstruct the 'early developmental stages' of economics and ecology to try and discover the sources of this conflict. It seeks to provide a historically informed analysis of the defining moments of two sciences, the moments at which they become 'normal sciences' with a paradigmatic research program that defined what counted as legitimate science. Ecology and economics are the two sciences in question and the relations between the two distinct worldviews or versions of nature produced by them are the concern of this thesis. And it is the general incommensurability of the worldviews generated by the two sciences that concerns us here, as manifest in the widely noted disjunction between the effectively infinite economic growth posited by orthodox economists and the dire predictions of deepening bisopheric crisis associated with the public interventions of ecologists.

One of the consequences of Kuhn's' notion of incommensurability is the following question: if two scientific theories are incommensurable, how can one compare them to each other in order to determine which is most true?[65] Such a view is antithetical to what we might call a Comtean or positivist view of science in which science as a whole is the straightforward accumulation of factual knowledge over time. As there is a single universe, scientific truth must ultimately be unified across all disciplinary areas.[66]

Using examples from the history of science, Kuhn argued that in reality, the evolution of scientific knowledge did not proceed in this way. Rather, knowledge creation was contingent upon the intellectual climate of the era or even of the specific disciplinary or social context within which it took place. What counts as a legitimate research program was not, for Kuhn, evaluable according to the performance of universal scientific method, but dependant on a host of underlying priorities, values, languages and semantic contexts that generate unique conceptual frameworks and methodologies, which Kuhn famously called paradigms. According to Kuhn, the proponents of different scientific paradigms cannot be completely reconciled to each other's point of view because they are, in a manner of speaking, living in different worlds. Among others, Kuhn gave as a reason for incommensurability between competing research programs that the vocabulary and problem-solving methods that the paradigms use are often different: the proponents of competing paradigms rely open different conceptual networks embedded in different terminologies. This means that knowledge resists complete translation across disciplinary boundaries. For some, the intolerable consequence of this view is ontological relativism: as Kuhn seemed to suggest when he wrote, "when paradigms change, the world itself changes with them".[67]

Kuhn's view of science as revolutionary, unstable and discursive rather than the incremental progress toward ever truer truth engendered an ongoing debate, with a rearguard action forthcoming from post-positivist falsificationists such as Karl Popper and Imre Lakatos. Kuhn's intervention led in another direction to the even more radical relativism of Paul Feyeraband. The Kuhnian account of the historical contingency of natural science preceded by four years and in many ways parallels Michel Foucault's account of the 'human sciences' in *The Order of Things* (originally published as *Les Mots et les Choses* in 1966) in which he claimed that all periods of history have possessed certain underlying conditions of truth (epistemes) that constituted what was acceptable as discourse, and that these epistemes underwent long periods of stability between moments of rapid change.[68] Foucault's discourse analysis of *epistemes* showed that language was not merely a set of necessary or even arbitrary signifiers, but the locus of social power, positioning subjects, objects and concepts in its hierarchical field and determining what it is possible to say and for whom it is possible to speak.

It is probably worth mentioning that Kuhn considered it his misfortune to be a favourite source among social 'scientists', and perhaps frightened into a more conservative position by the relentless attention of various undesirable radicals and relativists, in his late career frequently found cause to disassociate himself from the full implications of his account of science. (A similar back-pedalling under the glare of publicity can be observed in the latter writings of Darwin, which were often resolutely Lamarckian). Although avoiding his overworked terms such as 'paradigm', and the distinction between 'normal' and 'revolutionary' science, this thesis will probably commit the same insult. Nevertheless it is hoped that this thesis remains close to the spirit of the original analysis, and does not stray too far into the woollier areas of the sociology of scientific knowledge inhabited by the postmodernist bogeypersons of the 1990s 'science wars', who in their attempts to cut scientists down to size were reported to have applied the universal acid of Derridean deconstruction to the 'texts' of quantum electrodynamics, or to have suggested that Einstein's famous equation $E=MC^2$ was irredeemably 'gendered'.[69]

In steering a conveniently safer path, we might rest on the authority of some fairly respectable ecologists who note while humanities PhD students are encouraged to do solitary research and are rewarded for theoretical innovation with publications, neophyte scientists tend to work in teams supervised by a principal, and for the most part publish with their adviser. Conceptual innovation is an extravagance best avoided until tenure is achieved.

> "Within the social science discipline of history of science, Kuhn's notion of paradigm has been nitpicked to death. By contrast, we practising scientists know all about those tacit agreements not to ask certain questions. There is indeed structure to scientific revolution, particularly in the little revolutions in which editors and cliques resist and champions of radical new findings fight on to acceptance of some new method. Dark humour making the rounds says that science moves forward one funeral at a time."[70]

This section on methodology will attempt to outline a position that provides legitimacy for the research methodology employed here, it is hoped that the reader will recognize that to summarise these long, ongoing and often acrimonious debates in the philosophy of science is well beyond the scope of our present concerns. As a non-scientist largely reliant on secondary and interpretive sources as to what counts as science, this author wishes to avoid making spurious adjudications within what remains a highly charged debate. Rather the intention is to provide a partial genealogical and historical narrative account of the origins and emergences of the research objects called 'the economy' and 'the ecosystem', the main conceptual units of theories that, two many minds, are presently incommensurable. Suffice to say that Kuhn's suggestion that it is not possible to provide truth conditions for science independent of its historical paradigm has inspired the author to conduct an archaeological dig for the historical sources of the conflict between economic and ecological knowledge.

For our purposes, we will take Kuhn's' account to suggest that if economics and ecology are considered as distinct 'paradigms', then a reading of the lay literature on the subject gives one the impression that humans occupy simultaneously two 'economies of nature', called respectively 'ecosystems' and 'markets', which are analytically distinct and theoretically bounded one from the other. It seems to me that this compartmentalisation, ordinarily reproduced in the common reference to 'nature' as 'the environment', contributes greatly to the intellectual and political paralysis of modern society exposed to socially and technologically generated ecological risk, or what Ulrich Beck calls the 'apocalypse blindness' of the social sciences. Given the hegemony of the neoclassical approach and the primacy of economics in the policy field, this division between Nature and Society leads to fairly acute problems when trying to evaluate the relationship of the economic process to the biosphere for the purposes of policy, or 'knowing what to do'. Although this is becoming less so, environmental policy is still very much considered a separate and subordinate department of government: if I recall correctly, only ten years ago in Australia it was a part of a minor federal portfolio under the Minister for Sport, Leisure and the Environment. Thus we have the main task of government as facilitating the optimal conditions for national economic growth, with minor funds directed toward the scientific institutions that document the continued dismantling of the biosphere. From the Greek derivations, it is clear that economics (the study of the 'laws of the household', oikos + nomos) and ecology (the study of the 'logic' of the household, oikos + logos) approach the same problem from different angles. As these sciences have developed in the last century or so, however, the tendency has been for the former to excise non-humans in order to focus on the Nature of Society and the latter to exclude humans and their artefacts in order to describe the Society of Nature.

In the spirit of E. O. Wilson's notion of 'conscilience', it would seem logical and desirable that the basic knowledge of any science ought not be in contradiction with any other.[71] It is more than clear from a comparison of the prognoses of ecologists to those of economists on the future of industrial capitalism that disciplinary insularity and specialisation is a contributing factor in the persistence of business as usual. On the part of economists, their science continues to encourage genuflection to the gods of perpetual growth, even as the discussion of climate change, biodiversity collapse and water scarcity proliferates. Ecologists, for their part, it seems have not yet convinced publics that they know what to do to redirect Society away from a collision with Nature in a way that doesn't radically restrict the freedom and standard of living enjoyed by the one-fifth of humanity that enjoys unprecedented levels of consumer prosperity. What kind of peace terms can we expect of the two household sciences of the *oikos,* given they do not agree? Will we have an adjudicated debate, or will it be science versus science? Will the friction of these contradictions on the borderlands generate a fire strong enough to consume the house? Is the ideal consilient relationship one of convergence, symbiosis, or predation? Were we to follow Wilson's advice and search for general principles governing the complex wholes of which ecology and economics are but partial representations of, what kind of outcomes would be possible? What could the suited gurus of reserve banking and financial strategy submit to learn from the field ecologist in her muddy boots? Wilson's own efforts at consilience have meant a search for the ground zero of 'human nature' in sociobiology, the callous reduction of almost the entire field covered by the humanities and social theory to the hardcore genetic determinism of evolutionary biology and molecular DNA. This effort to reconstitute the terrain of universality, as has been pointed out by Mirowski, is complicated by the fact that Wilson's classic 1975 text employed simple Marshallian neoclassical models to describe insect behaviour, which was accorded little significance at the time, but speaks volumes for the prospects of a unified science that will tell us 'what to do' about the deepening conflict between the global economy and the biosphere.[72]

Wilson's project for interdisciplinary coherence is arguably a revival of the positivist spirit, after the decline of the strong programme of logical positivism advanced by Rudolf Carnap, Otto Neurath and others of the Vienna Circle in the 1930s. As Mary Midgely has argued, for Carnap, something called 'science' was not merely a store of value-free facts or "correct information" but an entirely comprehensive epistemological, moral, ideological and governmental system of knowledge that could "encompass the whole range of human thought on all subjects."[73] In the words of Carnap himself: "When we say that science is *unlimited*, we mean that there is no question whose answer is in principle unattainable to science." [my italic][74] Similarly, the basic proposition of Wilson's vision of 'consilience' "is that all tangible phenomena, from the birth of the stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics."[75] The idea that the inner workings of the Reserve Bank, the Liberal Party, the Australian Research Council, and the Bundjalung Aboriginal Corporation should all one day be described in mathematical terms integrated with the laws of physics may be reassuring to those who still hold out the hope for a coming 'social physics'. As we will have cause to argue again, this move to ground social values in science reverses the move made by Galileo when he narrowed the domain of physics, excluding from it all questions of value and meaning.[76]

On their own terms, the Vienna circle's project depended on the development of a rigorously logical, non-metaphysical and non-metaphorical language of *Einheitswissenschaft* (unified science) in which all scientific propositions could be expressed and which would allow consistent standards for empirical testing.

> "The analysis of the concepts of science has shown that all these concepts, no matter where they belong, according to the usual classification to the natural sciences or to psychology or the social sciences, go back to a common basis."[77]

For Carnap, what appeared to be fundamental differences between separate areas of scientific inquiry were merely: "the appearance of fundamental differences between the sciences [...] the deceptive result of our using different sub-languages to express them."[78] This project is admitted by all to have failed. One of the problems was the challenge presented by the philosophers Pierre Duhem and William Quine, who argued that it was impossible to test any specific scientific hypothesis in isolation, because any empirical test of the hypothesis requires testing of one or more of the background assumptions germane to the discipline in which it arose. Boylan and O'Gorman have discussed the meaning of the Duhem-Quine thesis for economics, but one might easily substitute 'ecology' for 'economics':

"Quine developed a holistic view of scientific language in which scientific descriptions are theory-laden. [...] As it developed in historical time, economic language is not independent of economic theory. A purely descriptive language, totally uncontaminated by theory, is not available to economists in their descriptive endeavours. The individual descriptive statements of economists are inextricably embedded in a holistic web of interrelated sentences which in turn are holistically connected to theoretical sentences. The descriptive language of economics is theory-laden."[79]

The wide acceptance that the language of theory and the language of description could not in principle be separated was one consequence of this intervention. Another was that in practice testing a theory requires the testing of one or more background assumptions (also called auxiliary assumptions or auxiliary hypotheses). To the extent that these background assumptions were also subject to the same underdetermination, the possibility arose that specific scientific statements could only genuinely be exposed to empirical testing (and thus falsification) if the entire network of interrelated hypotheses and assumptions were simultaneously tested. Unless one could finally reach some indisputable bedrock of knowledge, it would appear that we are faced with an infinite regress. The strong version of the Duhem-Quine thesis has been put this way by the philosopher of science Mary Hesse: "no descriptive statements can be individually falsified by evidence, whatever the evidence may be, since adjustments in the rest of the system can always be devised to prevent falsification."[80] Worse was the possibility that some of these 'auxiliary hypotheses' were not as scientific (in the logico-mathematical sense) than they had always appeared, and were rather held together with the dubious conceptual glue of what was generally seen by modernist science as mere literary device – metaphor.

In 1983, Donald McCloskey wrote a provocative article called 'The Rhetoric of Economics', in which he argued that despite practitioners assumptions to the contrary, the mathematical idiom of economics did not necessarily imply a rock-solid natural scientific foundation: due to its reliance upon scarcely examined metaphors, economics ought rather to be thought of as a branch of the old classical discipline of Rhetoric, the art of oratory and persuasion.[81] The fact that metaphors abounded in orthodox economics and the recommendation that they perhaps be taken seriously caused some consternation and ruffling of feathers among the disciplines stalwarts, most of whom had always proceeded as if metaphor were entirely absent from the field. The essence of metaphor, 'understanding or experiencing one kind of thing in terms of another,' [82] clearly implies an ambiguity in the way the subjects' perception and comprehension of objects operates. Such imprecision and ambiguity is expected from poets, but is anathema to science. Revealing metaphors in economics and thus comparing it to poetics provoked Robert Solow, a scientifically minded economist famous for the reigning model of growth (which won the 1987 Swedish Rigsbank Prize in Economic Science in Honour or Alfred Nobel)[83], to defend the intrinsic integrity of the approach. "What matters is that we, as scientists, write down in a precise way what we mean. Precision is one of the standards by which we measure science. And by that standard, metaphors are unscientific. If metaphor occurs in economics, so what? Its existence is incidental to the business of doing economics." [84] Remaining true to his own training in the neoclassical school, McCloskey did not suggest that an acknowledgement of the rhetorical function of economics altered the basic 'truths' of the discipline in any radical sense.

The thesis I wish to advance here takes precisely the opposite view; the piled high documents of socially generated global environmental change, and the fact that neoclassical economists of various shades are frequently found in the vanguard of anti-environmentalist, anti-regulation, infinite growth positions demand that we examine the scientific rhetoric of economics. Whether committed to the atomized, farsighted rational maximiser of the frictionless Walrasian equilibrium, or the paranoid, uncertain and war-like game theorist of the more up to date Nash equilibrium, or the self-realising optimal growth path of Solow et. al, economists frequently treat their graduate school microeconomics as a truth machine capable of subsuming all other discourses. An example of this may be found in the furore generated by Bjorn Lomborg, whose compendious statistical work *The Skeptical Environmentalist* (2001) claimed to dismiss not one but nearly all areas of 'the litany' of environmental concern.[85] Warnings of unsustainable population growth and soil exhaustion, rapid biodiversity decline, fishery collapse and systematic deforestation, desertification, looming energy supply crunches and the danger of runaway climate change were *all* portrayed by Lomborg as being radically overstated by environmental scientists and activists. While admitting that environmental degradation did exist, his conclusion was that all major global aggregated statistical indicators of environmental quality showed either profound improvement or the stabilisation of risk within an acceptable range. Applying cost-benefit analysis to prioritise attempts to further reduce these risks Lomborg showed that in most cases attempts at conservation or reform were simply a waste of money. Amid the firestorm of public debate that ensued, Lomborg was roundly criticised by earth scientists of various disciplinary persuasion, among them Stuart Pimm, the conservation ecologist, who wrote with some agitation:

> "I'm afraid there isn't much scientific controversy about Mr Lomborg. He occupies a very junior position in Denmark (an 'associate professor' does not exactly mean the same thing that it does in the United States), he has one possibly very flawed paper in an international journal on game theory, no publications on environmental issues, and yet manages to dismiss the science of dozens of the world's best scientists, including Nobel laureates, Japan and Crawford prize-winners and the like. As any sensible person would expect, his facts are usually fallacies and his analysis is largely non-existent."[86]

Despite vigorous debunking by a welter of specialists in climatology, biology and ecology and other sciences, that Lomborg's training was restricted to statistics and game theory was taken as evidence by his supporters of a superior mathematical ability to cut through the alarmist pretensions of actual scientists by holding them to the common-sense pragmatism and strict standards of mathematical proof required of cost-benefit analysis. His overall conclusion - that there was no real danger to the biosphere, and that general improvements in environmental quality had almost nothing to do with the regulatory policies fought hard for by environmental activism - was applauded by economists, who share his basic epistemology, in which free markets optimize all resource allocation decisions to maximum efficiency, and economic growth generates the resources with which to make investments in 'environmental quality' that are 'demanded' by high income earners. As growth raises incomes, growth is good for the environment. The conclusion, which won him the support of (among others) *The Economist* magazine, WTO chief Michael Moore, Australia's pre-eminent conservative libertarian think-tank the Centre for Independent Studies, and the US neoconservative journal *The Weekly Standard,* was essentially that deregulated global trade and unceasing economic growth would more or less automatically correct environmental degradation from whence it remains in the 'less developed' global South by raising 'incomes' to the point where everybody can afford to pay money for additional increments of 'environmental quality'. The alternative conclusion, that transnational economic growth and deregulated globalisation systematically shifts the non-monetised 'real' costs of resource extraction and exposure to pollution to disempowered social categories was clearly unpalatable.

While one could easily multiply examples of the different worlds inhabited by economists and ecologists, most interested followers of these debates, regardless of their epistemic commitments, would agree that radical incommensurability is a feature of mainstream public discourse on 'the real state of the world'. One response to this aporia is to simply accept that the mind-bending complexity of interactions between weather, financial markets, technological change, global trade, exotic debt instruments, and the fate of the Patagonian toothfish is beyond the scope of any model to finally decide the case for a 'zero-sum' or a 'cornucopian' model of human-environment relations one way or the other. However it seem to me that this fence-sitting is an intellectual unsatisfactory way out of the dilemma. At the level of the biosphere, economic growth cannot be both infinite and finite, both 'sustainable' and 'unsustainable' at the same time. The philosopher Gilles Deleuze and his psychiatrist co-author Felix Guattari subtitled their major work 'Capitalism and Schizophrenia'; the current enthusiasm for 'sustainable growth' seems to this author to best exemplify the affective dimensions of the promissory rhetoric of contemporary economics and its encounter with totality of the earth.[87] The rationale for this study revolves around the question of commensurability (or otherwise) between the two disciplines because its consequences are vital for contemporary questions regarding the ability of modern societies to adapt and respond to the self-produced risk of irreversible ecological meltdown and the consequent chaos of social disintegration. In politics, this question of commensurability plays out in the ideological clash between neoliberalism (known in Australia by the apposite term 'economic rationalism'), and the environmental movement in its many manifestations. If we accept that the dominant neoliberal worldview is the political expression of neoclassical economic science, and that environmental politics is similarly related to the findings of ecology, then this apparent incommensurability between the two disciplines is of grave concern and deserves analysis.

Neoliberalism rationalises its faith in the marketisation of social relations of production and exchange because of the presumed connection of free trade with the realisation of the 'efficiency' of comparative advantage and thus higher rates of economic growth. Environmentalism might be defined broadly as a social movement which seeks to place the degradation of the biosphere at the centre of political and economic debate, believing that unrestricted industrialisation will ultimately undermine the welfare gains of expanding GDP by collapsing the ecosystems which are ultimately the source of Earth's abundant life. Clearly, the assertion of infinite growth cannot be reconciled with the finite or limited character of the economic process as asserted by environmentalists. This polarisation of worldviews has been somewhat complicated by the emergence of such discourses as free-market environmentalism, sustainable development, and ecological modernisation, which assert that economic growth is or potentially is 'good for the environment' because the technological evolution associated with large-scale economies ultimately results in reduced environmental impacts. The popularity of the term 'sustainable development' since its introduction in the 1987 Brundtland Report, has allowed a compromise on this fundamental disagreement on the character of growth that paved the way for the institutionalisation and mainstreaming of environmentalism within the industrial corporation and the developmental state. The current acceptance by industry of certain forms of regulation represents the institutionalisation of part of the agenda of the radical 1960s movement then called 'the ecology movement'. The discourses of sustainable development and the practices of ecological modernisation, if they have led to laudable successes in some areas where technical innovations and more efficient processes led to reduced local impacts without effecting profits, have nevertheless required that the radical critique of growth be dropped from the agenda of environmentalism. *Cui bono?* In the words of Frank Popoff, the CEO of Dow Chemical Company,

> "[...] if we view sustainable development as an opportunity for growth, and not as prohibitive, industry can shape a new social and ethical framework for assessing our relationship with our environment."[88]

Nevertheless, it seems to remain an issue of elementary logic that, despite the political value of what has been called 'the compromise of liberal environmentalism',[89] economic growth as a cumulative material process occurring in space and time can be either infinite or not, but not both infinite and finite at the same time. Here is the fundamental point of incommensurability. In shaping a new social and ethical framework, it would seem timely to re-assess the actual material relationships constituted in 'the economy' of permanent industrial growth.

Leaving these public and political questions aside, another way to explain this disciplinary non-communication in the orthodox philosophy of science (known by its critics as the 'received view') would be to see it as a result of isolated and path-independent incremental developments amounting to 'progress' within the internally specified truth criteria of legitimately different areas of knowledge (legitimate because treating with ontologically distinct slabs of reality). However unsatisfying, this is one possible answer to the question of relationships between ecology and economics. Rather than fence-sit, this thesis seeks first to outline and then to argue the importance of a more or less hidden mutual history first suggested in a very brief discussion paper called 'Ecology in the Mirror of Economics', by Philip Mirowski. Recall that Kuhn posits the reason for 'incommensurability' as the result of *different* vocabulary and problem-solving methods between distinct 'paradigms': the proponents of competing paradigms misunderstand one another because they rely open different conceptual networks embedded in different terminologies. Mirowskis' insightful sketch, I think, opens a large can of worms for any proponent of the 'separate but equal' view of the exclusive theoretical development of the twin economies of nature, by noting some striking historical parallels in the respective careers of the two disciplines. Against Kuhn, we will argue that in the case under discussion, the proponents of ecology and economics rather share what at times appears to be an *almost identical* lexicon, and completely misunderstand one another nonetheless.

As far as I am aware, Mirowski has not developed these comments or written anything else beyond these remarks, nor has anyone else. It would only be proper to here acknowledge that the following two sentences clarified the approach to be taken in this thesis, and in due diligence ought to be quoted at length:

> "Perhaps the most important themes for our present purposes in this history are the following structural regularities: the long-term relationship to energetics; the trend from a 'soft' rejection of wholism and organicism towards a more concerted methodological individualism; the move from a diachronic to a synchronic analysis; the heuristic role of physics in providing the primary metaphors and the mathematical formalisms over time; the relative disengagement of empirical workers within the discipline form the strictures of the core theory and the failure to uncover any qualitative 'constants'; the hardcore insistence upon the equilibrium concept (usually constrained optimisation) by the mid 20th century and some back-pedaling from that commitment by the end of the century; progressive blurring of any distinction between Nature and Society; the withdrawal into arcane technical virtuosity in order to assert the possibility of escape from the highly-

charged political character of the incompletely constituted subject matter; but simultaneously a history of individual and institutional accommodations to state funding and demands to shape the research agenda; and increased reliance upon computer simulations and information processing metaphors as we approach the present. Perhaps the most striking phenomenon to the historian is the incongruous combination of assertions of arcane scientific methodologies with the simultaneous lament that the field had 'not quite yet' achieved a consensual body of knowledge.... All of these regularities, it appears, might equally characterize the history of ecology just as aptly as the history of orthodox economics." [90]

Following this lead, the thesis attempts a work of historical reconstruction in order to bring the processes by which 'the economy' and 'the ecosystem' were constituted in discourse as concepts, models, and metaphors worthy of stand alone disciplines by drawing out further the elective affinities between the disciplines hinted at above, thereby constructing a narrative that gives some social, intellectual, political and historical context to key moments where 'paradigmatic' approaches shifted, and the bearing this had on theory selection. The parallelism in the disciplinary formation of the two sciences is not merely coincidental: any explanation of their incommensurability, as I hope to show in the pages to follow, must deal not only with the above 'striking historical parallels' but also with genuine and disturbing, though intermittent and often indirect, cases of mutual influence at decisive moments of theory change. While it seems with hindsight that the various sciences would naturally and gradually come to assume their current shapes and contours, I would argue that the situation is more like Niles Eldridge and Stephen J. Gould's account of biological evolution as 'punctuated equilibrium', itself reminiscent of Schumpeter's entrepreneurial notion of economic growth as 'gales of creative destruction'.[91] Run the tape backwards, throw in some flapping butterfly wings to shift the initial starting conditions a few degrees, let that asteroid miss the Yucatan peninsula by harmlessly passing by ten kilometres above and continuing its perpetual journey through infinite space, allow 65 million years to pass by, and an entirely different biota may well have evolved. Unless we are Laplacean determinists, then we must concede that history could have been otherwise. Evolution may not have been destined to produce laptops and academics after all.

Since the falling of the iron curtain, the dominant view is that all the major social questions have been settled, ideology is dead, and the only social science to survive the 20th century' s ruthlessly Darwinian 'marketplace of ideas' with coherent and lasting explanatory power - retrograde nostalgia for Marxism or the 'fashionable nonsense' of constructivism notwithstanding - is orthodox mathematical economics, by virtue of its scientific character. On this question, the 'end of history' thesis of Francis Fukuyama, however much criticised is nevertheless the reigning view. The grand philosophical animus of debate in political economy has indeed exhausted itself within the hegemony of the neoclassical view, which sees itself as a purely technical knowledge emptied of idealism and ideology and aimed squarely at the ahistorical and timeless natural fact of 'the market'. Mirowski's various intellectual histories of economics are perhaps the most engaging and sophisticated of a slew of books that beg to differ from this view.[92]

Along with the minor industry that his major works have inspired, his historical critique of economics has been indispensable for the theorisation attempted in this thesis. His works, however discursive, critical and entertaining, and full of learned expositions on the philosophy of science and the relations between different branches of the Western knowledge enterprise, tend to remain focussed on the minutiae of the intellectual history of economics as an academic discipline. Although they are rich in historical contextualisation and offer a range of provocative theses, contretemps, and speculations on the status of the social sciences as sciences, as a historian of academic economics, Mirowski nevertheless remains internal to the discipline. A formidable (though by no means widely read) critic of neoclassical intellectual hegemony, his work strictly avoids the policy arena. My own reading of Mirowski's work, surfacing periodically as the thesis unfolds, sees it as an invaluable starting point for the critique of the intellectual validity of contemporary neoliberal political economy and especially its discursive framing of the debate around global environmental change. Such a critique is necessary, I believe, if we are not to be too naïve in hoping for the possibility of such outcomes as a meaningful 'ecological economics' (and not an ad hoc post facto 'environmental economics'), 'ecologically sustainable development' (as opposed to the preferred term 'sustainable growth'), 'ecological modernisation' (as against the ongoing 'modernisation of ecology' by the conversion of all ecosystems into technological artefacts), or 'environmental justice' (altogether different from the 'level playing field' imposed on the global sub-proletariat by the Masters of the Universe in the name of 'sustainable growth'). A historically informed sensitivity to the mutually constituted realms of Nature and Society, as expressed in economics and ecology, might well be useful in the construction of such ontologically hybrid knowledges and practices, and even more hopefully, in the emergence of a democratic science of 'sustainability' and global resource management in the interests not only of shareholders but of stake holders, including the unborn who must live on even after nature has ended and history has ceased.

## On the Anthropology of Classificatory Schemes

Against the neo-positivism of sociobiologists E. O. Wilson and similarly oriented economists, behavioural psychologists and statistical sociologists, who see the Social as ultimately deriving from the Natural and thus inevitably destined to succumb to reduction to the 'hardest' sciences in the onward march to the unification of the sciences, there is a burgeoning anthropological and sociological literature which seeks to reveal exactly the reverse, arguing against the Enlightenment hierarchy of knowledge that Nature is not independently given in discoverable and directly accessible form but discursively ordered through concepts ultimately derived from Society. Jeremy Rifkin has concisely put this argument in its dynamic and dialectical form in his book *The Biotech Century,* which notes the reduction of 'life' in the discourse of commercial computer-based molecular biotechnology to the processing, storage and reproduction of bioinformatic code (DNA) on the level of atomically individualised and ruthlessly competitive 'selfish genes':

> "Every major economic and social revolution in history has been accompanied by a new explanation of the creation of life and the workings of nature. The new concept of nature is always the most important strand of the matrix that makes up the new social order. In each instance the new cosmology serves to justify the rightness and inevitability of the new way human beings are organising their world by suggesting that nature itself is organised along similar lines. Thus, every society can feel comfortable that the way it is conducting its activities is compatible with the natural order of things, and therefore, a legitimate reflection of nature's grand design." [93]

This approach has its origins in the analysis of metaphor and classification which informed the social theories of Emile Durkheim, Marcel Mauss and Mary Douglas. Taken together these thinkers have generated a whole theoretical approach to the production of knowledge in society that has relativised positivist naturalism by documenting the co-constructedness of the categories of the Natural and the Social. Durkheim and his student Mauss argued in a classic essay called *Primitive Classification* (1903) that the Social is the source of all categories of human thought. "The classification of things" they argued, "reproduces the classification of men."[94] In his *Elementary Forms of Religious Life* (1912) Durkheim argued that the structure of existing social relations was projected into the supernatural realm. This study was largely drawn from the fieldwork of Carl von Strehlow who spent many years documenting the songs and stories of the totemic Aranda and Luritcha nations of Central Australia, who organise their societies through 'framing' complex marriage law, territorial hunting rights, sexual and food taboos, and relations with animals and plants through a religious system in which persons are positioned in spiritual reciprocal relation to animal ancestors. Through this process of super-naturalising social relations, religion provides stable norms – crucial to social interaction – and thereby ensured the continuity of the community's cultural and political order over time.[95] An example more familiar to Westerners might be medieval European depicting God as an absolute patriarchal monarch on a throne. Mary Douglas took this idea a step further in her study of the prohibitions of Leviticus and of natural symbols, arguing that understandings of the order of Nature across different societies could by explained by looking at the way Society was ordered. "The social body", she writes, "constrains the way the physical body is perceived. The physical experience of the body, always modified by the social categories through which it is known, sustains a particular view of society."[96] In this work, Douglas was able to link the prohibitions of Leviticus, with its passages on abomination, the ritual uncleanliness of human body fluids and forbidden animals, with more modern understandings of pollution, noting that what counted as 'dirt' was extremely different for her and for her husband, even though they were looking at the same kitchen. "Pollution" she says, "is matter out of place."[97] Poststructuralist anthropologists would of course argue that in this search for the universal structures of human social identity, Western assumptions about the distinction between nature and society, were smuggled in along with the assumption that Western social science was capable of encompassing the observed cultural universe and assessing subjective cultural interpretations against an objective nature that Western natural science alone has access to. This problem is to some extent attenuated in studies such as this one, which redirect the anthropological gaze back to the Western distinction between Nature and Society and the assumptions of rationality dependent upon such a tidy division.

The upshot of all of this for the sociology and anthropology of science, is the claim that all viable and abiding conceptions of order are inherently anthropomorphic, and the Nature-Society distinction exists in part to ensure the comforting legitimacy of positivist accounts of science, which proposing to view of natural objects objectively, purports to occupy a "view from nowhere" devoid of subjects. Re-stating the thesis as it stands in the contemporary sociology of science and technology literature, Mirowski has it this way:

> "[...] anthropomorphic ideas of mastery and control induce a bias in cultures to project their own social categories onto their explanations of the external world; but in an infinite regress subsequent reification of notions of order prompt others in the same culture to appropriate those preceding Natural concepts and re-project them back into models and images of society." [98]

But rather than taking this constructivist methodology to its logical conclusion, where Enlightenment meta-narrative of the impending systematic unity of Nature is replaced by a meta-science of the ineffably unified Social, Mirowski proposes that "the Natural and the Social are merely provisional designations for where explanation will halt in a crisis."[99] That is, the outlines of the categories remain hazy background assumptions until some unpredictable disaster confounds the juridical models which assign responsibility and guilt. Ever-present and inherently unstable, the Natural and the Social only come up for negotiation when pre-existing categories of order and disorder are in disarray. Mirowski's addition to the Durkheim-Mauss-Douglas thesis is the proviso that the oscillation of concepts between the Natural and the Social continues merrily along in the shadowy byways of knowledge production until some hazard or crisis emerges. During these crises, what counts as the final reference point for Nature or for Society comes up for negotiation, explicitly or otherwise. In so doing he avoids the somewhat rigid structuralism and functionalism of his predecessor's theories, keeping the account open and the emphasis pragmatic:

> "Using Natural metaphors in theories of Society fosters reassuring and graphically concrete images of order, situating humanity squarely at home in 'its' universe, while the parallel projection of social concepts onto Nature render what might otherwise be an unintelligible alien world comprehensible and accessible to human desires and purposes."[100]

Here it seems appropriate to briefly introduce another account in the tradition of the Durkheim-Mauss-Douglas thesis given by the philosopher Malcolm Bull, who has attempted to place modern philosophies of history and historico-political ideologies within a framework derived from a general theory of apocalyptic.[101] Although relevant to later arguments I want to make about the prevalence of 'secular millennialism' in contemporary economic discourse, his theory is too elaborate to discuss in full, so we shall merely attempt to summarise it here. Going against the particularism of recent anthropology and its easy rejection of 'binaries' and 'universals' as 'Western' pathologies, Bull goes out on a limb and argues that the anthropological record furnishes evidence for several candidate cultural universals. One of these is the existence of bivalence, of dualistic systems for classifying phenomena and deriving values. Similarly, he suggest that in most societies there is a fundamental taboo on incest, which is linked to other taboos and is perhaps the ultimate source of social order. Echoing Douglas' thesis, Bull argues that the social identity of persons is dependent on the demarcation and differentiation of natural and supernatural identities into their appropriate categories. However, as no bivalent conceptual system can completely banish contradiction in all cases and forever, the insistent reappearance of ambiguous entities renders the classificatory systems that house a particular society's ontological and moral postulates unstable, allowing for the further multiplication of hybrid identities and the general proliferation of undifferentiation. Chaotic undifferentiation, hybridity, multiple identity, contradiction, mixture or in Douglas' words 'pollution' thus threaten the social order by overwhelming the ability of ritual and sacrifice to maintain the coherence of the cosmos, and to restore the sacred balance between natural and the supernatural order. At this point, apocalypse looms, and the rules for redemption must either be re-imposed upon the world or reinvented anew by some messianic figure. Thus for Bull, apocalyptic (as a teleological framework for the understanding of evil, as a sense that each passing moment and individual action stands in some significant relation to the totality of past and future time) is not merely a genre of Judeo-Christian tradition but can be extended to many cultures as they respond to the crises that threaten the orderly reproduction of society over time.

With this in mind we can now return to Mirowski's discussion of a specifically European juridical model for the determination of the line between the Natural and the Social, an account played several octaves lower than Bull's. When life proceeds more or less normally, argues Mirowski, the generation of ambiguities, the production of contradictions and hybrid identities by the existing ideological systems buttressing the social order goes unnoticed. When people start getting hurt, however, justice is demanded. The need to punish the guilty and protect the innocent requires the juridical determination of causes and effects, a public process that momentarily performs the fixation of phenomena into their appropriate ontological categories. In support of this, Mirowski provides an intriguing discussion of parallels between medieval animal trials and more modern attempts to adjudicate between the Natural and the Social. Between the 13th and 18th century, a period which saw the rise of modern juridical institutions and the analogical style of common law reasoning, egg-laying roosters, child-killing pigs and other animals charged with murder, and freakish mutant animals that resisted categorisation were hauled before the courts. While frequently unable to attend court, plagues of rats, locusts, mice and other crop destroying vermin were similarly summonsed and excommunicated *in absentia* for their breach of the natural order. With the juridical apportion of blame and the dispensation of justice, the appropriate balance between the Natural and the Social (and thereby between the Natural and the Supernatural) was restored. [102] It is no accident that the symbol for justice has long been a set of scales, this dates at least as far back in time as the images of the soul's judgment found in the tombs of Egypt. Here perhaps is one of the oldest images of the perennial metaphor of the 'balance of nature' that seems ingrained in Western civilisation.

In a more recent example, Mirowski recalls an experiment that in 1987 prompted Nicholas Georgescu-Roegen (the erstwhile hero among the economists cited in this thesis) to resign in protest from the American Economics Association. Written up in the AEA's house journal under the title 'Animals Choices over Uncertain Outcomes', the experiment involved the long-term confinement of a multitude of laboratory rats within Skinner boxes at Texas A & M University, with food and its withdrawal signifying a continuum of utility/disutility from which the researchers were then able to derive 'demand curves for animal consumers'. Rats were able to express 'preferences' between two kinds of stale soft drink, with 'income' being a limited number of presses of the post-mix lever and 'prices' being the size of the cup.[103] The inquisition of mice within the truth-determining context of the modern laboratory had no identifiable empirical or theoretical purpose, says Mirowski, other than to provide experimental 'verification' for the universality of rigidly invariant neoclassical utility preferences, thus reassuring neoclassical economists and a few socio-biologists (the only conceivable audience of the report) of the natural and scientific basis of their social theory, at risk from the hostility of competing accounts of human psychology and social action.

Drawing on Bull and Mirowski, I want to up the ante here and extend this theory of crisis and resolution to the apocalyptic limit. I would argue that the whole cacophony of specific environmental crises can be taken as the ultimate case of an unpredictable disaster, where the power of industrial economies to liberate some populations from local ecological constraints threatens to undermine the basic biological and climatological contexts that human societies have evolved within since the domestication of plants and animals, since the emergence of abstract gods, numbers and written languages, since the earliest class-structured city states sprang up at the beginning of the warm interglacial Holocene period some ten thousand years ago. Deprived of reference to the revealed truth of God as the anchor of meaning and social order, modernity has looked ever to Nature to uphold its visions of the order of society. The intensifying anthropogenic restructure of the biosphere, means that this external referent is thus increasingly unable to unproblematically reaffirm visions of the social order as natural, legitimate and just. What is at stake for ecologists in all of this, is the destabilisation of given nature and the increasing rarity of ecosystems in pristine and primordial 'equilibrium'. In the seventies this was accomplished with accounts of the universal bioaccumulation of DDT, 2-4D, dioxin and strontium-90. In the eighties, by acid rain and biodiversity loss through habitat destruction. In the nineties, by the risks of ozone depletion and genetic pollution as much as by the admission that much of what had been classed as 'wilderness' was actually the result of the colonial removal of indigenous humans from what had long been cultured ecologies with autochthonous human presences. In the present time, actually existing climate change means that no ecosystem is external to social relations anymore. Many ecologists, faced with the Social pollution of their Natural research object, have been more or less pushed into becoming political figures and social scientists of a sort. What is at stake for economists? As purveyors of infinite growth and all-knowing markets that optimise all social decisions into a long term equilibrium, the ecological crisis represents, I think, nothing less than a standing refutation of their entire theory of the 'economy of nature', and by extension, of the rationality of 'capitalism'. Ecological crisis, if acknowledged, would be fatal to the liberal millennium of universal mass consumption after everything has trickled down, which is held out as a panacea to those suffering deepening poverty in the present day. The sad irony is, that in the so far successful attempt to defend the core postulates of economics from logical and empirical falsification, many opportunities have been irreversibly lost. In attempting to stave off the apocalyptic collapse of the economist's ontology – which in all fairness merely serves to naturalise the institutionalised interests of the global consumers of the 'postindustrial, post historical centres, the biosphere-wide ecological apocalypse must be denied for as long as possible and any attempt at the reform of political and economic institutions delayed.

This thesis is intended to contribute to the literature by analysing not only how particularly operative constructions of Nature have restructured Aristotle's *politikon zoon* ('Man' as a political animal) into the *Homo Economicus* beloved by rational choice theorists and mechanistic anthropologists everywhere, but how the emergence of environmental crisis, limits to growth, and biospheric risk may be considered the ultimate crisis and thus the ultimate test case for economics as an objective (i.e. naturalistic) science of the social. To this end, this thesis offers a grounded historical account of the constitutive metaphors of neoclassical economics and ecology, right up to their definitive moments where they become 'normal' sciences. This in the hope that through unearthing them we may begin to understand how the invigorating machine dreams of the Industrial Millennium (the automatic balance of the free market, perpetual growth of the economy) continue to suffuse debate about 'the environment' in the neoliberal economic order, despite the crisis talk of 'technics out of control' that informs the Industrial Apocalypse of modern environmentalism. The infinite regress of conceptual projection back and forth between the Natural and the Social will be borne out in our examination of the related histories of ecology and economics, which when accounts are settled (if the reader will excuse the metaphor) will reveal ecology as a habitual debtor in the trading of concepts that it has always engaged in with economics.

Anticipating the common and mistaken critique that metaphorical analysis and 'constructivism' supposes that the phenomenal world exists only in the effervescence of our minds – and therefore that any claim of global environmental degradation can be relativised to the interests of 'subject positions' – I would point out that nature is in a very concrete way 'constructed' by the modes of perception applied to it, be it by ancestral totemism or the 'central dogma' of molecular biology. Following Alf Hornborg's basic methodological point of departure, we can observe that capital accumulation is a problem at the very interface of the natural and the social sciences: "the operation of human economies... can only be understood in terms of the *interfusion* of objective, material conditions and subjective, cultural constructions." [104] In an age where agricultural chemicals show up in the cell tissues of Antarctic wildlife, where increasingly frequent and destructive cyclones are linked to human interventions in the composition of the atmosphere (and thus are artefacts of industrialism, henceforth only partially 'natural' disasters), it seems that the reified boundaries between nature and society, painstakingly erected and carefully policed by the juridical, scientific and technical apparatus of modern capitalism, are being eroded by the excessive success of that culture. As Barbara Adams has argued, it is now more profoundly the case than it was at any other time, that 'natural' landscapes, objects and bodies are infused with the determinations of 'culture' and its 'unintended side effects'.[105] Indeed this is one of many paradoxical features of ecological crisis: the collapse of absolute biological separateness between zones occupied by 'nature' and 'society'. Common-sense distinctions between 'nature' and 'culture' are eroded in the context of ecological crisis in which 'wilderness' - once the ominous zone beyond cultivated fields, now the last frontier of diminishing biodiversity - can only continue to exist as a socially negotiated legal construct in designated 'carbon sinks' or 'biosphere reserves'. Quoting the following remarks might indicate my own methodological predispositions and allow us to move on to the discussion of metaphor and the natural sciences.

> "Critical realism, along with critical theory rejects the basic polarisation that frames the opposition between positivism and postmodernist relativism – the standoff between empiricism and subjectivism as the only choices...epistemological and methodological pragmatism does not necessarily require ontological skepticism- the suggestion that we cannot confidently posit realities independent of our consciousness.... Critical realism does not require a correspondence theory of truth whereby concepts are held to mirror reality." [106]

In summary, realist naturalism is the philosophical default position of the natural sciences, and those social sciences that aspire to the same epistemological status which grants more or less automatic public respect. The constructivist challenge arises from developments in the philosophy of science which seek to interrogate the socially embedded meaning of concepts of nature and their interpretation (as opposed to the view that concepts of nature are simply explanatory and predictive) and a more general turn toward critical reflexivity on the part of the Western knowledge enterprise, which is cognisant of the re-orienting of the anthropological gaze of the social sciences away from the others of the colonial periphery and onto the cultural, social and political contexts of knowledge production 'at home'. It is likely that this reflexivity is, to an extent underappreciated by many, a result of the multiplication of 'side-effects' and hazards that went unforeseen and unpredicted by scientists over-confidently spruiking technologies that took on a life of their own after they left the confines of the laboratory and dramatically altered the natural world.[107] Classic examples here would be the downplaying of the risks of radiation in the age of atomic optimism, and the truly global risks of ozone depletion through the accumulation of chlorofluorocarbon in the atmosphere and the potentially radical destabilization of the climate through emissions of greenhouse gases. The increasing geopolitical reach of environmental science has had paradoxical effects: in applying scientific and ethical critique to the global irrationalities of 'business as usual', environmental scientists have succeeding in deeply politicising the very relationship between science and policy to such an unprecedented degree that their own pronouncements, made in the assumption that scientific truths are more or less value free and that ignorance of them is not in the public interest, are met with suspicion and vigorous debunking. Thus the scientific exposure of ecological crisis has set science against science in the public sphere. These examples in mind, we can conclude by re-asserting that constructivism is not a metaphysical position that insists that reality only exists in our heads, but is rather an epistemological position that acknowledges that there is no other way to make sense of reality except through ideas, and that these ideas do not stand permanently outside of nature and society but are generated in society, with all its contingent sets of interests, values, anxieties, narratives and evolving systems of meaning.[108] It need not imply an 'anything goes' relativism or postmodern paralysis, but increase the sophistication with which we account for what counts as Nature, a vital first port of call for any critical political economy of the biosphere. As Raymond Williams has argued, concepts of nature arise out of embedded practices. Whether explicitly or otherwise, concepts of nature thus emerge as concepts of human-environment relations.[109]

## Metaphor and Science

The question of the human meaning of scientific concepts leads us to the question of language and discourse, and one of the most intriguing elements of cognition and processes of thought is metaphor. Derived from the Greek *metapherin,* the function of metaphor is literally to 'carry over' meanings from one domain into another. Analogy works more or less the same way, with the main difference between metaphor and analogy being that the former is suggestive, the latter is explicitly comparative. While experts in epistemology, semantics and linguistic might object, herein we will treat the two is essentially similar phenomena with varying degrees of explicitness.

Metaphor is usually thought of as belonging to poetry and literature, where its purpose is to stimulate the imagination. "The moon was a ghostly galleon" is intended to initiate a long chain of novel associations and visual images in the mind of the reader, precisely through the boldness of its incongruity. To say that the moon was *like* a ghostly galleon (a mere simile) is far less interesting as poetry. The assertion of the identity of non-identical things arrests our attention because it attacks our ordinary classification of objects. In the process of the erosion of the semantic barriers that ordinarily separate planetoids and marine transportation machines, the initially barely related objects transfer some (but not all) of their qualities between one another, the moon drifts across the sky like a sailing ship across the sea, a galleon is bathed in the ghostly luminescence of the moon. A secondary image is the sea and sky being conflated and mirroring each other. Literary metaphors are suggestive rather than didactic. It is intended for the reader to be consciously complicit in the breakdown of the order of things and the undifferentiation of different entities, to suspend disbelief willingly for a moment and to savour the image as one would a fine scotch.

In a more subversive role, metaphor is an indispensable part of rhetorical persuasion, exploited particular in politics for its emotive possibilities. For example, we might consider the continuous equation by the neoconservative movement and Bush Administration of Saddam Hussein with Adolf Hitler. Beyond the visual symmetry of mustachioed dictators, this had several consequences for those who accepted the parallel: the opposition of the United Nations to an all–out invasion was equivalent to the appeasement of Hitler by Chamberlain upon the annexation of the Sudetenland in 1938, despite the fact the that Iraq's military was hardly capable of global Blitzkrieg; the Baath party were seen as Nazis; and the optimism for the 'reconstruction of Iraq' drew on the successful incorporation of West Germany and Japan into the liberal Bretton Woods order after World War II. President Bush notably invoked September 11 as a latter day Pearl Harbour, and even went as far as identifying an Axis of Evil that was anything but an actual alliance. In this example, the extended suite of analogies generated by the metaphor <Hussein is Hitler> can be regarded is an invocation of the urgency of pre-emptive action couched in nostalgia for a simpler age of just warfare, which appears to have even intoxicated its authors into ignoring the historical, cultural and political specificities of oil rich Arab nation-states, stateless Islamist militancy and the novel complexities of 21$^{st}$ century geopolitics, particularly looming resource conflicts. Here we see the deceptive possibilities of metaphor, which in invoking the familiar to explain the unfamiliar, can lead to sloppy and emotive thinking.

Metaphor is also present in innumerable ordinary speech acts, and in theory is only excluded from one sphere of discourse: scientific communication, due to the tendency of metaphor to escape the bounds of precise description and to engender vague and unruly open-ended processes of thought. Some theorists will allow the use of metaphor in science for pedagogical purposes. For example, in elucidating the counterintuitive proposition of Big Bang theory that the universe expands outward continuously although there is no centre to the explosion, the physicist Arthur Eddington introduced a novel metaphor. This involved imagining the cosmos as a balloon with dots on the surface representing galaxies. All galaxies were thus in motion relative to one another but none was at the centre.[110] According to Gentner and Jeziorski, metaphors in science may be classified as either pedagogical or pre-theoretical.[111] They can be used to explain theories which already have non-metaphorical interpretations – 'energy field', 'electron cloud' or 'wormhole' are examples – or they may be used as heuristic devices to explain theoretical claims which as yet have no non-metaphorical explanations. Metaphors are probably necessary preludes in many cases to the scientific labour that yields formal, predictive theoretical statements. On this view, ill-defined metaphors have a part to play in the discovery process, but a fertile metaphor is no substitute for formal theories. As a science matures, they suggest, metaphors are clarified and precision increases.[112] Successful prediction from formal models renders the original metaphor coincidental to the scientific process by downgrading it to an analogy external to the now non-metaphorical theory.

Much broader claims have been made for the role of metaphor in knowledge production. In their influential book *Metaphors We Live By*, George Lakoff and Mark Johnson posit that human thought and cognition operates irreducibly by way of metaphor, and thus our conceptual systems are in the final analysis metaphorical. Not only is the modernist dream of a pure conceptual language purged of metaphor exactly that - a dream – they assert that concepts themselves are inextricably bound up in the constitution of reality.

> "Our concepts structure what we perceive, how we get around in the world and how we relate to other people. Our conceptual system thus plays a central role in defining our everyday realities."[113]

If language and concept are metaphorically structured, by extension, action must be similarly structured. Metaphors, in this view are not merely decorative parts of speech only suitable perhaps for evocative poetry, or the literary simplification of non-metaphorical axiomatised theories, but are inescapably ontological. As Lakoff and Johnson put it, succinctly, 'metaphors matter'. By positing the identity of unlike objects they invite us to perceive non-obvious relationships between objects normally assumed to be unrelated. They both reveal and conceal aspects of reality in order to simplify and familiarise.

In line with this ontological view of metaphor, I follow the account of economists Arjo Klamer and Thomas Leonard, the ecologist Kim Cuddington and the historians of chaos theory Peter Weingart and Sabine Maasen, in arguing that the use of metaphor is not merely a heuristic device to communicate existing science to neophytes or the layperson, or new propositions to colleagues, but is a ubiquitous and even indispensable part of the scientific process.[114] This is not restricted to the 'soft' sciences of ecology and economics, but is prevalent even in the hard sciences, as Pierre Duhem for example, has argued:

> "The history of physics shows us that the search for analogies between two distinct categories of phenomena has been the surest and most fruitful method of all the procedures put into play in the construction of physical theories." [115]

According to the philosopher Mary Hesse, metaphors act to redescribe the phenomenon of a primary system in the contextual terms of a secondary system, thus opening a two-way interaction between both domains of knowledge.[116] Mutual interactions between different knowledge contexts are thus multiplied and may generate unanticipated multidirectional knowledge transfers.[117] While this leads often to progress in science by the transfer of concepts across borders between previously unrelated domains, it does not follow that a fully mathematised science can seamlessly import its formal structure fully into the new setting. Blocked by the Duhem-Quine thesis, the whole birds-nest of informal 'auxiliary hypotheses' that underwrite each specific knowledge claim within distinct 'paradigms' or 'epistemes' may not be reducible to any incontestable first principles. The upshot, for Hesse, is that metaphor can never be truly eliminated, although the entire project of 'becoming a hard science', which involves what Foucault terms 'mathesis' or the mathematisation of ordinary language, implicitly assumes this:

> "A formal symbolic language can never be a substitute for thought, because the application of a symbolic method to any empirical matter presupposes a very careful analysis of the subject matter [...] that the essentials have been grasped and properly expressed in language. In other words, it presupposes that the work of clarification has already been done [...] some necessary overtones of meaning are lost when a word is precisely and uniquely symbolised. The vagueness of living languages as compared with mathematics is the price they pay for their applicability to the world and their capacity for growth."[118]

Thus for Hesse, scientific revolutions can be described as 'metaphorical redescriptions' of nature. On this view of scientific innovation, the metaphorical transfer of knowledge is a regular occurrence. Whereas in the 19th century, aspiring scientists regularly claimed to have identified 'laws' of nature – a metaphor posing as an isomorphism that we will have much recourse to in this thesis – scientists nowadays generally restrict themselves to the construction of 'models'. Originally carrying the implication of a 'scale model' or a map, scientific models can be described as complex analogical systems attempting to relate to unmapped realms of the real world across many more vectors than scale.[119] Successfully elaborated concepts and models that have been built out of the systematic extension of a heuristic metaphor into an analogical system, in that they have been claimed as 'solutions' to problems within that domain of knowledge through empirical confirmation, are viewed by practitioners in other fields as promising hypotheses. Imported across disciplinary boundaries, these concepts and models bring with them an entirely new vocabulary, which in the new context provokes novel meanings which have to be reorganised, in turn generating new hypotheses and in some cases, new theories.[120]

Creating models therefore involves reasoning by analogy. Milton Friedman affirmed this when he argued that economists reason 'as if', for example, 'as if' rational human action is equivalent to the mathematical solution of a constrained optimisation technique according to the technique of Hamilton and Lagrange.[121] While the metaphor at the base of the model performs a useful heuristic function that may be incidental to the efficacy of the model to predict the phenomena it seeks to theorise, economists should be conscious that they are engaged in what Max Black calls the "willing suspension of ontological disbelief".[122] The perennial problem is not the use of metaphor (which is unavoidable) nor the use of analogical reasoning (which is creative) but the danger of what Marxist theoreticians have called 'reification', the objectification of theoretical propositions. As Klamer and Leonard put it:

> "[...] analogies may become elaborate things-in-themselves, and eclipse their founding metaphors. [...] Indeed most economists probably think of their work as making truth statements about the world. [...] Alertness to metaphor reminds us not only that our models are fictions, but that 'as if' reasoning – the characteristic mode of economic reasoning – is altogether incompatible with a positivist view of the world."[123]

In addition to the pedagogical and heuristic role of metaphors, Klamer and Leonard introduce a third variety of metaphor present in economics and other sciences: constitutive metaphors. These are of the most fundamental character, and are reserved for the conceptual modelling of phenomena that are as yet unknown or are simply too complex to directly observe and know: a condition which covers much of the phenomena that ecology, economics and physics seeks to bring into a single conceptual framework. Coined by Richard Boyd, the term is itself based on a metaphor: constitutive metaphors frame a discursive practice in the same way that the U.S. constitution frames U.S. legal discourse. Boyd defines this kind of metaphor as one which "constitutes, at least for a time, an irreplaceable part of the linguistic machinery of a scientific theory: cases in which there are metaphors expressing theoretical claims for which no adequate literal paraphrase is known."[124] An example of this would be the reference to gene expression as the 'writing of code': this is clearly a metaphor derived from the familiar language of information technology, but even if the metaphor is pointed out, it is simply not possible to think through the theory of genes in any other way. In many cases these grandest of scientific metaphors become so embedded in discourse and so essential to our thinking that they are usually invisible as such, and in some cases may even determine what accounts for truth.[125] Stephen Pepper has identified four 'root metaphors' (a metaphorical reference to the Tree of Knowledge) that each constitute and make intelligible vast realms of discourse, but may also preclude communication between practicing adherents of differing camps. These metaphors he describes as 'world hypotheses' are organicism, mechanism, formalism and contextualism.[126] As they have been inhabited, renovated, extended and lent legitimacy by thousands of different theorists, they cannot be simply discarded – a useful thought experiment is to try to invent a metaphor that might replace any of them.

This leads us to the strongest position on metaphor and science which is still as unsurpassably radical as it was when Nietzsche first established it in the 1870s, around the same time as economics and ecology got their start as distinct sciences:

> "What then is truth? A movable host of metaphors, metonymies, and anthropomorphisms: in short, a sum of human relations which have been poetically and rhetorically intensified, transferred and embellished, and which, after long usage, seem

> to a people to be fixed, canoninical and binding. Truths are illusions which we have forgotten are illusions; they are metaphors which have become worn out and drained of sensuous force, coins which have lost their embossing and are now considered as metal and no longer as coins [...] The drive toward the formation of metaphors is the fundamental human drive, which one cannot for a single instant dispense with in thought, for one would thereby dispense with man himself."[127]

In a nutshell, this thesis attempts to describe the parallel historical trajectory of ecology and economics (as mirrored paradigms of the Natural and the Social) up to the point of their collision in the debates around growth, limits and crisis that presided over the birth of neoliberalism, postindustrialism, and modern environmentalism. The reason for this is that it was at this time that many of the foundations of the current debate in the age of crisis were laid, and some remain unlit by the fall of the years.

To reassure the reader, the role of metaphorical analysis in this thesis will not be a tedious application of advanced linguistic theory to the fine grained grammatical subtext of the 'texts' of science, but a dialectical and historical account of the social context in which particular concepts got their start in life. The point is not to deconstruct the Natural sciences into so much relativised dust, but to situate them as the products of social history and as influences upon the character of applied social knowledge. In doing so I am not proposing that there is nothing but metaphor, or that nature is a 'text', or that science is self-delusory and purely contingent 'discourse'.

Rather, I would argue that the theorisation of complex, unknown phenomena inaccessible to immediate sense-perception requires (at least initially) meaningful organisation of incomplete data, and that this organisation usually proceeds by way of metaphor and analogy. Where there are controversies over what counts as measurement, we are usually encountering a problem of metaphorical interpretation. Conversely, controversies over the social meaning of scientific measurement may point to the rearguard action of a socially powerful 'metaphorical regime.' As Lakoff and Johnson have observed, the generation of social meaning through metaphor is anything but a level playing field.

> "[W]hether in national politics or everyday interaction, people in power get to impose their metaphors."[128]

Thus the value of the critique of the social context and role of science in our current era is to indicate how sciences are given access to or obstructed from the construction of policy, especially economic policy. Whereas once natural scientists could be called upon to lend the legitimacy of scientific neutrality and objectivity in the justification of the rationality of policy, in recent times we have witnessed precisely the opposite. Climatologists at the CSIRO in Australia and at NASA and the EPA in the United States both claim to have been actively censored by the neoliberal/conservative governments that fund their research. Australia and the United States, among the world's largest per capita emitters of carbon dioxide, have until very recently pursued the claim that the science regarding global warming was seriously flawed and subject to grave doubt. What is striking in these episodes is that in both cases, the scientists were warned against making 'political' statements. Thus our overall narrative regarding the competition for influence over the description of the human predicament between ecology and economics is ultimately directed not at scientific knowledge as such, but at the increasing politicisation and fragmentation of the social role of science because of the resistance of 'postindustrial' capitalism to having its core belief in infinite growth and the benevolence of Pareto efficient 'market forces' falsified by (what scientists claim to be) the existing state of nature.

Despite these caveats, and my own views that science provides better information to the democratic policy process than say, evangelical theology, this study of the metaphorical constitution and overlapping disciplinary matrices of economics and ecology might be characterised as part of the sociology of science and technology (SST) literature. Steven Fuller has proposed the following agenda for SST, which more or less fits the objectives of the following chapters:

> "(1) Situate the apparent progressiveness of science in a still larger master narrative -- such as the rise of capitalism -- which casts a more equivocal light on science.
>
> (2) Observe that the sequence of great scientists whose achievements would be typically mobilized in support of "progress" would not have agreed amongst themselves -- nor with us today -- about the ultimate goals of their inquiries in which their achievements would count as stages.
>
> (3) Argue that the "universal value" of science resembles that of *democracy*, in that both must be actively preserved because of the ease with which it can be corrupted, often by becoming a victim of its own success (e.g. governments become so popular that they turn authoritarian, sciences become so committed to one line of inquiry that they cannot entertain dissent).
>
> (4) Characterize STS as part of the "second phase" of secularization that began 400 years ago with the divestiture of state support for religion. SSTers thus assume the role of the Protestant Reformers in relation to those who would follow the Comtean impulse to turn science into a new high priesthood. In that case, the grand narrative of progress is little more than a thinly disguised salvation story." [129]

Despite claims to access an objective nature, both economics and ecology are inescapably studies that seek to mediate between the Natural and the Social and thus cannot avoid being linked to grander metanarratives: just as metaphor supplies Social meaning to Natural facts, so does science fit into a grander story about the human prospect. In the following section I will attempt to argues that the historical consciousness of millennium and apocalypse that presided over the pre-modern European cosmology have not been tamed away by the emergence of modernity and scientific rationality, but merely secularised into Progress ideology and thence vulgarised into the statistical measure of Gross National Product.

At the risk of making unwarranted generalisations, I would argue that each of the twin sciences has its own millennial narrative, shot through with apocalyptic tension: for economists, it is world where all capital and all factors of production are guided by frictionless markets devoid of political interference to the equilibrium point where production is the most efficient, and thus the possibilities of production converge upon an infinite horizon. Oil running out? No problem, stimulated by the price mechanism, the market will reward the entrepreneurs who rise to the challenge and deliver a new energy technology in the nick of time. Infinite growth is infinitely sustainable. Market failures aside, the apocalypse that seems most likely to exercise the minds of economists is that the naturalness of the Social order their science advocates will succumb to claims that it is both unjust (generating intense concentrations of wealth and poverty) and unnatural, thus rendering their claims to be apolitical scientists baseless. It is my suspicion that this is why 'conservatives' are so opposed to conservation. For ecologists, the situation is almost the reverse. Ecologists have an interest in pointing out the apocalyptic confrontation with the biosphere's delicate balances and its limited ability to supply materials and absorb pollution without collapsing. For them, only an ecologically enlightened public behind an enabling state will be capable of instituting the millennium: a low-energy, low impact, sustainable economy that thrives on closing nutrient and material cycles rather than through the 'creative destruction' of swathes of habitat as frontier after frontier is exhausted in the name of short-term, speculative and wasteful 'production' for the disembedded market.

Given these antagonistic cosmologies, this thesis hopes to convince the reader that is worth analysing the metaphorical underpinnings and socio-historical context of the following shopping list of key concepts (which we have already hinted are more than a little similar) by placing them within the 'salvation story' of disciplinary progress. Here we indicate those concepts that seem most worthy of analysis. Although all of the following are the outcome of metaphorical or analogical reasoning, some of these concepts are more immediately obvious as metaphor than others. In rough order:

| *Economics:* | *Ecology:* |
|---|---|
| Economy of Nature | Economy of Nature |
| Invisible Hand | Climax Community |
| Price Mechanism | Struggle for Existence |
| Market Forces | Climax Organism |
| Laws of Supply and Demand | Balance of Nature |
| Economic Equilibrium | Ecological Equilibrium |
| Production | Regeneration |
| Economic Growth (GDP) | Energy Budgets, Natural Primary Product (NPP) |
| Economy | Ecosystem |

As a rough guide to possible philosophical interpretations of the spiralling appropriation of metaphors, concepts and models from either side of the Western knowledge division of the Natural and the Social Sciences, it might be useful to reproduce below a table from Mirowski's edited volume, *Markets Read in Tooth and Claw: Natural Images in Economic Thought.*[130] Printed below, it demonstrates a range of philosophical positions on the ontological relationships between the Natural and the Social, and the corresponding epistemic and methodological commitments associated with them. This table is drawn an aid to the navigation of a volume that deals with natural images in economic thought. Unfortunately, his thesis also entertains the possibility of social images in ecological thought. And to complicate things further, it argues that the key site for metaphorical exchange between the Natural and the Social is the machine: an 'unclean' ontological hybrid of the first order. Nevertheless, Mirowski's table provides useful clarification:

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1. The Natural and the Social are identical in

a) every respect (extreme reductionism)

b) laws (Churchland)

c) epistemic methods (Glymour, Cartwright)

d) metaphorical structure (Schumpeter)

2. The Natural and the Social are disjunct but individually law-like due to

a) epistemic status (Windelband, Rickert, Weber, Kuhn)

b) ontological status rooted in psychology (Dilthey, Taylor)

c) purposes (Habermas, Dreyfus)

3. The Natural is objectively stable, whereas the Social is patterned on it but is not stable, implying

a) a sociology of collective knowledge (Durkheim, Mannheim)

b) sociology as epistemology (Douglas, Bloor, Shapin)

4. The Natural and the Social are both unstable and hence jointly constructed as mutually supportive

a) out of interests (Latour, Haraway, actant-network theory)

b) out of practices (modern pragmatists, Hacking, Rouse)

c) out of will (Nietzsche, Foucault)

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Position (1) of course, is that of Unified Science and considers the analysis of metaphor anathema. Position (2) is inhabited by those advocates of a clear cut division of the Natural and the Social, typically associated with the German historical school, but probably implicitly assumed by most sociologists and perhaps natural scientists of a humanist bent through the 20th century.

As to the argument of this thesis, if he may be permitted the apparent inconsistency, the author would like to have a bet both ways on positions (3) and (4). I accept position (3) because I believe that nature does impose causal limits on what we can ascribe to it in discourse in the form of reasonably 'stable' and regular material feedback. While the notion of an ecological 'crisis' opens up a can of worms (crisis for who, where are the thresholds, what are the boundaries of the ecosystem, has it ever been stable?), there are any number of reliable measurements that suggest nature is not what it used to be: i.e atmospheric carbon concentrations, long range meteorological data. My flirtation with position (4) involves some irony: after all, what is the ecological crisis but the material destabilisation of Nature and it subsequent unavailability as a stable external referent for Social narratives to found their apparent permanence upon? Machine metaphors, I will argue, are key to the epistemic conundrums of modernity. On the one hand, machines provide technological proof that science 'works' – even Berkleyan relativists fly Boeings to conferences – and thus machines are taken to speak with the clear voice of an objective Nature (position 1). Reified and fetishised into discrete objects and bounded artefacts, machines become the 'epistemological totems' of Western claims to a superior rationality and a direct relationship with an objective nature.[131] This is the received view of machines and underwrites the entire project of 'development', 'modernisation theory' and 'technology transfer'. Seen another way, from the perspective of Karl Marx and Lewis Mumford, machines are not only artificial 'objectified labour' but inextricably embedded in social relations, which they themselves may come to determine – for example the distinction between industrial capitalist and proletarian labourer.[132] To give an example, based on Alf Hornborg's thesis in *The Power of the Machine*,[133] I would argue that the fact that individual ownership of personal leafblowers is considered 'efficient' and 'rational' and is even possible where I live, is due to global inequalities in the value of labour, global uniformities in the spot price of oil, the fact that the atmosphere remains a free dumping ground for unpriced carbon dioxide, and the military, political and financial structures that maintain these discrepancies. The mysterious aesthetic preferences of Sydney leafblowers, who insist upon 'clean' footpaths, patios and carparks at the birdsong, peace and quiet and unnecessary contributions to climate change.

The reason there are few leaf blowers in the villages of Mali is that their hourly rate of pay is too low in relation to the cost of Iraqi crude to justify investing in a blower. Conversely, the slight 'efficiency' gained in labour time over the use of a broom in Sydney is offset by the much higher amount of fossil energy one can purchase with Australian dollars and wages, not to mention the fact that the blower was produced in some East Asian free-trade zone with low wages. For example, only a few years since they appeared, blowers are so 'efficient' as to be utterly indispensable for commercial gardeners and local councils (at least that is what I have been told upon making polite enquiries). Even in Marrickville, where a green bloc sits on council, leafblowers make an unending cyclical journey to every corner of the shire where trees shed leaves upon the public byways. On Hornborg's view, that machines are 'efficient' and 'do work' is utterly dependant on their geographical and socio-economic location of producers and consumers vis a vis access to global financial markets and the long chains of extraction, production and disposal. A leafblower in remote sub-Saharan Africa would no more be able to 'do work' and 'produce value' than a cow could produce milk on the moon. Social relations – flows of capital and natural resources in turn generated by the unequal value of human labour mediated through the symbolic value of finance- presuppose the 'productivity' of machines. This view of machines as existing in a 'dialectical penumbra' nevertheless accepts the stability of natural laws amidst the cultural construction of values such as 'efficiency' and the social construction of unequal exchange across the global division of labour (position 3).

Machines are both proof of Naturalness and irredeemably Social – thus they lend themselves to a host of metaphorical innovations. But as we shall see, we must choose our metaphors wisely, as they can conceal as much as they reveal. The discourse of 'energetics' was key to the complexity of the machine metaphor. As a major leap in the annals of physical science, and a fertile source of 'hard' legitimacy for the 'soft' sciences of general biology and sociology, the elevation of thermodynamic principles as universal 'laws of nature' begins with the study of the fiery hearts of industrial machines. Against mechanism, will argue that thermodynamics at this level reminds us that machines are subordinate to the limits imposed on the biospheres expansion by its basis in the biological process of photosynthetic energy capture and by the geologically slow process of carbon fixation. Even for machines, the economic process begins with life. Things get even stranger when, as we shall discover, the machine metaphor that crystallised the 'scientific' character of each of the sciences emerged through an intriguingly parallel structure of theory change, and ultimately used the same central metaphor (value=utility='energy'=price for economics, energy=currency in the case of ecology)

In summary, I would like to suggest that most neoclassical economists would consider the epistemic status of their discipline from position (1.a) or (1.b.). However, given the tendency of their account of 'the economy' to ignore the 1st and 2nd law of thermodynamics, and to drum out of the ranks anyone who casts aspersions at the centrality of permanent growth to a sane policy, I will argue that economics is a prime case for those who would seek to prove (4.b), and considering the general proximity of orthodox economists to wealth and power, I would sit them at the same table with Foucault and Nietzsche at (4.c), to see what they might learn. While cracks are appearing, the concepts of 'growth' and 'equilibrium' in economics seem so resistant to abundant opportunities for falsification that they thus must be considered as undeconstructable 'world hypotheses', the metaphysical cornerstone of the neoliberal economy of nature.

Things get more complicated when we move on to a discussion of ecology, as my account is more sympathetic to accounts of widespread anthropogenic change. Here I would argue from position (3.b.) with respect to ecology. Given the sheer complexity of notions of equilibrium and balance across economics, biology, ecology, mechanics and thermodynamics the notion of the 'stability of nature' is itself of course deeply problematic. The global ecology crisis itself has itself banished the possibility (if not the ideal) of stability as a reference point for many ecologists. Despite the open character of evolution and complex systems in the long term, I think a clear difference exists between the 'stability' of the climax rainforests of Sarawak and Kalimaantan over (say) the last several million years versus the period 1950 -2050, over which time it is projected that they will have been more or less completely logged and burned out of existence.

As a confessed lay reader of scientific literature who can claim no expertise (although even physicists sometimes admit to not fully understanding it), I am reasonably convinced that no-one has yet struck down the 2nd law of thermodynamics, which while explaining the contingency, irreversibility and energetic limitations of bio-economic and socio-economic systems, is itself (at least since 1865) as 'stable' as a 'natural law' can be. While aware that its close application to biological and especially social phenomena remains controversial, my own arguments are sympathetic to the cause of ecological economics, which, following Nicolas Georgescu-Roegen,[134] recognises the 2nd law as the ultimate point of reference for unifying the study of the nature of machinery and the machinery of nature, and thus potentially illuminating our predicament at the turn of the third millennium.

## Part I Endnotes

[1] Alfred North Whitehead, *Science and the Modern World: Lowell Lectures*, New American Library, [1925] 1956, pp. 288–89.
[2] Prime Minister John Howard MP, Archbishop Sir James Duhig Memorial Lecture,
St Leo's College Brisbane, 5 September 2002. <http://www.pm.gov.au/news/speeches/2002/speech1826.htm>
[3] President George W. Bush, Speech of 7 December 2001.
<www.whitehouse.gov/news/releases/2001/21/20011207.html>
[4] Angela Mitropoulous and Brett Neilson, *Academia Inc. and the Culture War*, unpublished article, University of Western Sydney, 2005.
[5] Australian Senate Hansard, 28 October 2003. Cited in Margot Kingston, 'Nazi Greens an Enemy of Democracy, Government Decrees', *Sydney Morning Herald*, 29 October 2003.
[6] Anon, 'Those Neo-Nazi Greens Should Be Taken Out the Back and Shot'.
<http://www.ironyparty.org/ipa02nov03.htm>
[7] See Sharon Beder, *Global Spin: the Corporate Assault on Environmentalism*, Scribe Publications, Melbourne, 1997; also Frederick Buell, *From Apocalypse to Way of Life: Environmental Crisis in the American Century*, Routledge, New York, 2003, p. 3 – 38.
[8] Ulrich Beck, *Ecological Politics in the Age of Risk*, trans Amos Wiesz, Polity Press, Cambridge, MA, 1995.
[99] Hayden White, *Metahistory: the Historical Imagination in Nineteenth Century Europe*, John Hopkins University Press, Baltimore, 1973.
[10] Georg Wilhelm Friedrich Hegel, *Lectures on the Philosophy of World History*, (ed.) Duncan Forbes, trans. Hugh Barr, Cambridge University Press, 1980.
[11] Merriam-Webster Online Dictionary, 'Definition of Dialectic', accessed 18 June 2007. <http://www.m-w.com/dictionary/dialectic>
[12] Karl Marx, *Grundrisse*, Harmondsworth, Penguin, 1993, p. 334. Cited in Melinda Cooper, 'Life, Autopoesis, Debt: Inventing the Bioeconomy', *Distinktion*, no. 14, 2007, pp. 25-43.
[13] Of course 'environmentalism' was not 'invented' in the 1960s and 1970s, but its modern suite of scientific claims, political and economic critiques, and broad-based political support and influence can be reasonably dated to this period.
[14] Intergovernmental Panel on Climate Change, 'Third Assessment Report: Climate Change Report 2001', 2001. <http://www.ipcc.ch/pub/online.htm>
[15] Robert Bradley, 'The Increasing Sustainability of Conventional Energy', *Cato Institute*, Policy Analysis No. 341, 22 April 1999. <www.cato.org/pubs/pas/pa-341es.html>
[16] Bill McKibben, *The End of Nature*, Viking, London, 1990, p. 7; Francis Fukuyama, *The End of History and the Last Man*, Avon Books, New York, 1992.
[17] Daniel Bell, Anthony Wiener and Herman Kahn, *The Year 2000*, Macmilan, London, 1967; Daniel Bell, *The Coming of Postindustrial Society*, Heinemann, London, 1974. Alvin Toffler, *Future Shock*, Random House, New York, 1970; Alvin Toffler, *The Third Wave*, Bantam Books, New York, 1981.
[18] Y. Modhrizinska and C. Stephanyan, *The Future of Society*, Progress Publishers, Moscow, 1973; V. Kosolopav, *Mankind and the Year 2000*, Progress Publishers, Moscow, 1976.
[19] Donnella Meadows et al., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*, Pan, London, 1972.
[20] Meadows et al., *Limits to Growth*, p. 73.
[21] Meadows et al., *Limits to Growth*, p. 86.
[22] Meadows et al., *Limits to Growth*, p. 189.
[23] Cited in Anthony Dolman, *Resources, Regimes and World Order*, Pergamon Press, New York, 1981, p.25.
[24] Cited in Dolman, *Resources, Regimes and World Order*, p.25.
[25] Eric Schumacher, *Small is Beautiful*, Abacus, London, 1973, p. 119.
[26] http://www.hubbertpeak.com/hubbert/
[27] M. King Hubbert, 'Nuclear Energy and Fossil Fuels', paper resented before the Spring Meeting of the Southern District, American Petroleum Institute, Plaza Hotel, San Antonio, Texas, March 7-9, 1956.
[28] Rachel Carson, *The Silent Spring*,

[29] Milton Friedman, 'The Social Responsibility of Business is to Increase Profits', *New York Times Magazine*, 13 September 1970, pp. 32-33.
[30] Andrew Hoffman, *From Heresy to Dogma: an Institutional History of Corporate Environmentalism*, New Lexingtion Press, San Francisco, 1997, p.3.
[31] Cited in Betty Jean Craige, *Eugene Odum: Ecosystem Ecologist & Environmentalist*, University of Georgia Press, 2002, Chapter 6.
[32] Friedman cited in Lewis F. Powell, 'Attack on American Free Enterprise System. Memorandum to Eugene B. Sydnor, August 23, 1971', *Media Transparency*. <www.mediatransparency.org/stor.php?storyID=22>
[33] Powell, 'Attack on American Free Enterprise System', p. 8.
[34] Paul Treanor, 'Neoliberalism: Origins, Theory, Definition' 2006. <http://web.inter.nl.net/users/Paul.Treanor/neoliberalism.html>
[35] Ravenscroft and Williams, 'Making Imaginary Worlds Real', p. 21.
[36] Cited in Ben Fine, 'Economic Imperialism and Intellectual Progress', *History of Economics Review*, vol. 32, 2000, p. 12.
[37] Fine, 'Economics Imperialism and Intellectual Progress,' 2000.
[38] Susan George, 'A Short History of Neoliberalism', paper presented at the *Conference on Economic Sovereignty in a Globalising World*, Bangkok, March 24-26, 1999.
[39] George Soros, *The Crisis of Global Capitalism: Open Society Endangered*, Little, Brown and Company, London, 1998, pp.126-128.
[40] Michael Hudson, *Super Imperialism: the Origins and Fundamentals of U.S. World Dominance*, Pluto, London, [1972] 2003. I am indebted to Melinda Cooper for this reference. Indeed much of this history of the early seventies derives from illuminating and productive discussions with her over the past few years. For her own take on the significance of this period, see her 'Life, Autopoesis, Debt: Inventing the Bioeconomy', *Distinktion*, no. 14, 2007, 25-43.
[41] Hudson, *Super Imperialism*, xv.
[42] John Dillon, 'Will US Debt Lead to a Financial Crisis?', Kairos Policy Briefing Paper No. 2, February 2006.
[43] Cited in Dillon, 'Will US Debt Lead to a Financial Crisis?', p. 3.
[44] Alfred Wohlstetter, 'Maintaining The Delicate Balance of Terror', *Foreign Affairs*, April 1959.
[45] David Suzuki and Anne McConnell, *The Sacred Balance: Rediscovering our Place in Nature*, Greystone Books, Seattle, 1999.
[46] P. Vitousek, P. Ehrlich, A. Ehrlich, and P. Matson, 'Human appropriation of the products of photosynthesis', *Bioscience*, vol. 36, no. 6, 1986, pp. 368 - 373.
[47] Wackernagel, M.L, Onisto, L., Callejas Linares, A., Lopes, I.S., Falfan, J., Mendez Garcia, A.I. and Suarez Guerrero, M.G *Ecological Footprints of Nations*, Centre for Sustainability Studies, Universidad Anahuac de Xalpa, Mexico City, 1997.
[48] World Bank, *Responsible Growth for the New Millennium: Integrating Society, Ecology, and the Economy*, World Bank Publications, 2004.
[49] Julian Simon, 'The State of Humanity: Steadily Improving. Cato Policy Report 17 (5)', Cato Institute, Washington, D.C. 1995, p. 14.
[50] Garrett Hardin, *The Ostrich Factor: Our Population Myopia*, Oxford University Press, New York, 1999.
[51] Jonathon Wiener, 'Beyond the Balance of Nature', *Duke Environmental Law and Policy Forum*, vol. 7, no 1, 1996, p. 1.
[52] Cited in W. Callebaut, (ed) *Taking the Naturalistic Turn*, University of Chicago Press, Chicago, 1993, pp. 262-3
[53] Philip Mirowski, *More Heat than Light: Economics as Social Physics: Physics as Nature's Economics*, Cambridge University Press, Cambridge, 1989, p. 1.
[54] Judy Wacjman, *TechnoFeminism*, Polity, Cambridge, 2004, p. 83.
[55] Bernard Cohen, *The Natural Sciences and the Social Sciences*, Kluwer Academic, Dordrecht, 1994, p. xv.
[56] Ann Laura Stoler, *Race and the Education of Desire: Foucault's History of Sexuality and the Colonial Order of Things*, Duke University Press, Amherst, 1995.
[57] Richard Cobden, 'Free Trade with All Nations', speech given at Manchester, England on the 15 January 1846. <http://www.cooperativeindividualism.org/cobdenonfreetrade.html>
[58] Philip Mirowski, *More Heat than Light: Economics as Social Physics: Physics as Nature's Economics*, Cambridge University Press, Cambridge, 1989, p. 1.
[59] Anson Rabinbach, *The Human Motor: Energy, Fatigue and the Origins of Modernity*, University of California Press, Berkeley, 1992.
[60] Cited in Robert E. Ricklefs, *The Economy of Nature: A Textbook in Basic Ecology*, W.W Freeman and Company, New York, 1997, p. 1.
[61] Ilya Prigogine and Isabelle Stengers, Order *out of Chaos: Man's New Dialogue with Nature*, Heinemann, London, 1984.

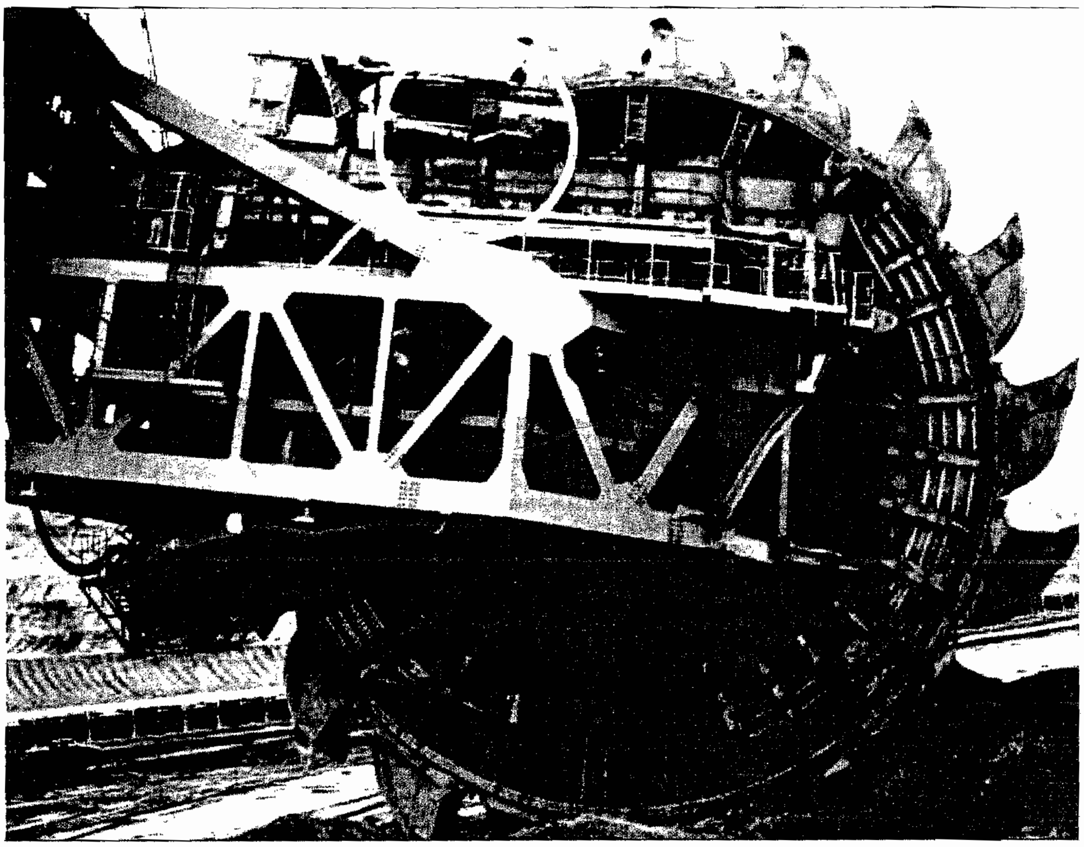
[62] Michael Rothschild, *Bionomics: Economy As Ecosystem*, Henry Holt & Company, 1995.
[63] Brad Cox, 'Bioeconomics: Economics as Ecosystem, not Machine', 2004. <http://www.virtualschool.edu/mon/Bionomics/>
[64] Thomas Kuhn, *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago and London, 1963, p. 4.
[65] Wikipedia contributors, 'Commensurability (philosophy of science)', *Wikipedia, The Free Encyclopedia*, 2 February 2007.
[66] In this view, dispute as to what counts as legitimate scientific knowledge could ideally be submitted to an automaton that would automatically accept or reject knowledge claims according to faithfulness to a fixed, programmatic scientific method.
[67] See especially Chapter 10 of Kuhn, *The Structure of Scientific Revolutions*, 1962.
[68] Michel Foucault, *The Order of Things: An Archaeology of the Human Sciences*, Pantheon, London, 1970.
[69] For a politicised critique of the attempts of the dreaded postmodernists to relativise the specific results of natural science to the class positions, cultures, genders and languages of scientists, and to expose the architecture of domination hidden within natural science, see Paul R. Gross & Norman Levitt, *Higher Superstition: The Academic Left And Its Quarrels With Science*, John Hopkins University Press, Baltimore, 1998. In the current decade, science faces much more dangerous opponents than Gross and Levitt's somewhat mischievously categorised 'academic left': the six-day creationist, no-such-thing-as-climate-change Christian Right embedded in the Whitehouse. See for example: Editorial, 'Science under attack by the Bush Administration', *Nature*, vol. 439, no. 7079, February 2006, p. 891.
[70] T. Allen, A. Zellmer and C. Wuennenberg, 'The Loss of Narrative' in *Ecological Paradigms Lost: Routes of Theory Change*, (eds.) Kim Cuddington and Beatrix Beisner, Elsevier, Amsterdam, 2006, p. 362.
[7171] Edward O. Wilson, *Consilience: the Unity of Knowledge*, Vintage, Cleveland, 1999.
[72] Philip Mirowski, 'The Realms of the Natural', in *Natural Images in Economic Thought: Markets Read in Tooth and Claw*, (ed.) P. Mirowski, Cambridge University Press, New York, 1994, p. 463.
[73] Mary Midgely, *Science as Salvation: a Modern Myth*, Routledge, London, 2002. p. 14.
[74] Cited in Midgely, *Science as Salvation*, p. 14.
[75] Wilson, *Consilience*, p. 2.
[76] Midgely, *Science as Salvation*, p. 17.
[77] Cited in Bruna Ingrao and Giorgio Israel, *The Invisible Hand: Economic Equilibrium in the History of Science*, trans. Ian McGilvray, MIT Press, Cambridge, 1990, p.189.
[78] Cited in Ingrao and Israel, *The Invisible Hand*, p. 189.
[79] Thomas A. Boylan & Paschal F. O' Gorman, 'The Duhem-Quine Thesis in Economics: A Reinterpretation', *Paideia*, 1998. <http://www.bu.edu/wcp/Papers/Econ/EconDvor.htm>
[80] Mary Hesse, 'Quine and a new Empiricism', in *Knowledge and Necessity*, (ed.) G.N.A. Vesey, Royal Institute of Philosophy Lectures, Macmillan, London, 1970, vol. 3, p. 195. Cited in Boylan and O'Gorman, 'The Duhem-Quine Thesis in Economics', 1998.
[81] Donald McCloskey, 'The Rhetoric of Economics,' *Journal of Economic Literature*, vol. 31, June 1983, p. 434-61.
[82] George Lakoff and Mark Johnson, *Metaphors We Live By*, University of Chicago Press, Chicago, 1987.
[83] Contrary to popular belief, there is no Nobel Prize in economics. Nobel's original endowment did not consider economics a science worthy of a prize. Controversy occasionally erupts over the legitimacy of economists claiming to have advanced the cause of science on the basis of receiving one of these prizes.
[84] Arjo Klamer and Thomas Leonard, 'So What's an Economic Metaphor?' in *Natural Images in Economic Thought: Markets Read in Tooth and Claw*, (ed. P. Mirowski), Cambridge University Press, Cambridge and New York, 1994, p.21.
[85] Bjørn Lomborg, *The Skeptical Environmentalist: Measuring the Real State of the World*, Cambridge University Press, Cambridge UK, 2001.
[86] Cited in, Anon, 'Science and Technology: The litany and the heretic; "The Skeptical Environmentalist"', *The Economist* vol. 362, no. 8258; Feb 2, 2002, p. 83.
[87] G. Deleuze & F. Guattari, *1000 Plateaus: Capitalism and Schizophrenia*, trans. Brian Massumi, Athlone Press, London, 1996.
[88] Cited in Andrew J. Hoffman, *From Heresy to Dogma: an Institutional History of Corporate Environmentalism*, New Lexington Press, San Francisco, 1997, p. 192.
[89] Steven Bernstein, *The Compromise of Liberal Environmentalism*, Columbia University Press, New York, 2001.
[90] Philip Mirowski, 'Ecology in the Mirror of Economics', editorial posting, *History of Economics Society*, posted 6 October 1996. <http://www.eh.net/lists/archives/hes/oct-1996/0042.php>
[91] Niles Eldredge and Steven J. Gould, 'Punctuated Equilibria: an Alternative to Phyletic Gradualism' in *Models in Palaeobiology*, (ed.) T.M. Schopf, Freeman Cooper, 1972, pp. 82-115.

[92] Philip Mirowski, *Against Mechanism, Protecting Economics from Science,* Rowman and Littlefield, Totowa, New Jersey, 1988; Philip Mirowski, *More Heat than Light: Economics as Social Physics: Social physics as Nature's Economics, Cambridge* University Press, Melbourne, Cambridge, 1989; Philip Mirowski (ed.) *Markets Read in Tooth and Claw: Natural Images in Economic Thought,* Cambridge University Press, Cambridge and New York, 1994; Philip Mirowski, *Machine Dreams: How Economics Became a Cyborg Science,* Cambridge University Press, Cambridge, 2002.
[93] Jeremy Rifkin, *The Biotech Century,* Tarcher/Putnam, New York, 1998, p. 197.
[94] Emile Durkheim and Marcel Mauss, *Primitive Classification*, trans. Rodney Needham, University of Chicago Press, Chicago, 1963.
[95] Emile Durkheim, *The Elementary Forms of Religious Life*, trans. Carol Cosman, Oxford World Classics, London, 2001.
[96] Mary Douglas, *Natural Symbols*, Penguin, London, 1973, p. 93. Cited in Philip Mirowski, 'The Realms of the Natural', in *Markets Read in Tooth and Claw,* (ed.) Philip Mirowski 1994, p.453.
[97] Mary Douglas, *Purity and Danger: an Analysis of Concepts of Pollution and Taboo, Routledge,* New York, [1970] 2002; Mary Douglas, *Leviticus as literature, Oxford* University Press, Oxford, New York, 1999.
[98] Mirowski, 'The Realms of the Natural', in *Markets Read in Tooth and Claw*, p.453.
[99] Mirowski, 'The Realms of the Natural', pp. 454-455.
[100] Mirowski, 'Doing What Comes Naturally' in *Markets Read in Tooth and Claw,* p. 14.
[101] Malcolm Bull, *Seeing things Hidden: Apocalypse, Vision and Totality*, Verso, London, 1999.
[102] Mirowski, 'The Realms of the Natural', pp. 456- 460. .
[103] For a full explication of two decades of modern animal trials conducted on presumably innocent rats and pigeons, see John Kagel et. al, *Economic Choice Theory: an Experimental Analysis of Animal Behaviour,* Cambridge University Press, 1995.
[104] Hornborg, *The Power of the Machine,* 2001.
[105] Barbara Adam, *Timescapes of Modernity: the Environment and Invisible Hazards,* Routledge, London, 1998, p. 29.
[106] R. A. Morrow, *Critical Theory and Methodology*, Thousand Oaks, New Delhi, 1994, p. 78.
[107] Ulrich Beck, Ecological Politics in an Age of Risk, trans. Amos Weisz, Cambridge Polity Press, 1995.
[108] J. D. Proctor, 'Environmental and Ecological Concepts of Nature', in *International Encyclopaedia of the Social and Behavioural Sciences,* Elsevier Science, 2001, p. 10399.
[109] Raymond Williams, 'Ideas of Nature', in *Problems in Materialism and Culture,* (ed.) Raymond Williams, Verso Press, London, p. 67.
[110] Klamer and Leonard, 'So What's an Economic Metaphor', p. 31
[111] D. Gentner and M. Jeziorski, 'The Shift from Metaphor to Analogy in Western Science' in *Metaphor and Thought*, (ed) A. Ortony Cambridge University Press, Cambridge, 1993, pp. 447- 80.
[112] Gentner and Jeziorski, *Metaphor and Thought*, p. 448.
[113] George Lakoff and Mark Johnson, *Metaphors We Live By,* University of Chicago Press, Chicago, 1987.
[114] Kim Cuddington, 'The "Balance of Nature" Metaphor and Equilibrium in Population Biology', *Biology and Philosophy*, vol. 16, 2001, pp. 464.
[115] Duhem, 1977, pp. 95-96, in Mirowski, *More Heat than Light*, p. 278.
[116] Mary Hesse, 'The Explanatory Function of Metaphor', in *Logic, Methodology, and Philosophy of Science,* (ed.) Yehuda Bar-Hillel, Elsevier, Amsterdam, 1972, pp. 249-259.
[117] Peter Weingart and Sabine Massen, 'The Order of Meaning: The Career of Chaos as a Metaphor', *Configurations,* vol. 5, no. 3, 1997, pp. 463-520.
[118] Mary Hesse, *Science and the Human Imagination*, Philosophical Library, New York, 1955, p. 88.
[119] Klamer and Leonard, 'So What's an Economic Metaphor?', p. 35.
[120] Weingart and Maasen, 'The Order of Meaning', p. 476.
[121] Milton Friedman, *Essays in Positive Economics,* University of Chicago Press, Chicago, 1953.
[122] Cited in Klamer and Leonard, p. 36.
[123] Klamer and Leonard, p. 36.
[124] Richard Boyd, 'Metaphor and Theory Change: What is Metaphor For?', in *Metaphor and Thought,* (ed.) Andrew Ortony, Cambridge University Press, p. 356-408.
[125] Klamer and Leonard, p. 39-42.
[126] Stephen Pepper, *World Hypotheses*, University of Berkeley Press, California, 1942.
[127] Friedreich Nietzsche, *Philosophy and Truth: Selections from Nietzsche's Notebooks of the Early* 1870s, (ed.) Daniel Brezeale, Humanities Press, New Jersey, 1979, pp. 84-89.
[128] Lakoff and Johnson, *Metaphors We Live By*, p. 157

[129] Stephen Fuller, 'Science Studies Through the Looking Glass: an Intellectual Itinerary', in *Beyond the Science Wars: the Missing Discourse about Science and Society*, (ed.) U. Segerstråle, State University of New York Press Albany, 2000, pp. 185-217.
[130] Mirowski, *Natural Images in Economic Thought*, p. 18.
[131] Michael Adas, *Machines as the Measure of Men: Science, Technology, and Ideologies of Western Dominance*, Cornell University Press, 1989.
[132] Karl Marx, 'Notes on Machines', *Economy and Society*, vol. 1, no. 3, [1908] 1973, p. 244- 254.; Lewis Mumford, *The Myth of the Machine: Technics and Human Development*, Harcourt Brace, and World, Michigan, 1967.
[133] Alf Hornborg, *The Power of the Machine: Global Inequalities of Economy, Technology and Environment*, Altamira Press, CA, 2001.
[134] Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process*, Harvard University Press, 1971; Kozo Mayumi, *Origins of Ecological Economics: the Bioeconomics of Georgescu-Roegen*, Routledge, London, 2001.

PART II: NATURE OF ECONOMY

# Industrial Millennium



*Krupps 'Bagger 288' Coal Trencher (detail)– the World's Largest Machine?* [1]

## Constructing the Economy: Social Physics and the Providential Machine

*- The ways of the Creator are not our ways, Mr Deasy said. All history moves toward one great goal, the manifestation of God.*

*- History, Stephen said, is a nightmare from which I am trying to awake.*

- James Joyce, 1922, *Ulysses* [2]

***machine*** *n. apparatus in which the action of several parts is combined for the applying of mechanical force to a purpose; person like a machine in regularity or insensibility; controlling organisation in politics etc*

- Shorter Oxford Dictionary

**The Origins of Progress and the Secularisation of the Millennium**

The world and its people are moving toward an ever more prosperous condition – despite the occasional structural adjustments of recession and war- and the 'motor' propelling this inexorable advance is economic growth. Such is, or has been the most enduring story about the historical *telos* of modernity. Even if it is never really explicitly recited, its narrative saturates our basic social institutions: our stock markets, savings accounts, parliaments, our corporate bodies, and international development, it is also confirmed in our permanent state of technological revolution. We are inhabited, so the students of mythology and the philosophers of history tell us, by forces we scarcely perceive.

Progress as the ideology of modernity posits the accumulative improvement of science, the increasing control and improvement of nature through the proliferation of powerful technologies and machines, and the increasingly rational political organisation of human labour and exchange. For some three centuries, since the discovery of 'the economy' as a defined subset of social existence, the elimination of oppression, poverty, drudgery, despotism, ignorance, warfare, and disease- have been associated more or less directly with what Karl Marx referred to as the 'advance of the productive forces' and what liberal modernisation theorists since World War II have called 'economic growth'. At the time of writing, the growth of the economy is the undisputable priority of all modern national governments, and the fundamental object of all politics in the West. . The growth of the economy is thus the historic task of government. Faster rates of growth confer political legitimacy upon governments; slower rates of growth attract accusations of managerial ineptitude. Up until 1989, modern political debate in industrial society was firmly divided upon ideological lines as to the most effective method of attaining growth; in short, the putative choice was either through egalitarian socialist planning, or through free-market liberalism. Rising material standards of living for everyone were the honourable Enlightenment goals espoused by the proponents of liberalism and its heretical twin, socialism. While the Left was united with the Right on the necessity of increased productivity and the increasing availability of industrial capital and consumer goods, the traditional Left argued that markets were inefficient institutions for guiding decisions regarding production and distribution. Its short-term focus on profit as the guiding motive of production generated wasteful competition, chronic instability and profound social inequality. The vicissitudes of the business cycle, with unemployed workers paying the costs for the irrationalities of speculation in downturns, could be ironed out through the social rationalisation of industry. While this is of course a massive simplification of left economics, the point is clear: socialists objected to the market because the profit motive inhibited a more optimal maximisation of industrial production, and consequently, delivered a less than optimal growth path toward a society of economic equality. The Plan would generate faster growth than The Market. Since 1989, the Marxist variant of this project has rapidly declined as a governmental practice, as has the Keynesian project with its mandate to managerially balance the business cycles, market failures and class conflicts of market capitalism. The neoliberal version is everywhere triumphant. Growth, measured at the national level in Gross National Product statistics, is taken as an automatic metric of the health of society with the success of governments measured almost exclusively in their ability to manage 'the economy'. The mainstream consensus on this view is unchallengeable. As Clive Hamilton observes,

> "The answer to almost every problem is 'more economic growth'. Unemployment is rife: only growth can create jobs. Schools and hospitals are under-funded: growth will improve the budget. Protection of the environment is unaffordable: the solution is growth. Poverty is entrenched: growth will rescue the poor. Income distribution is unequal: growth will make everyone better off. For decades we have been promised that growth will unlock possibilities previous generations could only dream about. Economic growth will deliver a life of ever-increasing leisure, more free services, devices to relieve drudgery, opportunities for enrichment, exciting space travel, and cures for the diseased of humankind. The lure of growth is endless."[3]

While the 20th century was dominated by an ideological conflict over the best way to engineer economic growth, it is generally accepted that the Marxist-Leninist program of centralised industrialisation focussed upon social equity has failed. Although there are any number of political economic possibilities between the old Soviet model and the new laissez-faire of neoliberalism – the Bolivarian socialism of the new Latin left, the Scandinavian welfare state, the mixed-market economies of Western Europe, the Japanese model of corporatist development through the planning powers of the Ministry of Trade and Industry, the authoritarian models of South Korea and Taiwan – it is the neoliberal model which dominates the process of globalisation. Institutionalised in the World Trade Organisation, the International Monetary Fund, the forum for Asia-Pacific Economic Co-operation, and the North American Free Trade Agreement it thus structures international economic relations and the everyday experience of countless individuals. Neoliberal policies underscore the management of intergovernmental debt, the structure of transnational finance and trade, and thus the conditions for the uneven integration of transnational trade and investment associated with globalisation.

Free markets, so the public discourse goes, have demonstrated their ability to generate the highest rates of economic growth. Where once political leaders promised freedom, social equality, free education, the restoration of national dignity, or as one satirist of the Australian Labour party put it, "to build a great nation under the Southern Cross where meat will be cheaper," [4] lofty ideals of humanitarian moral progress have generally been reduced to promises for more economic growth. As Hamilton notes, the catholicity of what he calls 'growth fetishism' is such that none of the major political parties differ on economic policy, and thus must generally differentiate themselves through marketing, engaging in the symbolic politics of spin and cultural style. No one dares challenge the rationalism of growth economics who hopes to be considered sane enough to govern. Economic growth is generally considered a very matter of fact, pragmatic and ordinary notion, merely a routine increase in the volume of goods and services produced annually. Unpacking this concept with a close and critical analysis however, reveals the contrary: to borrow a phrase from Marx's discussion of commodity fetishism, the idea of growth "abounds in metaphysical subtleties and theological niceties."[5]

In his 1995 book *Ecological Politics in an Age of Risk*, Ulrich Beck castigated his fellow German sociologists for holding too closely to the Durkheimian doctrine of excluding all but social facts as suitable for study.[6] Beck argues that sociology has proved blind by temperament to what he considers the most novel and crucial development in the transformation of late-industrial society: its exposure to large-scale ecological hazards and the emergence of institutions intervening for good or for ill in the social distribution of industrial side-effects. In 'simple modernity', ideological conflict condenses around the issue of how to grow the pie and how to cut it. In the 'risk society' arising from the post-war chemical, nuclear and genetic industries and the very success of growth economics, the question becomes what to do when the pie is poisoned? Writing in 1995, Beck excoriated a kind of disciplinary complacency he saw had set into the social sciences, which he characterised as "apocalypse blindness", a rich term when we consider that 'apocalypse' literally translates to 'unveiling' and thus the removal of impediments to clear vision of the truth. As Beck said,

> "[...] the following question has been criminally rejected by the social sciences: what does the threat of self-annihilation mean to society, its institutions, its understanding of progress and itself; to the legal, scientific and economic system; to politics and culture?" [7]

German sociology might be forgiven for this in that there exists there a long tradition of demarcating the methods and problems of *Gemeinwissenschaft* from *Naturwissenschaft*, and there is wisdom in the Durkheimian dictum that social science should deal only with social facts. Nevertheless, environmental degradation is a social fact – it is not 'natural' but artificial. Global ecological risks are social in origin and increasingly shape and constrain the options available to future generation. Things get more complicated when we consider the apocalypse blindness of neoliberalism. The emergence of this political ideology and social philosophy was in part a move to ward off the regulationist, anti-growth claims of 'apocalyptic' 1970s environmentalism. A project that claims to be grounded in the most scientific social theory ever devised, neoliberalism is frequently associated with anti-environmentalist rhetoric. Neoclassical economics, which might be regarded as the 'science of market exchange,' explicitly represents itself as a science of the 'Nature of the Economy'. What is intriguing about the claims of economics as science is that its fundamental analytic model of the economy is of system in 'equilibrium' – a concept, it would seem, fundamentally in contradiction with exponential 'growth'. The contradiction between growth and equilibrium, evident in the two most basic images of modern economics (the diagrams of supply-demand equilibrium and economic growth reproduced on page 1 of this thesis) is the essential problematic of our critique of economics as science.

This thesis is interested primarily in the historical basis upon which the claim of economics to the status of science was constructed, precisely because the neoclassical approach to economics is not only regarded as the most effective means for governments to engineer maximum economic growth, but has lately also became indispensable in resolving the greatest challenge facing modern societies, the suite of problems that add up to the 'global ecological crisis.' As the ex-US Vice President and global warming activist Al Gore is reported to have said,

> "Free market capitalist economics is arguably the most powerful tool ever used by civilization. As the world's leading exemplar of free market economics, the US has a special obligation to discover effective ways of using the power of market forces to help save the environment."[8]

Gore's recent film *An Inconvenient Truth* has done much to finally make climate scepticism the marginal position in the United States and Australia, where official denial was entrenched along with anti-Kyoto policies. Nevertheless the faith in perpetual economic growth governed by the spontaneous ordering of law-like market forces remains intact, even as it is being reconfigured to incorporate the realities of runaway global warming. Perpetual growth through deregulated market forces: is this formula the residue of a metahistorical political process once characterised by warring ideologies and now, in the age of liberal-democratic globalisation, subordinate to the universal illumination of the 'endpoint of mankind's ideological evolution' in tandem with the unlimited potential of science-based production, as claimed by Fukuyama? Will the 'power of market forces' yield ecological salvation as well as continuous increases in production? Is this the result of science? Or ought economics rather be seen as a rhetorical discourse, a persuasive meta-history that recuperates the millennial sense of expectation oriented toward a future temporal horizon?

In this first substantive half of the thesis, I argue that the ideological triumph of the economics of perpetual growth and the mastery of 'market forces' as 'the most powerful tool' of civilisation is not, as its defenders would argue, merely the result of the pragmatic success of liberal governance, in turn proof of the superior rationality of orthodox economics as a confirmed science. Examining the history of the constitutional metaphors of 'the economy' according to the archaeological method outlined previously, this history of the neoclassical 'Economy of Nature' will attempt to dig up the root metaphors of the tree of economic knowledge. In doing so, it will argue that despite its impenetrably 'scientific' format and resemblance to physics, the reason that economic science lends itself so well to the doctrine of infinite growth is that its theory of nature – manifest in the concepts of 'growth', 'production', and 'equilibrium' – so poorly incorporates modern science that its truth claims are essentially metaphysical and faith-based. I will argue that neoliberalism is a scientised philosophy of history, a form of secular millennialism profoundly haunted by machine dreams that is attempting to instantiate a utopia that daily generalises a genuine ecological apocalypse. Of course ecological politics might similarly be analysed as a form of secular eschatology, dependent for its prophetic power of utterance upon the revelations of biological science. For the philosopher of history Hans Blumenberg, "eschatology speaks of an event breaking into history, an event that transcends and is heterogenous to it".[9] Ecological politics, which has moved from marginality in the 1960s to increasingly infiltrate contemporary geopolitical discourse, is informed by scientific prediction of particular ends: to specific species, to the abundance of natural kinds, to natural resource stocks, to entire ecosystems and habitats, and to the relative stability of the cyclic functions of the biosphere. In aggregate these threats amount to a general 'end of nature' – or at least as we have known it – if left unchecked. An ambient fear permeates industrial society, the fear that it is running out of time. Redemption is posited in terms of an 'ecological morality' that positions the local subject – washing out their cans and calculating their carbon emissions – in deep time and in relation to the totality of the biosphere, from which perspective modernity appears as an 'industrial apocalypse'. The ecological crisis is the material, global event that has broken into the transcendent history of modernity as the history of human progress and emancipation from nature.

My term 'industrial millennium' seeks to describe the relevant cultural foundations of the industrial worldview as reflected in orthodox economics, and to show how this most formal and abstract of the human sciences engenders 'apocalypse blindness' with regard to the ecological context of the economy.

Rather than being a 'dismal science', I would argue that economics, has unacknowledged links to a utopian view of machine technology that is built into its theory of Nature, and thus severed from natural history is prone to (secularised) millennial expectations. John Bozeman has coined the term 'technological millenarianism' to describe the prophetic aura of cutting-edge science in social and religious movements "strongly holding the opinion that technology will bring about a new golden age in the near future that will create a substantial and permanent, fundamental improvement in the human condition".[10] As David Nye points out, throughout the history of industrialism, the spectacle of feats of engineering, of kinematic machinery in operation, generated experiences of 'the sublime'. Originally a category of experience reserved by continental Romantics for the transcendental experience of natural landscapes – as in the Germanic forests and wind lashed seas painted by of Casper David Freidrich, the 'sublime' refers to the sense of "awe and wonder, often tinged with an element of terror, that people have had when confronted with particular natural sites", a once common cultural experience that Nye notes was increasingly transferred in 19th century America from nature to the "architectural forms and technological achievements" that represented the conquest of nature by machine technology.[11] "The technological sublime" says Nye, "is an integral part of contemporary consciousness and its emergence and exfoliation into several distinct forms during the past two centuries is inscribed within public life. In a physical world that is increasingly desacralised, the sublime represents a way to represent the landscape and the works of men with transcendent significance."[12] This elevation of the productivist transformation of nature to an inexorable principle of historical liberation I will refer to as 'industrial millennialism', and I will argue that it an integral part of contemporary consciousness, inscribed within public life and inhabiting the basic structures of discourse about 'the economy'.

The association of economics and theology is not new, and has been made by many others. Gordon Bigelow for example, has explored the long-term historical links between the lassez-faire doctrines of the market and evangelical Protestant morality. Noting elective affinities between economics and theology, he proposes that:

> "Economics, as channelled by its popular avatars in media and politics, is the cosmology and the theodicy of our contemporary culture. More than religion itself, more than literature, more than cable television, it is economics that offers the dominant creation narrative of our society, depicting the relation of each of us to the universe we inhabit, the relation of human beings to God. And the story it tells is a marvellous one. In it an enormous multitude of strangers, all individuals, all striving alone, are nevertheless all bound together in a beautiful and natural pattern of existence: the market. This understanding of markets – not as artefacts

of human civilization but as phenomena of nature – now serves as the unquestioned foundation of nearly all political and social debate."[13]

Millennialism is generally conceived as a religious phenomenon, and most specifically as the Christian preoccupation with the cataclysmic change portended at the End of Time by such texts as the Book of Revelation. It has been defined by the medieval scholar Richard Landes as a belief that certain final events will "usher in a reign of Peace, Justice and Plenty *here on Earth* and that salvation for the Just will be collective and its rewards experienced while living in the flesh."[italics in original][14] Such a definition offers scope for the possibility of secular versions of millennialism, and scholars using this terminology have indeed identified many such movements. The term 'millennialism' has been used to refer either to philosophical questions about the totality of history within the high religious culture of European theology, or to the popular eschatologies of marginal religious movements more narrowly focussed on the present and the immediate political future, when the injustices visited upon the good and common 'salt of the earth' by the wicked and the powerful would be addressed in an apocalyptic transformation of the nature of society and the order of things.[15] As we are concerned with the high religious culture of global capitalism, we shall generally understand 'millennialism' as relating to questions about the totality of history, and reserve the term 'millenarian' to describe the popular and revolutionary movements marginal to the mainstream.

What is common to all forms of industrial millennialism is a secular sense of historicity vested in the apparently generative powers of labouring bodies and industrial machines. This chapter's attempts to point the way to a genealogy of industrial millennialism are generally directed at the liberal version. This is because I believe that the global ideological currency of neoliberal economics remains the greatest stumbling block preventing modern political discourse from taking environmental crisis seriously. In the applied politics of European integration, such as the fine-tuning of trade and banking conventions by the Bretton Woods institutions and negotiations between states and corporations, liberalism has generally retreated from historicist grandstanding. The utopian aspects of liberal philosophy are usually obscured by disguising them in a mathematical black box called Economic Science. (The obvious exception here is the messianic zeal of the George W. Bush administration regarding the historic mission of the United States to establish a beachhead of economic globalisation by military means in the last 'unglobalised' region of the world economy, the Middle East). But how does a science of modern industrial society come to be impervious to the data and conclusions of other sciences, such as climatology, biology, ecology, and thermodynamics, which contradict its prognostications of infinite growth with dire warnings of global degradation and mounting destruction? An answer to this question requires some historical background on the origins of the social sciences in general, and thus invites reflection on the character of 'the economy', that incomplete and unstable hybrid of Nature and Society. In recalling this history, we will point out the continuous association of industrial millennialism with the quest for a 'social physics', a social science capable of eliciting the hidden and invariant natural order within societies and thus providing the knowledge for the enlightened governmental engineering of human populations. Our argument is that this aporia within economic science and its applied forms derives from the relationship between the historicist and reductionist tendencies in the social sciences, or in other words, from the generative contradictions between 'industrial millennialism' and 'social physics' as manifest in economics. The remainder of the section will deal with the former, and the latter will be woven back into our narrative in the section that follows.

Since it was first published in 1957, Norman Cohn's *The Pursuit of the Millennium,* a study of the millenarian movements of the Middle Ages and early Reformation, has done much to return the question of the apocalyptic narrative to the terrain of modern political discussion.[16] His study dwelt on the Brethren of the Free Spirit of the middle ages (an underground heretical movement advocating sexual liberation, the avoidance of labour and the creation of communities of equals without property), and also discussed the prophetic leaders of the early Peasant Wars of Germany in the 1520s, particularly Thomas Muntzer's League of the Elect, and John of Leyden of the Anabaptists. During the early years of the 16$^{th}$ century, the peasantry of Southern Germany, who were more or less owned as property and subject to rising taxation and labour demands from their ecclesiastical and temporal lords, erupted in open revolt. The princes ruthlessly put down these rebellions with heavy cavalry and mercenaries, and it is thought that around a hundred thousand peasants were killed before the revolts ceased.

Marxist historians had claimed these movements as proto-communist movements, attempting to overthrow the oppressive psycho-sexual irrationality of medieval Catholicism, its bureaucracy of thought policing and Inquisition, and the economic slavery and serfdom supported by the Church and later maintained under Protestant princes. These millenarian anti-Church and anti-state movements were portrayed by both Soviet historians and the Western intellectuals of the Situationist Internatioanale as prototypes of 19$^{th}$ and 20$^{th}$ proletarian revolutionary movements that differed only in that they were not yet able to dispose of a transcendental view of history for the historical materialism of Marx. Against this, Cohn argued that modern revolutionary parties were the irrational continuations of the religious passion of millenarianism; and thus the *prophetae* of the 16$^{th}$ century were recognisable as the antecedents of fascist and communist totalitarian states. He characterised the revolutionary millenarians and mystical anarchists of his history as:

> "[...] a restlessly dynamic and utterly ruthless group which, obsessed by the apocalyptic phantasy and filled with the conviction of its own infallibility, set itself above the rest of humanity and recognized no claims save that of its own supposed mission. [...] A boundless, millennial promise made with boundless, prophet-like conviction to a number of rootless and desperate men in the midst of a society where traditional norms and relationships are disintegrating - here, it would seem, lay the source of that peculiar subterranean fanaticism." [17]

Cohn's book established an 800-year-old connection between anti-nomian mysticism, popular irrationality, purifying violence and utopian thought and suggested that these pre-modern cultural forms had survived into the modern period in rejection of modern science and liberal humanism. Here he echoed Karl Popper's classic work *The Poverty of Historicism*, written in Germany in 1937 when the question of the state justifying its radical restructure of society according to 'the laws of historical destiny' was at its most urgent.[18] In a sweeping and complicated critique of historicism, holism and utopian social engineering – which he associated with the idea that there were 'laws of history' available to be discovered by sociology – Popper concluded that only open societies, founded upon the ideals of individual freedom and the competitive search for scientific truth secured in liberal institutions, were conducive to the extension of scientific rationality to sociology and therefore to the development of non-utopian theories of progress. While provisionally sympathetic to this critique, I want to argue that contemporary neoliberalism exhibits an identical utopian tendency. While neoliberalism is not usually associated with 'revolutionary violence' – although the counter-revolutionary violence of Pinochet's Chile provides an exemplary exception – its power to execute its ideological predilections through the top-down restructure of international economic relations upon literally billions of people through unelected econocrats invites a critical discussion of the scientific basis of its social theory. All that is required is to restrict government intervention in the economy to the minimum, provide freedom of movement to capital flows and private business, and 'the market' as the most efficient 'motor of growth' will automatically optimise the structure of society such that the highest levels of productivity will be achieved. As no necessary connection is admitted between increased wealth in one location of the world system and increased poverty in another, nor between the accumulation of wealth and environmental degradation, the historical projection of neoliberalism is that if enough 'deregulation' occurs, ultimately 'everyone will become rich'. In order to establish my association of the mundane 21st century political economy of nations with the millennial metanarrative, some discussion of Christian and Enlightenment philosophies of history is necessary.

The Western phenomenology of historical time can be traced to the Book of Revelations, otherwise known as the Apocalypse of St. John, the book which completes the canoninical scriptures of the Western church and projects the salvation story of the New Testament from the time of its writing into the ever imminent future. It is primarily from this book that the branch of theology known as 'eschatology' arises, which translates to the 'doctrine of last things'. Eschatology marries the doctrine of the individual soul with the doctrinal narrative of the historical meaning of the cosmos as a whole. The termination of the individuals' life and the termination of the world are joined together in a cosmic event in which, after global warfare and the near annihilation of the earth, the elect are rehabilitated in a thousand year reign of peace, followed by the regenerative creation of a new heaven and a new earth. Eschatological narratives propose a temporal continuum with an 'end', in both the sense of a purposeful 'goal' and a 'terminus'. The end of time marks the beginning of eternity, an eternity in which the good are separated from the evil and biological death is separated from conscious life through resurrection to immortality.

The Greek term 'apocalypse' from which the English word 'revelation' comes translates to the 'lifting of the veil', and refers both to the divine transmission of truth to John and to the ultimate 'moment of truth', the imminent irruption of the divine into history as Christ returns, at which moment the truth of the Christian cosmology will no longer be 'hidden' but undeniably visible to all. The Apocalypse of St John is a thoroughly dense, delirious, grandiose and visionary book, which like all good prophecies is so semantically impenetrable that any exegete can extrapolate its symbolism to the present and thence to the immediate future. It was written during the height of Roman persecution of the nascent cult of Jesus, and is thought by some scholars to have been retroactively attributed to the apostle. One interpretation of the text is that it is an anti-imperialist manifesto, denouncing the tyrannical violence of the Roman state and its 'false gods', with a psychedelic revenge fantasy in which divine justice is restored at the end of history by the raising up of the martyrs, who are given a box seat to watch the spectacular destruction of the evil empires of the world. In accordance with the Hebraic tradition of Jubilees, in which all debts were to be settled or forgiven every seven years in order to restore justice to the Judaean community, Revelations provides a cosmic 'balancing' of accounts and the restoration of justice for all time. The Creation, poisoned by the sins of the arrogant, is purified when Christ returns, although this time he comes not as a pacifist mendicant, but as a warrior and judge wreaking untold violence. Amid the destruction of the earth and the Nations identified with the Whore of Babylon, the warrior Christ and his angelic hordes instantiate the Millennium, a thousand year period of peace and justice and plenty by in which the meek inherit a regenerated and purified world.

The revolutionary import of the Apocalypse later posed a problem when the Roman Empire was Christianised under Constantine, and later when the remains of the Roman Empire became the Holy Roman Empire, with the Papal See as its highest sovereign authority. The Apocalypse of John only just made it into the final cut of the authorized Bible at the canonisation councils convened to establish the unified doctrine required of a state religion. Had it been excluded, history would have been very different, both literally and philosophically. As it cemented its social power, the church faced the ongoing problem of trying to square its narrative of a messianic kingdom overturning the corruption of tyrannical states with its own position as the supreme institutional power in an obviously unredeemed world. St. Augustine, one of the founding Doctors of the Roman Church, attempted to solve this problem by insisting that the visions of Revelation were not to be interpreted literally as concrete or historical images of the near future. Rather, he asserted that John's polymorphous, libidinal and distinctly anti-imperial visions were purely allegorical: the millennial Kingdom of God was already present on Earth in the body of the Church.[19] This doxy was to be challenged in the twelfth century by the scholastic obsessions with the Apocalypse of a Calabrian abbot, Joachim of Fiore, who devoted his monastic life to the exegesis of the text and its correspondences with the other prophetic books of the bible, especially Daniel and Isaiah. Eventually, Joachim of Fiore came to believe he had discovered the keys to history, as Erik Davis explains:

> "Laying the Christian Trinity along a linear timeline, Joachim declared history to be the progressive realization of the Father, the Son, and the Holy Spirit. The earliest age of the Father was characterised by the rule of law and the fear of God, while the second age, kick started by Jesus and signified by the shift from the Old to New Testaments, was the Age of the Son, a time of faith and filial devotion to the gospel and the Church. But Joachim heard a third era knocking on the door: a new age of the Holy Spirit. With its coming, the edifice of the worldly Church with its institutional sacraments and scriptural law, would give way to a free eruption of love, joy and wisdom that would endure until the last judgment. Joachim's millennial utopia would see spiritual knowledge directly revealed into the hearts of all men, a kind of universally distributed charismatic gnosis that would fulfill Moses' lament in Numbers 11:29. "Would that all the Lord's people were prophets, and that the Lord would put his spirit upon them!'"[20]

While the Catholic Church has been unable to decide whether Joachim was a saint or a heretic, his writings have inspired a wave of movements that continually rocked the Church, including the mystical communists of Cohn's study, the voluntarily poor of the Franciscan order, and the more radical of the early Protestant sects. His philosophy of history was novel in that it promised radical and continuous improvements in the human condition, achieved through the individual pursuit of spiritual truth and accompanied by the falling away of existing social relations and sovereign powers. He also differed from Augustine as seeing the unfolding of history not in terms of the moral life of the church, but as the progressive fulfilment of prophecy as realised in concrete political and historical events. Most importantly for our narrative, by casting history as a self-transcending process, Joachim of Fiore laid the groundwork for entirely modern understandings of social development, revolution and progress.[21]

As Paul Rabinow has written, "Christian history until the Reformation is a history of expectations, or more exactly, the constant anticipation of the End of the World on the one hand and the continual deferment of the End on the other."[22] The central fixation of the Church on eschatology and the political sensitivity surrounding the task of exegesis of the Book of Revelation is representative of the perennial problem this hallucinatory text presented for the ecclesiastical dictatorship of Rome. Re-asserting its exclusive intellectual property right over prophecy at the Fifth Lateran Council in 1517, the year Luther nailed his critique of the Church to one of its doors, the Roman Catholic Church formalised a doctrine that beforehand had only been tacitly assumed: "claims about the future of the world must be authorised by the Church".[23] At this juncture the rapid multiplication of sects was being rapidly facilitated by the multiplication of texts: Gutenberg's press established an information revolution by making books and pamphlets widely available in vernacular languages, which enabled any literate visionary to bypass the Churches' Latin-based scholastic monopoly on exegesis and the production and transmission of knowledge.

Martin Luther's translation of scripture into vernacular German was prepared during the peasant revolts of the 1520s in Germany. Luther encountered a similar problem to Augustine: he found the vindictive Jesus of Revelations incompatible with the gospels and relegated it to the appendix of his translation of the New Testament, instead of to the body of scripture. Indeed, with the exception of Calvin, all the Protestant reformers regarded apocalyptic millennialism to be heresy.[24] During this period, Luther sheltered from excommunication behind the power of the German princes, and lent his authority to the brutal suppression of the peasants inspired to greater rebellions than his own by unauthorised vernacular interpretations of Revelations. The princes, for their part, were highly supportive of Luther's suggestion that the Universal Church reform itself by decentralising its finances and surrendering their control to national sovereigns.

The standard account of the emergence of the modern state sees it as the residue of the exhaustion of Europe after centuries of brutal wars that opened with Luther's schismatic pronouncements of 1517 and ceased with the 1648 Peace of Westphalia. According to modern liberal theorists such as John Rawls, Jeffrey Stout and Judith Shklar, the secularisation of public discourse and the emergence of liberal principles arose as the solution to the irreconcilable differences of competing religious notions of the public good. As Shkar puts it:

> "Liberalism was born out of the cruelties of the religious civil wars, which forever rendered the claims of Christian charity a rebuke to all religious institutions and parties. [..] The choice then set, and still before us, is not between classical virtue and liberal self indulgence, but between cruel military and moral repression and violence, and a self-restraining tolerance that fences in the powerful to protect the freedom and safety of every individual."[25]

The liberation theologist William Cavanaugh has argued that this view of the modern state as the peacemaker between Catholics and Protestants is irredeemably simplistic – various Protestant movements fought one another, as did Catholics, and Catholic and Protestant armies fought together against other shifting alliances. For example, the soldiers of the Holy Roman Emperor Charles V did not lay waste to Wittemburg in 1527, but to Rome. Rather, he argues, what has been portrayed as the 'Wars of Religion' were actually the labour pains of an absolutist conception of the state and its subsequent demolition of the medieval ecclesial order, a state which demanded ultimate loyalty and which laid an exclusive claim to the bodies and treasures of its subjects.[26] With Machiavelli we see the first intimations of the idea of a state as a political authority independent of the ecclesial courts, but it is only with the works of humanists such as Thomas Hobbes and Jean Bodin in the 16th century that there emerges the idea of the State as "a form of public power separated from both ruler and ruled, and constituting the supreme political authority within a certain defined territory."[27]

The subordination of religious authority to the absolute state was accompanied by the secularisation of the philosophy of history. Jean Bodin, a player in the rise of the absolute state in France, a *Politique* in the court of Catherine de Medici, exemplifies this moment. In a treatise on the sovereignty of state written during the struggles of the Reformation, Bodin inaugurated the secularisation of historical study as a tool for maintenance of the state and the reproduction of its legitimacy. Bodin made a distinction between divine history, natural history and human history, prudently according theological knowledge as the domain of greatest certainty, and conceding that the knowledge of social history was somewhat less certain, but necessary for the functions of government. As nature was then seen as fixed and unchanging between the Creation and the Apocalypse, its history was not relevant to the concerns of the state. According to Rabinow, "the uncoupling of human history from sacral history, and the legitimation of a modern state capable of subduing salvation oriented religious factions were for Bodin one and the same"[28] This secularisation of history during the rise of the modern nation-state was accompanied by the emerging self-consciousness of intellectuals that they were living in a Modern age that was qualitatively distinct from (although causally linked to) the Ancient or Medieval epochs that preceded it. The salvation history of Christendom faded into the emergent political history of nation-states.

The jurist and scientist Francis Bacon is a central figure in the secular genealogy of Progress and the hagiography of modern science. For himself, Bacon was convinced that the progressive revelation of the truth of prophecy in history spoken of by Joachim of Fiore had been realised in his time, and that he stood at the dawn of a new era. Reinterpreting Joachim, he believed that the Third Age was not to be one of monastic holiness, but of a Great Instauration of scientific knowledge and technological skill that would raise the dignity and power of humanity to unprecedented heights. His view was inspired by the recent major advances in astronomy and by the 'discovery' of the New World:

> "And this proficience in navigation and discoveries may plant also an expectation of the further proficience and augmentation of all sciences; because it may seem that they are ordained by God to be coevals, that is, to meet in one age. For so the prophet Daniel speaking of the latter times fortelleth, *plurimi petransibunt, et multiplex erit scientia* [many shall run to and fro, and knowledge shall be increased] : as if the opening and through passage of the world and the increase of knowledge were appointed to be in the same ages; as we see it already performed in great part."[29]

The discovery and colonisation of the New World, advances in the technology of navigation and transport, and progress in the basic sciences of astronomy and physics, augured the way to a new dispensation in which Man increasingly took control of Nature and bent her to his will under reason. Bacon's visionary account of history terminated in the New Jerusalem, a society of incredible abundance based upon the absolute mastery and control of nature. The opening of a vast new frontier of space and natural resources is often underestimated as a source of the millennial optimism characteristic of the period, especially in those nations that were active in navigation and the colonisation of the Americas.

Despite the inclusion in Western metahistory of scientific and technological progress, and the subordination of ecclesial history to a separate history of the secular state, Classical and Christian views continued to dominate historical consciousness until the second half of the eighteenth century. The seventeenth century saw a powerful resurgence of apocalyptic and millenarian thinking, extending, as is now well known, even to such scientists as Isaac Newton. As in the Middle Ages, this view of time limited interest in the present to a period of waiting and preparation; the anticipated future arose providentially from the present, not as the result of conscious human action. While this was so, there could be no true concept of modernity.[30] Dorothy Ross has comprehensively argued that the emergence of the social sciences is inseparable from the acute forms of historical consciousness particular to modernity, especially those associated with the formation of powerful, centralised nation-states and the birth of capitalism. Social science, she argues, arose from philosophical inquiries into history in an attempt to guide societies into the future. Deriving from the Renaissance traditions of moral philosophy, the new disciplines of political economy, political science and sociology emerged during the $18^{th}$ and early $19^{th}$ centuries out of an effort to understand the character and future of modern society. Dorothy Ross lists several works as exemplary of this intellectual moment: Montesquieu's *Spirit of the Laws* (1748), Adam Smith's *Wealth of Nations* (1776), Condorcet's *Outline of an Historical View of the Progress of the Human Mind* (1795) and Herder's *Ideas Toward a Philosophy of History* (1791). Reflecting the view of numerous scholars that the social sciences originated in historical questions, Ross writes that: "[t]he effort to create social sciences was bound up with the discovery that history was a realm of human construction, propelled ever forward in time by the cumulative effects of human action, and taking new qualitative forms." [31] I will argue that this view of the independent origins of the social sciences tends to seriously neglect the history of crucial influences from and exchanges with the natural sciences. Nevertheless, the Augustinian view of time and history associated with an unchanging universal human nature and society, as Krishan Kumar has put it,

> "[...] was gradually undermined in the second half of the nineteenth century, so opening the way to a new concept of modernity. A critical part was played by Christian philosophy of history, which finally delivered up the idea of modernity that was inherent in it from the start. But it could only do so by being decisively secularised. What Kant called the 'moral terrorism' of Christianity – the apocalyptic expectation of the world's end – had first to be exorcised. This happened especially with the millenarian form that was so vigorous in the seventeenth century. In reflecting on it, and its relation to the new scientific perspectives of the age, thinkers from the late seventeenth century onwards converted secular beliefs into a millennial idea of progress. The millennium became scientific and rational, the dawn of an era of unending human progress on earth. The idea of progress, as elaborated by Kant,

Turgot, Condorcet and others during the eighteenth century, was the central building block of the new idea of modernity." [32]

The philosopher of history Karl Löwith has argued that the modern ideology of Progress can be interpreted as the secularisation of Christian eschatology, and thus far we have compiled some evidence to support this view. The enlightenment belief in 'Progress' did not, he claimed, arise spontaneously as a fully formed secular ideology. "The irreligion of progress" he argued is still a sort of religion, derived from the Christian faith in a future goal, though substituting an indefinite and immanent *eschaton* for a definite and transcendent one."[33] In the famous debate about the origins of Progress Löwith undertook with Hans Blumenberg, he is regarded as having defeated his opponent, who argued instead that Progress ideology could be traced to the realisation of early astronomers that the long series of empirical observations of planetary motion required to prove their theories would require several lifetimes. Malcolm Bull interprets Löwith as suggesting that the idea of progress itself is "an identifiable product of the apocalyptic tradition."[34]

Immanuel Kant took the colourful Christian drama of an apocalyptic end to time (and to mortal embodiment) giving way to the infinity of reunion with God as a parable, merely symbolic of the unending, incremental penetration of reason into earthly affairs. In a passage reminiscent of Adam Smith's invisible hand, Kant wrote that "Individual men, and even whole nations, little think, while they are pursuing their own purposes – each in his own way, and often one in direct opposition to another – that they are unintentionally promoting, as if it were their guide, an *end of nature*, which is unknown to them." [my italics] [35] Of course when Kant speaks of the 'end of nature' he means not some final catastrophic meltdown of the biosphere, or the apocalyptic universalisation of the artificial – these are senses which I will entertain later – as this would obviously have been inconceivable in 18th century Konigsberg. Rather he is referring to a hidden goal to which the historical process is oriented. Kant's infinite progress resembles Xeno's paradoxical arrow: it is a goal toward which the world continually approaches but never arrives. To the great chagrin of Nietzsche, who recognised a theological instinct when he saw one, Kant conceptualised 'the moral law' as the essence of the real world and the hidden inner working of nature, manifest in the unfolding of human history. Similarly, the structure of progress ideology in the version supplied by Hegel, according to Karl Löwith, took from eschatology the notion that history has "an irreversible direction toward a future goal" and transposed "the expectation of the end of time into the course of the world process, and the absolute of faith into the rational realm of history."[36] According to Bull, Hegel viewed history from a universal perspective as part of a divine plan manifest in a sequence of periods or stages which culminates in a new era which is, in some sense, also an end to history." [37] Either way, for many thinkers in the tradition of *der Aufklarung* and the modern political movements that have been informed by their historicism, modern natural science with its self-correcting, rational core and its continual accumulation of knowledge has provided a model of the progress of reason which might be extended to the political sphere with the development of social sciences.

To the standard secularisation thesis I would like to add that the transformation of the Western narrative – from a theological eschatology to Enlightenment teleology - is not one that took place only within the rarefied sphere of philosophical or political discourse, but was connected to the co-evolution of machine technology with European societies. Joachim of Fiore, with his futurist drive to perfect history, contributed to the profound alteration of the medieval approach to technology, and under his influence monasteries began to incorporate the once lowly 'mechanical arts' into their divine labours.[38] As David Noble has shown in his book *The Religion of Technology*, machines were taken as embodiments of the divinely given superior rationality of the human mind over the rest of nature.[39] The dominion of humans over nature through technology was not only seen as having utilitarian value: the human ability to reveal the secrets of nature, to transform nature and command it to serve human ends was associated with the active redemption and regeneration of a fallen world. For Noble, technology has always been linked to eschatology, and the technological development that has been built into Western cultural history for the last few centuries remains suffused in millennial faith. However as Kumar notes, it was only with the British Industrial Revolution of the late eighteenth century that modernity took on a distinctive material form, and Progress ideology became irrevocably tied to scientific materialism. Industrialisation was seen by early secular theorists and social scientists as a liberating force that would terminate in an emergent equilibrium of universal prosperity, a process that would drive societies to a new point of stability: to a new plateau, on a higher plane where all the dynamic contradictions of the past would be resolved.[40] According to Kumar, this was

> "[..] because of the very explosiveness of the development [...] a speeding up of economic evolution to the point where it took on revolutionary proportions. Modernity has a before-and-after quality that is also a hallmark of revolution. With the Industrial Revolution, such a quality increasingly became evident, to the extent that for many [social scientists] the only significant division in history appeared that between pre-industrial and industrial civilisation. [...] Industrialism turned societies still largely poor and agrarian into centres of power whose goods, guns and ships overwhelmed the resistance of all non-industrial people. [...] It is difficult to think about modernity without thinking about steel, steam and speed. From the

Great Exhibition of 1851 in England to the World's Fairs of the 1930s in America, industrialism trumpeted its achievements and pronounced itself the salvation of humanity."[41]

Later I will argue at length that the success of 'industrialism' in liberating the English and the Americans (and others) from the Malthusian constraints of pre-industrial times was to no small extent due to the opening of two immense resource frontiers that were unavailable to previous generations. The first of these was 'pristine' ecospheres encountered in the colonial possessions of the British Empire in the New World, and for the Americans, the long frontier of Westward expansion, that did not stop at the Californian coast but was built into the myths of Manifest Destiny and American exceptionalism. The second resource frontier was of course the tapping of the vast reserves of energy stored in the 'subterranean forests' of mineralised fossil fuel, without which industrial machines could not at all appear to be productive. Nevertheless, in the late 19th century industrialism decisively embodied and generalised the ideology of infinite Progress. The expounders of this ideology, then as now, had an interest in attributing the concentration of wealth in their own lands as the pure result of superior knowledge, and not as the displacement of other people from their lands and the exploitation of their labour and resources. The progressive realisation of the industrial millennium was relocated in 'economic evolution', which was presented both as the moral triumph of Ricardian free trade and as a technological tour-de-force, and cleanly abstracted from the machine-determined social relations embedded in the factory floor, and in the profoundly unequal structures of colonial commodity trade, without which the accumulation of wealth would arguably have been impossible.

To Karl Marx we owe an intellectual debt, for his philosophical critique of the social relations embedded in industrial capitalism – although the fossil-fuelled industrial revolution was only beginning to gather pace when he made his interventions. According to Popper's critique of Marx, presented under the title 'The High Tide of Prophecy' in the second volume of his major work, *The Open Society and its Enemies*, Marx's impeccable moral and humanitarian commitments and formidable analytical powers were betrayed by his adoption of a utopian historical system overly influenced by Hegel.[42] According to Popper, Marx prophesied an end to human suffering not as a goal towards which we must strive to move (Kantian progress), but rather as a pre-existing and ensured future (Hegelian progress). For Popper this historical determinism led to the easy rejection of democratic principles in the states run by Marx's political executors and heirs. It seems to me that the ideological problem of the Marxist-Leninist state qua Marx's historicism is identical to that of Augustinian Catholicism in relation to the Apocalypse of St John: social justice, ensured by the 'laws of history', was supposed to be realised permanently within the state upon the revolutionary accession of the Marxists to power. When the end of history was not achieved as advertised, the powers that be were forced into the perpetual deferral of imminent perfection and the repression of heterodox accounts of the scriptures. However, as we will later see, it was not ultimately the moral evolution of society that Marx settled upon as the driver of his dialectical materialism, but the 'advance of the productive forces' that would finally assure joyful liberation and equality in the industrial millennium to come. In this respect, Marx is no different from his neoliberal critics at the end of history, although they have vulgarised and rendered banal the moral eschatology of industrial millennialism in the mundane quarterly accounting of perpetually rising GDP in societies driven, so they say, by nothing more than 'consumer sovereignty.'

Throughout the history of the social, political, technical and environmental transformations driven by the emergence in Europe of industrial capitalism, its colonial adventures and the providential histories of post-colonial national development, many versions of the 'industrial millennium' have come and gone. The term could include a range of ideologies and social movements from the utopian industrialism of Saint-Simon, Charles Fourier or Robert Owen, through German fascism, Italian futurism, Marxist-Leninism, Taylorism, and to post-war modernisation theory. It also provides a comparative framework for the discussion of contemporary formations of 'postindustrial millennialism', a concept I will develop only in the concluding chapter. The distinction between industrial and postindustrial millennialism is the distinction between a culture of productivism organised around a discourse of infinite growth organised by the metaphorical nexus of industrial machines, and a culture of productivism that emerges after the apocalyptic revelations of ecosystems ecology from the late 1960s, organised by the information processing metaphors (and technical practices) said to have fundamentally transformed the industrial mode of production into the 'frictionless' and 'dematerialising' information based 'new economy' asserted in the 1990s. While we could continue this history of philosophy of history by multiplying examples of 'industrial millennialism', I would argue that the height of this belief system was reached in the 1960s, just prior to the emergence of the discourse of ecological crisis which has made serene faith in the liberatory qualities of industrialism less secure. To conclude, the following quote from a 1965 book entitled *Men, Machines and History*, by the British socialist Stephen Lilley encapsulates in concentrated form the secularisation of eschatology that I have described as 'industrial millennialism':

> "Just as there are laws of nature that we must understand if we want conquer our environment through technology, so also there are laws of social change that must be understood if we wish to control the history of the future. [...] What we know of science tells us that there can be no end to discovery and hence to the extension of man's control over nature. But it is unlikely that men will want to use this power to multiply their material wealth for more than

another century or so. After that they may decide that they are rich enough, and that there are better purposes for which they can use their knowledge and their mastery over the universe." [43]

While few would now assert the possibility of scientific social engineering according to the revealed 'laws of social change', the machine dream of perpetual economic growth remains with us. The global neoliberal consensus has placed the promise of perpetual growth at the core of its program to restructure whole societies. This time around, the promise is secured by the self-organising nature of the free market, not by the laws of history but by the invariant and universal 'laws of supply and demand'.

With this in mind, we now turn from the historicism of the secular millennium to the other side of the dialectic that I have earlier proposed: the movement to expunge all questions of meaning, morality and history from the social sciences and to construct a unified science of society that is universal precisely because it can be reduced to the universally operating 'laws of nature.' Before delving more deeply into the specific case of economics, we will briefly look at some of the early formative moments in the social sciences that, in attempting to eliminate the subjectivity and irrationalism of political discourse, sought to and raise their status to that of the physical sciences. As we shall see, the social physics project was not as antithetical to the utopian search for the millennium as one might suppose.

## Social Physics: Positivism and the Natural Law Tradition

The science of political economy was profoundly implicated from its inception in the arrival of what Michel Foucault refers to as a 'biopolitics of the human race'. For Foucault the birth of biopolitics in the late 18$^{th}$ century is heralded by the appearance of technologies of sovereign governmental power directed at the life of humanity-as-species, as "a global mass that is affected by overall processes characteristic of birth, death, production, illness and so on." [44] Birth rates, death rates, fertility rates and a range of other political and economic problems become for the first time objects of knowledge and subsequently targets of biopolitical control. Arguably, the two greatest achievements of early modern science were the astronomical mechanics of Galileo and his descendants, and the medical physiology of William Harvey. With the rise of the social sciences, both physiology and statistical mechanics became fertile sources of metaphors for early attempts to theorise the 'nature' of society, as early social scientists sought to replicate the success of these sciences, either through methodological borrowing, or simply through the appropriation of terminology esteemed for its acknowledged 'scientific' qualities. While the organismic tradition in early sociology is of interest to our research agenda to historicise the metaphor of 'growth' in economics, we will restrict our attention to the 'social physics' tradition, because this is the direct lineage from which orthodox economics came into its present form. For at least two centuries mainstream economists have generally avoided systematic extrapolations of the organismic metaphor. Foucault's notion of biopolitics is useful, and especially relevant to contemporary social critique. However, the construction of a state social science directed at the 'global mass' of the population was primarily associated with the superior prestige of physics. While the attempt to develop a social physics may seem to fulfil an entirely different impulse to that served by the grand dramas of millennial teleology, I would like to suggest that these two 'tendencies' have dwelt in a reciprocal and contradictory relationship to one another since the origins of modernity, and that this dialectical relationship between society and science is with us still, manifest in the assertion the 'market' as a domain of 'natural law', and in the default assumption of infinite growth.

Classical Greek philosophy posited a distinction between 'nature' (*physis*), on the one hand and 'law', in the sense of 'custom' or 'convention' (*nomos*) on the other. Customary law varied depending where you were, but what was 'natural' should be the same everywhere. The idea of a 'law of nature', an indispensable notion for early modern science, would to the Greeks have reappeared quite paradoxical.[45] The legal doctrine of 'natural law', derived from Kantian and liberal notions of universal human rights, ought to be distinguished form the idea of 'laws of nature'. Both are notably dualistic concepts, which use the metaphor for the corpus of rules that maintain social order (law) to describe observed regularities 'governing' material extra-social phenomena. Here we see a classic example of the Durkheim-Mauss-Douglas thesis. Social relations, specified customs regarding behaviour and punishment given legitimacy because embodied in the Kings sovereign body, itself a metaphor standing for the 'social body' of the national population, are projected into nature, and then in the bourgeois era, reprojected into social relations – the laws of supply and demand. The cycle of reification is complete when the liberal economists demand that the sovereign powers of the national parliament recognise, uphold, foster and legislate to uphold the smooth operation of the laws of nature embodied in commodity exchange.

With the rise of modern science came the shattering of the pre-modern cosmos with all its souls and certainties, and for many intellectuals, this generated a profound void. The 'material', denoted as the fundamentally objective domain of the world immune to humane influence, became the bedrock of unquestionable truth. The medieval cosmos was subsumed from the 17th century onwards by physical theory that insisted upon explanation in terms of *mechanism*. The Enlightenment decisively placed positive science at the centre of social practice, rejecting religious fatalism and its otherworldly salvation history for action in the here and now to improve and transform the human condition. Rather than supplicating to divine will as the Aristotelian final cause of phenomena, philosophers redefined causality as *mechanism*, and sought it in Descartes' *res extensa,* physical matter as distinct from consciousness (*res cogitans*). Bauman suggests that the *horror vacui* generated by modern reflexivity required that the material, the immutable and objective substratum of reality be beyond question. The sovereignty of God became the sovereignty of the material: an external object world distinct from representations of it.[46]

Isaac Newton is justly famous as the father of modern physics. His *Principia Mathematica,* published in 1687, looms large in the canon of the greatest of scientific works. In it, Newton explained a host of seemingly unrelated phenomena, such as the acceleration of falling objects, the precession of the equinoxes and the motions of tides according to his mathematical theory of forces. During the 17th century those engaged in what we would now call experimental science were predominantly considered as inventors, and their explanation of natural phenomena tended to refer to analogies and metaphors drawn from the mechanical devices they worked with. The *Principia* fundamentally altered this by revealing abstract, universal laws dictating the behaviour of the physical world through the use of fundamental mathematical principles.[47] In so doing, Newton made the physicist a "towering authority capable of grasping all the secrets of the universe."[48]

Given his representation as the archetype of scientific rationality by later writers with an agenda to present a Whig history of modern science as heroic progress towards crystalline rational truth, it might be interesting to note that Newton was also swept up in the millenarian and apocalyptic preoccupations of his time. The millennial impulse began to be excised from what counted as 'science' around the mid 17th century, although there was by no means a clear excision of meaning from the material. For some the End of the World became a problem of astronomical and mathematical calculation, and eschatology was forced into a natural history capable of explaining and contextualising political events.[49] Newton was no exception to this. On his own account, the reason for his enrolment at Cambridge University in 1660 to study mathematics was "because I wish to test judicial astrology", that is to predict events by the stars.[50] Newtown devoted much of his astronomical study to geopolitical astrology and his mathematical talents to the kabbalistic exegesis of prophetic biblical passages, as did many thinkers who lived through the turmoil of the English Revolution. Indeed the genealogy of the word 'revolution' itself betrays the indistinction made between astrology and astronomy, between politics and planetary motion. Rather than our contemporary usage of the term, which implies a profound transformation, to many contemporary observers, including Hobbes who coined the term, the events of the English civil war seemed to resemble a planets' heavenly course or 'revolution', with the status of the Realm returning to its original position with the Restoration of Charles II. The cosmological physics of Isaac Newton and his successors ultimately led to the demise of astrology as a political science, although this was not among his intentions. One of his prophecies was that the Papal Office would be abolished in the year 2000 AD. Indeed much of the astronomical data which modern theories developed from was collected with a view to perfecting astrological knowledge, compiled in order to reduce the uncertainty faced by sovereign rulers whose concerns about dynastic succession and war motivated the support of astronomical research perhaps as much as the practical or purely scientific benefits of improved knowledge. Nevertheless, by the late 17th century, scepticism toward prophetic religious conviction among the educated was already opening the way toward the rationalist humanism of the Enlightenment, and even though he was the head of the Royal Society, Newton was obliged to keep his hermetic pursuits to himself. His works on astrology and the Apocalypse were only published posthumously.

Strictly speaking, Newton was not a Newtonian, believing that the universe was evolutionary and its path of historical development corrected by divine intervention, as history moved toward "the coming of the Kingdom for which we daily pray."[51] Nevertheless his name has come to be synonymous with secular modernity and 'the' scientific method. The *Principia's* success in establishing universal 'laws of nature' through mathematics is generally heralded as the epitome of reason and scientific method. Newton's name became exemplary of the radical progress in scientific knowledge, and the mathematical universality of Newton's gravitational theory of motion provided the benchmark formal model for scientific method and thus for social theory with scientific aspirations.

In the 18th century, philosophers explicitly attributed the order in nature to the hand of God. God imposed physical laws on nature in much the same way as moral laws were imposed upon human beings. These two domains of law were separate: human beings were free to reject moral laws, but neither human beings nor the other parts of creation were allowed to contravene physical laws.[52] The two domains were alike, in that whatever humans might think or do, the 'laws' were invariant. Early attempts to save theology from science by asserting the certainty of an ordered *and* meaningful material cosmos involved some torturous accommodations to theology, as the following excerpt from d'Alembert's conversation with Diderot attests:

> "I confess that a Being who exists somewhere and yet corresponds to no point in space, a Being who, lacking extension, yet occupies space; who is present in his entirety in every part of that space, who is essentially different from matter and yet is one with matter, who follows its motion, and moves it, without himself being in motion, who acts on matter and

> yet is subject to all its vicissitudes, a Being about whom I can form no idea; a Being of so contradictory a nature, is an hypothesis difficult to accept."[53]

Here the acceptance of contradiction is posited as necessary for religious belief: I would ask the reader to keep this in mind for our later discussions of the contradictions of contemporary economic orthodoxy.

The astronomer Pierre-Simon Laplace disposed of these convolutions in his *Exposition du Système du Monde* (1796). There is a famous story that upon presenting Napoleon with a volume of this work on celestial mechanics, Napoleon asked him where God was in his system. Laplace is said to have replied 'I have no need of that hypothesis.' In his 1812 *Essai sur les Philsophique les Probabilitès*, Laplace inaugurated the field of social physics – and ultimately neoclassical economics, as we shall see – with the following suggestion:

> "Let us apply to the moral and political sciences the method founded upon observation and upon calculus, the method which has served us so well in the natural sciences."[54]

Their exists a debate among historian as to whom first coined the term social physics, and exactly what was meant by this. We shall leave this to the specialists, but note that the most important contenders are Adolphe Quetelet and Auguste Comte. Quetelet, considered the father of statistics and demographics, was fascinated by Laplace's observation that the number of letters arriving annually in the Paris dead-letter office conformed to simple probability distributions equivalent to accepted natural laws. He set about taking Laplace's ideas to their full extension, and produced and analysed reams of data on all kinds of subjects, including the chest sizes of Scottish males. Using the method of statistical probability analysis he borrowed from Gauss' theory of errors (later expressed as the 'normal law', or the bell curve), which was developed to correct differences in large numbers of astronomical observations, Quetelet eventually came to the view that the there were 'social laws' of nature of equivalent regularity and deterministic probability as the 'laws of nature' revealed by celestial mechanics, and that the science of government would be best placed upon statistical foundations. These ideas were advanced in his 1835 book *On Man and the Development of Human faculties: an essay on Social Physics,* which also introduced the quotidian figure of 'sur l'homme', the average man.

Auguste Comte, the inventor of the terms 'biology' and 'sociology' and the founder of 'positivism', was an early champion of the notion of a 'physique sociale'. Comte's notion of social physics resembled that of Quetelet in that his version was dedicated to putting the 'science of society' on the same bases as the physical sciences, which meant applying d'Alembert's principles of analytical mechanics – the 18th century's formulations of the problem of physical motion – to the determination of regularities in society. The term 'sociology' is said to have been coined by Comte because Quetelet, his rival, had already published using his preferred term: 'social physics'.

"The statical study of sociology" Comte wrote, "consists in the investigation of the laws of action and reaction of the different parts of the social system – apart, for the occasion, from the fundamental movement which is always gradually modifying them."[55] Where he differed from Quetelet was that he saw social physics as the key to a thoroughly scientific philosophy of history. Comte was a disciple of the utopian socialist Henri Saint-Simon, and collaborated with him in conceiving a work entitled *A Plan of the Scientific Operations Necessary for the Reorganization of Society*, published in 1822, which claimed that politics would soon become a social physics and discover scientific laws of social progress. Comte saw history as the progressive unfolding of human knowledge, a theory he elaborated in the exhaustive systematisation of the sciences presented in the *Cours de Philosphie Positive* (1832). Not only did he feel that the methods of physical science were applicable to the study of social phenomena, he argued that social science had evolved from these methods and was destined to overtake the physical sciences in explanatory power.

In his hierarchy of the sciences, Comte placed the social sciences, which he viewed as the most complex and the most dependent for their emergence on the development of all the others, as the highest in the hierarchy.

> "Social science offers the attributes of a completion of the positive method. All the others are preparatory to it. Here alone can the general sense of natural law be decisively developed, by eliminating forever arbitrary wills and chimerical entities, in the most difficult case of all." [56]

Comte's influential account of the sciences involved an ascending trajectory of increasing complexity and differentiation in the historical development of the sciences, with the 'higher' sciences building upon the 'lower' sciences according to the order in which they arrived at a 'positive' condition of modern scientific legitimacy. Comte's influence continues to be felt insofar as most people today believe that if any forms of knowledge have a right to claim universality they are mathematics and the natural sciences, especially physics and chemistry. Writing in the 1830s, Comte suspected that social and biological phenomena would prove too complex to be governed by precise and calculable laws. Nevertheless he shared the view with John Stuart Mill that progress was an unconditional and absolute trend reducible to the 'laws of human nature' revealed by "the positive theory of human nature".[57]

When in 1840 the English mathematician and philosopher William Whewell coined the word "scientist", he indicated the profoundly new direction being taken by modern society in its intellectual relationship to the natural world. Increasingly, it was one mediated by a growing group of academically trained professionals with a shared methodology and ethic. This ethic was the careful accumulation of 'positive knowledge'. Clearly implying that other knowledges were less credible, scientists began to assume the exclusive capability of and responsibility for producing 'positive knowledge', a reliable store of genuine and concrete truth by which long-term human progress might be served.[58] The search for positive knowledge among this new subculture of intellectuals differed from the undertakings of gentleman amateurs or the holists of the continental *Naturphilosophie* tradition in a number of ways. Rather than seeking a cosmic vision of nature that included aesthetic categories and drew sweeping moral lessons, scientists distinguished themselves by disciplined, analytical theory building, empirical experimentation, and review by trained peers.

Comte regarded positivism not merely a philosophical doctrine that stressed the value of logic and observation, but more importantly, as a philosophy of history. Human knowledge, Comte wrote, had evolved through three stages. The first stage was theological, the second metaphysical, and the final was to be 'positive.' Comte believed himself to be living on the revolutionary cusp of a new age. His teleological three-stage model recalls the 'pattern of threes' established by Joachim of Fiore, which also influenced Hitler's insanely millennialist Third Reich, as well as more recent breathlessly optimistic accounts of the 'postindustrial economy' such as Alvin Toffler's *The Third Wave.*[59] As a philosophy of history, Comtean positivism was a political program for constituting scientists as a managerial elite that would not only run societies according to positive knowledge; scientists would also assume the moral guidance functions of the Roman Catholic Church. During the 1860s, Positivism briefly enjoyed popularity as an intellectual movement that claimed to be capable of replacing Christianity as the ordering *milieu* of rapidly industrialising European society by virtue of its concern to locate an ethics of society within the scientific approach to knowledge they believed was driving this transformation. The primary ethical value was technical efficiency and thus it was envisioned that the tasks of politicians and engineers would become increasingly indistinguishable. As the labour force become more rationally integrated with the mechanised factory system of production, the social system was imagined as a hierarchy of working parts, merely another type of orderly machine governed by natural law. Positivism never had many adherents as a fully-fledged secular religion, perhaps due to fact that its anti-religious and anti-democratic vision of *ex cathedra* government by sovereign social physicists could only by appealing to the intellectual elites of the European ruling class. In an article dedicated to the question of 'secular millennialism', David Nash suggests that positivism as a philosophy of history and a form of secular millennialism was eclipsed by the rising popularity of collectivist movements, and the many variants of socialism largely took over its vision of a total science of social rationalisation and the engineering of Progress.[60] Against this, I would argue that the project continues in a new form, executed by economists who believe themselves immune to political prejudice and subjectivity, in the neoclassical conception of 'the market' as a sovereign law of nature, and in its political justification as the font of endless growth.

As Prigogine and Stengers have noted, the sense of confidence and power in modern science came from the identification of eternal, unchanging natural laws at the core of matter and material transformation. For generations, the discovery of order within nature stirred within the bosom of European intellectuals such as the French anthropologist Levy-Bruhl:

> "[...] a feeling of intellectual superiority ... so deeply anchored that we even do not see how it could be shaken. Even if we suppose that we could observe some phenomena quite mysterious, we still would remain persuaded that our ignorance is only provisional, that this phenomenon must satisfy the general laws of causality.... Nature around us is order and reason, exactly as is the human mind. Our everyday activity implies a perfect confidence in the universality of the laws of nature."[61]

Perhaps the most exemplary avatar of the god–like 'view from nowhere' attributed to science's gaze upon the totality of nature was the astronomer and mathematician who inspired the social physics enterprise, Pierre-Simon Laplace:

> "We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace *in a single formula* the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes." [my italics] [62]

Ilya Prigogine, the contemporary physicist renowned for his studies on the relation of evolution and biochemical emergence to far-from-equilibrium thermodynamics, confirms that despite common misconceptions to the contrary, the origins of western science are in theology. Leibniz, he says, clearly spells out the position of early scientific method. For Leibniz, the role of science was to bring man closer to knowledge of God. He supposed that for God there would be no difference between past, present and future, as his being was eternal. Therefore the goal of the scientist was to eliminate time, and thus to gain the perspective of immortal deity, removed from embodiment in a mortal body trapped in the circumscribed time of biological life. This is why, Prigogine says, classical and basic science has no time, although time is phenomenologically present to us at all times, so to speak.[63] With the exclusion of temporality, science presents the world as an automaton. As Isabelle Stengers and Prigogine have elsewhere commented:

> "To the extent to which dynamics has become and still is the model of science…it is still the prophetic announcement of a description of the world seen from a divine or demonic point of view. It is the science of Newton, the new Moses to whom the truth of the world is unveiled; it is a revealed science that seems alien to any social or historical context identifying it as the result of the activity of human society." [64]

It seems to me that all of these remarks apply directly to the intellectual underpinnings of the image of 'the market' at the core of contemporary orthodox economic discourse, an argument I will take up more forcefully later. For now, the reader may recall from the Löwith-Blumenberg debate discussed earlier that the defining origin of modernity and its forms of historical consciousness (the ideology of progress) has been attributed variously to the secularisation of Christian eschatology or to the promise of incrementally increasing knowledge yielded by the success of rational-empirical method in early astronomy. In the case of economics, I would argue that the current belief of neoliberal globalists in both infinite growth and the seemingly contradictory idea that deregulated markets exhibit a general macroeconomic equilibrium state akin to a natural law - assumptions present in all exponents of general equilibrium theory from Adam Smith in the 1770s to Kenneth Arrow in the 1980s - suggests that both arguments are correct.[65]

Having established the outlines of a dialectical relation between industrialism millennialism and social physics as interwoven tendencies abiding over the formative moments of the social sciences, we are now in a position to deal more directly with the specific origins of political economy. We began this section by posing the question of why the 'biopolitical' task of developing a governmental master science directed at a population of humans drew so little from medical biology, or natural history, or from prevalent organismic metaphors – approaches that might have later rendered economics more amenable to ecology when, in the latter half of the 19th century, both were instantiated as independent sciences. One answer to this, proposed by Keith Baker, is simply that mathematical physics was in the 17th and 18th centuries the epitome of scientific explanation, and almost by definition agreement with rational 'mechanics' was what counted as proof of the validity of claims to scientific knowledge.[66] In the following section we will discuss a third factor influencing the formation of economics: the metaphor of the machine.

**Machine Metaphors and the Discovery of the Economy**

*All things are full of gods.*

- Heraclitus

*Everything is a machine.*

- Gilles Deleuze

With apologies to the great literary satirist Jorge Louis Borges, a very short universal history of the master concepts of Western onto-theology might go something like this. First there were many anthropomorphic gods, which were then condensed into a single God. God came to be identified with Nature, a process that went hand in hand with the rise of the Machine. Nature expanded toward infinity in every direction with a commensurate shrinking of Man until the Natural Machine was the only thing to be seen when Man looked into the mirror of Nature.[67] *Homo Economicus,* when surveying the landscape, saw everywhere different kinds of utility maximisation machines.

In the basement of the London School of Economics, reports Paul Ormerod, an object of wonder gathers dust:

> "In the 1950s, Bill Phillips, an engineer turned economist, built a machine to teach his students about the workings of the economy. Levers are pulled, buttons are pressed. Sluice gates open, and liquids of different colours rush around the system in a controlled way."[68]

What follows is an attempt to explain how this concretised metaphor, "the very embodiment of the economists' view of the world", came to be there. In giving this account of the rise of the economics, I will argue that the 'apocalypse blindness' of contemporary economics can be traced to the triumph of the constitutive role of the machine as a metaphor for life, the universe and everything in 19th century industrial society, the context in which the economics we have inherited was born. The failure of economic theory, policy and institutions to grapple adequately with widening inequality and ecological crisis, I will argue, can be illuminated by a historical analysis of the central ideological value of machine technology in Western discourse. Since Descartes, Nature has been represented as a particular kind of machine. In economics, this representation is extended to by physical analogy to the study of the 'price mechanism', claimed with all the authority of science as a Natural datum external to social relations. In the process of reducing Society to a purely mechanical mathematical abstraction stolen from physics and conflated with Nature, economics has systematically occluded the social relations generated by industrial society as well as ignoring the empirical physicality of actual machines: the uneven geographies of resource extraction, ecosystem simplification and waste disposal.

Michael Adas has documented the way in which Western perceptions of their superiority over cultures have shifted over time from a belief in transcendent truths, possibly accessible to others, to a certain smugness regarding Western technological artefacts and scientific objects.[69] Whereas the colonial theorists of the European Enlightenment believed in the possibility of native assimilation into the superior social forms of Europe through education in language and culture, the racial theorists of the 19th century suggested an essentialised biological classification of races according to their evolutionary incapacity to understand technology and adapt to an industrialised social order. Indigenes had no concept of honest labour or accumulation, Negroes were well suited to service and menial labour, and while India and China produced half-decent labourers, they were clearly moribund ex-civilisations sunk in a fatalistic 'Asiatic mode of production' that stifled any scientific or technical innovation. Such notions were frequently rehearsed in the explanations of European imperialists for their superiority. Alfred Marshall, the most important of the British neoclassical economists, was an exponent of such views. "Savage tribes" he wrote, "have proven incapable of keeping themselves long to steady work...there seems no reason to doubt that nearly all the chief pioneers of progress have been Aryans."[70]

The civilising mission of European colonialism was expected to generate a technologically literate and industrially useful labour force among its subject Others, but only *eventually* because the common imperial wisdom was that adaptation to technology and the discipline of work was fundamentally physiological, occurring at a slow evolutionary pace and located at the level of racial biology. In the post-1945 United Nations era of official disparagement of racial ideology, decolonisation, and the Bretton-Woods restructure of international economic relations, the post-imperialist metropolitan powers redefined themselves as benevolent agents of 'development' and 'technology transfer'. Although stripped of its racial overtones, liberal internationalism as hegemonic discourse still regards machines as 'the measure of men', to use Adas' phrase. Categorising the world's peoples into the technological categories of 1st and 3rd world, development discourse temporalises international economic and political relations onto a historical trajectory which takes the form of a technological race toward the finish line of mature industrialisation and high consumption market economies. Built into the very language of modernisation theory and development economics is the implication that capital accumulation is purely the result of superior know-how.

Machines belong to the world of artefacts constructed by humans, and a key definition of Nature is simply 'the non-artificial'. (It is in this sense that I will most commonly use the word 'nature'.) The concept of Nature has undergone several profound changes in the Western tradition since its putative origins in Greek antiquity. One of the most important aspects of the pre-industrial concept of nature was the basic quality of biological emergence: something being born. This heritage is reflected in the Latin word 'natal' signifying birth, the root word of 'nature', 'native', and 'nation'. In this view, nature is the potential state from which another state of being can potentially emerge. As has been pointed out by a number of scholars, this general quality of nature as 'potentiality' emphasizes aspects that are distinctly different from the 'modern' views that emerged in Europe from the 16th century. From this time on, the processual aspects of living nature are downplayed and the 'object-like' or 'mechanical' qualities are emphasised.[71]

According to historians, the objectification of nature and the formation of the modern subject occurred at around the same time as the formation of 'landscape' painting as a genre of art, by which we understand as the depiction of nature arranged on the canvas as an object of pleasurable aesthetic contemplation. The origins of the word "landscape" belie the common association of the term with the Romantic depiction of natural grandeur and sublime untrammeled wilderness in the manner of colonial artists such as Alfred Bierstadt, whose works transcendentalised the Yosemite Valley and the Californian redwood forests, or Eugene von Guerard who likewise incorporated an Australian nature depopulated of indigenes into the visual canon of emerging settler nationalism. Landscape as a subject of art sufficient unto itself (rather than as the backdrop to classical myth or scriptural narratives) first emerges in the Netherlands around 1600. Deriving from an old Germanic root word *Landschaft*, which signified a jurisdictional unit of human occupation, the original *Landshaps* that were eventually rendered *landskip* in colloquial English were celebrations of the human design and use of the landscape on the Netherlandish flood fields, the site of formidable human re-engineering of ecosystems and geoengineering of the earth itself.[72]

If we accept the critique of holist philosophers such as Martin Heidegger, this apparently innocent cultural watershed is crucial to modern consciousness and its epistemic crisis. In an essay entitled 'The Age of the

World Picture', Heidegger famously condemns the objectifying vision of modernity, which converts reality into a picture for the visual consumption of a distant spectator. [73] There are no important differences, he argues, between such commonplace phrases as "a picture of the world", "the modern world picture" or a "world picture of the modern age". They all assume "something that could never have been before, namely a medieval and an ancient world picture." What is at issue in defining the modern age is not the difference between modern and pre-modern world pictures, but "the fact that the world becomes a picture at all."[74] Elsewhere in the same volume he carries the analysis of the pictorial metaphor further in his influential critique of technology, complaining that the 'enframing' perspective of technical modernity damages the 'Being' (*Dasein*) of nature – he uses the example of the Rhine - by revealing it as a 'standing reserve' of controllable stocks and flows, or in other words, something roughly equivalent to a machine. Notably, this damage is metaphysical; he does not mention the biological poverty of the river due to the eutrophic effects of the toxic effluent discharged by industry into the river.

It is not the visuality or picture-ness of 'the modern world picture' (nor indeed Hiedegerrian metaphysics) that I would like to draw attention to here, but to the particular picture of the world generated by the quest for a properly scientific economics. Given the historical primacy of technology in the self-representation of Westerners on the subject of their global hegemony, and the role of machine technology in fundamentally re-ordering the composition of society, or human/environment relations and the surface of the earth, no account of the economic world picture would be adequate without a discussion of the prevalence of machine metaphors in the formative discourses of early modern science. The general origin of Western science can be found in the rise of philosophical mechanism, their trajectories have been more or less indistinguishable until recent developments in physical and biological science.

The machine metaphor fulfilled an important role in facilitating conceptual exchange between the physical and the human sciences in the proliferation and stabilisation of modern academic disciplines and practices. The formative period of the neoclassical project, the mid to late 19$^{th}$ century, was one of fertile exchange across the more porous membranes separating the nascent physical, biological and social sciences which were united in the quest for a kind of universally applicable scientific method, and the most privileged model of explanation, at least in the Anglo-American tradition of analytic philosophy, was the rational mechanics of Cartesian-Newtonian physics.

The mechanistic view of nature first required the emergence of a particular machine, and the most important machine of the early modern period was the mechanical clock. As Otto Mayr notes in his *Authority, Liberty and Automatic Machinery in Early Modern Europe,* the clock was an intellectual achievement of the highest rank. Nothing of comparable ingenuity had ever been invented before, and up to the advent of the steam engine it remained Europe's most intellectually demanding mechanism.[75] The influence of the clock on the European habitus was profound. Clocks first disciplined the labouring body away from its embeddedness in the 'organic' temporalities of subsistence agriculture, and with the rise of factory labour, became inseparable from it. As tangible artefacts, early horological masterpieces (such as the 1517 Strasbourg cathedral clock which measured and displayed the astronomical position of the observer relative to the continuous motions of cosmic bodies) and automatons (Vaucanson's mechanical ducks and ballerinas for example) were intended to exemplify and embody the virtues of regularity, order and harmony through the mechanical integration of smoothly interacting parts, subject to a central power source. Early viewers were most impressed by the regularity, consistency and orderliness of clockwork, qualities that had been previously been reserved only for things eternal and divine. As Mayr shows, these pedagogical objects "illustrated and reinforced the general worldview of determinism."[76]

From the sixteenth century until the mid-nineteenth century, clockwork was the key metaphor of the extraordinary intellectual debates about the nature of the world and the place of humanity within it, debates that we now describe as the Scientific Revolution. The new mechanical philosophy of nature articulated by the key figures of early modern science; Copernicus, Galileo, Bacon, Kepler, Descartes, Boyle, Leibniz, and especially Newton, profoundly transformed every facet of European civilisation, leading to sweeping changes in theology, politics and technology. Rene Descartes is justly famous for being the quintessential mechanist philosopher, and his name designates the entire mechanist tradition. His revolutionary reconceptualisation of Nature dates from the 10th of November 1619, when he claimed to have received a vision from the Angel of Truth, a vision of the universe as great machine composed of a vast number of lesser machines, each entirely determined by iron laws of motion. From this vision he began to articulate his view that the principles by which inventors constructed mechanical devices were the correct ones with which to approach all problems from the composition of the universe to the study of 'animal oeconomy', the early name for physiology. The master metaphor of the clock, which posited the identity of nature with a machine, become one of the constitutive elements of the new science, and what followed on from the metaphor was a belief that nature 'obeyed the laws of mechanics'. All of nature, so early modern science insisted, was subject to the same sovereign laws: from the movement of celestial bodies (as was shown by the gravitational mechanics of Newton), through to earthly phenomena, including the physiology of organisms, whose organs were compared to the parts of a clock. The conflation of organisms and machines was coincident with the search for underlying 'mechanism' becoming almost the very definition of scientific inquiry. Descartes' provocation was to assert:

> "There are certainly no rules in Mechanics that do not belong to Physics, of which it is a part or special case: it is no less natural for a *clock* composed of wheels to tell the time than for a tree grown out of a given seed to produce the corresponding fruit." [italic in original][77]

The central feature of the 'mechanical hypothesis' was its proposal to analyse the phenomenon of nature as though they were the actions of machinery. Robert Boyle reduced this principle of scientific method to a simple formula, "there can be no fewer principles than the two grand ones of mechanical philosophy, matter and motion." [78] In one of countless uses of the clock analogy in the early scientific literature, Boyle describes the Cartesian mechanical hypothesis as one:

> "[...] supposing the whole universe (the soul of man excepted) to be a great Automaton, or self moving engine, wherein all things are performed by the bare motion (or rest), the size, the shape and the situation, or texture of the parts of the universal matter it consists of; [...] So that the world being but, as it were, a great piece of clockwork, the naturalist as such, is but a mechanician; however the parts of the engine, he considers, be some them much larger, and some of them much minuter of those of clocks or watches."[79]

This new mechanical world picture also provided a series of metaphors for talking about political constitutions. Corresponding with the rise of the absolute state in 16th century Europe, clockwork became a key metaphor in the rhetorical justification of an authoritarian conception of order and system of government. The order and regularity of clocks was likened to the orderliness of a machine, with its rigid transmission of forces and the same deterministic logic was centralised execution of the sovereign will through national bureaucracies. In perhaps the earliest description of the state as a political machine, John Trenchard, in his *Short History of Standing Armies* (1698), argued that "a government is a mere piece of clockwork, and having such springs and wheels, must act after such a manner: and there the art is to constitute it so that it must move to the public advantage." The secret is "to make the interest of the governors and the governed the same [...] and then our government will act mechanically, and a rogue will as *naturally* be hanged as a clock strike twelve when the hour has come." [my italics][80] Writers deploying similar analogies to the absolutist state, as manifest for example in the quasi-military hierarchy of Prussian bureaucracies, pointed out that the machinery of state required an external engineer to wind its springs and set it in motion. Suffice to say, the important feature of this political machine was its unquestioning ability to transmit the commands of sovereign power into concerted mass action. This use of the machine metaphor in political writings clearly parallels the deistic conception of the universe as the transmission of divine power and authority through the various hierarchies of the great chain of being, accomplishing through this parallel the naturalness of a social order with strict designations of rank.

Political liberalism, a rising movement in the $18^{th}$ century, sought limitations on the unchecked exercise of political authority, and one of its projects was the designing of constitutional systems that ensured the automatic function of democracy by institutionalising various mechanisms to maintain a balance of forces between the different divisions and agencies of government.[81] It is at this juncture that we see the influence of 'Newtonianism' on philosophers such as John Locke and Montesquieu, to whom we owe the liberal theory of constitutional government. The French historian Raymond Aron has pointed out that "Montesquieu's essential idea is not the separation of powers in the juridical sense but what might be called the *equilibrium of the social forces* as a condition of political freedom." [82] Written a century after the publication of the *Principia,* the roots of the United States constitution were in a certain conception of political mechanics, as Woodrow Wilson wrote:

> "The admirable expositions of *The Federalist* read like thoughtful applications of Montesquieu to the political needs and circumstances of America. They are full of theory of checks and balances...Politics is turned to mechanics under his touch." [83]

'Equilibrium', it appears, is the constitutional metaphor of the Constitution.

In his *Spirit of the Laws* (1748), Montesquieu sought to build a science of society on the basis of Newton' s celestial mechanics. For example, in describing the 'principle of monarchy', he asserted that "[it] is with this kind of government as with the system of the universe." By this, he means that "there is a power that constantly repels all bodies from the centre, and a power of gravitation that attracts them to it." [84] The historian I. B. Cohen has pointed out that while Montesqueiu was clearly attempting to bring political theory into conformity with Newtonian principles such as that of universal gravitation, he had an incorrect understanding of Newton's system of the world, which expressly denies the balancing of centripetal and centrifugal forces, this notion of balance being carried over from defunct Cartesian mechanics. His 'Newtonianism', from the point of view of elementary physics, was simply wrong. It is quite obvious, as Cohen argues, that no social scientist would deliberately propose to advance their field on the basis of erroneous science. It seems to this writer that the more important question is whether political theory would be any better if it were derived from a correct understanding of gravitational mechanics.[85] It is this type of question that I would ask the reader to bear in mind as we now turn to the special case of economics. In what follows we will discuss how the 'mechanisation of the world picture' occurred in tandem with the study of the 'economy of nature'.

The 'economy' has not always been conceived as an autochthonous natural object. It should be clear that there is no such object as 'the economy' pre-existing 'out there' in the external world. It is difficult to separate the discovery of 'the economy' from its invention; as Foucault has argued, every new science creates its own object. For many philosophers of science, it is simply assumed that science begins with 'metrology', the art of measurement. The conceptualisation of accurate metrics of weight, length, volume, pressure, temperature, time, heat, force, chemical affinity, and light are integral to the development of basic science as we know it and it is through metrics that scientific theory connects with nature. 'The economy' is not something that can be placed between callipers or upon a scale. The measurement of 'the economy' is thus vital to the scientific ambitions of economists, because the existence of the discipline is valid only if 'the economy' can be separated out from other potential areas of social inquiry, i.e. sociology, politics, history, anthropology, the biological aspects of social existence, material culture, legal traditions and norms, the state of technology, the local possibilities for agriculture, or whatever. Since its inception, the study of economics has been concerned to envision some fundamental, measurable unit of value with which to elevate 'the economy' up and out of this mire of complexity and present it as an independent fact of social existence. Controversies over value theory are as old as written speculation on social existence itself. Within economic theory itself, shifts in the reigning theory of value mark the rise and fall of different research programmes. Measurement controversies often point to deep problems of metaphoric interpretation.

The problem of value theory first emerges in Aristotle where he distinguishes between *oikonomia* and *chresmatica;* the former term is used to refer to the art of stewardship on the family farm, and the latter, disparagingly, to profiting from speculation and exchange in the agora. The historian Donald Worster has dated the earliest contemporary uses of the word 'oeconomy' to around 1530, when it came to refer to the political administration of a moral community or a state's resources for orderly production. Christian theologians had a much older tradition of using the word *oeconomia,* to describe the 'dispensations' of God toward Man and Creation through successive ages or covenants. By the 17$^{th}$ century the term was frequently used by theistic naturalists to describe the order of Creation.[86] The origin of economics in 'moral science' – concerning the just disposition or covenant between a law-governed Nature and the laws of Society – is fully consonant with this usage. The secularisation of the term progressed in tandem with the rising sovereignty of the national state, and as the notion of divine right gave way to Enlightenment theories of popular sovereignty, moral science gave way to 'political economy'.

One of the remarkable effects of the discovery (or invention) of a scientific object, according to Susan Buck-Morss, is the rapidity with which that object takes on independent agency once it has been 'visualised.' Once this occurred, 'the economy' could now be seen to act in the world causing events and creating effects. "Because the economy is not found as an empirical object among other worldly things, in order for it to be 'seen' by the human perceptual apparatus it has to undergo a process, crucial for science, of representational mapping."[87] Importantly, 'the economy' is thus always to some extent a representation. As Klamer and Leonard put it:

> "We may attach a name ('the economy') to the unimaginably various and complex activities of a nation's economic life, but we have not thereby ensured that it is a thing."[88]

The first systematic attempt to reveal this heretofore-unknown object was conducted in 1758 by François Quesnay, the most important figure among the Physiocrats and arguably the first economist. Reflecting the Enlightenment preoccupation with natural law, the term *physiocracy* translates as 'the rule of nature'. Inspired by William Petty's dictum that land was the mother and labour the father of wealth; the Physiocrats began life as critics of the mercantilists' direct equation of the national wealth with the quantity of silver flowing through the state exchequers. As the sum of silver in Europe was relatively fixed (with the exception of the small inflow of silver from the mines of the New World) trade was a zero-sum game, and wealth could only be increased in one nation by draining the coffers of another. Prior to the 18th century and the discovery of the economy as a realm of mechanical force, the dominant choice of metaphor for the discussion of national wealth was physiological. Hobbes and Rousseau, for example, inherited the medieval idea of a society is a 'body politic', with various parts of the body corresponding to social classes or state institutions. Quesnay was a physician who, influenced by William Harvey' recent discovery of the circulation of the blood, believed that the basic 'health' of the national economy resolved to the unobstructed natural circulation of an organic value substance ( *ble* or corn) derived entirely from the fertility of the soil. Like blood, the life giving fundament of agriculture was essential to the health of all the other organs.

The 'economic picture' provided by Quesnay's (1758) *Tableau Économique,* a graphic representation of the French national economy, was novel in that it attempted to include both circulation *and* production. Buck-Morss reports that Quesnay's economic picture assumed a revelatory near-mystical importance among the Physiocrats, who influenced by Cartesian doctrines, were disposed to view the universe as a gigantic machine regulated by natural laws of divine origin.[89] "The natural laws of the order of society" he wrote, "are precisely the physical laws of the *perpetual* reproduction of the goods necessary for man's subsistence, conservation and well-being." [my italics][90] Here we have an organicist steady-state which emphasises the biological cycles of reproduction while appealing to a mechanist conception of natural law.

According to Marx, what was revelatory about Quesnay's 'economic picture' was that it located the origins of surplus value in production - in labour applied to the fertility of the soil - and not in circulation. The more wealth men and women could produce over and above their consumption, the more profitable they were to the state.[91] Quesnay's chart [Fig 1], first published in 1759, was addressed to an elite audience of the kings' political advisers and taxation officials. Its reading of productivity must have been reassuring to an absolutist monarchy with much to fear from the rising power of the bourgeois commercial classes; the *Tableau* notably assigned the negative value of 'sterility' to the activity of commodity trading. On the other hand, one can infer from the chart that the centralised governance of the economy by Enlightened autocrats according to the principles of natural law can enhance the productivity of the nation. As the biological fertility of land is the fundamental source of value, it is thus only the regenerative potential of *natura naturans* that offers the possibility of increase. In this early and profoundly different understanding of the phenomena that we moderns know as 'economic growth', *nature* and *nation* are conceptually fused in the soil from which populations ultimately spring.

If the Physiocrats can be said to have ultimately represented the national economy as utterly derivative to biological processes, it was a very mechanistic form of organicism, resonant with the themes of sovereign law and mechanical control by a divinely appointed engineer guiding the system from without. Indeed, when Quesnay wrote in 1763 (through his expositor the Marquis de Mirabeau) about what "propels the economic machine", even though he believed agriculture was the only source of productive increase through the divine gifts of the sun, the rain and the 'natural energy of beasts', he nevertheless instantiated what would become a dominant metaphor in economics.[92]

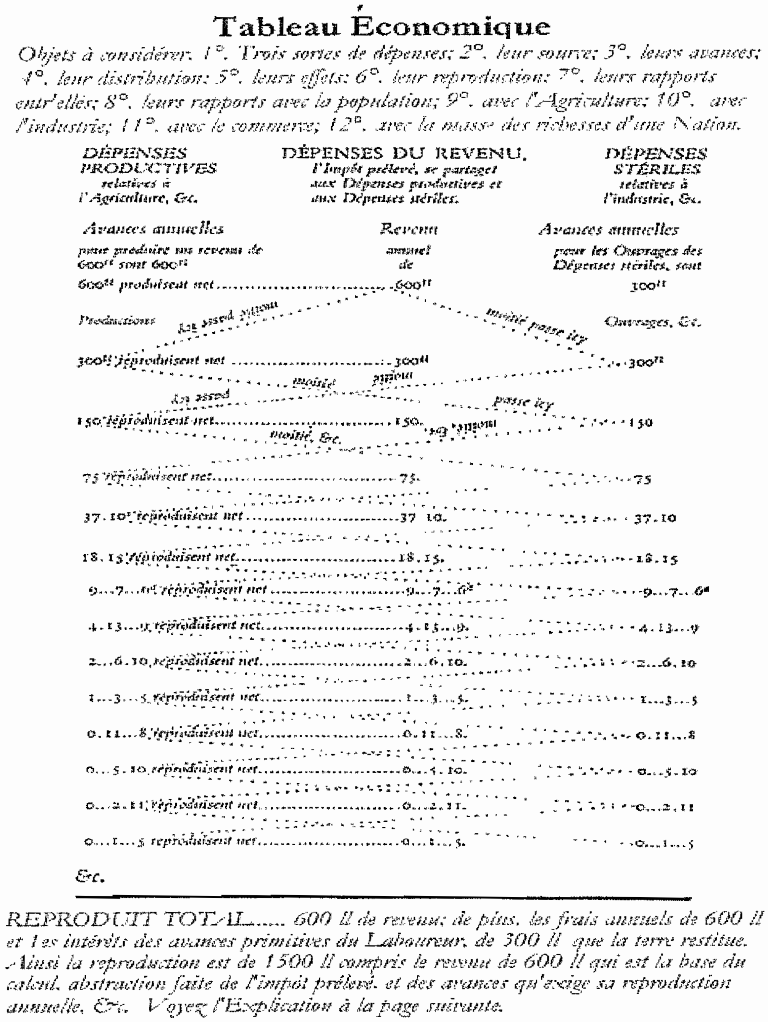



**Figure 1: Quesnay's Tableau Économique of 1759.**

Source: <www.econlib.org>

With the bourgeois revolution in Britain came a quite different notion of the natural law governing the economy of nature. Although it retained a machine metaphor as a central feature, it broke with the organic, autocratic and natalist implications of the Physiocratic world-picture. In Britain in the 18th and late 19th century, the mechanical theory of the authoritarian state was rejected in the name of freedom and liberty, variously by Chartists, anti-slavery activists, political philosophers and most effectively by the emerging commercial bourgeoisie. With the revolutionary currents of liberal humanism, clockwork authoritarianism was replaced with a radically different conception of order, what Mayr terms the *liberal theory of self-regulation.* The idea of an automatically balancing dynamic mechanism was applied by the early liberal reformers to the critique of mercantilist trade theory, with its demands for a rigorous state policy to ensure that trade led to a net inflow of precious metals, or a positive 'trade balance'. The mercantilists equated the national wealth with the quantity of silver and gold in the nation's coin-purses and coffers. Free traders argued that increased flows of silver coins into national circulation did not necessary correspond to increasing wealth and well being, because currency inflows had effects on local industry that counteracted their benefits. Spain, after all, had been laid waste by the gold of the New World. Trade accounts would better balance 'automatically.'

It was, of course Adam Smith who developed the laissez-faire doctrine of economic liberalism, a key figure in the isolation of an object called 'economy' available for systematic analysis. In the *Wealth of Nations* (1776) he dismissed both the arbitrary sovereignty of mercantilism and the agricultural bioeconomics of Physiocracy. For Smith the proper system would be described as one of 'natural liberty', which discharges the sovereign from 'the duty of superintending the industry of private people and of directing it towards the employments most suitable to the interest of the society.' The chief concerns of the liberal movement - the deregulation of commerce, landholding and industrial production and the democratic devolution of sovereign power to a constitutional body of propertied men – were reflected in the machine metaphor that eventually came to dominate the subject of political economy as it in turn came to be dominated by British thinkers. This was the metaphor of balance or *equilibrium*. This metaphor referred to a long-range stability achieved by a self-regulating 'market mechanism' inherent in social activity, which automatically co-ordinated the dynamic material activities of societies characterised by monetary exchange and a complex division of labour. Classical liberalism, as Melinda Cooper explains:

> "[...] discovers laws of movement which are immanent to the apparently random movements of commercial profit and loss; an order which arises spontaneously from the disordered self-interest of multiple economic risk-takers. The accident, in its collective, chaotic effects, is constitutive of its own order, and tends of its own accord to establish equilibrium – the equilibrium of buyer and seller, supply and demand. The most famous affirmation of this principle lies in Adam Smith's fiction of the invisible hand, the hidden pivot which is supposed to coordinate the blind self-interest of economic actors into the most perfectly regulated of social orders." [93]

In a passage reminiscent of his famous metaphor of the 'invisible hand', the hidden principle of automatic regulation that providentially equilibrates the random acts of buyers and sellers, producers and consumers, Adam Smith likens human society to "a great, immense machine, whose regular and harmonious movements produce a thousand agreeable effects."[94] Although Smith himself never used the phrase 'market mechanism', the association of individual liberty and automatic machinery was not lost on his contemporaries or successors.[95] Despite the odd association of humanist individualism with mechanical order, no phrase could be more central to the claims of contemporary post-classical economics to be a hard science. It was through metaphors derived from a properly industrial conception of the machine that classical liberalism came to discover 'equilibrium' in the constitution of the national state and natural economy. There is little knowledge of this in contemporary political theory, as David Wootton observes. Wootton shows that the liberal reformist ideals of limited government, of constitutional checks and balances separating the key departments of state power, originally depended upon the metaphor of a constitution as a machine in a state of equilibrium. "The history of the idea of constitutional checks and balances" he suggests, "can only be understood in relation to the idea of a constitution as a machine, particularly a self-regulating machine.[96]

Similarly, Mayr argues that the conception of self-regulating 'equilibrium' that led to the popular acceptance of liberal doctrines among the literate English population (with its unique enthusiasms for 'popular mechanics' magazines) can be traced not to the appropriations of Newtonian physics by *philosophes* but to the exemplary analogue provided by the centrifugal steam governor invented by James Watt in 1785 (Fig. 2). Its purpose was to adjust the speed of steam engines. As the speed of the engine increases, the central spindle of the governor rotates at a faster rate and the two flyballs move outwards, and this motion is translated by the series of rods to a throttle valve, reducing its aperture. The rate of steam entering the cylinder is thus reduced and the speed of the prime mover falls. If the speed of the prime mover falls, the reverse effect occurs and the throttle valve opens, releasing more steam into the cylinder which in turn drives the engine faster.[97]

The compound metaphor 'market mechanism' is rarely taken literally in the sense the market *is* a machine, but that it is self-regulating or self-stabilizing, in the manner of a 'feedback system' - to use the current cybernetic systems analysis terminology, itself derived from mechanical engineering.

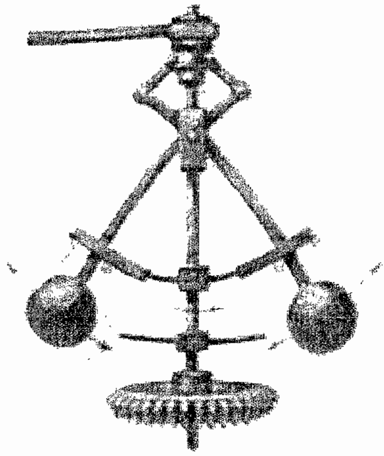


**Figure 2: The Watt steam-governor of 1785.**
Source: David Wootton, 'Liberty, Metaphor, and Mechanism', 2003.
<http://www.constitution.org/lg/check_bal.htm>.

To delve deeper into the significance of notions of equilibrium, we should begin by observing that clockwork metaphysics were altered beyond recognition in the late 19th century. As Mayr puts it:

> "The eighteenth century machine was a product of the Newtonian universe with its multiplicity of forces, disparate sources of motion, and reversible mechanism. Engineering problems in the design of steam engines had led to the discovery that under certain conditions, dynamic systems can be capable of regulating themselves, maintaining themselves *in equilibrium upon their own resources* – without the external intervention of higher forces." [my italics][98]

Before proceeding it is necessary to point out that these definitions are both somewhat misleading in their representation of 'equilibrium', and indeed reproduces a common fundamental error generated by ungrounded and imprecise applications of this metaphor. Steam engines and petrol motors do maintain a form of self-regulation analogous to 'homeostasis', which in living organisms, for example, relates to their (far more complex) physiological capacity to regulate their internal environment and to maintain a stable, constant condition - life. As thermodynamic systems, however, both Holdens and aardvarks cannot be systems closed to their environments and continue to produce 'work' for very long, and certainly not 'upon their own resources'. Mammals, for example, maintain their body heat at higher temperatures than the surrounding environment by eating large amounts of food. Cut off the food supply and the aardvark will eventually reach thermal equilibrium and inertial stasis with its environment, but it will also be dead. Motors and engines similarly require constant access to a stream of energy inputs in the form of fuel. As open systems, both engines and organisms are best described, following Ilya Prigogine and his colleagues, as 'dissipative structures', in that they are structurally maintained *far from equilibrium* by dissipating available energy from their environment.[99] Whereas animals are equipped with the wherewithal to locate their own sources of available energy, the availability of fuels and ores for the maintenance of working industrial machinery is, as Hornborg has pointed out, ultimately Social, in that it is a question of socially constructed regimes of access.[100] Although this is often achieved through 'primitive accumulation' – for example in the violent actions of American oil companies and their state allies against the Huarani in Ecuador or the Ogoni in Nigeria, the capacity of industrial machinery to produce 'work' ultimately resolves back to the availability of continuous and irreversible flows of energy, which ultimately are a matter of inter-subjective and symbolic evaluation (global market prices).

Nevertheless, Mayr does well to point out the key shift in the cultural habitus generated by the updated machine metaphor. It is therefore no surprise that classical economics, in line with the natural science of its day, was similarly dependent on "a new understanding of the possibilities of mechanical systems, for even imaginary machines, if they are to be seen to work, must abide by recognizable mechanical principles."[101] The transition from the clock to the steam engine as the key totem of modernity brought with it a revolutionary re-imagining of political and economic systems, and of their fundamental unity with the laws of Nature revealed by scientific materialism. It seems, in conclusion, an overwhelming irony of the development of economics as the 'queen of the social sciences' is its defence of 'individual freedom' in terms of deterministic, mechanical action.

Before going into a more detailed discussion of how economics became a fully-fledged social physics along the path of analogical reasoning opened by of the updated machine metaphor, it may be useful to consider some of the political, cultural and historical contexts that may have provided the impetus for the scientisation of politico-moral philosophy around the notion of the 'equilibrium' of exchange.

**Liberal Millennialism and the Moral Law of the Market Price**

*Some harsh employers and politicians, defending exclusive class privileges early in last century, found it convenient to claim the authority of political economy on their side; and they often spoke of themselves as "economists."*

- Alfred Marshall (1902)

According to Ludwig von Mises, the pre-eminent scholar of Austrian post-classicism and an ardent defender of lassez-faire capitalism, the origin of economics as a positive science rather than as shopping list of utopian ideals was in the discovery of "a hidden order in human intercourse", which he terms the "interdependence of market phenomena."[102] This hidden order is of course the providential mechanism of the 'invisible hand of the market,' where exchange operates as the regulator of the division of human labour first described by Adam Smith. Smith and Ricardo's vision of the spontaneous ordering of a liberalised national society maximising the growth of production through the win-win logic of free trade and the naturally emergent division of labour notably left out the fact of slavery, and like all the classical economists, his privileging of *labour* as the primary source of value disguised an indispensable source of the material success of British liberalism: economic imperialism which ultimately resolved to the appropriation of land. This occurred through the net transfer of 'surplus' wealth from the subject peoples of India through the highest land taxes its peasantry had ever endured, and through the domestic consumption of the cheap labour and natural resources shipped in bulk from the vast frontier tracts of *terra nullius* under the flag, where whole regions were rapidly converted into second nature by the ecologically destructive market driven logic of the fur trade, of forestry for the navy, of grazing for wool and meat, or of industrial monocultures organised around the profitable imperatives of global commodity exchange.

One of the avowed intentions of the founders of neo-classical economics was to develop an account of economic phenomena that avoided the class polemics and moral exhortation associated with the career of classical economics and its labour theory of value. Time spent in labour was accepted by Smith, Ricardo and Marx as the 'real' source and measure of value, underlying the stochastic fluctuations in commodity prices. The policy recommendations of English political economy had been cast into disrepute in the public eye after the 1840s, as anti-colonial nationalisms and international workers movements gathered momentum in the latter part of the $19^{th}$ century. It might be worth looking briefly at certain 'ecological' disasters that brought out the contradictions in labour-value liberal economics: the 19th century famine events in Ireland and India. After such these, 'Liberal' political economy was viewed with great suspicion by Irish and Indian nationalists and an increasingly self-conscious working class as a form of political machinery, designed to callously force the imperatives of distant government on enclosed peasants and those displaced and rebuilt as urban workers. This may help to illustrate the Social contexts within which political economy – seen as a providential economic discourse with religious overtones – increasingly sought refuge in Nature. It is in this period that economics emerges as an objective social physics.

During the long rise of agrarian capitalism, the growing population in Ireland was subjected to the imperatives of their English landlords to supply wool and grain to English and other overseas markets, and land available for subsistence became increasingly scarce. The effect of the Corn Laws, which kept English grain prices artificially high, was to keep wheat and barley out of reach of the peasants, who were subsistent on the margins of the market exchange, working for Anglican landowners not for wages but for the right to grow the newly introduced potatoes on increasingly small subsistence plots, with the product of Irish soil mostly being exported. The succession of anti-Catholic 'Penal Laws' enacted upon the Irish between 1691 and 1760 created a society of confessional apartheid, forbidding the Irish from practising their religion, acquiring new freehold property, or from participating in public office. Upon the death of a Catholic landlord, his existing property by law went to his sons in equal shares, unless one of them converted to Anglicanism, in which case the Anglican son received the entire property, along with the right to immediately wrest management from his family.[103] This policy won few conversions, and rather led to the continual division of fields into smaller lots. Under such cramped conditions, the potato offered the greatest yield of food for the smallest amount of soil. As a result of the colonial exercise of spatial power, the Irish became largely dependent upon a mono-crop of four or five varieties, and the failure of subsequent potato harvests to 'the wet blight' led to intensifying famine between 1840 and 1845. The famine and hazardous exodus suffered by millions of Irish is entirely misrepresented in much popular history as a simple ecological disaster. Its gruesome effects were in part caused by and in part amplified by the practices and ideologies of the middle class, which mythologised the just origins of its own wealth in comparison with the abject poverty that surrounding them by equating social position to a moral hierarchy arranged according to the obscure but just dictates of Providence, or 'natural law'. In reality this wealth was acquired by land appropriation and the realisation of export of crops from countries facing famine. Behind the 'natural law' of the market was legislative fiat backed up by the sovereign violence of the King's army, and for political dissenters the utter isolation and systematically brutalising imprisonment of Van Dieman's Land, an island whose indigenes were brought to the brink of extermination within 30 years of colonisation.

The dour and moralising English bourgeoisie, the target of the social satire of Charles Dickens, railed at the negative representation of their activities in the classical economic writings, for example, of Smith and Ricardo. Adam Smith thought of his contributions as belonging to moral philosophy and not economics: he disdained the pursuit of wealth for its own sake. Rather than the hero of contemporary liberalism, the businessman was portrayed as an avaricious bystander in *Wealth of Nations* (1776). Smith also had very little moral enthusiasm for the publicly traded joint stock companies that under exclusive Royal charter established the Flag of empire around the globe.

David Ricardo, who established the basics of comparative advantage and trade theory with *On the Principles of Political Economy and Taxation* (1817), was a successful stock market trader who retired young on the proceeds of financial speculation. With this familiar career, the entrepreneurial class took no issue. His vision of political economy, however, lacked their providential faith in the morality of laissez-faire and its tendency to produce a harmonious social ordering, which was later imputed to his theories by free trade enthusiasts. Working from an analysis of the profits of land ownership, he argued that there were perpetual conflicts of interest between owners, renters, investors and labourers. Here we follow Gordon Bigelow in arguing that the now familiar neoliberal ideology, with its praise of the entrepreneurial investor, its calls for a laissez-faire, market oriented social policy and a providential moral ordering of society through the market, does not come to us directly from classical political economy, but has its origins largely in the Evangelical movements of the early 19th century.[104]

> "The group that bridled most against these pessimistic elements of Smith and Ricardo was the evangelicals. These were middle-class reformers who wanted to reshape Protestant doctrine. For them it was unthinkable that capitalism led to class conflict, for that would mean that God had created a world at war with itself. The evangelicals believed in a providential God, one who built a logical and orderly universe, and they saw the new industrial economy as a fulfilment of God's plan. The free market, they believed, was a perfectly designed instrument to reward good Christian behaviour and to punish and humiliate the unrepentant."[105]

The parliament of evangelical Anglicans that enacted the Poor Laws of 1834 were, not coincidently, advocates of the divine ordering of society as accomplished by market forces. Whereas the care of the sick, the elderly, the orphaned and the destitute had been previously organised by local parish churches, the Poor Laws nationalised and bureaucratised the problem of poverty. Banning the direct payment of cash relief to the unemployed and the unemployable, they provided the new industrial poor with no option but enrolment in the mass 'welfare' of the workhouse, which became warehouses and asylums for all of the above rejects of industrialism. Those able-bodied people who failed to find work in the factories had their utilitarian value as labouring bodies redeemed by such instruments as the treadmill, a miserable and brutal pedagogical device for communicating the labour theory of value. The misery of poverty and indebtedness was thought to be a goad to religious conversion and the reform of poverty stricken individuals, whose sins of idleness were frequently castigated by the middle-classes.

When the failure of the potato harvest became known to the Tory Prime Minister John Peel, he secretly arranged for the government purchase and import of cheap cornmeal from the United States, to be sold in Ireland at wholesale prices in order to avert famine, a policy which contravened the Corn Laws. The incoming Whig administration under Lord Russell, with its staff of evangelicals, promptly halted the relief efforts on the grounds that this was an 'artificial' intervention into the free market: there would be no remedy for the poor but the workhouse. Lord Trevelyan, the incoming administrator given responsibility for responding to the crisis, saw the program as a 'monstrous centralisation' that would only distort the providential laws of the market. Famine was clearly a natural force that would discipline the Irish, who had foolishly become dependent on the potato, into accepting the modernisation of agriculture. Peasants forced off the land by hunger, bailiffs and bankruptcy would liberate the countryside for more rational (lucrative) uses by its English owners, such as raising cattle and wool for the world market. The depopulation of the countryside would provide a highly flexible urban labour force that would lead to the rapid development of manufacturing and industrial production in Ireland. The problem of unemployment would be easily remedied by allowing 'the market' to lower the value of wages to the point where the 'real' value of the labour force ensured full employment. However, the predicted boom never materialised, and up to a million Irish perished as a result, with another 2 million going into exile in America.[106] To be sure, the hypocrisy of colonial political control and the protectionism of the Corn Laws were at odds with supposed freedom of economic actors and markets

The Irish tragedy was paralleled in the even more disastrous Indian famines of 1876-78 and 1895-1896. After the failure of successive monsoons, attributed by contemporary meteorologists to El Nino oscillations, almost 60 million people faced chronic food shortages.[107] Despite this, the British Raj refused to provide any effective aid or regulate the grain market. The collection of land rents from peasants, which were paid not in cash but in kind, was continued. The produce of Indian peasants, whose crop was taxed heavily by local zamindars and the Raj, continued to leave the ports of Calcutta and Bombay for external markets. As speculators began hoarding grain in anticipation of sky-high prices during famine conditions, Vice-regal administrators refused to provide any form of relief for the destitute but harsh labour on government organised public works. Labour camps were often located far from districts experiencing famine. This meant that camps were sources of further exhaustion, and the unbalanced diet did little to aid the resistance to infectious diseases. The minimum diet given in Bengali prisons, one pound of rice per day, was considered adequate for continuous backbreaking labour. While no figures were compiled for the whole of India, by 1878 between 3.5 and 4 million people were thought to have died of starvation and the epidemics that followed in the Madras Presidency alone. When famine struck again between 1895 and 1898, the passionate commitment of Lord Elgin to laissez-faire ideology held firm. Despite pressure from Queen Victoria and others to forbid hoarding and speculation, to buy as much local and imported grain as possible and distribute it, the viceroy repeatedly argued that state interference in the market mechanism was an "extreme measure" which no emergency could ever justify.[108] While the expanding network of railways had added to the mobility of bulk goods transport, perhaps contributing to the population growth in the interim years, up to 33 million people are thought to have died, a figure probably smaller than that of the previous famine. The complacent chief commissioner of Gujarat, when pressed upon the failure of government action to prevent thousands of deaths even among those who had access to rations through forced labour, attributed the body count to the endemically weak and work-shy habits of the people. The famine clearly showed that 'the Gujarati' was a 'soft man',[109] evidently unfit in evolutionary terms for survival under the emergent conditions of industrial labour and market exchange.

The irony of free market fetishism in the colonial context is the general absence of freedom ensured by the racial policing functions of the colonial state in enforcing its sovereignty, monopoly enterprises and land-rent. The natural laws of economics must be adhered to, and deviations from equilibrium are to be corrected by sovereign violence, neglect or ecological disaster. Through the machine metaphor, the fetishism of the automatic balance of the market is linked to another aspect of economic ideology: that of the creationist machines implied by the concept of 'production.' This most ordinary of terms conceals the common technological myth of the industrial machine as an independently productive material device, independent of the natural environment and separable from the social conditions of radically unequal exchange that contribute to its apparent 'efficiency'. The mechanised cotton mills of Manchester are still cited as evidence for the independent productivity of machines. But as Vandana Shiva reminds us, Manchester only took over India's position as the leading manufacturer and exporter of textiles after over a century of increasing East India Company monopoly control and suppression of Indian weavers and associated Indian merchants, a process which began when the Company built its first factory in Bengal in 1653. After receiving a free-trade order from the Mughal emperor in 1717 which allowed them to legally and forcefully assert their rights to trade, the Company began a process of 'primitive accumulation', strong-arming the traditionally independent master weavers and the populations dependant on them and attacking Bengali merchant vessels at sea. Eventually weavers were indebted to company agents, who bound them to contracts that did not permit them to work for others. The English East India Company fixed prices in all places at least 15%, and in some even 40%, less than the clothes would sell in the public bazaar on a free sale. In the wake of continual military conquests, the British acquired monopoly control over the entire Indian weaving industry, driving down wages and increasing the export of commodities and capital overseas. Cheaper prices for calico on British markets, however, threatened to undermine local weavers, who campaigned for high import tariffs upon Indian goods. As English cloth making came to be dominated by industrial factory production, this pressure increased, and eventually British policy was to increasingly export its own cloth and to forcibly shut down the Indian workshops. From this point on, the trade balance between the two countries came to favour England for the first time in history.[110] The impoverishment, deskilling and displacement of the populous Indian weaving caste was completed. As Shiva notes, this key moment reflected the more general capture and restructuring of India's subsistence agriculture and artisanal communities, processes that led to its modern status as a 'third world' economy, a market for Western manufactures and a source of cheap labour and primary commodities. In the era of paternalistic 'development loans' under the free-trade auspices of the IMF and the WTO, corporate capital is similarly protected from the claims of weak local industries and elected governments, in the name of stimulating 'technology transfer' and 'growth', or industrial modernisation. What is notable here is the metaphorical use of the words 'development' and 'growth', which refer to the bounded, self-organising metamorphosis of the organism. With this metaphor, the dominant discourse attributes 'production' and thus 'fertility' to industrial technology and the efficiency of deregulated global market forces, as it simultaneously re-presents India's abundant social, agricultural and ecological diversity as sterile.

Reports of the famines in British India caught the attention of William Stanley Jevons, a key figure in the development of the neoclassical price theory. Jevons set to work on a theory that the incidence of famine could be correlated with the observed phenomena of sunspots on the surface of the sun. Deprived of modern climatology and long-range data sets, Jevons devoted quite a lot of energy into seeking proofs of his hypotheses that periodic fluctuations in the intensity of solar radiance caused (for example) the Indian monsoons to fail. Sunspot events could radically alter food production, and were thus were the root cause of the booms and busts of the trade cycle, macroeconomic instability, credit collapse and recurring financial crisis as impacts to agriculture percolated through to other sectors. While this speculation impressed very few even at the time – with one unkind satirist positing a correlation in results of boat races between Cambridge and Oxford to sunspots – the effect of this theory was to preserve the idea that the 'free market' was a stable, self-equilibrating system that failed temporarily only because of 'exogenous shocks' from the 'outside' (such as solar flares or the meddlesome interventions of misguided reformers using state power) and would return to equilibrium rapidly of its own accord. The point was to cast the 'the market' as a stable natural process.[111]

It seems reasonable to argue that much of the social and ideological impetus given to the scientisation of political economy (by Jevons among others) came from the imperative of the Victorian ruling class to present the 'free market' as a moralising agent of civilisation. This tied into the evangelical movements activism against slavery and the moralising tone of the Victorians, who particularly after the Indian mutiny of 1857 sought a mandate other than mere 'primitive accumulation' to justify the legitimacy of their global empire. Given the holdover of providential assumptions about the natural order until the early 19[tth] century and troubling conclusions of Darwinian biology, both natural law and (divine) moral harmony were not seen as contradictory. As present political configurations seem to indicate (e.g. the neoconservative alliance between neoliberalism and the anti-evolutionist, climate-change-denying religious right), the conservatism of Evangelical social analysis is indistinguishable from the spiritual esteem in which the benevolence of market 'forces' is held by ardent free-traders. In an 1846 speech given to fellow Manchester industrialists and members of the bourgeois reformist movement campaigning against the Corn Laws (which were abolished after Parliament was convinced by David Ricardo of the theory of comparative advantage two years later), Richard Cobden outlined a prophetic liberal economic millennialism which married the progressive historicism of Kant to a Newtonian social physics:

> "I see in the Free Trade principle that which will act on the moral world as the principle of gravitation in the universe - drawing men together, thrusting aside the antagonisms of race, and creeds and language, and uniting us in the bonds of eternal peace. I have looked even farther. *I have speculated, and probably dreamt, in the dim future - aye, a thousand years hence - I have speculated on what the effect of the triumph of this principle may be.* I believe the effect will be to change the face of the world, so as to introduce a system of government entirely distinct from that which now prevails. I believe the desire and the motive for large and mighty empires and gigantic armies and great navies... will die away... when man becomes one family, and freely exchanges the fruits of his labour with his brother Man." [my emphasis] [112]

To the contemporary reader, the oddness of this gravitational theory of trade (which echoes Adam Smith's theory of the 'natural price', discussed in the following section) might appear to be as easily dismissed as its prophetic framing. And yet such rosy and prophetic views of market exchange are entirely consonant with Fukuyama's end of history thesis, which announced the millennium of liberal globalisation, as well as the influential output of contemporary neoconservative US think tanks such as the Hudson Institute, whose website sports the above quotation on its banner.[113] The comment about changing the face of the earth is indeed prophetic, though for all the wrong reasons. Indeed the Hudson Institute appears way more optimistic than Cobden was: the emphasised line about having to wait a thousand years for the perpetual peace of market equilibrium is cut from their citation of him. One wonders why the line was cut: did the pandits at the Institute wish to avoid being associated with speculation, dreams, and millennialism, and would rather espouse 'economic science'? Perhaps they realise that the globalisation of the market has happened 850 years early in most places, but needs to be just a bit more laissez-faire before the armed forces can disband? The Hudson Institute was founded in the 1960s by the right-wing futurist, nuclear war strategist and RAND adviser Herman Kahn, and is currently funded by Eli Lilly, Monsanto, Dow, Ciba-Geigy, Cargill and Proctor and Gamble.[114] Such think tanks, committed to deregulated growth and more up–to-date articulations of laissez-faire, have quite effectively led the media front of the neoliberal revolution in our time, and have played no small part in fuelling an organised corporate-funded anti-environmentalist 'brownlash' movement to repudiate the findings of climate science, to de-legitimise environmental law controlling pollution, and to defend the doctrine of infinite growth from the discourse of ecological crisis.

To the argument that capital creates antagonistic class relations, free traders respond by identifying the motion of capital with the very mechanism upon which the industrial social order remains balanced and in harmony, the market. Where critiques of free trade mention the unequal trading positions of (neo)colonial power relations, its supporters draw upon neoclassical economic science to prove that free-market economics is above all historicist and anthropomorphic projections. On the basis of this, economics claims a scientific foundation and a charter as an entirely free-standing discipline. But all is not well in the state of Denmark, as we shall see.

As historians have documented, such as Foucault in *The Order of Things,* the late nineteenth century saw the comprehensive systematisation of a plethora of novel sciences. While not all of these have stood the test of time, it was in this period that those that are still with us began to adopt forms much resembling our present institutions. Political economy in the late $19^{th}$ century was largely divided into positive and historicist schools, positions that can be broadly identified with England and Germany respectively. English political economists, building the case for free trade, insisted that the 'laws' revealed by their discipline were universal and timeless, a position that was generally maintained until the centre of neoclassical orthodoxy shifted to the United States in the 1930s and 1940s. Free trade would benefit all countries and was, as British experience showed, the most efficient passage to industrialisation. The German Historical School resisted this generalisation of British attitudes on the grounds that it erased the

British Empire's historically specific trade advantages given its wide access to colonial labour and resources. Germany was initially well behind the British in the process of industrialisation, and had comparatively negligible access to exploitable colonial labour and markets. Thus its economists recommended that national industries be built up behind the shelter of high tariffs according to expert bureaucrats, a strategy that was also used successfully by Japan and the United States until they were in a competitive position, able to benefit from free trade and avoid being locked into stratified relations of unequal exchange. The neo-classical school, on the other hand, proceeded with its positive program to discover mechanical principles of economics that operated universally, and thus to bring the social sciences into methodological unity with the natural sciences.

Only Whig historians, however, hold to the official narrative of modern science, the happy myth that suggests that the present condition of the sciences is due to a progressive series of heroic advances internal to each discipline, with scientific success and recognition accruing as a direct result of the extent to which they apply a single, unitary method called 'Science'. The word 'science' or the word 'nature' has different cultural meanings across different European languages and because of this 'rationality' can be less uniform than empiricism would admit. Utilitarian value theory developed from Jeremy Bentham's psycho-physiological model of the individual as a desiring body that sought to maximise pleasure and minimise pain. Updated by William Stanley Jevons, the methodological 'individual' or universal subject of economics came to be modelled as an instantaneous calculator of rational choices in terms of these sensations. In other words, Joe Bloggs was modelled as a mathematical economist, instantly performing a complex Hamiltonian calculus to evaluate the value of the costs and benefits of all the available commodities he encountered in his protean drive to maximise his personal 'utility'. Nietzsche was of course sceptical of all positivist attempts to use physics to do away with metaphysics, arguing that the modern faith in science was still a metaphysical faith, loaded with specific cultural meanings. As he commented in *The Gay Science:* "Man does not strive for happiness: only the English do that." [115]

## Social Energetics: Equilibrium and the Neoclassical Economy of Nature

*The secret of great wealth with no obvious source is some forgotten crime, forgotten because it was done neatly.*

– Balzac

After a ten-year intellectual search for the 'laws of history', the hidden order behind the transformation of human affairs through the ages, the *fin-de-siecle* American writer Henry Adams had an epiphany that led him to propose a new science, which he called 'social physics'. (It is remarkable how many writers believe they are the first to think of this). This vision came in the form of a vertiginous encounter with the technological sublime while visiting the Gallery of Machines at the Great Exposition of 1900, in Chicago. Contemplating the vast energies churning through the great hall of dynamos, Adams believed the increasing mastery of energy could be measured in a way that revealed a law of acceleration as the fundamental secret of social change. Progress in the late 19th century was commonly measured in terms of the output of coal. In the early 1800s, production of coal in the United States was close to nothing, but by 1900 US production (more correctly extraction, or depletion) of coal had reached 300 million tons annually. Between 1840 and 1900 coal output had doubled every ten years, and due to increased efficiency in engine design, the power yielded per tonne of coal had more than tripled over the same time period. Adams noted that the exponential expansion of harnessed energy was accompanied by the ever increasing complexity of scientific knowledge: as the burgeoning number of "minds engaged in pursuing force [...] trained to a sharpness never before reached [...] chased force into hiding places where nature herself had never known it to be."[116] As it was for Comte, for Adams the task of social physics was to discover the objective 'laws of history': Adams' contribution to the genre was to derive the 'laws of history' from the 'laws of energetics.' The social physics Adams proposed linked the accumulation of scientific knowledge to the quantitative mastery of 'force' and he devised a mathematical metric for progress he called the 'dynamometer', which was modelled on the laws of velocity. In the graphs he produced to demonstrate the predictive power of his social physics, the J-curve of human progress – defined somewhat reductively as the increasing total quantity of force harnessed by an increasing number of increasingly powerful combustion engines – approached infinity on the vertical axis some time in the near future.[117] Despite the contemporary relevance of this characterisation of the economy of machines and the 'science of force' as one of exponential increases in resource consumption and energy conversion, Adam's metrology of progress has had no impact on social theory, and is now just one of many forgotten interludes in the history of attempts to instantiate a social physics. It is worth bearing in mind, however, as we consider the case of modern economics and its ever-increasing metric of human progress – Gross

National Product. In this section we will discover through examining its historical origins that economics has always been a social physics (albeit one that suffers from all of the problems attending that project) despite the ignorance of this fact by its contemporary exponents.

In the opening passage of his famous 1957 critique of social science methodology, *The Poverty of Historicism*, Karl Popper lamented the fact that although the science of society appeared at certain periods (i.e. that of Aristotle) to have advanced beyond the science of nature, since the resounding success of physics after Galileo and Newton they had lagged far behind even the biological sciences. "[T]he social sciences," he mused, "do not as yet seem to have found their Galileo."[118] And yet in a footnote 54 pages later, Popper concedes an exception to his case against the extravagant failures of sociology. Hinting that he is thinking of the work of Freidrich von Hayek (at the time a committed neoclassical although he would increasingly drift away from the core orthodoxy as he aged), Popper wrote: "it must be admitted that the success of mathematical economics shows that at least one social science has gone through its Newtonian revolution."[119]

Since the 'marginalist revolution' of 1871 - 1874, promoted as such by such leading lights as Leon Walras, Alfred Marshall, Ysidro Edgeworth, Vilfredo Pareto and William Stanley Jevons, economics has enjoyed an aura of superiority over all the other social sciences in rigour, precision and technical expertise. Indeed, some have even described economics as the theodicy of our era. In this section we will follow Mirowski in arguing that the reason it has been able to assume this *gravitas* is because "economics has consistently striven to be the nearest thing to a social physics in the constellation of human knowledge."[120] The motivation behind such attempts at social physics, it would seem, is to expel uncertainty and risk from the social, to eliminate the accident, to subject the political wrestle over sovereign power and just law and social justice to the impartial calculus of an undeniable law of nature, to tame chaos into a smooth Gaussian bell curve. Wherever this instinct arises, we ought to anticipate the arrival of social engineers. Their task is to reduce risk by increasing predictability. If we assume that social life is inevitably shot through with risk and that risk is distributed by power (few toxic waste dumps are sited in affluent suburbs), then the attempt to banish the political negotiation over who is exposed to risk and who takes risks on behalf of others by asserting 'natural law' immediately prompts the question *cui bono*? Who benefits from the naturalisation of what is inherently political?

Having said that, we might ask whether social physics is always a deplorable detour? The success of such an endeavour, it seems to me, ought to be an account of economic activity, structure, and function that coheres with the knowledge claims of other sciences founded ultimately in the study of the physical world.

This is not to preach the doctrine of Unified Science, which usually means the Laplacean reduction of everything to physico-mathematical axiomatics, but merely to confront the social physicists with their own criterion of truth. Of particular relevance here, I would argue, is the ultimate question of whether economics gives us adequate understanding of the phenomenal world in which we live, and for our purposes, what we can learn about the material embeddedness of modern societies within the 'economy of nature' at the broadest level: the biosphere.

I would like to begin with one of many available metaphors with which to give conceptual shape to that empty cipher, that infinitely complex *tabula rasa* nonchalantly referred to as 'the economy' as if such an object was immediately familiar to everyone and required no further explanation. The author of the following passage was none other than Alfred Marshall (1902), the father and system builder of the Anglophone school of neoclassical economics, in his *Principles of Economics,* a plea for a science of economics:

> "In the later Middle Ages a rough beginning was made of the study of the industrial organism, regarded as embracing all humanity. Each successive generation has seen further growths of that organism; but none has seen so large a growth as our own. The eagerness with which it has been studied has grown with its growth; and no parallel can be found in earlier times to the breadth and variety of the efforts that have been made to comprehend it. But the chief outcome of recent studies is to make us recognize more fully, than could be done by any previous generation, how little we know of the causes by which progress is being fashioned, and how little we can forecast the ultimate destiny of the industrial organism."[121]

However, the study of the economy as an 'industrial organism', as a metabolising, evolving, self-replicating 'living system', shaping and being shaped by its environment, an attempt to understand its appetites, its continually enlarged physical dimensions and its ultimate destiny was not at all what Marshall and his colleagues bequeathed to the world. Instead, we have a social physics of 'equilibrium' where 'individuals' are directly represented as 'atoms' in a deterministic field of commodity 'forces'. The organismic metaphor of would seem the most relevant approach in our era of rapid, risky, and unpredictable anthropogenic transformations of the biosphere. Once occupied entirely with highly diversified biomass, the narrow band of planetary surface amenable to extant forms of life is being increasingly simplified and penetrated by an unforeseen emergent feature of human social evolution: technomass, the diverse and unevenly distributed totality of machines and industrial infrastructure, inclusive of their effluvia, decay and unassimilable wastes. The application of the organismic metaphor has indeed recently led to novel approaches in industrial ecology such as 'materials flow analysis', which attempts to quantify and map the 'industrial metabolism' of national economies.[122] At the level of the biosphere, technomass must surely compete with biomass for 'resources' and space. Industrial organism: here is a metaphor that renders the abstract conceptual object 'the economy' easily visible – think for example of the globe at night, with Europe and the Pacific Rim aglow with the intensity of energy transformation, and Africa, North Korea and Central Asia dark through failure to accommodate and attract capital.[123] The metaphor indicates a welter of possible approaches to systematic measurement of an integrated network of machines, despite the discomfort of the inference that somehow the machines live (inherent after all in our everyday term 'economic growth') or that the biomass of human life integrated into the operations of technomass may not be the prime analytical feature revealed by scientific materialism. Regardless of the current relevance of the road not taken by Marshall –industrial growth being completely innocent in 1902 of the charge of leading to the collapse of ecosystems and thus the End of the World – the reigning metaphor for 'the economy' is a system of floating prices, the reliable trace of rational mass social action and all relevant underlying socio-economic realities, balancing the cycles of supply and demand in a stable 'equilibrium' through the price 'mechanism'.

Despite the constant invocation of physical mechanism in economics, it is striking that the analogy is used to place the exchange of symbolic, abstract 'value' on the same deterministic and universal footing as matter in motion. Where are the really-existing machines in the industrial theory of economy? The metabolic, physico-material and spatially embedded analysis of the industrial economy within the environment was a subject relegated only to suspect boundary crossers such as Alfred Lotka and Frederick Soddy in the 1920s; it then languished for half a century before being revitalised (to deafening orthodox disinterest) according to the entropy law by a recalcitrant Romanian mathematical economist (Georgescu-Roegen, in 1971), and systematised according to energetic principles by a cybernetic ecologist in the same year (Odum). Despite encouraging new fields emerging within economic science such as ecological economics, green political economy, and industrial ecology, the core theoretical tradition remains remarkably unmoved by daily reports of environmental degradation. What we have learned to see from economists as 'the economy', is something dematerialised and abstracted from the specific characteristics – both ontogenetic and phylogenetic, to borrow from biology - of human bodies and machines. In what follows we shall consider how a frictionless balancing of 'equilibrium prices' in a field of 'utility' became the central metaphorical set piece of economic science, and how 'growth', was relegated to an epiphenomena of mechanical 'equilibrium', all the while being assumed to be the a normal and permanent condition of the economy.

Neoclassical economists, the tribe who presently hold the broad majority of economics teaching positions in the worlds universities, are focussed on 'the individual', and the use of this universalised proxy for the purposes of axiomatisation, tends to downplay the historical importance of human institutions such as the family, the military, or the state. Most importantly for the purposes of this thesis, inquiry into the details of the material processes whereby human social intercourse transforms the Earth around us into utilitarian 'value' or 'second nature', the method of political economy, is rejected as 'historical', or merely narrative. Social theory is restricted to the level of 'the economy', evidence of which is reduced to the traces of monetary transactions left by 'the market', a system of flows and exchanges of equivalent values between individuals governed by an inherent equilibrium. Predicated on the belief that markets operate in a scientifically knowable fashion, the orthodoxy of our *fin –du- siecle* market fundamentalism sees them as self-regulating mathematical miracles, as autopoetic 'delicate ecosystems best left alone.'[124] Indeed, the most written about feature of recent economic history is the phenomena of globalisation, a world-wide experiment in free-market economics. Global institutions representing the world's largest transnational corporations (eg. The World Economic Forum) and powerful organisations of wealthy states (the OECD, the G7) have attempted through international financial institutions (the World Bank, the International Monetary Fund, the World Trade Organisation) to set up a system of internationally binding rules and treaties that reflect the 'laws of economics', derived from the theory that the quotidian neoclassical individuals' desire to freely maximise leads to a general equilibrium which represents the most efficient distribution of resources, in the sense of Pareto's dubious welfare function. Seen this way, globalisation must therefore be the outcome of the democratic desires of several billion sovereign individuals, and the result of the most 'scientifically' successful of the social sciences: economics. While neither of these claims is true, the latter intuition is of direct relevance to this thesis and the forms the subject matter of this section.

The attempt to purge economics of normative, political and psychological factors, in order to formalise economics as an exact science, represents the deepest epistemological break between the classical economists and the neoclassicals of the late 19th century.[125] Unlike the ethical and phenomenological concerns that mark the work of utilitarians such as John Stuart Mill and Jeremy Bentham within the 'moral science' of political economy, the neoclassical school aspired to achieve for the discipline the sublime epistemological status of physics by rejecting such anthropomorphic questions as ethics and identifying its theoretical propositions directly with 'natural law'. The conceptual ideal of 'natural law' appealed to is the Cartesian-Newtonian image derived from analytical mechanics, of nature stripped of all qualitative changes and reduced to pure motion. I use the term 'Newtonian' for its familiarity among non-specialists (myself included), with strong caveats. The term may carry a number of meanings with regard to historical attempts to bring sociology (and other sciences) to a condition of 'Newtonian' legitimacy. There are at least two clear senses, as noted by Bernard Cohen. The first simply refers to the hope that sociology (of which economics is a sub-branch) might one day become "methodically arranged and systematised" according to formal, unitary principles governing inquiry, equivalent to Isaac Newton's achievements in rational mechanics. The second sense would be the notion that the actual scientific content of the Newtonian paradigm in physics (which could be strictly limited to the gravitational cosmology of the *Principia*) could be applicable directly or by analogy to social phenomena.[126] Clearly Popper did not intend the second sense in his bestowal of the mantle of legitimate social science upon mathematical economics; but as the following discussion will demonstrate, the methodological success of economics is certainly an open question, particularly with regard to the vexed question of our thesis, the apparent paradox of 'equilibrium' as the natural state of market activity and the normalcy of perpetual economic 'growth'. The very term 'equilibrium' reveals the heritage of physics metaphors, whereas the term 'growth' is clearly biological. Both of these articles of contemporary faith are part of a matrix of seemingly opposed and yet, as I have hoped show, dialectically enmeshed tendencies in Western philosophical and political discourse: the secular millennialism of unceasing 'Progress' with its theological resonances recurring in utopian political eschatologies that sought to realise the full dignity and meaningful life of humanity on this earth, and on the other hand the avowedly anti-utopian schools of thought – which we have called 'social physics' that sought to abolish metaphysics and metaphor once and for all by demonstrating the necessary conformity of the social to the indifferent statistical calculus of invariant physical law. This dialectic I have referred to as 'industrial millennialism', because the vector through which the humanist, historicist and utopian tendencies converge upon the mechanist, rationalist and abstract tendencies is within the labyrinthine chambers of the ever-evolving machine metaphor.

To consider the current validity of economics, given both its political dominance and its theoretical indifference (or more generously, ambivalence) to the manifold pressing concerns subsumed under the label 'global ecological crisis', it is necessary to re-open a more or less forgotten chapter in what might be called 'the cultural history of science': the discovery of 'energy', which in the wake of the formal enunciation of the first (and some years later the second) law of thermodynamics revolutionised physics. The doctrine of 'energy' revolutionised the understanding of nature within the hard sciences, and what followed was the subsequent exfoliation of the discourse of energetics through biology, physiology, politics, the arts and the social sciences. The term 'energetics' – which is used incautiously by some as interchangeable with 'thermodynamics' – here refers to a particular intellectual movement originating within the natural sciences which, during the latter half of the twentieth century, sought to unify all branches of natural and social science within the universality of the energy concept.

I should mention that here I am largely following the narratives provided by Phillip Mirowski, in his formidable *More Heat Than Light* (1989) and Anson Rabinbach, in his *The Human Motor* (1989).[127] The reader that wishes to undertake the arduous task of following the parallel development of energy physics and its dubious mathematical appropriation by neoclassical economics in its full detail is directed to the former volume. Here we will attempt only to sketch the essential features of Mirowski's critique of economics. Although Mirowski is a highly entertaining guide to such formidable arcana, those that experience oncoming headaches at the thought of trudging through the finer details of mathematical economics and high end physical theory simultaneously are directed toward Rabinbach's volume, which safely skirts the fine detail of physics and economics altogether, focussing instead upon on the broad variety of cultural, social and political manifestations of the European 'social energetics' or 'productivist' movements of the late 19th and early 20th centuries. Both deal directly with the question of the fundamental importance of the machine metaphor in social theory, and it is with the profound transformation of this metaphor that occurred two hundred years ago that we begin.

The 'clockwork metaphysics' of Descartes and Newton were altered beyond recognition in the mid-19th century as the industrial revolution gained pace and the previous solar-based sources of mechanical power – wind, water, firewood and the labour of humans and beasts – began to be complemented and then displaced by the superior forces realised by steam engines burning fossil-fuels. The first practical steam-pump was built by Thomas Savery in 1702, and was the first ever device to use heat to convert chemical energy into mechanical work. Thomas Newcomen built the first genuine steam engine, five times more powerful than its predecessor in 1712, with steam-engine technology really coming into its own with the James Watt engine in the late 18th century and its radically improved successors in the mid-nineteenth century.[128]

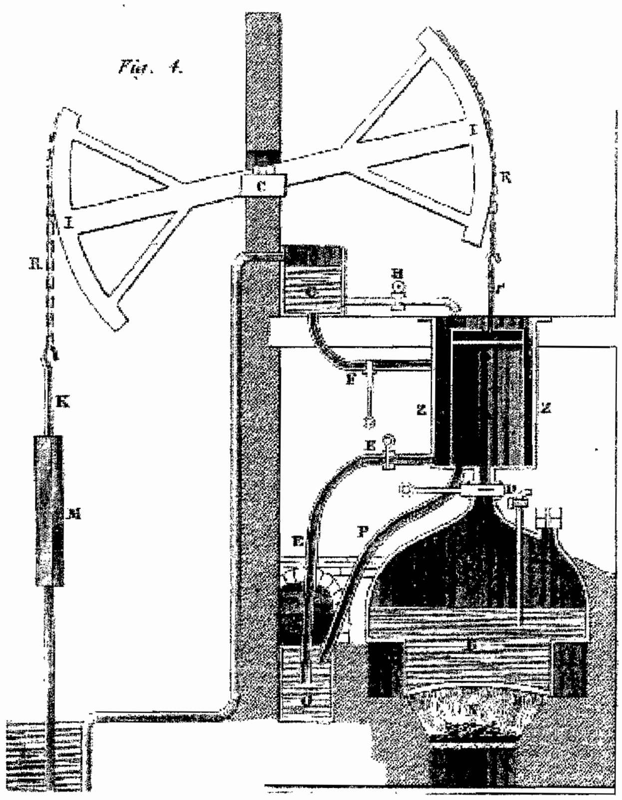


**Figure 3. Newcomen's Atmospheric Steam Engine in the 1832 *Edinburgh encyclopaedia.***

Source: John H. Lienhard. 'Engines of Our Ingenuity', 1997.

<www.uh.edu/engines/epi69.htm>

It is little remembered that each of these innovations were ultimately responses to a European-wide energy crisis of increasing severity– the serious and widespread shortage of wood. In addition to the use of timber for housing, ship-building and bridge building, by the early $18^{th}$ century the depletion of forests threatened to seriously retard the output of numerous industries dependent on heat: glass, ceramics, soap, potash, tin, lead and iron production. Nearly all of Europe's forests within range of water transport were depleted by this time, with peasants in areas of southern France, for example, simply unable to heat their hovels in winter. [129] The most radical deforestation occurred in the English countryside as a result of the incredible combined appetite of all industries, but especially that of ironworks for charcoal and the navy's shipbuilders. Increasingly, even the wealthiest of the English were forced to resort to sulphurous coal to heat their homes, which was widely regarded as an inferior fuel. Coal mining tended to be in pits no deeper than a few metres: as soon as the water table was reached, the pit had to be abandoned. The coal-fired steam pump developed to keep the water out of coal pits, a response to the looming crisis of European deforestation, unforeseeably led to the revolutionary shift away from biomass to non-renewable fossilised carbon fuels as the energy basis of industry. Previously, the work of pumping out mines was driven by horses, which allowed a direct comparison to be made between the machine and the animal. Since then the power of engines has been measured in 'horsepower' or metric equivalent, as the power of fossilised biomass has supplanted that of animals in supplying energy to human economies.[130]

Due to its high sulphur content and other impurities, coal was initially unsuited to many production processes, and especially iron-making. Technical progress in improving the purity of coke went hand in hand with the development of iron technology, with pig iron being eventually replaced by wrought iron, and much later, by the Bessemer process of rolled steel milling. Higher quality iron allowed precise, thin castings such as those needed for the cylinders of Newcomen engines. As Frank Niele writes: "[..] advanced coal-fired cooking in ironworks made production of Newcomen's steam engine possible, which in turn enabled deep shaft mining, thus boosting coal supply. This way the coal-based societal metabolism evolved through industrial symbiosis, or cooperative relations between several industrial processes."[131]

The textile industries usually presented as the cutting edge of mechanisation and the factory system of labour were among the last industries to employ steam power. These industries emerged from the solar-based agricultural capitalism of what world systems theorists refer to as 'the triangular trade'. Mississippi cotton, grown with systematic mass slave labour, was imported to England on wooden wind-powered ships, and was processed by wooden spinning and weaving machines that were largely powered by water wheels well into the 19th century. Economic historians for more than a century have portrayed steam-engine *technology* (eg, the design specifications of the machines in themselves) as the "pivot on which industry swung into the modern age" and as the "central fact of the industrial revolution, "[132] however it is far more accurate, as Niele argues, to speak of the "steam engine complex" as a whole.[133] This was a result of the iron-works that produced the locomotives, rolling stock and ships, as well as the infrastructure such as railways and bridges connecting them to coal mines. Together with the concurrent mass production of the precision high-powered weaponry that for a hundred years gave Europeans a nearly complete military advantage elsewhere in the world, it was this complex that gave imperial Britain (and other European powers soon after) access to the vast, untapped colonial resource frontiers of the New World's peripheries. In 1840, Britain imported no more than 5% of its food, however by 1900, 80% of its grain, 70% of its dairy products and 40% of its meat was imported. Importing food and raw materials and exporting excess population, Britain displaced the impending Malthusian crisis onto the native populations of Australia and other peripheral regions converted to its supply hinterlands, allowing the majority of England's land and labour to be 'restructured' toward the iterative accumulation of industry and machine manufacture. The subsequent radical improvement in iron and then steel based industrial technology, in shipbuilding, in the design of rail and dock infrastructure, canal construction, and arms manufacture radically enlarged what we would now call Britains 'ecological footprint'. These technologies enabled greater economies of scale by increasing Britain's dominance of world trade both militarily and through the increasing ability to ship ever greater quantities of bulk goods from ever more remote locations. Thus 'economic growth' and 'globalisation', usually treated separately, can be seen as the same self-reinforcing process arising from the need of industrial technology to consume ever greater quantities of raw materials in order to gain access to resource frontiers which are increasingly further away as local resources are consumed first.[134] As Sieferle observed as recently as 1982;

> "Considering the central importance of coal as the energy basis of the Industrial Revolution, it is quite astonishing that...it has been almost completely ignored by economic history."[135]

Many historians now recognise that the industrial revolution was primarily an energy revolution, which shifted the ancient 'pyrocultural' technologies of fire mastery from biological sources of recent solar origin (predominantly wood, but also peat, dung and whale oil) to the seemingly vast store of several hundred million years worth of ancient sunlight stored geologically in the 'subterranean forests' of coal, oil and natural gas deposits. Nevertheless the fascination with the technological artefacts in themselves (abstracted from the flows of energy and the expanding consumption of global resources that underwrote their development and operation) has tended to present 'development' and 'capital accumulation' as a national feat, the result of a pure fund of superior know-how applied directly to nature and unmediated by social relations. This is as important to consider as the fact that the singular qualities of geological energy input to industry remain by and large invisible to orthodox economists who almost exclusively portray the process of economic growth and capital accumulation in late 19th century Britain as a result of the wise adoption by the Parliament of 1848 of David Ricardo's' policy that free trade in agriculture would stimulate economic growth in Britain and by allowing it to specialise in manufactures.

In what follows I will argue that the reason for this invisibility of the importance of site-specific reserves of natural resources to theorists of economic growth is, quite counter-intuitively, located in the effect of the 'social energetics' movement on the founders of economic 'science'. The social energetics movement was the result of profound developments in science arising from the study of the mechanics of steam engines. Rabinbach and Mayr have pointed out the key shift in the cultural habitus generated by the updating of the machine metaphor in the mid-18th century. The transition from the clock to the steam engine as the key totem of modernity brought with it a revolutionary re-imagining of political and economic systems, and of their fundamental unity with the laws of Nature revealed by the new scientific materialism of energetics. With the development of the steam engine, the secular culture of industrial society became permeated with the lexicon of a new vocabulary of machine metaphors, as Mayr notes.

> "The eighteenth century machine was a product of the Newtonian universe with its multiplicity of forces, disparate sources of motion, and reversible mechanism. Engineering problems in the design of steam engines had led to the discovery that under certain conditions, dynamic systems can be capable of regulating themselves, maintaining themselves in equilibrium upon their own resources – without the external intervention of higher forces." [136]

Rabinbach develops this idea further, noting that in contrast to its mechanical predecessor, the clockwork mechanism (which required an external force to wind its spring and set its timing),

> "the nineteenth century machine, which was modelled on the thermodynamic engine, was a 'motor', the servant of a powerful nature conceived as a reservoir of motivating power. The machine was only capable of work when powered by some external source, whereas the motor was regulated by internal, dynamical principles, converting fuel into heat, and heat into work. The body, the steam engine, and the cosmos were connected by a single unbroken chain of energy."[137]

Classical economics, in line with the natural science of its day, was similarly dependent on "a new understanding of the possibilities of mechanical systems", for as Wooton argues, "even imaginary machines, if they are to be seen to work, must abide by recognizable mechanical principles."[138] Indeed this tendency is fundamental to the claims of economists have to a truly scientific methodology, as the Austrian economist Ludwig von Mises reports of the hidden bedrock of objective truth undergirding the scientific formalisation of economics:

> "In the course of social events there prevails a regularity of phenomena to which man must adjust his actions if he wishes to succeed. It is futile to approach social facts with the attitude of a censor who approves or disapproves from the point of view of quite arbitrary

standards and subjective judgments of value. One must study the laws of human action and social cooperation as the physicist studies the laws of nature." [139]

In rejecting merely 'subjective' judgements of value, which he attributes to the misguided moralising of utopian pre-neoclassical social philosophers, Von Mises suggests that 'economic value' has an underlying, objective standard, and takes social reformers to task for carving out a malleable realm of the social distinct from that of nature, for failing to seek the fundamental invariance within the complex 'interdependence of market phenomena'. But this desire to escape from the perennially politicised content of economics, to devise a social physics with which to calmly calculate the 'laws of human nature' should alert us to the conceptual ambiguity associated with the metaphor of a 'law governed' nature external to social relations. 'Law' and 'government' are after all socially constituted relationships of power, invoking social norms and taboos, as well as the possibility of deviance and punishment. As Nietzsche once warned: "Let us be on our guard against saying that there are laws in nature. There are only necessities: there is no one who commands, no one who obeys, no one who transgresses."[140] This fundamental ambiguity of the 'natural law' metaphor should be kept in mind, as it is at the heart of the neoclassical attempt to derive an *objective* standard of value with which to discern the timeless natural laws governing social interaction.

That there exists an unalterable 'balance of nature', a *nomos* to which the *oikos* must conform, is a persistent theme in Western culture. The origins of the metaphorical theme of natural law, however, are older than the monotheistic metaphor of God the Lawgiver, and goes back to the ancient Greeks, who believed that all phenomena were balanced in totality: heat with cold, wet with dry, dark with light, predator with prey. The idea of natural law, as should be clear by now, is a concept that comes to us through theology. We have also seen how the early 19th century bourgeois evangelical movement saw Smith's 'invisible hand of the market' as verging on the sacred, the mechanism through which Gods' providential gifts were realised and the vehicle of justice to reward the prudent and punish the indolent. Natural law was second nature to the philosophers of the Enlightenment, who as Akiyoshi puts it, "transferred the grounds for the existence of God from transcendental revelation to scientific discovery, and relocated divine truth from God's words embedded in the Holy Bible to the mathematics employed in natural and social sciences." [141] Some with an economistic bent attempted to show the divinity and unity of natural and social processes, such as the deistic Physiocrats with their agrarian 'economic machine'. More ambitious souls believed that with the mathematics of analytical mechanics, one could more or less actively usurp the perspective of God, as in the hardcore determinism of the astronomer and mathematician Pierre-Simon Laplace:

> "We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace *in a single formula* the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes." [my italics] [142]

Here the hubristic ambition of science is to banish all chaos and see it merely as a different form of universal order, to reduce all apparent randomness, change, flux or development to special cases of a *single* mathematical formula of eternal validity. Mirowski argues that this 'Laplacian Dream' has continually underscored the project to elevate economics to the status of science.

The search for principles of invariance on the model of physics underlying all the complexities and vagaries of exchange phenomena goes back at least to Adam Smith's doctrine of the 'natural price'. In *The Wealth of Nations* Smith discriminated between the market price (which is determined by the exchange of equivalent values of human labour invested in commodities) and the natural price (which is determined by the demand-supply balance for commodities), maintaining that the economy converges to this natural price position naturally, thus economising on labour and maximising production simultaneously. Summarising Smith in development of his own labour theory of value, Marx wrote that, "[i]t suffices to say that if supply and demand equilibrate each other, the market prices of commodities will correspond with their natural prices, that is to say, with their values as determined by the respective quantities of labour required for their production."[143] What is natural about the natural price has nothing to do with intrinsic qualities of land or resources transformed into commodities but the 'motion' of fluctuating prices converging on the 'real' underlying value of labour as a kind of substance somehow suffused in the commodity. Smith wrote that "the natural price is [the] central price to which the prices of all commodities are continually gravitating." As Cohen notes, Smith was well versed in Newton's writings, and this statement would seem to invoke Newton's third law of motion, that action and reaction are always equal. However, the corollary of physical gravitation is that all bodies are not only 'gravitating' toward some 'central' body, but to all other bodies in the system. The result of a complete transferal of the gravity metaphor into Smith's price theory would mean that all prices are 'gravitating' toward one another and that the natural price would be gravitating to the 'prices of all commodities',[144] a condition that I would tentatively suggest would render the distinction between price and value incalculable and thus inoperative. For Marx as for many political economists, fluctuating money prices were a distorting veil that acted to obscure the genuine value of human labour equivalents in exchange. For Marx, money was an obfuscating and ultimately exploitative way of rendering unlike commodities commensurable which would be done away with in the more scientific modes of production of the future. The key question of classical political economy was the origin of a 'surplus' in the coextensive operations of labour time (which conferred all value) and the regime of fluctuating market prices (through which value was socially transmitted and distributed). Whether this approach led to every economic actor getting their just reward for enlightened self-interest or a systemic extraction by exchangers of the life-blood of the productive labouring bodies was a matter of political taste. Moreover, the distinction implied between use value and exchange value meant that calculation was difficult to apply when it had to bridge these difficult and different notions of value.

Prior to the middle of the 19th century, physical astronomy was the crowning jewel of physico-mathematical science. The Newtonian system with its smooth continuous mechanics, its temperature independent and time-reversible geometry of inertia, momentum and velocity was subsumed with other forms of mechanics by the science of energetics from the 1850s until it in turn was subsumed within quantum theory around the turn of the century – a development which is thankfully well beyond the scope of our thesis. Thermodynamics returned physical science from the solar system back to earth and remains the only branch of physics in which life matters. Moreover, thermodynamics is directly economic, derived from the study of the fiery bellies of engines and question of their relative efficiency in transforming heat to mechanical work. There is a long and convoluted history attached to the 'discovery' of energy which we will not undertake here, except to indicate that its 'discovery' was more or less inseparable from the 'discovery' of the Law of the Conservation of Energy, the 1st law of thermodynamics. Similarly, the subtleties of the historical debates among physicists about what energy actually 'is' and how it relates to mathematics and other sciences is beyond the scope of this section. Our account will be limited to the impact of energetics upon the generic neoclassical presentation of 'the economy', the claims of neoclassical economists to be 'scientific', and our broader questions: if economics is a science of *equilibrium* (the static balancing of supply and demand in self-regulating markets) then why is the perpetual maximisation of *growth* its main political application and source of justification? If economics is indeed a science, then how come the most vigorous proselytisers of its supposed findings, the 'think-tanks' promoting various versions of lassez-faire, corporate tax-cuts, the abolition of minimum wages, the hobbling of labour unions in the interest in the healthy growth of 'the economy', have in general been the most ardent deniers of the existence of anthropogenic global warming, which is doubted by very few earth scientists, climatologists, biologists or ecologists? [145] The standard Marxist answer to this would perhaps best satisfy Ockham's principle of parsimony: 'scientific' economics is the ruling ideology not because it is the most true but because it is the ideology that best serves the interest of the ruling class. A less simple and more intriguing answer, at least to the historically minded, lie in the cultural habitus within which neoclassical economics formed its scientific claims, and this returns us to the work of machines.

Thermodynamics as a discipline began with the experiments of Sadi Carnot, a French military engineer who suspected that the superior efficiency of the recently mechanised British coal industry had ultimately led to the defeat of Napoleonic forces because of its contribution to accelerated coking and iron production for armaments. Inspired by the relative inefficiency of the French war machine, his research was to have profound ramifications for classical physical theory. His treatise *On the Motive Power of Fire,* published in 1824, outlines the fundamental process by which heat energy is converted to kinetic energy, or 'work'.[146] The physico-mathematical conception of 'work' that entered physics through this French tradition of practical applied physics was directly economic, as Navier, one of the graduates of the military engineering *ecoles* wrote: "[t]he comparison of diverse machines, for the merchant and the *capitaliste*, comes naturally after the quantity of work which they execute, and the price of the work."[147] Carnot's work also laid the conceptual groundwork for the study of irreversible systems. Carnot demonstrated, among other things, that heat engines never gave as good as they got, and could never achieve anything approaching perfect efficiency in the conversion of burning fuel to 'work'. Other intellectual moments on the rising horizon of thermodynamics are the attempts of William Thomson and James Joule to establish conversion ratios for heat to mechanical work, and the realisation that heat and work where interconvertible at the same 'exchange rate', a discovery that led to enunciation of the principle of the conservation of energy.

While there are a number of candidates for this discovery, it was Herman von Helmholtz who most rigorously combined several previously separate areas of inquiry under the doctrine of energy conservation, uniting the search for the mechanical equivalence of heat with rational mechanics, doing away with earlier substance theories of heat (fire was previously attributed to a mysterious fluid called 'caloric') and the vitalist notions of *vis viva* or *Lebenskraft* ('living force') that had been central concepts of physiology ('animal economy') and the broader Continental *Naturphilosophie* tradition. The German physicist Wilhelm Rankine, who was a key contributor to the theory of the steam engine, provided the formal definition of mechanical energy in 1845. Building ambitiously on Rankine in his book *Über die Erhaltung der Kraft* (*On the Conservation of Force*, 1847) Helmholtz postulated a relationship between heat, light, electricity, mechanical force, and magnetism by treating them all as manifestations of a single force. This 'ur-substance', a continuous field pervading the entire universe, he called *Arbeitskraft,* in

German meaning 'labour power', and is what was later dubbed 'energy'. The word comes from the Greek *energeia*, which is loosely translated as 'work'. It is worth noting that the Greeks had no concept of work or labour remotely translatable to its modern meaning in the era of late 19th to early 20th century European industrial society, when 'labour' became not only the central political and social question, but with the popularisation of energetics, the central metaphor of the reigning version of scientific materialism.

In formulating the first law of thermodynamics, Helmholtz updated the reigning machine metaphor for the 19th century's interest in the steam engine and its ability to harness awe-inspiring amounts of *Arbeitskraft*. Initially known as the Law of the Conservation of Force, it came to be known as the Law of the Conservation of Energy after the older language of forces was subsumed in the greater generality of energy physics, in which the action of 'force' is merely one of the possible phenomena attending the transformation of energy. The Law of the Conservation of Energy was an attempt to unify all previously disparate conservation principles in physics. Mirowski defines a conservation principle as "[the] rule that some particular aspect of a phenomenon remains unaltered or invariant while the greater phenomena undergoes certain specified transformations."[148] Helmholtz showed most rigorously that the quantity of energy was fixed: energy could not be created and could not be destroyed, but was constant through all transformations. Matter and motion were unified in the concept of energy and subjected to a system of mathematical equivalents. Nature, it would seem, balanced her own accounts and could not be cheated. This is not to imply, however, that energetics provided an image of the laws of the universe resembling 'the laws of the shop till', the complaint earlier directed at political economy by Robert Carlyle in the tirade against J.S Mill that provided the unshakeable characterisation of economics as the 'dismal science.'[149]

Here, it is important to caution the lay reader against even trying to imagine energy as some kind of 'stuff'. As Richard Feynman noted in his lectures to undergraduates, physicists still don't know what energy *is*, rather its existence is reliably inferred from its effects:

> "There is a fact, or if you wish, a law governing all natural phenomena that are known to date. There is no known exception to this law – it is exact so far as we know. The law is called the conservation of energy. It states that there is a certain quantity, which we call "energy," that does not change in the manifold changes that nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is a strange fact that when we calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same. It

> is important to realize that in physics today, we have no knowledge of what energy "is." We do not have a picture that energy comes in little blobs of a definite amount. It is not that way. It is an abstract thing in that it does not tell us the mechanism or the reason for the various formulas."[150]

Despite the curious ontological emptiness of energy in this formulation, as the philosopher Michel Serres observes, nature under the investigations of thermodynamics was profoundly transformed in the European imagination, and this reshaped the entire social environment in which we now live and work. Contemplating the paintings of Turner he writes: "Matter is no longer left in the prison of a diagram. Fire dissolves it, makes it vibrate, tremble, oscillate, makes it explode into clouds."[151] The material world became ever more transient and ephemeral as energy underwent its myriad temporary transformations; only energy itself was "protean and constant."[152]

Physics envy may be the only constant in the convoluted history of the history of the social sciences, and the internal attempt to unify the natural sciences around the concept of energy had its corollary in the social energetics movements that shadowed the development of energy physics, as numerous inheritors of the Comtean view of sociology attempted to ground their study of the dynamic creative destruction of industrial modernity in the abiding laws of energetics. Anson Rabinbach has bequeathed to us a fascinating study of the origins of productivism in the social energetics movements that flourished between the 1850s and the 1930s. The thesis of this work is that:

> "The discovery of labour power – and its subsequent elaboration in political economy, medicine, physiology, psychology and politics – was emblematic of a society that idealised the *endless productivity* of nature [my emphasis]. Semantically, this meant that the word *work* was universalised to include the expenditures of energy in all motors, animate as well as inanimate. The Promethean power of industry (cosmic, technical and human) could be encompassed in a single productivist metaphysic in the concept of energy, united with matter, was the basis of all reality and the source of all productive power – a materialist idealism, or as I prefer to call it, *transcendental materialism* [author's emphasis]. The language of labour power was more than a new way of representing work: it was a totalising framework that subordinated all social activities to production, raising the human project of labour to a universal attribute of nature." [153]

In his many lectures on the subject of energetics, of which he was perhaps the most important populariser, Helmholtz was fond of referring to the El Dorado of eighteenth century inventors. The Cartesian-Newtonian representation of the cosmos as a frictionless clock with a motion that never needed to be wound was parlayed back into speculation about the development of machine technology. Many engineering and scientific enthusiasts of this period, as Helmholtz noted in an 1861 address to the Royal Institution, were driven by the dream of a "machine which would give perpetual motion and produce any mechanical work they liked. They called this machine a perpetual mover. They thought they had an example of such a machine in the body of every animal."[154] Helmholtz explained the death of this dream in economic terms:

> "The solution of this problem promised enormous gains. Such a machine would have had all the advantages of steam without requiring the expenditure of fuel. Work is wealth. A machine which could produce work from nothing was as good as one which made gold. This problem had thus for a long time occupied the place of gold making, and had confused many a pondering brain. That a perpetual motion could not be produced by the aid of the then known mechanical forces could be demonstrated in the last century by the aid of the mathematical mechanics which had at that time been developed. But to show also that it is not possible even if heat, chemical forces, electricity, and magnetism were made to co-operate, could not be done without a knowledge of our law in all its generality. The possibility of a perpetual motion was first finally negatived by the law of the conservation of force, and this law might also be expressed in the practical form that no perpetual motion is possible, that force cannot be produced from nothing; something must be consumed."[155]

In this lecture Helmholtz addressed the problems of physiology from the perspective of the conservation of force, arguing that "it was extremely probable that the law of the conservation of force holds good for living bodies", the analogy being drawn between human bodies and steam engines, as both produced work and heat, all the while dissipating high quality inputs into useless wastes. He referred to the work of Edward Smith, a physiologist who had extensively studied the problems of work efficiency and fatigue given the poor diet, working conditions and long hours of factory workers, convicts and imprisoned debtors working on treadmills. Whereas Smith wrote papers to the learned of Manchester society calling for the abolition of treadmills, Helmholtz believed that Smith and other European researchers developing the new 'sciences of work' had shown that "the best method of getting the greatest amount of work out of a human being is the treadmill."[156] Equivalent to continuously walking uphill, these studies had shown that one quarter of the effort resulted in mechanical work, while the rest was lost as heat. Accordingly, Helmholtz argued that " the human body is.. a better engine than the steam engine only its food is more expensive than the fuel of steam engines."[157] In all his writings on *Arbeitskraft*, Helmholtz made no distinction between the work of nature, the work of machines, or between the mental labour of violinists and the muscular work of labourers. Nature was indifferent to the social uses to which energy-conversion was put, labour power was an objective and quantifiable economy of force distinct from its cultural, social or biological setting. "The sum of all forces capable of work in the totality of nature remain eternal and unchanged throughout all variations. All change in nature amounts to this, that the labour power can change its form and locality without its quantity being changed."[158] In doing so, Helmholtz did not 'reduce' the organism to a thermodynamic motor, but posited their essential indistinguishability. In so doing, the metaphor of an energy-converting machine was transposed to the entire universe and its essence was anthropomorphised as 'labour power'.[159]

The monistic unity of the principles governing the working body, the motor, and the cosmos parlayed into a proliferation of publications and ideological movements on the significance of labour power and the vital importance of economising upon its use. These doctrines, popularised chiefly by the physicist Helmholtz, the biologist and founder of ecology Ernst Haeckel, and the industrial chemist and magnate Ernst Solvay, were subsequently developed by many others into detailed programmes for social reform. Rabinbach has documented these diverse and mostly forgotten social and intellectual movements in great detail and here we can only hint at some of the thematics by mentioning some examples from his study. The defining feature of the various social energetics movements was the realisation that because energy could not be created, its direction into useful activity was paramount. The social energetics movement made no essential distinction between muscular and psychological exertion, as the undifferentiated laws of *Arbeitskraft* determined the function of cognitive, emotional and physiological activity in the human motor. Thus idleness, indolence, sloth, dissolute sexuality, masturbation, begging, nomadism, aristocratic privilege and other forms of energetic expenditure were railed against from all quarters as reducing the efficiency of the conversion of society's energy budget and thus the optimum output of society, by misdirecting energy into unproductive uses. As the principles of energy conservation were extended into the physiology of the working body on the micro-level, and extended to the macro-level of the 'health of the nation', the objective language of a science of work was developed which claimed to transcend the utopianism that attended culture and politics. The efficient unity of worker and machine was both explicitly implied in the metaphor of *Arbeitskraft*, and it was also the goal of the popularisers of 'productivism'. For socialist reformers campaigning for a living wage and limits on the working day, the question of optimising labour meant the reduction of exploitation, and a whole series of statistical studies were compiled which showed that those nations whose factories operated the longest working days, paid the lowest wages and thus deprived workers of a high quality diet, were the least efficient because their workers were poorly fuelled and excessively fatigued. The result of these studies in the 'sciences of work' were that the happiness of workers was co-extensive with the most rational use of labour power and thus higher productivity was compatible with social justice. These reports culminated in controversial and radical French legislation in 1903 to enforce one day of closure upon factories to allow workers to rest and restore their energies. Conversely, nationalists and industrialists, particularly in Whilhelmine Germany, accused the labour activists of sapping the energies of the nation in wasteful strikes and the propagation of class conflict. With its moralising aesthetics and utopian innocence of science, militant socialism acted to disrupt the efficient unity of the labour force and to prevent the perfect harmonisation of the labouring body's movements with those of the industrial machines and conveyers of the factory line. Later versions of the productivist 'science of work' took different forms as they interacted with national ideologies. In France a whole science of 'psychotechnics' was developed, particularly under military tutelage, in order to discover the performance limits of the working body under conditions of stress. In the United States, the dominant approaches to the ergonomics of industrial organisation are known to us as Taylorism, and in every plant an engineer was trained as a 'time-and-motion' man, who subordinated the totality of the movements of the worker to a rational calculus of profitability and a tight ergonomic discipline such that the speed of the production line could be intensified. Finally, both conservative authoritarians and Marxists criticised the liberalism of the American science of factory labour for accepting a system of pointless and speculative inter-factory competition that wastefully diminished the potential of the productive forces.[160]

The question of labour had become central to economics with Adam Smith, who argued that the annual product of society derived ultimately from a national fund of aggregate labour time. Smith's concept of labour value was inherited from the moral philosophy of Locke and the Scottish Enlightenment, in which labour was an explicitly social activity and a philosophical category of 'moral science.' On the continent, under the influence of Hegel and the German historical school (whose dialectics were influenced by Smith's famous discussion of the pin factory as an example of the productivity of specialisation[161]) labour was understood subjectively as the essential human activity through which came the specificity of human consciousness as distinct from nature and also the self-recognition of humans as social beings. Under the sway of energetics and the sciences of work, however, labour power became objectified as a quantifiable input to the production process.

> "By the last quarter of the nineteenth century, the social implications of the doctrine of energy were becoming apparent. In national economy, as in the work of Marx, the body was the site where the natural force of labour power was converted into energy to power the industrial dynamo. [...] Political economy was thus harmonised with the doctrine of protean energy. Energy is the universal equivalent of the natural world, as money is the universal equivalent of the world of exchange."[162]

In the earlier writings of Karl Marx, the Hegelian concept of sensuous, social labour is evident. By the time of the writing of the first volume of *Das Kapital*, however, Marx had become acquainted with Helmholtzian energetics, and distinguished between social labour and 'labour power', the latter of which the work of living bodies and machines are just special cases. From this distinction, Marx was able to argue that the key problem of the capitalist division of labour is that in the drive to extract and accumulate surplus labour from the working class, capitalism subordinated living people to the mechanical regularity and functional requirements of industrial machinery, transforming the worker into the "automatic motor of a detail operation."[163] Transcending the exploitative class contradictions of capitalism was by definition dependent upon the redemption of the social value of labour, in turn requiring the liberation of workers from the exhaustive burdens of repetitive, mechanical and soul-destroying work. In the mature Marx, the inevitability of a more scientific, humane, and socially just modernity was thus an emerging theme audible within the overwhelming teleological roar of the industrial forces of production as they exploded into the future.

Writing about the social discourses of late-nineteenth-century scientific naturalism, Seltzer detects a mirrored and seemingly contradictory impetus; on the one had, "the insistence on the materiality or physicality of persons, representations and actions" and on the other hand "the insistent abstraction of persons, bodies, and motions to models, numbers, charts, and diagrammatic representations."[164] Seltzer gives as examples of such phenomena the emergence of statistical representations for human behaviour - the meaning of 'social physics' introduced by the master statistician Quetelet - and the interest in the ergonomics of the human body evident in the sciences of work. One focuses on behaviour abstracted into statistical ensembles of data, and the other on the material processes of energy consumption and dissipation. The former illustrates the construction of bodies as probability distributions while the latter represents them as material objects.[165] These different facets of what counted as scientific materialism under the reign of classical energetics were parlayed into economics. If the physiological measurement of the working body's metabolism represents the empirical tendency of attempts to devise a social science consistent with energetics, it was in the new neoclassical approach to economics that we see the alternative tendency, the insistent drive toward mathematical abstraction from nature.

With the early neoclassicists, a bid was made to create a decisively scientific economics, a 'pure' economics devoid of politics, rhetoric, metaphor and moral suasion. For our purposes, what was fundamentally new about the neoclassical approach was its specific and, it must be said, dogmatically peculiar construction of 'the economy of nature.' It is in the key question of value theory that we can see the changing representation of human-environment relations as moral science becomes political economy and political economy becomes economics. With the neoclassical school, wealth was no longer attributed to ultimate derivation from the transformation of nature's bounty, as it was exclusively in Physiocracy. Although Smith routinely mocked the Physiocrats for their rustic obsession with agriculture, the labour theory of value of classical political economy was still tempered by natural restraints in the classical approach: most famously by Malthus, whose grim bioeconomics was expressed as an 'iron law of wages', and Mill, whose optimism about industrial progress was tempered by the assertion that all growth was just a postponement of some inevitable (though quite ill-defined) steady state of population and capital. As the economic historians Margaret Schabas and Phillip Mirowski have shown, the neoclassical model of 'the economy' directly appropriated its mathematics, models, and metaphors and from the rational mechanics and proto-energetics of the 1860s.[166]

This thesis is concerned to excavate the origins of the current aporia in modern capitalism – its unshakeable faith in infinite growth and the optimising, self-regulating lassez-faire market in the face of polarising wealth and poverty and multiple ecological crises. For my money, the greatest and most tragic irony of this dematerialised and transcendental materialism is that in the bid to raise the epistemological status of economics from that of a social science to a natural science, the economic order was represented as a distinct order of its own, with no reference to an external nature. The economic order was placed squarely within the realm of the artificial – the circulation of 'utility', a proxy for abstract exchange value, in idealised 'markets'. As neoclassical economics provides the 'scientific' compass of neoliberal policy, it is crucial to understand the origins of the doctrine of infinite growth in economic science, particularly now that even oil executives acknowledge the inevitability of looming supply crunches for energy inputs (the global 'Hubbert's peak' where total oil demand finally exceeds the discovery of new oilfields) and the unforeseen side-effects of hydrocarbon dependence (climate change). Thus we will continue to focus our attention closely on the question of energy in the neoclassical moment.

For our narrative, the most important element of the neoclassical synthesis is the transformation in the realm of value theory. Indeed, some have argued that the neoclassical school is best known as 'post-classical' because of their abandonment of the classical labour theory of value and the concomitant questions of where surpluses came from and how they were distributed. As a full discussion of the theoretical multiplicity and internal variations of neoclassical economics is beyond our scope, we will present only a rude sketch of its basic postulates in the work of two key originating figures: William Stanley Jevons and Leon Walras. Conventional accounts refer to the invention of 'marginal analysis' as the triumph that opened the pathway to the mathematisation of social science and thus inaugurated economics as a science. Marginal utility theory was developed to overcome 'substance' theories of value such as the labour theory of value, by attempting to explain exchange and consumption behaviour in terms of utilitarian psychology. The following parable, written against Marx by the Austrian economist Eugen von Böhm-Bawerk, outlines the starting point of marginal analysis:

> "A colonial farmer, whose log hut stands by itself in the primeval forest, far away from the busy haunts of men, has just harvested five sacks of corn. These must serve him till the next autumn. Being a thrifty soul he lays his plans for the employment of these sacks over the year. One sack he absolutely requires for the sustenance of his life till the next harvest. A second he requires to supplement this bare living to the extent of keeping himself hale and vigorous. More corn than this, in the shape of bread and farinaceous food generally, he has no desire for. On the other hand, it would be very desirable to have some animal food, and he sets aside, therefore, a third sack to feed poultry. A fourth sack he destines for the making of coarse spirits. Suppose, now, that his various personal wants have been fully provided for by this apportionment of the four sacks, and that he cannot think of anything better to do with the fifth sack than feed a number of parrots, whose antics amuse him."[167]

Each sack of flour has the same labour value or cost of production, but if one of the sacks were lost, the colonist would not divide the remainder equally over the five uses, but let the parrots starve. The 'utility' of the grain is different depending on how much one has. There are many subtleties to the theory of marginal analysis that Bohm-Bawerk's colonial idyll does little to answer, and that we shall not attempt to summarise. Suffice to say, that for the Austrians, this meant that value was always *subjective* and thus unquantifiable. By contrast, for the English, French and Italian (and later American) marginal economists, precise measurement was essential to the ambition of attaining scientific status Where most histories consider the notion of marginal utility the key to the palace of pure economics, here we consider the largely ignored metaphorical conflation of 'value' to 'energy' as the crucial development of the neoclassical 'science'. This metaphor allowed the application of the infinitesimal calculus to 'value', objectified as a continuous and conservative energy field.

This was explicitly asserted by Jevons in his unfinished *Principles of Economics*: "the notion of value" he wrote, "is to our science as that of energy is to mechanics."[168] In his 1872 work, *Theory of Political Economy*, Jevons began by elaborating upon utilitarian psychology, arguing that all conscious human activity could be reduced to a calculus of rational decisions about maximising pleasure and avoiding pain. This formulation provided a continuous field, or spectrum, of value as 'utility'. Agents would tend to minimise disutility (i.e. hard labour) and maximise utility (i.e. leisurely consumption of fine whiskey). In his treatment of utility, as Michael White argues, Jevons introduced a new conception of the body into British political economy, by represented the work decision of the representative labourer as a mechanical analogue of balancing the pain of work with the pleasures of consuming commodities for which work was exchanged at the margin.[169] Behaviour was asserted as being analogous to a "force" in mechanics, and this allowed the introduction of infinitesimal calculus into the representative agents decisions to exchange 'at the margin'. This in turn meant that the prices governing and generating economic behaviour were the instances of a mechanical equilibrium between the opposing 'forces' of subjective valuations of past and future experiences of pleasure and pain manifest in commodity production and exchange, and aggregated across the national bourse. As Jevons put it:

> "The theory of Economy thus treated presents a close analogy to the science of Statistical Mechanics, and the Laws of Exchange are found to resemble the Laws of Equilibrium of a lever as determined by the principle of virtual velocities. The nature of Wealth and Value is explained by indefinitely small amounts of pleasure and pain, just as the Theory of Statics is made to rest upon the equality of indefinitely small amounts of energy." [170]

The content of the references to physics need not concern us in their detail here, except to note the intellectual ambition of the research program. Two things should be noted: Jevons never satisfactorily demonstrated the coherence of the analogy (much less the inferred isomorphism) of 'force' and 'value' with the relevant mathematics, which according to White, he did not understand. Secondly, the earliest drafts of his theory of political economy (written around 1862) are oblivious to the earth shaking Continental developments in energetics (as is evident in the above) but by the time of writing of the *Theory of Political Economy* (in 1871), Jevons had made some efforts to acquaint himself with the new vocabulary, and replaced much of his discussions of utility as a mechanical 'force' with the metaphor of 'energy'.[171] 'Utility', the value 'substance' of the neoclassical paradigm, was like 'energy' or 'money', infinitely divisible. Economic value was no longer connected to the harnessing of the biological yield of the national territory or the silver of its treasuries and mines, nor to some quantity of 'labour time' mysteriously embedded in the commodity, but in the psychology of the individual consumer in relation to a continuous commodity space, where the desired manufactured goods and the detested work required to obtain them were unified in a single field of 'utility'. As Margaret Schabas observes, it is with this step that 'the economy' becomes entirely artificial and 'value' was detached from any recognisably social or natural setting. As the physical reality of economic activity was neglected for the abstract indications of consumer sentiment in the traces of prices registered in 'the market', even capital was recast subjectively with the neoclassical theory of value, not as a specific set of wage goods or industrial machines, but simply as 'that which is expected to yield utility in the future'.[172]

What is even more striking is the utter simplicity of the representation of the mind as way station in the global fluxes in the field of 'utility'. Inspired by Charles Babbage's heroic attempt to build an Analytical Engine that could in principle perform any algebraic calculation (not forgetting the contribution of Lady Ada Lovelace, who wrote the first programming language), Jevons built what he called a 'logical piano', in attempt to mechanise the process of logical inference. This was comprised of a set of several piano keys marked A, B, C and D, + , or, and =; a set of levers connected with a few brass rods. It has recently been demonstrated that Babbage's proposed machine, a room full of finely milled brass cogs, spindles, gearwheels, powered by a steam engine and using punch cards adapted from the Jacquard loom for input, information storage and output, would have achieved what is nowadays accomplished with microelectronics and silicon: that is, to provide a prosthesis to radically reduce human labour and error rates (economising) by materialising the mathematical functions in metal (building a machine).[173] By contrast, Jevon's music-less toy piano was of far less engineering sophistication than the first mechanical cash register built in 1883 by James Ritty and John Birch. This did not stop Jevons from claiming to "have made a successful working model of this contrivance which may be considered *a machine capable of reasoning*, or of replacing almost entirely the action of the mind in drawing inferences." [italics in original][174] Here is a case of unparalleled enthusiasm: his entirely *useless* machine is declared to be 'thinking', accomplishing 'almost entirely' the same cognitive functions of the human mind,[175] the purpose of which, it will be remembered, is to calculate *utility*. Nevertheless it is this promiscuous indistinction between the 'laws' of simple mechanical action and what he called 'the laws of thought' that underlies the representative actor of Jevons' price theory. The 'psychology' of this catatonically autistic individual's decision is then extrapolated to 'the Economy' as a whole, which exhibits exactly the same behaviour as the 'individual', a lever equilibrating the pleasurable attracting force of utility with the painful repelling force of disutility. A simple machine toy is taken as a proxy for society in its totality, value is reduced to exchange value, and the only empirical referent accepted for the economy is 'prices', the aggregate of an utterly impoverished aggregated 'rationality'.

Touted as 'revolutionary' in standard economics textbooks, marginal utility theory was developed in the 1870s almost simultaneously by Jevons in Britain, Carl Menger in Austria and Leon Walras in France. The 'revolution' that established the now dominant form of economic analysis is routinely presented as the becoming-scientific of economics. Jevons himself contributed to this characterisation of the intellectual moment. In 1871, as Paris was in the chaos of revolutionary movement and largely under control of the Communards, Jevons wrote:

> "If, instead of welcoming inquiry and criticism, the admirers of a great author accept his writings as authoritative, both in their excellences and in their defects, the most serious injury is done to truth. In matters of philosophy and science, authority has ever been the great opponent of truth. A despotic calm is usually the triumph of error. In the republic of the sciences, sedition and even anarchy are beneficial in the long run to the greatest happiness of the greatest number. [...] Our English Economists have been living in a fool's paradise. The truth is with the French School, and the sooner we recognize this fact, the better it will be for the world."[176]

The mainstream tradition tends to accord Jevons with priority for developing a scientific theory of price, while omitting the baroque analogies underwriting it and quickly moving on. Unlike the English empiricists, the French School derived its rationalist approach from the mathematics of engineering and is associated with Augustin Cournot, Jean-Baptiste Say, Leon Walras and Vilfredo Pareto. Say reformulated economics by reinterpreting Adam Smith's figure of the unseen hand – clearly a deistic conception of order - as the study of the 'balance' between the 'forces of supply and demand'. While no phenomenologically detailed theory of the nature of this balance had been proposed, that the 'laws of supply and demand' accomplished equilibrium was accepted as axiomatic by the French, as it was later by Alfred Marshall, the British economist who presided over the first hey day of neoclassical economics as policy.[177] It was Walras who was to complete the neoclassical 'revolution' in 1874 with the publication in *Elements of Pure Economics* of a model of general equilibrium, a static and ideal system of economy modelled on the static mechanics of the day. It contained a proposed theoretical proof of general equilibrium that is regarded as the defining moment and superlative achievement of the neoclassical school. Joseph Schumpeter called this work 'the Magna Carta of Economics', while Milton Friedman is supposed once to have remarked that "we curtsey to Marshall, but we dance with Walras."[178] Walras believed that only one aspect of the social reproduction of the lifeworld (assuming this to be the basic and prior reason for being of 'the economy') was amenable to 'pure' scientific analysis: the configurations of market prices in a regime of perfect free competition. The neoclassical theory that individual markets for all kinds of goods and services converge upon a general equilibrium found its initial basis among the untutored in the prevalent assumption of the 'balance of nature' and among the scientifically minded, with the wide acceptance of the doctrine of the conservation of energy. General equilibrium theory remains the theoretical jewel in the crown of economics. Indeed the Walrasian general equilibrium is the point of departure for the majority tradition of neoclassical analysis and is the generic model of 'the market' (albeit enhanced with an ever more mathematically elaborate superstructure) consistently referred to by our latter day 'market fundamentalists'.

Walras formulated economics as the study of a static balance of forces between supply and demand and directed economic enquiry into the question of whether there exists a set of prices such that all demand matches supply and 'clears' the market – i.e. everything offered is sold and no buyers walk away disappointed. This vision is clearly analogous to the Conservation of Energy framework: equilibrium is achieved because value is conserved through each exchange; machines, commodities, labour and land are all fully convertible to abstract exchange value, which is presented as equivalent to a certain version of the concept of energy. Adhering firmly to the script of positivist metaphysics, the marginalists sought to 'ground' social theory in the 'bedrock' of physics and mathematics - mediated at all times, we might add, by machine metaphors. As Mary Midgely has pointed out, this Comtean model of knowledge is a form of reasoning which completely accepts the gravitational and geological metaphors its hierarchical model of truth is mapped onto.[179] One of the assumptions made to get this model to 'work' are first the assertion of the universality of 'the market' as a frictionless, self-regulating machine:

> "... the whole world may be looked upon as a vast general market made up of diverse special markets where social wealth is bought and sold. Our task then is to discover the laws to which these purchases and sales tend to conform automatically. To this end, we shall suppose that the market is perfectly competitive, just as in pure mechanics we suppose to start with, that machines are perfectly frictionless."[180]

The Walrasian model has correctly been labelled as "a system devoid of human beings", and a "form of analysis without much substance".[181] The 'actors' in the perfectly frictionless market are ideal automatons without any purchase on the world. In the Walrasian economy of nature, persons, machines and commodities disappear entirely and only prices remain. While Walras legitimately develops a 'frictionless' machine as an aid to abstraction and does not undertake to describe the physicality of the economy, it is worth noting that assuming perfectly frictionless machines in order to say that 'the economy is in (or tends toward) equilibrium' essentially robs theory of any concrete analysis of an industrial economy. Like all physical objects in motion, machines are subject to friction. Internally, an engine's moving parts cannot avoid losing some efficiency to friction, which dissipates the systems energy in the form of heat (and wear on the parts). Friction is sometimes defined in physics as 'resistance'. As Franz Reuleaux's classic definition of the machine tells us, friction is integral to its ontology: he defines a machine as "a combination of resistant bodies so arranged that by their means the mechanical forces of nature can be compelled to do work accompanied by certain determinate motions."[182] Motion is essential to distinguish a machine from a simple structure, and they are built for no other reason but to change the magnitude, direction or point of application of moving forces.[183] Machines designed for cutting, welding, drilling, boring, milling, digging, grinding, processing, and transportation all apply the force realised from fossil fuel combustion to surfaces in ways useful for the transformation of nature into artefacts, or for otherwise enhancing the 'exosomatic' architecture of the human body by various prostheses.

The removal of all 'friction' in perfect markets (i.e. taxation, monopoly, monopsony, imperfect knowledge, irrationality, transaction costs, labour unions, hoarding, strikes, unwillingness to exchange at the equilibrium price, supply crunches) lies in the assertion of the so called 'welfare function' (Paretian *ophelimity* or optimality) of the 'economic equilibrium' achieved by frictionless markets. An important predecessor of neoclassical economics was the German national economist Henri Gossen. Largely ignored during his lifetime, his work directly inspired Walras (who was also largely ignored in his lifetime) by conceiving of the problem of national economy as beginning with a strictly budgeted quantity of the ur-substance *Kraft,* morphing into different manifestations of capital, labour and commodities in perpetuity:

> "Upon removal of all obstacles that interfere with not only each person's most purposive use of the money but also his choice of productive activity that, under the circumstances, is most advantageous to him, each person will receive a portion of the means of employment that corresponds exactly to the burden assumed by him in the productive process. Thus what socialists and communists conceive to be the highest and ultimate aim of their efforts is accomplished here with the cooperation of the forces of nature." [184]

Here the physical quantity *Kraft* is illegitimately conflated with all human activity involving spending money and earning it, and a conservation principle resembling the first law of thermodynamics is pressed into service to ensure that no-one gets a free lunch. In a precise reversal of the Marxist slogan "from each according to his ability, to each according to his needs", Gossen's economy exacts productive labour from each according to her desires and returns an exact equivalence of commodities to each according to her diligence. This telling passage retains a striking currency in the present age's hegemonic insistence upon the global removal of all obstacles to financial flows, while insisting on the moral value of deregulated corporate activity. As I write, there is debate in the Sydney papers about the head of Macquarie Bank receiving an annual payout of $33 million, a record for corporate largesse in Australia, while the conservative Liberal government is demanding that, in the interests of 'the economy' workers be prevented from collective bargaining, and be hired under individual short term contracts (Australian Work Agreements) that significantly restrict hard won conditions, forbid employees from discussing their contracts with one another and further discipline labour by undermining employment security. Clearly the intention is to 'atomise' the 'workforce' in order to impose upon them the 'true value' of their contribution to production as recognised by the blind justice of 'market forces'. While economists routinely debate whether a minimum wage causes unemployment, few ever put forth proposals for a maximum wage. Any calls to reinstate collective bargaining, national wage cases or place higher taxes on capital gain is said to be 'bad for the economy'. As it was with Gossen a century and a half ago, 'the economy' is conceived of as a Laplacean daemon both enacting moral justice and optimising the output of the 'labour force' through a supposedly impartial and automatic 'price mechanism'.

While long since disavowing the ontological ambitions of that generation of economists regarding the cardinal measurability of 'utility' as the equivalent or analogue of 'energy', what has persisted in neo-classical economic theory since its openly physicalist period is the notion of *the permanent conservation of value* in the cycles of trade,[185] reflecting the posited equivalence of 'energy' with 'utility', the ethereal value substance that superseded the labour theory of value in British political economy. By definition, the equilibrium model of the market requires that 'value be conserved' through each exchange in the circular economic process. But this raises an important question: if the quantity of value can neither be created nor destroyed, then how is economic growth possible? Another key assumption of the equilibrium model is that "all resources, commodities and services can be produced entirely from linear combinations of others in the system - the economic system is closed to fresh inputs and outputs of waste."[186] As was pointed out by the Nobel-winning chemist Frederick Soddy as long ago as 1922, this effectively means that the economy is a perpetual motion machine.[187] But even more striking is that in the Walrasian model of the economy, natural resources are implicitly assumed to be *generated* by labour and capital! To take the consequences of this assumption to its logical conclusion, the biosphere and the geosphere must be seen as subsystems produced by of the socio-economic system, and not the other way around. Thus we have arrived at the basic problem of economics as a source of policy in an age of soaring energy demand, oil wars and overflowing carbon sinks. If we were to assume (too generously of course) that policy follows theory and that the real economy is the result of policy it might be possible to argue that the current ecological crisis is the result of poor metaphor choice. An impoverished metaphor of Nature (the living cosmos reduced to mechanical equilibrium) is subsequently reified into an impoverished abstraction of society, which is then re-projected back into nature. Thus in mainstream attempts to consider ecological problems, environmental degradation is glossed as merely a temporary 'market failure', an 'externality' traceable to unclear property rights, and not a necessary condition of permanent increases in 'production'.

As economics is conceived of as a science of equilibrium, its theory of 'production' and 'economic growth' is an entirely subsidiary afterthought. Economic theory thus contributes to the general paralysis of 'apocalypse blindness', by referring to 'the economy' as an interdependent, abstract system of 'floating' prices rather than as a linear process of material conversion and physical throughput. As the physicist Robert Ayres observes:

> "Although they relied to some extent on physical analogies, the early neoclassicists (Walras, Pareto and their successors) did not fully face the fundamental contradiction of growth in the equilibrium state. [...] The Walrasian equilibrium is inherently static." [188]

If the sins against the first law of thermodynamics committed by the neoclassical model of general market equilibrium were not bad enough, we will now discover that economics simply ignores the crucial principle of the fully realised science of energetics: the second law of thermodynamics. The second law is a notoriously difficult subject, yet we must attempt to give enough of an account such that the lay reader can understand what is surely the gravest blind spot of orthodox economics. This critique is crucial to the current legitimacy of the universal neoliberal project of infinite growth under self-equilibrating markets, and its incredible resilience and resistance to the myriad of scientific evidence pointing to a generalised global ecological crisis. In other words, how are we to explain why economists reproduce the productivist optimism of 'industrial millennialism' in the face of the 'industrial apocalypse' prophesied by ecologists and other earth scientists? As Mirowski argues in *More Heat than Light,* neoclassical economics has internalised the cosmology of what he calls the 'proto-energetics movement', which flowered briefly in the eighteen year period between Herman von Helmholtz's 1847 formulation of the first law of thermodynamics, and the elaboration in 1865 by Clausius and Kelvin of the second law of thermodynamics, the entropy law, with all its implications of exhaustion, depletion, dissipation and decay. The productivist optimism that arose from this interregnum has, he argues, been maintained within the core mathematical postulates of neoclassical economics more or less down to the present day. In the search for a unifying measurement of the substance of economic exchange, the neoclassicals found what they where looking for within the pre-entropic physics of a specific historical moment, building a theory of value upon an outdated notion of 'energy' quarantined from of all later developments such as the second law of thermodynamics and the theory of relativity. The physics thus transported to social theory is entirely outdated. In Mirowski's words:

> "The metaphor of energy-utility that was appropriated by neoclassical economics was derived from the physics of a specific historical moment, namely, the middle of the 19th century just prior to the elaboration of the second law of thermodynamics...In this vintage of physics, all physical phenomena are portrayed as being perfectly reversible in time; there was no room in the theory for hysteresis. In other words, nineteenth-century physical law could have no history. This stubbornly antihistorical bias of neoclassical economics has been excoriated by critics.... In pre-entropic physics, all physical phenomena are variegated manifestations of a protean energy that can be fully and reversibly transformed from one state to another. When this metaphor was smuggled into the context of economic theory, it dictated that all economic goods be fully and reversibly convertible into utility, and thence into all other goods in the act of trade...In the mathematics, the analogue to money has not been to some lubricant that greases the wheels of trade, but rather a superfluous intermediate crypto-energy which all other energies must become in transit to their final state."[189]

So what has the entropy law got to do with economics? As our ordinary experience tells us, things fall apart. Cars rust, chewing gum goes stale, and organisms and machines wear out and die. Our next task then, is to attempt a simple account of the second law of thermodynamics. The following is closely adapted from Frank Niele's recent book *Energy: Engine of Evolution.*[190] The First Law posits an *invariance* in the *quantity* of energy within a system regardless of any process of transformation. Uniting the principles of the conservation of mass and the conservation of force within the greater generality of the energy concept, the first law can be simply stated in ordinary language as 'energy is conserved.' But what is meant by 'conservation'? Ultimately, this can only be explained by introducing the Second Law, which insists that for any *change* to occur, the *quality* of energy must be altered. For our purposes, the quality of energy refers to the capacity of energy to be available to do 'work', i.e to cause some kind of transformation. This quality of energy is referred to as available energy, free energy, or in some formulations, 'exergy'. Entropy is thus a measure of the unavailability of energy within a system to perform 'work'. Here we might use the example of your ordinary garden-variety leafblower. After an hour of joyfully fighting the autumn breeze and blowing the leaves from one end of your garden to the other (doing 'work'), the energy stored in the machines' now empty fuel tank is dissipated as heat into the environment through radiation and friction. The concentrated, high quality energy (low entropy) stored in the two-stroke fuel is converted into low-quality energy (high entropy) dissipated into the atmosphere as diffuse heat, no longer available to do work. While the total sum of energy is conserved, its quality is irrevocably degraded.

Formalised by Rudolf Clausius and Lord Kelvin around 1865, the Second Law was formulated because nobody could find a way around its various constraints on heat and work. No known violations exist, even at the molecular level.[191] Clausius proved that it is impossible for a self-acting machine, unaided, to transfer heat from one body at a low temperature to another having a higher temperature. Heat flows in only one direction, and it is gradients in the condition of energy that allow the possibility of mechanical work to be performed. On its own the first law would seem to maintain the invariance and ideal reversibility contained within the multiplicity of concepts of 'balance' and 'equilibrium', metaphors which as we have seen have been much abused in the 'physics envy' of the social sciences since Newton set the benchmark of 'science'. The second law, however, is resolutely and rigorously historical, and covers all the phenomena of change governed by 'times arrow' and accessible to our ordinary experience. Energy can be concentrated, but tends toward diffusion. For example, an inflated balloon with a pinhole in it will deflate until its internal pressure is equivalent to that of the atmosphere surrounding it. Drop a ball on the floor, and it will bounce for a while and then come to rest. Bring a boiling pot of soup into a warm, perfectly sealed room, and the temperatures of the room and the pot will converge until they are not different. Energy dissipates as heat to the surroundings, which act as a sink. The room and the pot of soup form a closed system and once in thermal equilibrium, will not change from that state. Open the door to the winter night, and the rooms' temperature will equalise with that outside. The reverse of these processes, a spontaneous movement from dissipated energy to concentrated exergy, never occurs. Soup does not heat itself, balls do not start bouncing on their own, and balloons don't self-inflate. In each of these cases energy required for the transformations is sourced externally, and ultimately from the sun. In the case of the soup, in the primary capture of solar energy by the ancient trees that through geological time become the natural gas burned on the stove top, in the case of the ball and the balloon, by the far more recent capture of solar energy by the pumpkin vine that produced the vegetable that went into the soup to give somebody enough energy to maintain the muscular activity of their body to a sufficient standard so that they can inflate balloons and play with balls.

Introducing temporality and irreversibility into physics, the entropy law states that in the unidirectional flow of energy through isolated systems, the overall quality of energy is degraded in each exchange.[192]

First hinted at in the discoveries of Carnot, it is the entropy law that both makes it possible for engines to 'work' and also limits their efficiency in converting the potential heat energy stored chemically in the fuel to mechanical work. What Carnot discovered in 1824 was that it was the temperature gradient - the difference between the parts of the engine heated by the combustion of coal and the parts cooled by air flow or water condensers – that was *solely* responsible for the work realized by the engine. Just as the 'work' of a watermill wheel is realised by harnessing some of the energy flow manifest in the coherent falling of water molecules, converting what we would call the potential energy of position into motion, work was produced in engines from the actions of the "fall of caloric" between a hot body and cold sink. Since any thermodynamic engine requires such a temperature difference, it follows that no useful work can be derived from a system in thermal equilibrium with its environment: there must always be an external energy source and a cold sink for heat to flow out to for a portion of the heat to be convertible to work. Most of the heat generated within the engine is 'wasted', dissipated to the cooler surrounds of the engine and thus permanently inaccessible to the engine as useful energy. The second law of thermodynamics is generally considered to be the foundation of all modern physical theory. Sir Arthur Stanley Eddington held it to be the most secure and fundamental of all the laws of nature. As he put it,

> "The law that entropy will always increase – the second law of thermodynamics – holds, I think, the supreme position among the laws of Nature. If someone points out to you that your pet theory of the universe is in agreement with [James Clerk] Maxwell's equations, then so much the worse for Maxwell's equations. If it is found to be contradicted by observation, well these experimentalists do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics then I give you no hope: there is nothing for it but to collapse in deepest humiliation." [193]

Given the assertion of the universality of the entropy law the problem was immediately posed: if everything is winding down, if order is always reduced to chaos, then how do organisms grow in size and complexity? How is the process of biological evolution possible? Some pointed to evolution to try and fault the second law, whereas Creationists persist in using the second law to falsify evolution. This problem ricocheted around the halls of science for many years until Ervin Schrödinger, in his 1944 work *What is Life?,* first set out clearly the relationship of biological life to the rigorous limits of entropy.[194] In it, he foreshadowed Ilya Prigogine's concept of 'dissipative structures', by suggesting that "the device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists in sucking orderliness from its environment."[195] Organisms exist by maintaining their 'order', importing what Schrödinger referred to as 'negentropy' (negative entropy) from the environment and exporting or externalising back to it waste, disorderliness and heat (entropy). Ecosystems and socio-economic systems are thus both examples of 'dissipative structures': in the terminology of Gibbs, "islands of order in a sea of disorder", maintaining and increasing their 'orderliness' by dissipating inflowing energy into more chaotic forms (and thus more probable, according to the second law).

The consequences of this for the question of long term 'sustainability' are clear enough. The biosphere, having evolved an adaptive complement of species life that forms a near-perfect system for the recycling of biogeochemical materials, is 'sustainable' for as long as the earth is daily bathed in high quality (though diffuse) solar energy. A small fraction of this incoming sunlight is captured by plants and certain microbes, 'primary producers' whose unique photosynthetic abilities to capture, concentrate and store solar energy are the foundation of nearly all forms of life. The remaining solar energy not embodied in the biosphere, having performed 'work' on the earth by heating it and driving biochemical, atmospheric and geological processes, is eventually radiated out as diffuse heat into the cold sink of outer space. On the other hand, global industrial technomass is radically unsustainable as long as it consumes fossil energy faster than it is produced by geological processes, even were it not the case that the biosphere is being dismantled in order to make room for industrial technomass, as the global economy's supply frontiers widen, as the space it takes up increases, as pollution sinks fill up and overflow. Although physicists were themselves propelled into strange new lands by the *impetus* of the paradoxical implications of the tension between the first and second laws of thermodynamics, and were overtaken by an ontological revolution as they grappled with the weird results of relativity and quantum theory in the early 20th century, the neoclassical economists remained faithful to the timeless universality of Walrasian 'market equilibrium', ignoring the anachronous ghost of 1860s energy physics inhabiting their mathematical metaphors.

It may be objected that the import of a metaphor from one field into another need not imply an isomorphic correspondence: in the history of the sciences, metaphorical exchange has often proven useful in providing novel heuristics that have led, via analogical reasoning to valuable breakthroughs. Thus the equilibrium concept could be seen to have found an autonomous meaning within economics and detached itself from the original signifier in physics. This defence would be acceptable were it not the case that the precise rationale for equating subjective utility with energy was to avoid the analogical reasoning of political economy – and as I have suggested earlier – to thus bury the imminently political questions raised by the labour theory of value: of class in the metropolitan centres of 19th century Europe, and of race given the exploitation of non-white slave or indentured labour in the colonial peripheries. 'Equilibrium' was not intended to be just another metaphor to conjure with; its task was to do away with metaphor by reduction to axiomatic natural laws governing production and exchange. But without doubt the most serious problem of the neoclassical equilibrium model is that its metaphor of equilibrium so badly coheres with, and indeed acts to obscure, the physical reality of the economic process.

The strictest definition of equilibrium is provided by the second law of thermodynamics, where it refers to a final maximization of entropy. In the words of Robert Ayres:

> "Equilibrium is a homogenous unchanging state in which there are no gradients of any kind, including the time dimension. This implies uniformity of temperature, pressure, density, chemical composition as well as uniform gravitational and electro-magnetic fields. The equilibrium state is one in which no part of the system can be distinguished from any other part of the system."[196]

So much for *ceteris paribus:* economists take note.

Whereas thermodynamics is the study of natural phenomena in the approach to equilibrium, economics purports to be the study of equilibrium itself. This leaves us with the question of how economists have managed to maintain use of the term 'equilibrium' to describe Society, despite routinely violating the content of the original metaphor, in order to convince themselves and so many others that they are in fact scientists? Perhaps they have indeed transcended the 'context of discovery' by proving the existence of a natural order of society in a new 'context of justification', to use Popper's phrase. This has indeed been the dominant account. In a work promisingly entitled *The Concept of Equilibrium in American Social Thought* (1966), Cynthia Russet explains her exclusion of economics from the category of 'social science', and thus disappointingly from her otherwise useful study, by repeating the conventional wisdom that "most scholars agree that economics has become 'scientific' according to the norms of the natural sciences [...]."[197] Citing Schumpeter's insistence on the centrality of equilibrium analysis to economics, she notes that economists can isolate a small number of quantifiable variables – price, supply, and demand – and with them determine the price at which supply and demand will be at rest, "like a physicist."

Turning to a more up to date and detailed work that deals directly with 'economic equilibrium' and the idea of 'law' in social science – Ingrao and Israel's *The Invisible Hand: Economic Equilibrium in the History of Science* (1990) – we come across an interesting episode that sheds light on this question. In the latter years of his career, Walras attempted to garner support for (and answer criticisms of) his 'pure economics' program in a series of letters to Henri Poincaré, the eminent French polymath who made many contributions to mathematics, celestial mechanics, relativity theory, and who is credited with the foundational insights of modern complexity theory. Upon reading Walras' book, Poincaré responded to the effect that in order to continue with the potentially illuminating application of the abstraction of calculus to units of 'satisfaction' beyond the point of pure speculation, some empirical foundation must eventually be found to eliminate the reappearance of the initial arbitrary assumptions in the concluding phases of calculation. In other words, if a secure link to empirical data could not eventually be found, then abstraction was meaningless. In addition to this empirical problem of measure, he pointed out with polite irony another problem with the theory: "You regard men as infinitely selfish and infinitely farsighted. The first hypothesis may perhaps be admitted in a first approximation, the second may call for some reservations." [198] While the details of these exchanges need not be reproduced here, the correspondence ended with Walras convinced he had secured legitimacy for his social physics from the great authority himself. In reality, he had taken from Poincaré precisely the opposite message intended by him. His utopianism coming to the fore, Walras mistook a plea for cautious descriptive realism both in measurement and in assumptions about human qualities to be a vindication of the scientific value of his pure economics, and thus its usefulness as a normative program. Where Poincaré was advising to Walras to try and remove the assumption of 'frictionlessness' from the model, Walras took him to mean that because in fact 'friction' remained in real markets, the task of economic theory was thus to point out the necessity of its complete removal. That the theory of optimal distribution required perfect foresight meant that the economists' duty to society was "to seek a more perfect maximum in the development of foresight and not through the substitution of an authoritarian mechanism for the free mechanism of competition."[199]

However, as several years passed without any further 'encouragement' from Poincaré, and frustrated by his general lack of recognition (though Pareto had, with reservations, referred to him as the Newton of economics), Walras set out in an essay entitled 'Economique et Mechanique' (1908) a final attempt to establish economics on a scientific footing. He began by dividing mathematical data into two categories. The first was that of external or physical data, which are measured in terms of objective magnitudes and come under the domain of the 'physicomathematical' sciences. The second is that of intimate or psychic data, whose estimation is subjective and which forms the subject matter of the 'psychomathematical' sciences.[200] Walras writes:

> "*Mechanics and astronomy* belong to the first category; *economics* to the second. [...] It is a question of the determination of prices under free competition and of knowing how this depends on our preferences...this question alone is the substance of *pure economics*. Pure economics is perhaps not a physicomathematical science. All well and good! Then it is a psychomathematical science. And I think mathematicians can easily

be shown by means of two decisive examples that its procedure is rigorously identical with that of the two most advanced and least challenged physicomathematical sciences: *rational mechanics* and *celestial mechanics*." [italics in original] [201]

Leaving the examples aside, we can note the begrudging surrender of the assertion of the identity of economics with physics, all the while attempting to recapture it by asserting the mathematical equivalence of physics and psychology and thus the theoretical possibility of the precise computation of 'satisfaction' through inference from 'prices'. The equation of mechanics with psychology is particularly dated: although Freud liked to use energetic metaphors to describe the soul as a 'psychomotor' achieving a homeostatic 'balance' between its internal and external social environment, the implication of his libidinal theory of the unconscious was that individuals didn't really know what they wanted, much less perform complex Hamiltonian calculations on the basis of price data to determine all future actions. In a later review of Walras' 1908 essay that took it as a starting point for the critique of the economics of Cournot, Jevons and Pareto, the mathematician Paul Painlevé began by asking a crucial question: is it possible to follow Laplace's program in economics? The answer, he wrote, was a simple no. "The likening of the laws of economic equilibrium to the principles of static mechanics is for now no more than a verbal image. [...] Thus we have quantitative reasoning about things which are not quantities because they cannot be measured."[202] He went on to predict that all value theory in economics was bound to fail where it sought to determine intrinsic and absolute values for objects, and that even if such a science could be erected it would still not be able to convince those that lacked social justice and those that refused to submit to it.[203] One would imagine that this was the last nail in the coffin for the social physics of equilibrium. What was to reverse the fortunes of neoclassical theory, however, was not some further innovation in economic method or theory, but what we might call 'jurisdiction shopping', the convenient discovery of a philosophical definition of 'science' more acceptable to economists. After 1910, report Ingrao and Israel:

"[...] the central position that mechanical analogy had played in classical reductionism was now assigned to mathematical analogy. It was no longer a matter of reducing the laws of phenomena to the form of mechanical laws (the orthodox method followed by Walras in economics), but rather the formal unification of different laws by means of mathematical frameworks bringing out the basic analogy (*'empty schemata of possible contents'* as the exponents of axiomatic mathematics were to call it ). [...] Such a concept involved radical change in the concept of verification of laws and, more generally, in the view of the relationship between mathematical laws and experimental

> reality. The connection between the two becomes looser and less rigorous than in the classical approach. *Not only is mathematics no longer the language of nature, but all claims to derive mathematical laws from nature are dropped.* [...] The foundations were thus laid for promising new developments in our discipline. The evolution of mathematical modelling (based on the idea of mathematical analogy) made it possible to again attempt to found a mathematical economics worthy of the name of science *without losing one's way in the maze of problems concerning the relationship between theory and empirical reality.* In fact, when developments resumed in economic equilibrium theory there was less interest in such questions as measurability or the best way to 'remove the impediments' (the realism of the assumption of the 'infinite foresight' of economic assumptions and so on). Without a word having been said on the matter it was clear that the paradigmatic climate was totally different." (my italics) [204]

It is here that we must part company with Ingrao and Israel, as they merrily leave nature and empirical social reality behind in order to get on with what they consider the real work of economics – the application of increasingly complex mathematical methods to essentially the same set of arbitrary and restrictive assumptions in order to 'prove' the existence of an invisible hand. Against these approving remarks, I would argue that an economic science worthy of the name must surely be something more than a purely self referential and completely isolated maths puzzle with no empirical referent in nature or society. Indeed, though the terms 'science' and 'equilibrium' appear on most of the pages of their book, mechanics remains untransformed by energetics in their account. Indeed the reference section of their paean to economic science contains not a single reference to energy, thermodynamics or even such a fundamental category such as economic growth. Economics as a science is presented as entirely self-sufficient within its own universe of discourse, immune to other sciences and even its own applied forms in banking and credit, the theory of the firm, fiscal policy, development theory, macroeconomics, etc. Indeed it is perhaps partly due to these beliefs about what counts as science for economists – given the realities of energy use in the real economy – that the real climate will be totally different in the future.

Best conceived of as the most abstract and abiding 'social physics' project of the European energetics movement, economics internalised within its mathematical metaphors "the image of inexhaustible natural energy and labour power (*Arbeitskraft*), reflecting the optimistic faith of science in the productive potential of the [industrial] age".[205] The utilitarian hopes attached to Victorian industrialism were reflected in the Society of the economists as the frictionless circular interaction of energy, biological life and social reciprocity (prices), all of which conflated with a model of Nature rendered as a reversible heat engine with a perpetual fuel supply. Perhaps this goes some way to shed light upon the persistent Western belief in 'intrinsic machine fertility' identified by anthropologist Alf Hornborg.[206] Within this crypto-physical model of economy, production, distribution and consumption, are transcendentalised and the model rules out *a priori* the possibility of unequal exchange, depletion or waste. It remains to be asked: what is it about the metaphorical content of neoclassical economic theory that has proved so successful in displacing all other schools of economic thought? As Mirowski has said,

> " [...] The physics metaphor implies that economics is a *science* and deserves all the legitimacy that is granted to physics itself, because no great difference exists between the two modes of inquiry. The economy is portrayed as a self-contained subset of social life and as such has the character of a stable natural process. 'Capitalism' as a natural entity is implied to be timeless; it has always existed and will always continue to exist. Human beings within this sphere of social life behave as if they were automatons, in that their rationality is conflated with the existence of mechanical decision rules, most notably constrained maximisation over a conservative vector field. Humans behave differently in other spheres of social life, but since this behaviour is 'irrational' by definition, there is nothing left to be explained. Finally the physics metaphor endows differential ontological validity upon sets of social phenomena: the 'individual' is taken to be more real than any other social formation, be it the family, the firm, the nation state, and so on." [207]

The importance of this to the question of ecological crisis was first established by Georgescu-Roegen in 1971;

> "[...] the founders of the neoclassical school set out to erect an economic science after the pattern of mechanics [and thus], the analytic pieces that adorn the standard economic literature [...] reduce the economic process to a self-sustained mechanical analogue. The patent fact that between the economic process and the material environment there exists a continuous mutual influence which is history making carries no weight with the standard economist." [208]

Since Popper, the standard distinction between scientific theory and ideology is the possibility of falsification, but economics has been singularly resistant to the standard facts of environmental degradation, which I would argue are the most eloquent testaments to the intellectual failure of economic science. According to Herman Daly, none of the senior exponents of the neoclassical tradition have even acknowledged Georgescu-Roegen' s devastating critique of thirty years standing, much less answered it. His own attempts to gain a response from Robert Solow and Joseph Stiglitz on the question of the relationship of thermodynamics to the economic process yielded not a systematic defence, but approximately five short and evasive lines.[209] The only possible conclusion we can make, as Mirowski has it, is that:

> "The reason that neoclassical economists have proven incapable of seriously confronting these facts is that they would then have to face up to the futility of their entire research program: the physical metaphors are spuriously grounded in natural phenomena. To admit the failure of the physical metaphor in the very area that it should seemingly be most natural, the description of putatively physical processes, would be the last straw, and would even encourage doubt that the metaphor was adequate in the sphere of psychology, i.e., utility."[210]

Hopefully by now we have convinced the reader that the core doctrines of economics are intellectually spurious. How then, do we explain the ongoing integration of neoclassical economic theory into all levels of social life? Does not the success of economics speak for itself? Do not the models of market equilibrium work? There can be little doubt that the co-ordination of supply and demand through competition of floating prices has been a relatively efficient way to co-ordinate supply and demand and maximise production. The Soviet experiment at central control of pricing has borne this out, as the latter half of the twentieth century was largely a competition between two systems of production, not the least driven by the insatiable demands of the arms race. This 'efficiency', the agnostic and Darwinian 'welfare function' of Pareto optimality says nothing about the distribution of this output. Since adopting free-market capitalism and the full packet of IMF reforms, crucial indicators of general social welfare (especially the life expectancy of adult males) have gone into decline in Russia.

Interestingly, the "proof" provided by Leon Walras of the tendency of free markets toward equilibrium, does not mean immediate scientific defeat of 'socialism'. Walras is said to have demonstrated that there exists a unique set of prices such that all demand is met by sufficient supply and that all markets clear. An obvious objection to this would be the problem that all demand is not effective: homeless people can demand houses all they like but will only get one if they have money. This aside, if the possibility of determining and calculating such a set of prices does indeed exist theoretically for the economy, then why not do away with the fluctuations of actual prices in the liberal economy's inefficient markets, by calculating the system of equilibrium prices and have them set by a central agency?[211] This question was at the centre of the 'socialist calculation controversy' that began in the early 20th century and reached its height during the McCarthyist anxiety regarding the work of Oskar Lange. Lange was a rare bird: a neoclassical Marxist. Lange was a developer of applied general equilibrium planning models for the Cowles Commission in the United States during the war economy of the 1940s. Using newly available computers in the 1950s, Lange pioneered the novel econometric techniques of linear programming, which were subsequently adopted in the Soviet Union. Arising from the need to subject the total war economy of the superpowers to an iron-clad standard of rational centralised control, linear programming attempted to further rationalise the Walrasian theory by introducing 'equilibrium' through the centralised planning agency. Nothing could be further from lassez-faire. Indeed despite his canonisation by ultraliberals, Walras himself espoused a particular version of socialism, believing that only if all land and natural resources were nationalised would the monopolistic interests and corporations that distorted free competition in production be prevented from forming. In addition, government revenue from land rent would allow wage income to go untaxed, allowing workers to save enough to invest in production. Laissez-faire in production of goods and services would thus allow social reform and the best fit with his theoretical model.[212] Worse for the advocates of spontaneous order, is the fact that the 'market clearing mechanism', an intellectual device Walras invented to make his equilibrium 'work' was an all-knowing auctioneer that processed all offers and bids and ensured that traders only exchange at what he calculated to be the equilibrium price. This resembles nothing if not a cyborg bureaucrat authoritively overseeing the economy from the centre.

Professor Freidrich von Hayek – the candidate Newton of economics hinted at earlier by Karl Popper in *The Poverty of Historicism* – wrote in his similarly anti-historicist *The Fatal Conceit: the Errors of Socialism* that "the curious task of economics is to demonstrate to men how little they really know about what they imagine they can design." For Hayek, the focus of social science should be on the complexity of phenomena that are the product of human action but not human design, and the limitations imposed by deep moral codes, natural liberty and spontaneously evolving order of society, upon utopian schemes of social engineering. One of his main critiques of what he calls 'socialism' is the view that blueprints for social engineering can be derived from disembodied concepts of society, and its destination formed by rationalised processes in the minds of individuals or members of elite groups. The 'fatal conceit' for Hayek, is the idea that "man is able to shape the world around him according to his wishes." [213]

While not wishing to defend Soviet socialism and its totalitarian drive to remake nature and society according to a rigid interpretation of the productivist social energetics of Marx and Engels, I would argue against Hayek, that the point of developing the kind of knowledge that economics seeks is not merely the disinterested pursuit of objective knowledge of an objective natural datum called the economy purely for its own sake. For better of for worse, the purpose of social physics is to generate basic science *from which to assemble the tools of social engineering.* The continued claims as to the scientific qualities of economics qua political economy allow all questions of value – questions that are inherently political despite the understandable temptation to bury them in the precise mathematics of an objective theory of value – to be passed over by decision makers claiming to govern rationally according to economic reality.

Such 'realism' is contrasted to the prophetic discourses of those who wish to moralise the economy as the reproductive domain of human community, best served by co-operation in the interests of long term survival rather than the myopic pursuit of individual advantage. And yet the realism of economics, drawn from the pale mimicry of physics, essentially denies the physicality of the economic process and the existence of social being beyond selfish consumption. Although laudably committed to a certain superficial notion of 'freedom', contemporary neoliberal economics, true to its embrace of the Walrasian paradigm, is itself entirely utopian in its embrace of the industrial millennialism of the proto-energetics movement. In support of this argument we can briefly cite several related critiques of the institutional project to establish the 'natural order' of a global marketplace after the end of history. It is hoped that the readers' patience will not be tested by a series of quotations that say essentially the same thing but derive from slightly different approaches.

The first of these comes from international relations theory. As the IR theorist Kenneth Waltz notes, since the British Empire's production of a 'single' international economy in the early 19th century, liberal economists have periodically argued that economic interests are personal and universal, announcing that spurious political interests are being rapidly subsumed by the genuine economic interests of a unitary world, which through increasing interdependence, is becoming more prosperous and peaceful.[214] But as he points out,

> "To think of interdependence in simple market terms is appropriate where economic units interact without their mutual adjustment being affected by the ability of some of them to use their superior capabilities to influence the market or by the intervention of government. All economies work within orders that are politically contrived and maintained."[215]

Neoliberalism might be described as a political project to universally re-model global society according to the prescriptions of neoclassicism; as we see in the phenomena of 'export processing zones', to remove the 'friction' of tariffs, capital controls, labour unions, environmental law and social security taxes in order that the axioms of the Walrasian model can finally be realised in the real world. Along these lines, Pierre Bourdieu has argued that rather than representing the global institution of a scientifically rational regime of production and exchange that soberly reflects the natural laws of social existence, neoliberalism represents 'a utopia of infinite exploitation'.

> "Neoliberalism tends on the whole to favour severing the economy from social realities and thereby constructing, in reality, an economic system conforming to its description in pure theory, that is, as a sort of logical machine that presents itself as a chain of constraints regulating economic agents. That said, this 'theory' that is desocialised and dehistoricised at its roots has, today more than ever, the means of *making itself true* and empirically verifiable" [italics in original].[216]

Bourdieu's concern was to highlight the destructive nature of this logic toward the collective social structures of family and community, and the social-democratic organisations of solidarity and social provision enshrined in the welfare state. These comments take on a deeper relevance when considering ecological realities, which standard economics also separates from its sphere of enquiry. One need only look at the draconian imposition by the IMF of 'structural adjustment programmes' on hundreds of indebted Southern nations, fiscal straightjackets which in order to maintain payment on exponentially expanding sovereign debts to the World Bank, demand that social services be cut to the general population and that the debt should be serviced by 'export led growth'. In practice this means exporting forests, mineral resources and cheap factory labour to the wealthy cores of the global economy. Subsistence agriculture for local consumption must be overturned for the production of luxury industrial crops for Northern consumers. In addition to the contractionary 'shock therapy' suffered by the ordinary citizen of the South, the irreversible conversion of the natural patrimony of coal, oil, natural gas, fisheries, rainforests and also agricultural soil into the 'hard currency' of export earnings is held out as the only way to one day 'buy back the farm', although there will be little of it left once the debt has been paid. Thus in the name of maintaining the equilibrium of the global finance markets by ensuring that debts are paid and not defaulted on, Southern nations become resource satellites for the industrial heartlands, effectively paying for the privilege of being systematically drained of 'natural capital' through the inexorable growth of compound interest. As the apostate ex-World Bank economist Herman Daly points out, these material flows are not measurable in 'development economics', and the transcendental view of 'the economy' still holds: "the pre-analytic vision with which neoclassical economics begins posits an isolated circular flow of abstract exchange value between firms and households, into which nothing enters and from which nothing exits."[217] As evidence of the persistent reification of such a counter-intuitive abstraction, he notes that until protest modified its position in 1995, the International Monetary Fund insistently maintained the view that "macroeconomics has nothing to do with the environment".[218] Similarly, Nancy Cartwright has argued that the fact the contemporary econometric models 'work' and are at all stable is not the result of using basic 'natural laws' in their construction, but rather that stability is an *a priori* condition necessary for the model to 'work' like a machine.[219] Echoing Bourdieu's critique of neoliberalism and Walras' fateful misreading of Poincare's critique of pure economics, she argues that:

> "Models in economics do not seem to begin from a set of fundamental regularities from which some further regularity to be explained can be deduced as special case. Rather, they are more appropriately represented as a design specification for a socio-economic machine which, if implemented, should give rise to the behaviour to be explained."[220]

This understanding of the machine recalls Lewis Mumford's argument that the machine is first and foremost a form of social organization, arising from the application of knowledge to the chain of productive, disciplined mass labour under technical supervision, rather than a technological artefact abstracted from its social context.[221] Kanishka Jayasuriya notes that far from evacuating the power of the political realm and reducing 'big government', globalisation requires powerful extra-national forms of sovereignty in order to impose the *Pax Economicus* upon compliant and resistant populations. Capitalism, quite obviously, is buttressed by a system of rules and regulations that shape market environments and make possible large-scale exchange and accumulation. These rules gain their force if not their legitimacy, through the authority and power of their political authors and supporters, who operate over and above elected national governments in the global space of capital flows. The aggregated financial, trade and economic regulatory 'regimes' add up to what has been called a system of 'economic constitutionalism' which appears to be self-regulating and disciplining.[222] Michael Hudson gives ample demonstration of this in his history of the construction of the Bretton Woods system of international finance under American leadership in the wake of the WWII, a war which had destroyed the non-system of autarchies and left the United States as world creditor while nearly bankrupting all the other combatants. Hudson argues that with the establishment of the International Monetary Fund and the World Bank in 1952, a deal was struck whereby the US would provide dollars to the world through its balance-of-payments deficits, which enabled the US to obtain foreign resources through its status as provider of reserve currency, instead of parting with its own real resources. Why did other countries join the dollar bloc? Hudson quotes Leon Fraser of the First National City Bank, a former president of the Bank for International Settlements:

> "We are told that 44 nations agreed to this. I think a more exact statement would be that 3 or 4 groups of very expert chaps got together and wrote a plan and then took it up with 44 other technicians, stating 'this is what the United States and Great Britain are willing to stand for with you. [...] Of course, in the condition of the world as it was at the time of those negotiations, these fellows said, "Sure why not? They had nothing whatsoever to lose. They looked to us for their military salvation and for their economic salvation, and any proposal within human reason would in the nature of things be acceptable."[223]

Finally, it must be noted that sometimes the combined 'forces' of finance, trade, and regulatory institutions are in themselves insufficient to render operational the frictionless 'laws of economics'. One need only consider the historical idealism and faith in markets of George Bush and the neoconservative movement, an idealism backed up by the sovereign, command-and-control violence of the world's largest and most expensive military machine. Activist Naomi Klein was one of the first to analyse the economic transformation of Iraq under its new Constitution, written into law by US 'proconsul' Paul Bremer before any elections were held in Iraq. Klein argues that the radical and unilateral re-organisation of Iraq's economy represents the violent imposition of the Washington Consensus or 'structural adjustment by force'. From being an insular state run economy, Bremer overnight imposed a kind of 'shock therapy' on Iraq far more radical than the IMF delivered to Russia after the events of 1989, sacking half a million state employees, privatising all state industries and making Iraq (on paper at least) perhaps the most globalised economy in the world. Although currently the millennial dream has yet to come true, Klein explains that Iraq was intended by the Bush administration to be:

> "a gleaming showroom for laissez-faire economics, a utopia such as the world had never seen. Every policy that liberates multinational corporations to pursue their quest for profit would be put into place: a shrunken state, a flexible workforce, open borders, minimal taxes, no tariffs, no ownership restrictions. The people of Iraq would, of course, have to endure some short-term pain: assets, previously owned by the state, would have to be given up to create new opportunities for growth and investment. Jobs would have to be lost and, as foreign products flooded across the border, local businesses and family farms would, unfortunately, be unable to compete. But to the authors of this plan, these would be small

prices to pay for the economic boom that would surely explode once the proper conditions were in place"[224]

As John Ruggie has captured in his concept of "embedded liberalism", the global economy is indistinguishable from its interventionist system of institutions, including the unbalanced distribution of military power.[225] The declaration of unlimited war by the Bush Administration in the wake of both the September 11 terrorist attacks and the crash of the NASDAQ driven 'new economy' might be described as a kind of 'military Keynesianism' as it has warded off recession and the downward pressure on the US dollar by runaway deficit-financing of the partially privatised US military sector. In our contemporary milieu, Hayek's critique of utopian social engineering is best applied not to 'socialism' but to the phenomena of elite neoliberal politicians creating a global regime of lassez-faire according to the rationality of general equilibrium theory, a corporate utopia from which no national state has the right to exempt itself.

To sum up, in this section we have argued that the often violent project of instituting a self-equilibrating liberal global economic order rests on a dichotomy deriving from the Enlightenment concept of 'natural law', embedded in the application of analytical mechanics to the question of social order and harmony. The neoclassical analysis claims to describe positively how this purely natural object called the economy 'works', but also prescriptively insists on the normative requirement that welfare and justice are the necessary outcomes of this equilibrium (Pareto efficiency). We have also seen that a concept derived from the study of industrial machines (the 'energy' of proto-energetics) was more or less made equivalent to money through the metaphorical complex <value=utility=energy=price>. This metaphorical appropriation was in turn derived from another metaphorical innovation: Helmholtz's conflation of the thermodynamic engine with the labouring human body in the term *Arbeitskraft*. Finally, we have argued that as a social physics, neoclassical economics invites a particular corpus of social engineers to mobilize the state to defend the freedom of the 'laws of economics' with the sovereign coercion of the 'force of law.'

**Apocalypse Blindness: the Contradiction between Growth and Equilibrium**

The economist Joseph Schumpeter once defined imperialism as what you have "when a state evinces a purposeless propensity to expansion by force, beyond all definable limits"[226] Can states can be distinguished sufficiently from the economies that they are enmeshed with, and whose need for legal order and security they serve? If the answer is no, then the consequence of Schumpeter's definition is that all states that measure their succuss according to exponentially rising GNP are by definition both irrational in their purposeless expansion and imperialist in their application of the sovereign violence of the state to the project of infinite growth. And what is growing by this process is what Marshall earlier referred to as the "industrial organism". In what follows, we explore the contradiction of perpetual growth and automatic equilibrium in the context of the development of the global liberal economic order, and offer an alternative explanation of the machine dreams of 'industrial millennium', grounded in classical thermodynamics and the critique of machine fetishism.

I would like to return briefly to an already cited quotation from Ulrich Beck:

> "[...] the following question has been criminally rejected by the social sciences: what does the threat of self-annihilation mean to society, its institutions, its understanding of progress and itself; to the legal, scientific and economic system; to politics and culture?" [227]

In the early days of sociology, the exclusion of nature helped to mark off the discipline of sociology from competing systems of explanation such as biology and psychology, and was a useful methodological stricture that helped keep crude scientisms such as racial socio-biology or geographical determinism out of the mainstream canon. Earlier in this chapter, it was noted that Comte's original notion of sociology as the supreme science (and as the culmination of all human history no less!) was of the manner of a 'social physics'. To achieve sovereignty over all the other fields of knowledge, sociology must reveal the objective laws of society, a project that would require the grounding of sociology in the material, natural sciences. Comte's vision of a technocracy of philosopher kings called 'sociologists' may appear comic to us moderns, who know that they are affable characters but not real scientists. By comparison, the economists of the neoclassical school are without doubt the most politically powerful theorists of the academy (with the possible exception of the schools of business administration). Doors open to them in the boardroom and the cabinet room. Economists, not sociologists, are the social engineers and privileged purveyors of social knowledge in our current dispensation, and thus it is the "apocalypse blindness" of economics that requires the most urgent attention.

Neoclassical economists are the Comtean sociologists of our time: in possession of a theory of everything, and unchallengeable in their occupation of the commanding heights of their protean research object, 'the global economy'. If one lives in a 'first world' democracy, it is more than likely that that the two major parties agree wholeheartedly upon the neoliberal narrative – free markets, privatisation, deregulation, entrepreneurship, efficiency and competition. If one lives in a 'third world' country, it is likely that these priorities have been imposed upon the country by external agencies managing the countries' debt, limiting the policies of parties who are in no position to resist structural adjustment. Economists have a privileged autonomy within public discourse and the governmental apparatus in the era of neoliberal globalisation.

Increasingly the social good – presumably the object of politics – is identified as indistinguishable from 'the growth of the economy'. If we consider how many people and lifeworlds are directly affected by the policy decisions of unelected econocrats at the World Trade Organisation, the World Bank, the International Monetary Fund, and how these partially transparent institutions committed to 'development' are outweighed by far more powerful purely profit-driven private interests on Wall Street and other business districts, it is clear that grave epistemological authority has been granted to economics and international level. While perhaps few neoclassical economists would describe themselves as 'social physicists' or worse, 'social engineers', undoubtedly many are as confident in the universal applicability of their profession as Lawrence Summers, currently president of Harvard University. In 1997, in an interview with the cyber-libertarian journal *Wired* during his tenure as US Deputy Treasury Secretary, Summers asserted that:

> "The laws of economics are more like the laws of physics than many people once supposed. You can't wish them away and they don't change because of politics." [228]

Summmers here grants economics the status of a Laplacean truth machine. The idea of single natural law governing all the economic activities of the world and uniting them in the natural justice of the market is hard to argue with when phrased this way, for what fool would attempt to go against the laws of physics? Earlier still, in his role as Chief Economist of the World Bank, Summers had actively argued in a leaked internal memo for the relocation of toxic waste and polluting industry to the poor countries of the developing world (the text is reproduced in the footnote). [229] Summers claimed (in the face of widespread NGO condemnation) that the memo was merely satire. While appropriately expressing mild opprobrium, *The Economist* magazine noted that his economic reasoning was impeccable,[230] although clearly the essence of the argument can be reduced to the tautological observation that the lives of poor people are of less 'value' and thus 'utility' than those of the rich. Either way, Summers took a lot of heat for merely representing explicitly in the terminology of the dominant discourse a process that already exists globally. Here the ambiguity of the notion of 'the laws of nature' is evident: on the one hand, Summers can appeal to economics as the expression of inexorable physical laws of nature independent of fanciful human wishes. On the same basis, Summers argues, joke or otherwise, for a politically established global financial institution to actively accelerate the transfer of toxic environments to developing countries, wherefrom they can export manufactured goods back to the metropoles at cheaper prices. This process was already well underway as a result of the imposition of 'austerity measures' upon the bank's debtor nations. Later renamed Structural Adjustment Programs, these agencies of the blind 'laws of economics' were of course entirely *artificial* policies he himself argued for in the political sphere and actively administered. Where they encouraged governments to attract foreign investment by offering private corporations the most attractive lassez-faire tax and labour conditions in 'export processing zones', they led to the restriction of civil action, workers rights and the scaling back of environmental regulation. The strategy of 'export led growth' imposed upon these countries likewise ensured a stream of natural resources and agricultural products to wind up in Western markets. It should be noted that the top-down imposition of financial, fiscal and economic structures even to preferences for certain kinds of industry, transmitted from the level of supranational institutions operating over above sovereign national governments, completely reverses the order of causation in the neoclassical theory that is mobilised to justify the policy recommendations. Economics is built on the microeconomic foundations of the quotidian 'desires' of sovereign individuals, whose free and rational action supposedly results in the spontaneous emergence of macro- forms of organisation.

In an obscure text dealing with the possibilities for social control offered to by central banking and a tolerance for ever-expanding debt, Vladimir Nuri mentions in passing what I have argued must surely be the key contradiction of contemporary economic thought:

> "[...] any rational model of the economy absolutely *must* consider the *equilibrium* state one that does *not* involve growth. A century and a half of the 'dismal science' ...may be based on an evasion or defiance of that principle. It is quite possible that economics is based on a mass collective rationalization in much the same way that U.S. citizens subscribed to the vision of the 'manifest destiny' during the era of the expansion to the west. Relative to serious worldwide dangers of environmental degradation (*eg.* global warming, pollution, deforestation, *etc*), at the dawn of the 21st century the rationalization is taking on the signs of mass psychological delusions of grandeur." [italics in original][231]

These remarks encapsulate in a nutshell the incredulity toward the official metanarrative of economics that any student sobered by the intransigent realities of widening global gaps between rich and poor and mounting environmental degradation must experience when entering the *unheimlich* world of the economists. It is to the discursive maintenance of this contradiction through discourses of scientism (and to the political-economic effects of such discourses) that the main arguments of this thesis have been so far directed. One would imagine that if anything would shake the confidence of a social theory claiming to be scientific and grounded in the order of nature, committed to the reasonableness of the 'balance of nature', it would be claims from the natural sciences that the order of nature itself is radically 'out of balance' as a result of the globalisation of economic activity. The analytic fiction of general equilibrium theory was that it held constant arguably the most important factors – population, capital and technology – and excluded 'land' altogether in order to derive a self-balancing market. That this 'as-if' reasoning is necessary for 'equilibrium' in Walrasian models seems to be forgotten by Alan Greenspan, who recently observed that globalisation

> "[...] has altered the economic frameworks of both advanced and developing nations in ways that are difficult to fully comprehend. Nonetheless, the largely unregulated global markets, with some notable exceptions, appear to move smoothly from one state of equilibrium to another. Adam Smith's invisible hand remains at work on a global scale." [232]

As representatives of neoclassical policy, Summers and Greenspan appeal to this supposed balancing quality of the deregulated market as the most reliable means to ensure unceasing economic growth - presumably the expansion of population, capital and technology. The irony is more deeply compounded when we recall that what ecological economists argue is the only solution to the biospheric crisis, which we can gloss as the increasingly irreversible violation of the 'balance of nature', is a transition from perpetual growth to some kind of steady state. Herman Daly for example, argues that the most pressing legitimate task of economic science is to discover the optimal scale of the economy (as a total industrial metabolism) that can be shown to be sustainable from the point of view of the earth sciences, and then hold population and capital constant at those levels to achieve a steady state economy.[233] While such a policy would be politically impossible, this to me seems a much more sensible 'biophysical' interpretation of the equilibrium concept, satisfying the 'mass-balance' condition of the first law of thermodynamics, and the logic of 'predator – prey' balance in ecology, which simply says that a population of consumers is limited by the size of its food supply.

Prior to the Second World War, economists as policymakers were largely concerned with bringing the wild boom and bust business cycle under stabilisation. Reflecting a myopia opposite to the farsightedness conferred upon their rationally maximising 'representative agent', economists have rarely concerned themselves with the long-term consequences or horizons of growth. Prior to WWII, even as sophisticated an economic thinker as John Maynard Keynes tended to think of economic growth as a short-term phenomena, neither enduring nor important. He expected economic growth in the industrial countries to cease within two or three generations at most, arriving at a plateau of consumption (called 'bliss' in the that period's literature) as the declining marginal utility of consumption approached zero.[234] A key instrument of social technology was developed in this era and applied to society at large, an informatic tool of the '*tableau entière*' with which the productivist state continues rationalises its decisions regarding the great machine of the national economy. I am referring to what Alan Greenspan referred to in 1999 as 'one of the great inventions of the 20th century', the system of national accounts developed by Simon Kuznets.[235] First designed in the 1930's, in response to the economic crisis of the Great Depression, the development of national accounts was a major project driven by the planning needs of the total war economy of World War II. The need to rationalise society for the maximum output of war materiel was the impetus behind the development of production estimates (Gross National Product). By the mid-1940's, the accounts had evolved into a consolidated set of income and product accounts, a model which generated an "an integrated birds-eye view of the economy." [236] Despite the normal ubiquity of the growth fetish in our day, maintaining growth became the central concern of applied economics only in the post-war period. Though Kuznets himself stridently refused to accept GDP as a measure of welfare or progress, it has been taken as exactly that, to the point where it is the ground zero of political measurement, ranking all nations according to the scale of less-developed, developing and advanced. While countries with high per capita GDP do have on the whole a high standard of living, the problems of GNP, which measures only the money value of sales of goods and services realised annually inside a nation's borders, are well known, and needn't be rehearsed here.[237] What is more interesting to our narrative is how the proto-energetic ontology of equilibrium analysis accommodated the newfound vocation of economics as a science of 'growth' and 'development' in the post-war era, particularly as the re-consolidation of neoclassical intellectual hegemony coincides historically with the emergence of the discourse of environmental crisis in the 1970s.

As we have seen, the Walrasian model of the economy, which focussed exclusively upon defining the mathematical preconditions for the theoretical existence of an invisible balancing hand, is fundamentally static. The basic model was to be much upgraded by arch-cyborg John von Neumann in 1932, although his classic multi-sector growth model was only published in English in 1945. Despite its influence upon the upper echelons of the mathematical economics academy, and its increased complexity, the model suffered from much the same drawbacks. Growth occurred only homothetically – that is smoothly, continuously and with all sectors expanding at exactly at the same rate. Moreover, the model ruled out technological change and resource depletion, as it specified a closed system in which there were a fixed number of processes and all sectoral outputs were produced by combinations of inputs from other sectors.[238] Later models, including those developed by Robert Solow (his first, developed in his article *A Contribution to the Theory of Economic Growth* (1956) won him the 1987 Sveriges Riksbank Prize in 'Economic Sciences' in Memory of Alfred Nobel), are more flexible in their portrayal of technology and open to empirical time-series data from capital markets. Nevertheless, they repeat the same sins against ecology and the laws of thermodynamics by essentially assuming that nature is infinitely expandable, infinitely convertible (or at least infinitely substitutable) and infinitely pollutable. In his earlier models, Solow presented natural resources as completely substitutable for capital or labour. In later models, some natural resources were required, but the amount of 'growth' that could be accomplished with some unspecified initial quantity was again unlimited. Herman Daly has compared this to a chef who, in order to increase the number of cakes generated by a favoured recipe, does not order more eggs, butter and flour, but hires a kitchen hand, stirs the mixing bowl faster and increases the size of the baking tray.[239]

The theorist of economic methodology Mark Blaug, has had this to say about growth theory:

> "Consider, for example, the preoccupation since 1945 of some of the best brains in modern economies with the esoterica of growth theory, when even practitioners of the art admit that modern growth theory is not yet capable of casting any light on actual economies growing over time. The essence of modern growth theory is simple old-style stationary state analysis in which an element of compound growth is introduced by adding factor-augmenting technical change and exogenous increases in labour supply to an otherwise static, one-period general equilibrium model of the economy. In view of the enormous difficulty in handling anything but steady-state growth (equiproportionate increase in all the relevant economic variables), the literature has been almost solely taken up with arid brain-twisters about 'golden-rules' of capital accumulation."[240]

In 1932, Lionel Robbins gave the following textbook definition of the 'nature of economic science', which has become textbook standard: "economics is concerned with that aspect of behaviour that which arises from the scarcity of means to achieve given ends. [...] What the ends are is rather unimportant to the economist - he is more concerned with how a person chooses between scarce alternatives." [241] To gain some insight into what was different about the neoclassical growth literature, we can note from what follows that a new assumption has been added to the traditional list of perfect foresight, perfect information, perfect competition, rational maximisation of fixed preferences:

> "[..] the objective of the 'representative agent' (Oikos Nomos) is to maximize utility over an infinite horizon. Let us suppose that the utility function at any time $t$ is hedonistically defined as a positive function of consumption per capita at time $t$, $U(c_t)$. Given an infinite horizon and continuous time, consumption will thus be infinite and continuous." [242]

In the post-war period 'scarcity' was quietly abolished as a fundamental constraint upon economies. Exemplary of the condition of the applied social sciences when ecology began to be a site of economic critique, is Walt Whitman Rostow's *Stages of Economic Growth: a non-Communist Manifesto* (1961), the classical example of the development genre.[243] In this work, Rostow employs what is essentially an organismic metaphor for industrialisation, arguing that all national economies can reproduce the pattern of industrialisation experienced by Western Europe and North America. 'The economy' is presented ontogenetically, that is, as going through several pre-determined 'stages of growth' resembling the organism's genetically programmed pathway from embryo to maturity. Seeing the problem of national development as beginning with a *tabula rasa,* Rostow explains poverty as the ideological obstruction of traditional culture to the transition to a 'Newtonian' view of nature. 'Traditional society', agriculture and socio-economic organisation is thus fundamentally confined by pre-modern visions of nature to "limited production functions." [244] The realisation that nature is knowable according to "a few simple laws", he argues, allows the systemic manipulation and transformation of nature in the direction of progress. Thus he associates 'Newtonianism' by implication with 'unlimited production functions'. Rostow saw the universal goal of all national development as the achievement of "high mass consumption", an economy of cornucopian consumer abundance similar to that realised in the United States for the first time ever in the 1950s. He argued that this historical process could be engineered by policies favourable to capitalisation and industrial development. Where Rostow departs from his implicit metaphor of the industrial 'organism' is that the final 'mature' state of an economy is not an end to growth, nor a transition to the maintenance of the body's integrity in the face of inevitable senescence and death. In the mature Rostovian economy, "growth is the normal condition."[245]

Against the zero-sum model of dependency and post-colonial theory, which argued that concentrations of wealth in the 'advanced' nations reflected more or less concentrations of poverty in the underdeveloped world mediated by unequal relations of exchange, modernisation theorists saw perpetual growth as the historical destiny available to all nations willing to embrace a "Newtonian" view of social relations and of nature. Two years after Rostow's essay, and only a decade before the *Limits to Growth* report, an economic inquiry into the burgeoning resource demands of US industry by Barnett and Morse returned the following reassuring verdict on the relationship between *Scarcity and Growth* (1963):

> "Advances in fundamental science have made it possible to take advantage of the uniformity of matter/energy, a uniformity that makes it feasible *without preassignable limit* to escape the quantitative constraints imposed by the character of the earths crust." [my italics] [246]

While this does nothing to reassure us of the unlimited availability of fertile soil, tropical timber, and fisheries, at least in the mining sector it was thought that science had simply banished scarcity. Here the topsy-turvy world of the Walrasian equilibrium, where the heterogenous qualities of life and non-life, of the natural and artificial are illusory manifestations of the 'uniformity of matter/energy', where technology 'produces' resources can be seen reified directly into human environment relations. No doubt this optimism was bolstered by the early 1960s faith in the 'peaceful atom'. What was utopian about the neoclassical model was its proto-energetic assumption of absolute convertibility and the Providential distributional justice of the frictionless market price. Remember that, strictly speaking, the metaphorical appropriation of the conservation principle of the first law of thermodynamics implied there could be no 'creation' in production, only conversion. For the assumption of balance to work, the value substance could neither be created nor destroyed. With Rostow, Barnett and Morse, however, the utopianism of the proto-energetics metaphor hidden in their neoclassical ontology of production knows no bounds. Even if the earth were made entirely of a fixed quantity of lead there would be no limit on the amount of gold that fundamental science could be produced from it? Growth economics begins to look like alchemy. In response to this technological optimism, it is sufficient to ask why we do not mine the oceans for uranium, which is present in infinitesimal quantities in sea water. Obviously, the exergy expended in trying to concentrate useful amounts of exergy-yielding uranium would make it an impossibly 'diseconomic' venture.

Rostow's view of the malleability of nature exposed to predictive scientific calculation and modern technology, derived from his economy of nature, was also into his understanding of political economy and historical change. According to John K. Galbraith, another of the 'best and the brightest' assembled by the Kennedy Administration, Rostow in his role as political advisor to war planner Robert MacNamara advocated the systematic bombing of the Vietnamese countryside on the view that this would lead to migration to towns and cities. Reminiscent of the approach of the British to the Irish famine, he argued that this evacuation of the 'low-value' subsistence agriculture sector would provide a cheap urban labour force, which in turn would trigger the crucial stages of industrial modernisation, without the erroneous diversion through Marxist-Leninism.[247] When the obscene policy of carpet-bombing was actually applied to the farms of Cambodia, where nearly 2.8 million tons of ordnance were dropped (the Allies are thought to have used 2 million tons in the Second World War) it yielded only the auto-genocidal year-zero "communism" of an agrarian population totally traumatised into the absolute rejection of modernity.[248] Ironically, it is usually only the Marxists who are remembered as the utopians and the historical determinists of the period. McNamara later served a dignified stint as the chair of the World Bank, presiding over the first decades of development aid, and issuing the initial debts to which many nations remain in thrall generations later. These loans were made to provide the initial 'savings' that neoclassical theory then saw as the key driver of economic growth (capitalisation in industry), in order to place the nation a stage or two higher on Rostow's ladder of industrial development, to the point where national economic growth become a self-reinforcing process such that growth rates would easily outstrip the interest on the 'development loan' and allow the loan to be repaid. This alarming contradiction between the imperatives of the 'free' market and violent social engineering would be less so if it were safely confined to the dustbin of history.

On the fall of the Soviet Union in 1989, Francis Fukuyama argued optimistically that the impending globalisation of liberal democratic capitalism would bring more or less universal peace and general prosperity. Winston Churchill once described popular democracy is the worst system except for all the others, and while few humanists would disagree with this – what is troubling in Fukuyama's view of liberal capitalism is his underlying ontology of human-environment relationships. Glossing over the polarisation of wealth and poverty across the global North-South divide, the pure politics of structural adjustment and financial dependency, he located the origins of wealth and freedom in economic science and technology:

> "[...] modern natural science establishes a uniform horizon of economic production possibilities. Technology makes possible the *limitless* accumulation of wealth, and thus the satisfaction of an ever-expanding set of human desires. [...] the logic of modern natural science would seem to dictate a universal evolution in the direction of capitalism." [my italics] [249]

The obvious question would be why does everyone not drive a Mercedes SUV made of gold, or live by the seaside, or eat sashimi tuna three times a day? At the core of Fukuayama's argument was the notion that liberalism as an ideological system was free from internal contradictions, and yet his appeal to modern natural science seems to contradict completely the first and second law of thermodynamics. It also suggests his innocence of any knowledge of ecological history, geography, or, as the Club of Rome would say of 'the simple fact that the earth is finite.' As far as I can gather, the only discourse where infinity is contemplated with any seriousness is in cosmological physics, pure mathematics, and theology, all of which has little to do with the immediate facts of life for mortal, embodied creatures trying to make a living – although it seems that Fukuyama's economics has elective affinities with the former group of arcane pursuits. 'Wealth' is removed entirely from any biological, geographical or physical referent and located in boundless technological wish-fulfilment. Perhaps Fukuyama is using a definition of science suitable to his Hegelian idealism, which requires one to believe that "consciousness will ultimately remake the world in its own image."[250] To the extent that the powerful of the world are able to impose their favoured metaphor upon what counts as legitimate political discourse, he may correct. Here, Fukuyama has taken his transcendental secular millennialism, grafted it onto an erroneous view of evolution as Progress, and inferred the naturalness of capitalism. Consumer societies are wealthy not because they have monopolized oil consumption, or successfully expanded their ecological footprint through advantageous financial arrangements, but simply because of the ideological virtue of their superior social system and their 'know how'. In Fukuyama's world, the billion hungry people wandering the dusty slums of the global South remain outside the post-historical world of consumerism precisely because they have the wrong Ideas.

Fukuyama is admittedly an easy target, but only because he has stated explicitly the assumptions necessary to accept the legitimacy of the order he represents. Not an obscure academic, Fukuyama was one of the intellectuals behind the Project for a New American Century – a neoconservative group on the right of US politics who argued in the Clinton years for a 'neo-Reaganite' foreign policy of military hegemony and unilateral American leadership. Many of the signatories of this document went on to assume key positions in the Bush administration in 2001. If the history of development economics occurred first as tragedy in Macnamara's Vietnam, it was repeated as farce with the appointment of Paul Wolfowitz, an architect of the 'liberation' and 'liberalisation' of Iraq, to the Chair of the World Bank upon retirement from his work at the Whitehouse.

## Conclusion

Since Smith, it might be said, we have been living in the Age of Economics. The fundamental flaw of all the economics derived from the classical focus on the dynamics of exchange is its neglect of the depletion of natural resources in production, and the limited resilience of ecosystems to disturbance. This blindspot has encouraged the kind of extreme optimism exemplified by Engels, who wrote: "the productivity of land can be *infinitely* increased by the application of capital, labour and science." [my italics][251] Although Engels had perhaps reasonable excuses to be ignorant of the now global problems of the loss of biological abundance and diversity, deforestation, soil erosion, desertification, depletion of fisheries, and the many artificial side-effects of industrialism, current champions of infinite growth do not.

As much as with the exponential consumption of fossil energy, the continuing polarisation of wealth within and between nations in the last thirty years of neoliberal globalisation suggests that the widening discrepancy in the exchange value of human life can be correlated with the acceleration of 'economic growth'. Since Rostow, these disparities have been presented as temporary features of the historical process in the debt-financed economics of industrial development – wealth would one day trickle down – because the future of all nations that followed the Newtonian star of industrialisation was a "state of high mass consumption" where "growth is the normal condition", and "compound interest becomes built [...] into habits and institutional structure."[252] This suggests that the fetishistic view of thermodynamic machines as independently 'fertile' in modern discourse is connected to the fetishism of money: after all, both industrial machines and abstract financial wealth are ambiguously referred to as 'capital', in turn defined as 'that which will yield more capital in the future'. It might appear that money in a bank account can increase infinitely; after all it is only digital information. The logic of compound interest over time, when anchored to a physical indice such as the gold standard, yields utterly implausible outcomes. According to the calculations of Heinrich Haussman, one Deutsch *pfennig* (trading at about half a US cent at the time) invested from the year 0 AD at five percent compound interest, would by 1990 have yielded a volume of gold bullion equivalent to 134 billion times the weight of the earth. [253] The need to repay debt out of future earnings is fine if growth is perpetual, but to the extent growth depends on depletion, today's credit binge risks emptying the bank of 'natural capital' should Nature, as the insurer of last resort, fail to cover all these claims.

These illogical contradictions at the heart of contemporary politics can to some extent be traced to the central metaphor of economics: <energy=utility=value=price>. It would, however, be a profoundly Cartesian mistake to simply believe that the damage of this metaphor can be undone by insisting that money is symbolic and thus illusory, and that energy is material and thus real. Money, energy, work, machines, power and human value are linked in an impenetrable ontological thicket of metaphors that cannot be simply disposed of, as they are inherent in our everyday conceptual categories, as well as being built into our machines and institutions of exchange. Recall that according to Fenyman, physicists still don't know what energy actually *is*; only that it is a conserved quantity evident in all mathematical descriptions of natural phenomena involving exchange and transformation. The implications of the following comment made a lifetime ago by Frederick Soddy are still with us today, and increasingly urgent:

> "Energy, someone may say, is a mere abstraction, a mere term, not a real thing. As you will. In this, as in many other respects, it is like an abstraction that nobody would deny reality, and that abstraction is wealth. Wealth is the power of purchasing, as energy is the power of working. I cannot show you energy, only its effects.... Abstraction or not energy is as real as wealth – I am not sure that they are not two aspects of the same thing."[254]

The questions raised by this observation have only been touched on here, and our history of the relationship of economics to nature has neglected to deal with nature as biological life. In the next half of the thesis we will discover that these questions of energy have also been central to the disciplinary history of ecology as it matured as a science and announced the industrial apocalypse in the early 1970s.

Looking back, it seems that as prophesies of ecological apocalypse loomed in the early 1970s, an existential space opened up where capitalism as such was open to question. At the 1972 United Nations conference in Stockholm, it was widely argued that far from carrying a 'technological cross' for the underdeveloped countries, developed countries were building their development upon the impoverishment of the Third World. Since the Brundtland report of 1987, and the subsequent World Commission on Environment and Development at Rio in 1992 and Johannesburg in 2002, the consensus has been established that there is no contradiction between economic growth and global sustainability.[255] Even though we now have plenty of discussion of 'sustainability', fully functioning state institutions regulating specific ecological risks, and an entire industry of 'green' advertising and triple-bottom-line accounting, the general question of infinite growth as been culturally quarantined from discussions of ecological questions. For example, Nicholas Stern's recent report on 'the economics of climate change' has been seen as a major breakthrough in a year that saw outright denial as no longer 'one side of the debate' but beyond the pale of legitimate discourse. Describing global warming as 'the biggest market failure the world has ever seen' was shocking language in the age of the neoliberal consensus, but Sterns' revelation that runaway climate change left untreated might "damage economic growth" seems to have clinched the argument for many a mainstream economist. "Tackling climate change is the pro-growth strategy for the longer term" says the report, "and it can be done in such a way that does not cap the aspirations for growth of poor or rich countries." [256] The solution is to apply the power of markets to correct the market failure by trading pollution permits to reduce carbon emissions. Here even the threats of a radically unstable climate (biodiversity crashes, the flooding of major cities, major threats to agriculture, decline in the availability of fresh water and major flows of environmental refugees) are mobilized to secure our faith in unceasing growth. Even as nature is rendered radically unstable by economic activity, the auto-equilibrating growth economy remains a timeless, natural condition. The apocalyptic horizon of environmental reform is perpetually deferred to the future and imposed upon future generations.

The radicalism of the 1970s was embedded in a hope that human beings could avert apocalypse, and progress intellectually, politically and morally. Since then, progress has been reduced to promises that the gods of the market will bring more economic growth. The following comments, made on the cusp of the neoliberal revolution in 1972 in an address to the American Economics Association by its then president J.K Galbraith, would be quite unthinkable in that forum today:

> "The most commonplace features of neoclassical and neo-Keynesian economics [i.e. the American Keynesianism made to fit neoclassical microeconomics] are the assumptions by which power, and therewith political content, is removed from the subject [...] If the state is the executive committee of the great corporation and the planning system, it is partly because neoclassical economics is its instrument for neutralising suspicion that this is so. I have spoken of the emancipation of the state from economic interest. For the economist there can be no doubt where this begins. It is with the emancipation of economic belief."[257]

Here we return to our original postulate, suggesting that the faith of contemporary economics in infinite growth, despite all its hollow appropriations of physics, is ultimately a metaphysical faith that recapitulates in secular form the temporal structure of the transcendent eschatologies inherited from Christian apocalyptic. The social engineers of the neoliberal revolution, responding to the crisis of limits in the early 1970s and ascending to the height of supra-national economic power in the age of globalisation, recall with only a small stretch of the imagination the description given by Cohn of the *prophetae* of the 16th century Peasant Wars in his *Pursuit of the Millennium:*

"[…] with the conviction of its own infallibility, [this group] set itself above the rest of humanity and recognized no claims save that of its own supposed mission . . . A boundless, millennial promise made with boundless, prophet-like conviction to a number of rootless and desperate men in the midst of a society where traditional norms and relationships were disintegrating."[258]

Of course, this time around, the millennialists occupy the thrones of global power, and it is the biosphere itself that is threatened with disintegration.

**Part II Endnotes**

[1] From an original photograph posted on the Internet by: Mark Wilson, 'World's Largest Digger: Digs, Potentially Destroys World', 18 November 2006. <http://gizmodo.com/gadgets/krupps/worlds-largest-digger-digs-potentially-destroys-world-215801.php>
[2] James Joyce, *Ulysses*, Penguin Books, London, 1992 [1922], p. 42.
[3] Clive Hamilton, *Growth Fetish*, Allen and Unwin, Sydney, 2003, p. 3.
[4] Alex Buzo, *Meet the New Class*, Angus and Robertson, 1981, p. 56.
[5] Cited in Hamilton, 2003, p. 3.
[6] Ulrich Beck, *Ecological Politics in an Age of Risk*, Polity Press, Cambridge, 1995.
[7] Beck, *Ecological Politics in an Age of Risk*, p.82
[8] Or at least according to a highly suspect 'think-tank' that quotes Al Gore without citing him. See: The Thoreau Institute, 'FAQS on Free Market Environmentalism', 2006. <http://www.ti.org/faqs.html>
[9] Hans Blumenberg, *The Legitimacy of the Modern Age*, Cambridge, MIT Press, 1983, p. 83.
[10] John M. Bozeman, 'Technological Millenarianism in the United States' in *Millennium, Messiahs and Mayhem: Contemporary Apocalyptic Movements*, (eds.) T. Robbins, and S. Palmer, Routledge, New York and London, 1997, pp. 139-158.
[11] David E. Nye, *American Technological Sublime*, MIT Press, Cambridge, London, pp. 222-257.
[12] Nye, *American Technological Sublime*, p. xiii.
[13] Gordon Bigelow, 'Let There Be Markets', *Harper's Magazine*, vol. 310, May 2005.
[14] Richard Landes, 'Lest the Millennium Should Be Fulfilled: Apocalyptic Expectations and the Pattern of Western Chronography, 100 – 800', in *The Use and Abuse of Eschatology in the Middle Ages*, eds. W. Verbeke, D. Verhelst, and A. Welkenheysen, Leuven, Leuven University Press, 1988, p. 206.
[15] Malcolm Bull, 'On Making Ends Meet' in *Apocalypse Theory and the Ends of the World*, (ed.) Malcolm Bull, Blackwell Publishers, UK, 1995, p. 3.
[16] Norman Cohn, *The Pursuit of the Millennium: Revolutionary Millenarians and Mystical Anarchists of the Middle Ages and its Bearing on Modern Totalitarian Movements*, Secker & Warburg, London, 1961.
[17] Cohn, *The Pursuit of the Millennium*, p. 69.
[18] Karl Popper, *The Poverty of Historicism*, Routledge, London, [1957] 2002.
[19] Erik Davis, *Techgnosis: Myth, Magic, and Mysticism in the Age of Information*, New York, Harmony Books, 1998, p. 258.
[20] Davis, *Techgnosis*, p. 257.
[21] Davis, *Techgnosis*, p. 258.
[22] Paul Rabinow, *Anthropos Today: Reflections on Modern Equipment*, Princeton, N.J. Princeton University Press, 2003, p.59.
[23] Rabinow, *Anthropos Today*, p.59
[24] Michael Ortiz Hill, 'Mine Eyes Have Seen the Glory: Bush's Armageddon Revisited', *CounterPunch*, January 4, 2003. <http://www.counterpunch.org/hill01042003.html>

[25] Cited in William T. Cavanaugh, 'A Fire Strong Enough to Consume the House: the Wars of Religion and the Rise of the State', *Modern Theology*, vol. 11, no 4, p. 397.
[26] Cavanaugh, 'A Fire Strong Enough to Consume the House', p. 397.
[27] John Figgis cited in Cavanaugh, 'A Fire Strong Enough to Consume the House', p. 397.
[28] Rabinow, *Anthropos Today*, p. 59
[29] Cited in Bull, *Seeing Things Hidden*, p. 122
[30] Krishan Kumar, *Prophecy and Progress: The Sociology of Industrial and Post-Industrial Society*, Penguin, Hammondsworth UK, 1978
[31] Dorothy Ross, *The Origins of American Social Science*, Cambridge University Press, Melbourne, 1991, p. 3.
[32] Kumar, *Prophecy and Progress*, p. 45.
[33] Karl Lowitt, *Meaning in History*, Chicago, 1949, p54. Cited in Malcolm Bull, *Seeing Things Hidden: Apocalypse, Vision and Totality*, Verso, London, 1999, p. 116.
[34] Bull, *Seeing Things Hidden*, p. 116.
[35] Immanuel Kant, 'On History' (1784), trans. Lewis White Beck, published as 'Idea for a Universal History from a Cosmopolitan Point of View', Bobbs-Merrill Co., 1963.
[36] Karl Lowith, *From Hegel to Nietzsche*, London, 1965, p.35.
[37] Bull, *Seeing Things Hidden*, p. 65.
[38] Davis, *Techgnosis*, p. 259
[39] David Noble, *The Religion of Technology: the Divinity of Man and the Spirit of Invention*, Alfred A. Knopf, New York, 1997.
[40] Kumar, *Prophecy and Progress*, p. 46.
[41] Kumar, *Prophecy and Progress*, pp. 78 – 83.
[42] Karl Popper, 'The High Tide of Prophecy: Hegel, Marx and the Aftermath', vol. 2 of *The Open Society and its Enemies*, 1945
[43] Stephen Lilley, *Men, Machines and History: The Story of Tools and Machines in Relation to Social Progress*, Lewis and Wishart, London, 1965, p. 331, 336.
[44] Michel Foucault, *Society Must Be Defended: Lectures at the Collége de France, 1975-76*, trans. David Macey, Allen Lane, London, 2003, pp. 242-43.
[45] David Sills, 'Natural Law', *International Encyclopedia of the Social Sciences*, Macmillan Company, New York, 1968.
[46] Zygmunt Bauman, *Intimations of Postmodernity*, Routledge, London, 1992.
[47] For this reason, to speak of the solar system as a 'Newtonian machine', is quite incorrect because no one has ever designed or built a Newtonian machine. It is rather a 'system' in that it can be described with a system of equations.
[48] Peter Rowlands, 'What if? 1684, the Difficult One', *New Scientist*, 20 August 2005, p. 37.
[49] Reinhardt Koselleck, *Futures Past: on the Semantics of Historical Time*, trans. Keith Tribe, MIT Press, Cambridge Ma, 1985, p. 10.
[50] Cited in Eugen Weber, *Apocalypses: Prophecies, Cults and Millennial Beliefs through the Ages*, Pimlico, London, 1999, p. 96.
[51] Weber, *Apocalypses*, p. 97.
[52] James Fieser and Bradley Dowden, 'Laws of Nature', *Internet Encyclopedia of Philosophy*, 2007. <http://www.iep.utm.edu/l/lawofnat.htm>
[53] Jean Stewart and Jonathan Kemp (eds.), 'Conversation between D'Alembert and Diderot' (1769) from *Diderot, Interpreter of Nature*, International Publishers, 1943. <http://www.marxists.org/reference/archive/diderot/1769/conversation.htm>
[54] Bernard-Pierre Lecuyer,. 'Probabilistic Thinking', in *The Natural Sciences and the Social Sciences: Some Critical and Historical Perspectives*, (ed.) I. B. Cohen, Kluwer Academic, Dordrecht, 1994, p. 141.
[55] Larry Coser, *Masters of Sociological Thought: Ideas in Social and Historical Context*, Harcourt Brace, New York, 1977, p. 11-12.
[56] Coser, *Masters of Sociological Thought*, p. 12.
[57] Cited in Karl Popper, *The Poverty of Historicism*, Routledge, London, [1957] 2002, p.141.
[58] Donald Worster, *Nature's Economy: The Roots of Ecology*, Sierra Club Books, San Francisco, 1977, p. 130.
[59] Alvin Toffler, *The Third Wave*, Bantam Books, New York, 1981.

[60] David S. Nash, 'The Failed and Postponed Millennium: Secular Millennialism Since the Enlightenment' *Journal of Religious History*, vol. 24, No. 1, February 2000, p.79.
[61] Cited in Ilya Prigogine and Isabelle Stengers, *Order out of Chaos: Man's New Dialogue with Nature.* Heinemann, London, 1984, p. 292.
[62] Cited in Mirowski, *More Heat than Light*, p. 27.
[63] Ilya Prigogine, panel discussion on the topic of 'The Chaotic Universe', in *Art Meets Science and Spirituality in a Changing Economy,* (ed.) Louwrien Wijers, Academy Editions, London, 1996, p. 95.
[64] Ilya Prigogine and Isabelle Stengers, *Order out of Chaos: Man's New Dialogue with Nature,* Heinemann, London, 1984, pp. 74-76.
[65] Kenneth Arrow, 'General Equilibrium', *Collected Papers*, vol. 2, Blackwell, Oxford, 1983.
[66] Keith Baker, *Condorcet: from Natural Philosophy to Social Mathematics*, University of Chicago Press, Chicago, 1975.
[67] And also to Mirowski, whose adaptation of Borges I have adapted. Jorge Louis Borges, 'The Fearful Sphere of Pascal', in *Labyrinths: Selected Stories and Other Writings*, (ed.) J.W Donald, 1962; Philip Mirowski, *More Heat than Light: Economics as Social Physics: Physics as Nature's Economics*, Cambridge University Press, Cambridge, 1989, p. 1.
[68] Paul Ormerod, *The Death of Economics*, St. Martins Press, New York, 1994, p. 37.
[69] Michael Adas, *Machines as the Measure of Men: Science, Technology, and Ideologies of Western Dominance,* Cornell University Press, 1989.
[70] Alfred Marshall, *Principles of Economics*, vol. 1, Macmillan for the Royal Economic Society, London, 1961, pp. 773-4.
[71] Hermann Haken, Anders Karlqvist and Uno Svedin (eds.) *The Machine as Metaphor and Tool*, Springer Verlag, Berlin, 1993, p. 5.
[72] Simon Schama, *Landscape and Memory,* Fontana Press, London, 1995, p.10.
[73] Martin Heidegger, 'The Age of the World Picture' in *The Question Concerning Technology*, New York, 1977, p. 130.
[74] Cited in Malcolm Bull, *Seeing Things Hidden: Apocalypse, Vision and Totality,* Verso, London, 1999, p. 172.
[75] Otto Mayr, *Authority, Liberty and Automatic Machinery in Early Modern Europe,* John Hopkins University Press, Baltimore, MA, 1986, p.119.
[76] Mayr, *Authority, Liberty and Automatic Machinery,* p. 119.
[77] Descartes, *Principia Philosphiae*, [1631], cited in Mayr, *Authority, Liberty and Automatic Machinery,* p. 62.
[78] Mayr, *Authority, Liberty and Automatic Machinery,* pp. 54-55.
[79] Robert Boyle, *The Excellency of Theology Compared with Natural Philosophy,* [1665], cited in Mayr, *Authority, Liberty and Automatic Machinery,* p. 55.
[80] John Trenchard, *An Argument Shewing That A Standing Army Is Inconsistent With A Free Government* [1697], cited by David Wootton, 'Liberty, Metaphor, and Mechanism: Checks and Balances and the Origins of Modern Constitutionalism. Viewed 23/11/05. <www.constitution.org/lg/check_bal.doc>
[81] Mayr, *Authority, Liberty and Automatic Machinery,* p. 163.
[82] Cited in I.B. Cohen, 'Analysis of Interactions', in *The Natural Sciences and the Social Sciences: Some Critical and Historical Perspectives,* (ed.) I. B. Cohen, Kluwer Academic, Dordrecht, 1994, p. 61.
[83] Woodrow Wilson, *Constitutional Government in the United States,* Columbia University Press, 1908.
[84] Cohen, 'Analysis of Interactions', p. 61.
[85] Cohen, 'Analysis of Interactions', p. 61.
[86] Donald Worster, *Nature's Economy: the Roots of Ecology,* Cambridge University Press, New York, 1977.
[87] Susan Buck-Morss, 'Envisioning Capital: Political Economy on Display' in *Visual Display: Culture Beyond Appearances,* (eds.) Lynne Cooke and Peter Wollen, Bay Press, Seattle, 1995, p. 116.
[88] Arjo Klamer and Thomas Leonard, 'So What's an Economic Metaphor?', in *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* (ed.) Philip Mirowski, Cambridge University Press, Cambridge and New York, 1994, p.31.
[89] Buck-Morss, 'Envisioning Capital', p. 118-199.
[90] Cited in Ingrao and Israel, *The Invisible Hand*, p. 43.
[91] Buck-Morss, 'Envisioning Capital', p. 118-199.
[92] Abhijit Banerjee, 'Inside the Machine: Towards a New Development Economics', *Boston Review*, vol. 32, no. 2, 2007, pp. 12.

93 Melinda Cooper, 'On The Brink: From Mutual Deterrence To Uncontrollable War', *Contretemps*, vol. 4, 2004, pp. 2-18.
94 Adam Smith, *The Theory of Moral Sentiments*, (eds.) D. D. Raphael and A. L. Macfie, Indianapolis, Liberty Fund, 1976, p. 31
95 Otto Mayr, *Authority, Liberty and Automatic Machinery in Early Modern Europe,* John Hopkins University Press, Baltimore, 1986.
96 David Wootton, 'Liberty, Metaphor, and Mechanism: "Checks and balances" and the Origins of Modern Constitutionalism,' 2003. <http://www.constitution.org/lg/check_bal.htm>.
97 Wikipedia contributors, 'Watt steam governor', 2006. <http:/en.wikipedia.org/wiki/Watt_governor>
98 Mayr, *Authority, Liberty and Automatic Machinery*, p. 139.
99 Ilya Prigogine, Gregoire Nicolas and A. Bablyoantz, 'Thermodynamics of Evolution', *Physics Today*, vol 23, no. 11/12, November/December 1972, pp. 22-28 (Nov.) and 38-44 (Dec.).
100 Alf Hornborg, *The Power of the Machine: Global Inequalities of Economy, Technology and Environment,* Altamira Press, Walnut Creek, 2001.
101 Wootton, 'Liberty, Metaphor, and Mechanism'.
102 Ludwig von Mises, *Human Action*, Auburn, Alabama, [1949] 1998, p. 1.
103 Jerry Desmond, *Desmond's Concise History of Ireland*, 1998, <http://members.tripod.com/~JerryDesmond/index-2.html>
104 Gordon Bigelow, 'Let There Be Markets', *Harper's Magazine*, vol. 310, no. 1860, May 2005.
105 Bigelow, 'Let There Be Markets', p. 6.
106 Bigelow, 'Let There Be Markets', p. 9.
107 Mike Davis, *Late Victorian Holocausts: El Nino Famines and the Making of the Third World,* Verso, London, 2001.
108 Lawrence James, *Raj: The Making and Unmaking of British India,* Little, Brown and Co., London, 1998, p. 304.
109 James, *Raj: The Making and Unmaking of British India*, p.306.
102
110 Vandana Shiva, 'How Free is Free India?' *Resurgence*, June 1997. <www.resurgence.org/resurgence/articles/shiva_jun97.html>
111 This loss of scientific face perhaps tarnished another of his physical correlations, *The Coal Question,* in which he argued that British military, commercial and industrial pre-eminence relied almost entirely upon the unrepeatable consumption of the nations coal resources. Philip Mirowski, 'Macroeconomic Instability and the 'Natural' Economic Process in Early Neoclassical Economics', *Journal of Economic History*, vol. 44, no. 2, pp. 345-354.
112 Richard Cobden, 'Free Trade with All Nations', speech given at Manchester, England on the 15 January 1846. <http://www.cooperativeindividualism.org/cobdenonfreetrade.html>
113 At the time of publication, the design of the website had changed and Cobden's speech is now absent. The Hudson Institute, 2004. <www.hudsoninstitute.org>.
114 SourceWatch, entry on 'Hudson Institute', 2007. <http://www.sourcewatch.org/index.php?title=Hudson_Institute>
115 Friedreich Nietzsche, *Twilight of the Idols,* trans. Duncan Large, Oxford University Press, Oxford, vol. I, [1888] 1998, p.12.
116 Henry Adams, *The Education of Henry Adams: An Autobiography*, Boston and New York, 1918, pp. 494. Cited in Bell, 1976, p. 79.
117 Cited in Daniel Bell, *The Coming of Postindustrial Society,* Heinemann, London, 1974, p. 344.
118 Popper, *The Poverty of Historicism*, p.1.
119 Popper, *The Poverty of Historicism*, p.54n.
120 Philip Mirowski, *Against Mechanism, Protecting Economics from Science,* Rowman and Littlefield, Totowa, New Jersey, 1988, p. 5.
121 Margaret Shabas, 'The Greyhound and the Mastiff', in *Natural Images in Economic Thought,* (ed.) P. Mirowski, Cambridge University Press, New York, p.329 –330.
122 See for example Marina Fischer-Kowalski and Walter Hüttler, 'Society's Metabolism: Review of the Intellectual History of Materials Flow Analysis Part II 1970 - 1998', *Journal of Industrial Ecology*, no. 30, 1998, pp. 107-136.
123 I am indebted for this image to Alf Hornborg, *The Power of the Machine*, Altimira Press, p. 28.
124 Bigelow, 'Let There Be Markets', p. 1.

[125] Susan Buck-Morss, 'Envisioning Capital: Political Economy on Display' in Lynne Cooke and Peter Wollen (eds.), *Visual Display: Culture Beyond Appearances,* Bay Press, Seattle, 1995, p. 134.
[126] Bernard Cohen, 'Newton and the Social Sciences, with Special Reference to Economics, or, the Case of the Missing Paradigm' in *Natural Images in Economic Thought: Markets Read in Tooth and Claw*, (ed.) Philip Mirowski, Cambridge University Press, Cambridge and New York, 1994, pp. 55-56.
[127] Philip Mirowski, *More Heat than Light: Economics as Social physics: Social Physics as Nature's Economics,* Cambridge University Press, Melbourne, Cambridge, 1989; Anson Rabinbach, *The Human Motor: Energy, Fatigue and the Origins of Modernity,* University of California Press, Berkeley, 1992.
[128] Frank Niele, *Energy: Engine of Evolution*, Shell Global Solutions, Elsevier, Amsterdam, 2005, p. 66.
[129] Clive Ponting, *A Green History of the World*, Penguin, London, 1971, pp. 277-282.
[130] Robert Ayres, 'Two Paradigms of Production and Growth', Occasional Paper, Centre for the Management of Environmental Resources, INSEAD, 2002, p.24.
[131] Niele, *Energy: Engine of Evolution*, 2005, p. 66.
[132] E.S. Gooding, *Economics and the Environment*, Prentice Hall, 1999, p. 81.
[133] Niele, *Energy: Engine of Evolution*, 2005, p. 66.
[134] Stephen Bunker and Paul Ciccantell, *Globalization and the Race for Resources*, John Hopkins University Press, Baltimore, 2005.
[135] R.F. Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution,* White Horse Press, [1982] 2000, p. 132.
[136] Mayr, *Authority, Liberty and Automatic Machinery*, p. 139.
[137] Rabinbach, *The Human Motor*, p.52.
[138] Wootton, 'Liberty, Metaphor, and Mechanism'.
[139] Ludwig von Mises, *Human Action,* trans. Bettina Greaves, Foundation for Economic Education Irvington, [1940] 1996, p. 1. <http://www.mises.org/humanaction.asp>
[140] As the Durkheim-Mauss-Douglas-Mirowski thesis suggests, descriptions of nature anthropomorphically recapitulate social relations, and are in turn re-projected as natural phenomena back into descriptions of social relations, naturalising them. Friedrich Nietzsche, 'The Gay Science', in *Nietzsche: Selected Writings*, (ed) Stephen Metcalfe, Shristi, New Delhi, 1995, p. 55.
[141] Arakawa Akiyoshi, 'Economics as Social Physics (Part II) The Natural Law Tradition', 2003. <www.jef.or.jp/en/jto/200005_012.html>
[142] Cited in Mirowski, *More Heat than Light*, p. 27.
[143] Karl Marx, 'Value, Price and Profit': Speech by Marx to the First International Working Men's Association, June 1865. <http://www.marxists.org/archive/marx/works/1865/value-price-profit/>
[144] I. B. Cohen, 'Analysis of Interactions' in *The Natural Sciences and the Social Sciences,* (ed.) I. B. Cohen, Kluwer, Dordrecht, 1994, p. 63.
[145] Andrew Glikson, 'Climate of Denial: Climate Change Skepticism and the Price of the Earth', 2005. < http://www.mapw.org.au/>
[146] Robert U. Ayres, *Information, Entropy and Progress: A New Evolutionary Paradigm,* American Institute of Physics, Woodbury NY, 1994, p. 21.
[147] Cited in Ivor Grattan-Guiness, 'Work for the Workers', *Annals of Science*, vol. 41, 1984, pp. 1- 33. Cited in Mirowski. 1989.
[148] Mirowski, *More Heat than Light*, p.13.
[149] For all the wrong reasons: Carlyle's argument against political economy was that it deprived white West Indies plantation owners of their natural right to coerce black slaves to work for them. As he wrote in an 1853 pamphlet called 'Occasional Discourse on the Nigger Question': "That social science... which finds the secret of this Universe in supply and demand and reduces the duty of human governors to that of letting men alone ... is a dreary, desolate, and indeed quite abject and distressing one; what we might call ... the dismal science." It is a common misapprehension that the phrase refers to Malthus' warnings about population. Robert Dixon, 'The Origin of the Term "Dismal Science" to Describe Economics', Working Paper 1999/715, Department of Economics, University of Melbourne, 1999. <www.economics.unimelb.edu.au/research/workingpapers/wp97_99/715.pdf>
[150] Robert Leighton, Matthew Sands, Richard Feynman, *The Feynman Lectures on Physics*, Addison Wesley, 1989.
[151] Cited in Rabinbach, *The Human Motor,* p. 63.
[152] Rabinbach, *The Human Motor*, p. 63.
[153] Rabinbach, *The Human Motor*, p. 4.

[154] Hermann von Helmholtz, 'The Application of the Law of the Conservation of Force to Organic Nature', 1861. Cited in Suzanne Raitt, 'Psychic Waste: Freud, Fechner and the Principle of Constancy' in *Culture and Waste: The Creation and Destruction of Value*, (eds.) Gay Hawkins and Stephen Muecke, Roman and Littlefield, Lanham MA, 2003, p. 75.
[155] Hermann von Helmholtz, 'On the Law of the Conservation of Force', 1863. Available <http://www.fordham.edu/halsall/mod/1862helmholtz-conservation.html>
[156] Cited in Michael White, 'In the Lobby of the Energy Hotel: Jevon's Formulation of the Postclassical "Economic Problem"', *History of Political Economy*, vol. 36, no. 2, 2004, p. 253.
[157] von Helmholtz, 'The Application of the Law of the Conservation of Force to Organic Nature', 1861. Cited in White, 'In the Lobby of the Energy Hotel', p. 249.
[158] Rabinbach, *The Human Motor*, p. 61.
[159] Rabinbach, *The Human Motor*, p. 61.
[160] Rabinbach, *The Human Motor*, p. 59
[161] Buck-Morss, 'Envisioning Capital: Political Economy on Display' in *Visual Display: Culture Beyond Appearances*, (eds.) Cooke and Wollen, 1995.
[162] Rabinbach, *The Human Motor*, p. 61.
[163] Karl Marx and Freidrich Engels, *Collected Works: Karl Marx: Capital, Vol. II*, International Publishers, 1996, p. 469.
[164] Cited in Katherine Hayles, *How We Became Posthuman: Virtual Bodies In Cybernetics, Literature, And Informatics*. University of Chicago Press, Chicago 1999, p.99.
[165] Hayles, *How We Became Posthuman*, p. 99.
[166] Margaret Schabas, 'From Political Economy to Market Mechanics: The Jevonian Moment in the History of Economics' in *The Natural Sciences and the Social Sciences*, (ed.) Bernard Cohen, Kluwer Academic, Dordrecht, Netherlands, 1994, pp. 235-56 Mirowski, *More Heat Than Light*, 1989.
[167] Eugen von Bohm-Bawerk, *Capital and Interest*, Libertarian Press, South Holland, vol. 2, book 3, 1959, pp. 143-145.
[168] William Stanley Jevons, *The Principles of Economics: A Fragment of a Treatise on the Industrial Mechanism of Society and Other Papers*, (ed.) Henry Higgs, London, MacMillan. Cited in White, 'In the Lobby of the Energy Hotel', p. 241.
[169] White, 'In the Lobby of the Energy Hotel', p. 241.
[170] William Stanley Jevons, *Theory of Political Economy*, London, MacMillan, 1871, p. viii.
[171] White, 'In the Lobby of the Energy Hotel', p. 241.
[172] Margaret Shabas, 'The Greyhound and the Mastiff' in *Natural Images in Economic Thought*, (ed.) Philip Mirowski, Cambridge University Press, New York, p. 329 –330.
[173] This was demonstrated by the Australian historian of computation Allan Bromley, who directed a team at the London Science Museum that completed the calculating section of Babbage's Difference Engine No. 2 in the late 1980s.
[174] William Stanley Jevons, *Pure Logic and Other Minor Works*, Macmillan, London, 1890. Cited in Mirowski, *Machine Dreams*, 2002, p. 39.
[175] Mirowski, *Machine Dreams*, 2002, p. 39.
[176] William Stanley Jevons, *Theory of Political Economy*, 1871, p. 275-6, p. xliv-xlv.
[177] Ayres, *Information, Entropy and Progress*, p.134. The second would be the continuous ascent of the Chicago School since its first 'success' in Pinochet's Chile to the triumph of neoclassical ascendancy in the late 1990s, when the Washington Consensus united Wall St, the US Treasury, and the Bretton Woods Institutions with the neoliberal policy view derived from the elite schools of economics at Chicago, Yale, Harvard and Stanford, whose graduates filled senior positions at all of the above.
[178] Hoos, 1983, cited in Ayres, *Information, Entropy and Progress*, p.134.
[179] Mary Midgeley, *Science as Salvation*, p. 24.
[180] Léon Walras, *Elements of Pure Economics*, 1874: p.84.
[181] Ben Seligman, *Main Currents in Modern Economics*, Free Press, Glencoe, 1962, p. 385.
[182] Franz Reuleaux, *The Constructor: a Handbook of Machine Design*, Philadelphia, 1894.
[183] J.B. Calvert, 'Machines', 2007. <http://www.du.edu/~jcalvert/tech/machines/machines.htm>
[184] Henri Gossens, *The Laws of Human Relations*, 1989, p.114. Cited in Mirowski, 1989, p.216.
[185] Mirowski, *More Heat than Light*, p. 64.
[186] Ayres, *Information, Entropy and Progress*, p.134.

[187] Frederick Soddy, *Cartesian Economics,* Hendersons, London, 1922.
[188] Ayres, *Information, Entropy and Progress*, p. 135.
[189] Mirowski, *Against Mechanism,* pp. 152-153.
[190] Niele, *Energy: Engine of Evolution*, pp. 150-153.
[191] C. W. F. McClare, 'Chemical machines, Maxwell's demon and living organisms', *Journal of Theoretical Biology*, vol. 30, 1971, pp. 1-34.
[192] The second law can be stated in a number of ways. It is notoriously difficult to express in non-anthropomorphic, non-specialist terms once outside of the discipline of statistical thermodynamics. The applicability of the notion of entropy to economics and to human-environment relations remains controversial. For an introductory discussion see: Fritz Sollner, 'A Re-examination of the Role of Thermodynamics for Environmental Economics', *Ecological Economics*, vol. 22, 1997, pp. 175-201.
[193] Sir Arthur Stanley Eddington, *The Nature of the Physical World*, Cambridge University Press, Cambridge, 1928, p. 74. Cited in Evelyn Fox Keller. *Refiguring Life: Metaphors of Twentieth-Century Biology*, Columbia University Press, New York, pp. 45-46.
[194] Ernst Schrödinger, *What is Life?*, Cambridge University Press, Cambridge, Mass., [1944] 1967.
[195] Schrödinger, *What is Life?*, p. 79.
[196] Ayres, *Information, Entropy and Progress,* p. 3.
[197] Cynthia Russet, *The Concept of Equilibrium in American Social Thought,* Yale University Press, New Haven and London, 1966, p.5.
[198] Cited in Ingrao & Israel, *The Invisible Hand,* p. 159.
[199] Cited in Ingrao & Israel, *The Invisible Hand*, p. 160.
[200] Cited in Ingrao and Israel, *The Invisible Hand*, p. 169.
[201] Leon Walras, 'Economique et Mechanique', *Metroeconomica*, vol. 12, no. 1, [1908] 1960, pp. 3-11.
[202] Cited in Ingrao and Israel, 1990, p. 169.
[203] Ingrao and Israel, 1990, p. 170.
[204] Ingrao and Israel, 1990, p. 171.
[205] Rabinbach, *The Human Motor,* p.55.
[206] Alf Hornborg, *The Power of the Machine: Global Inequalities of Economy, Technology and Environment*, Altamira Press, Walnut Creek, 2001, p. 89.
[207] Mirowski, *Against Mechanism*, p.159.
[208] Nicholas Georgescu-Roegen, 'The Entropy Law and the Economic Problem', in *Valuing the Earth: Economics, Ecology, Ethics,* (eds.) Herman E. Daly and Kenneth Townsend, MIT Press, 1993.
[209] Herman Daly, *Ecological Economics and the Ecology of Economics*, Edward Elgar, Cheltenham UK, 1999, pp. 85-88.
[210] Mirowski, *More Heat than Light*, p. 318.
[211] See Philip Mirowski, 'Do Cyborgs Dream of Efficient Markets' in *Machine Dreams: How Economics Became a Cyborg Science,* Cambridge University Press, Cambridge, 2002, pp. 232-302.
[212] Renato Cirillo, 'The 'Socialism' of Léon Walras and His Economic Thinking', *American Journal of Economics and Sociology,* vol. 39, no. 3, 1980, pp. 295-303.
[213] Freidrich Hayek, *The Fatal Conceit: The Errors of Socialism*, (ed.) W. W. Bartley III, Routledge, New York, 1988.
[214] Kenneth N. Waltz, Theory *of International Politics,* Addison-Wesley, Reading, Massachusetts, 1979, p. 140.
[215] Waltz, *Theory of International Politics,* p. 141.
[216] Pierre Bourdieu, 'The Essence of Neoliberalism', *Le Monde Diplomatique,* trans. Jeremy Shapiro, December 1998.
[217] Herman Daly, *Beyond Growth: The Economics of Sustainable Development,* Beacon Press, Boston, 1996, p. 75.
[218] Daly, *Beyond Growth*, p. 144.
[219] Cited in Simon Shackley, 'Trust in Models? The Mediating and Transformative Role of Computer Models in Environmental Discourse', in *The International Handbook of Environmental Sociology*. (eds.) Michael Redclift and Brian Woodgate, Cheltenham UK, Edward Elgar, 1997, p. 246.
[220] Nancy Cartwright, 'Ceteris Paribus Laws and Socio-Economic Machines', *The Monist*, vol. 78, 1995, pp. 276-94.
[221] Lewis Mumford, *The Myth of the Machine: Technics and Civilisation*, Harcourt Brace and World, 1934.
[222] Kanishka Jayasuriya. 'Globalisation Sovereignty, and the Rule of Law: from Political to Economic Constitutionalism', *Constellations*, vol. 8, no. 4, 2001, pp. 442-460.
[223] Michael Hudson, *Superimperialism: the Economic Strategy of American Empire,* Pluto Press, [1972] 2003, p. 134

[224] Naomi Klein, 'Baghdad Year Zero: Pillaging Iraq in Pursuit of a Neo-con Utopia', *Harper's Magazine,* September 2004. Available: < http://www.nologo.org/>
[225] John Ruggie, 'International Regimes, Transactions and Change: Embedded Liberalism in the Post-war Economic Order', *International Organization*, vol. 36, no. 2, 1982.
[226] Cited in Marc Ferro, *Colonization: a Global History*, Routledge, 1997.
[227] Beck, *Ecological Politics in an Age of Risk*, p.82
[228] Lawrence Summers interviewed by editor John Heilemann in *Wired* magazine, July 1997.
[229] The text of the memo (as cited by Doug Henwood on Thursday, 19 Sep 2002, on http://amsterdam.nettime.org/) was as follows:

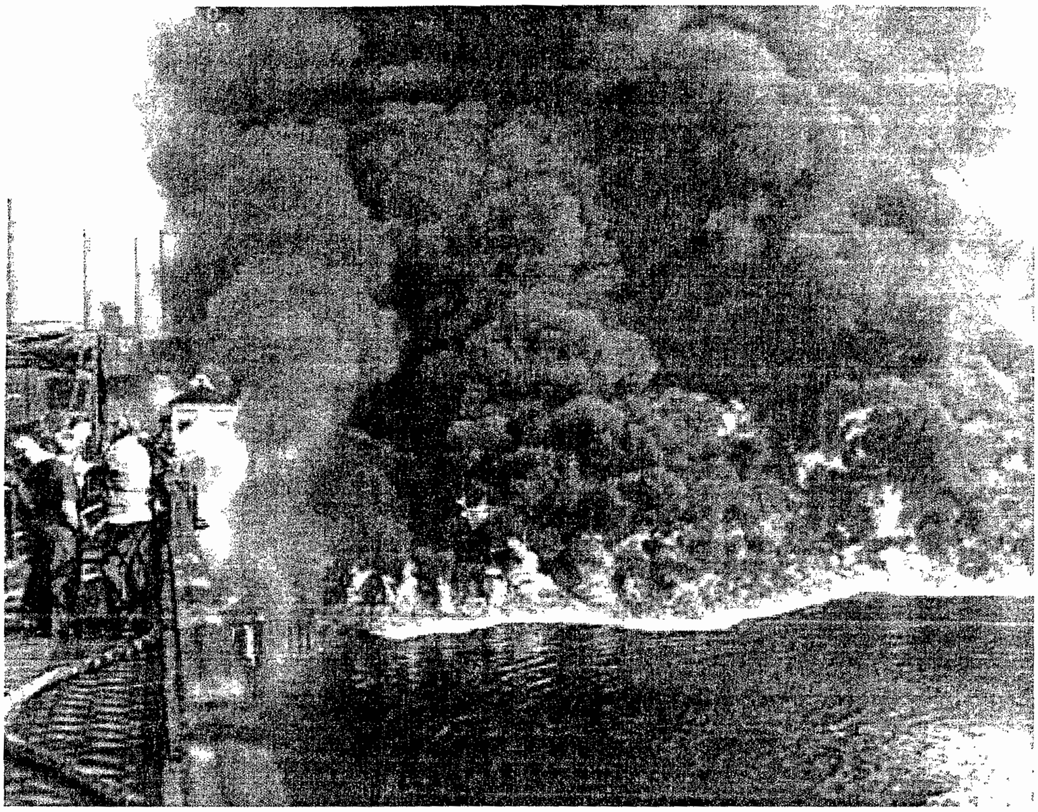
> December 12, 1991
> To: Distribution
> From: Lawrence H. Summers.
> Subject: 'Dirty Industries':
> Just between you and me, shouldn't the World Bank be encouraging MORE migration of the dirty industries to the LDC's (Less Developed Countries)? I can think of three reasons:
> 1) The measurements of the costs of health impairing pollution depend on the foregone earnings from increased morbidity and mortality... from this point of view health impairing pollution should be done in the country with the lowest wages...
> 2) The costs of pollution are likely to be nonlinear as the initial increments of pollution probably have very low cost. I've always thought that underpopulated countries in Africa are vastly UNDERpolluted: their air quality is probably vastly inefficiently low compared to Los Angeles or Mexico City...
> 3) The demand for a clean environment for health reasons is likely to have very high income elasticity. Concern over an agent that causes a one in a million change in the odds of prostate cancer is obviously going to be much higher in a country where people survive to get prostate cancer than in a country where under 5 mortality is 200 per thousand...

[230] Anon, 'Let them eat pollution', *The Economist,* February 8, 1992.
[231] Vladimir Nuri, *Fractional Reserve Banking as Economic Parasitism: A Scientific, Mathematical, and Historical Exposé, Critique and Manifesto,* 2001.
[232] Alan Greenspan, 'Globalization', speech to the Council on Foreign Relations, New York, March 10, 2005. < http://www.federalreserve.gov/BOARDDOCS/Speeches/2005/20050310/default.htm>
[233] Herman Daly (ed.) *Valuing the Earth: Economics, Ecology, Ethics,* MIT Press, 1993.
[234] Ayres, *Information, Entropy and Progress,* p.137
[235] J. Stephen Landsfeld, 'GDP: One of the Great Inventions of the 20th Century', January *2000 Survey of Current Business*, U.S. Bureau of Economic Analysis, 2000.
[236] Landsfeld, 'GDP: One of the Great Inventions of the 20th Century'.
[237] The standard problems are as follows. "Measures of GNP typically exclude unpaid economic activity, most importantly domestic work such as childcare. This can lead to distortions; for example, a paid childminder's income will contribute to GNP, whereas an unpaid mother's time spent caring for her children will not, even though they are both carrying out the same economic activity. ...GNP takes no account of the inputs used to produce the output. For example, if everyone worked for twice the number of hours, then GNP might roughly double, but this does not necessarily mean that workers are better off as they would have less leisure time. Similarly, the impact of economic activity on the environment is not directly taken into account in calculating GNP. ...Comparison of GNP from one country to another may be distorted by movements in exchange rates. Measuring national income at purchasing power parity can help to overcome this problem at the risk of overvaluing basic goods and services like for example subsistence farming. ..GNP does not take into account many factors that may be important to quality of life, such as the quality of the environment (as distinct from the input value) and security from crime. This can lead to distortions - for example, spending on cleaning up an oil spill is included in GNP, but the negative impact of the spill on well-being (e.g. loss of clean beaches) is not taken into account....GNP is the mean wealth rather than median wealth. Countries with a skewed income distribution may have a relatively high per-capita GNP while the majority of its citizens have a relatively low level of income, due to concentration of wealth in the hands of a small fraction of the population." Wikipedia contributors, 'Measures of national income and output', *Wikipedia, The Free Encyclopedia,* Wikimedia Foundation, 18 May 2007.
[238] Ayres, *Information, Entropy and Progress,* p. 146.
[239] Herman Daly, *Ecological Economics and the Ecology of Economics: Essays in Criticism,* Edward Elgar, Cheltenham UK, 1999, p. 86 - 87.

[240] Mark Blaug, *The Methodology of Economics,* Cambridge University Press, Cambridge UK, 1980, p. 254.
[241] Lionel Robbins, *An Essay On the Nature and Significance of Economic Science*, New York University Press, New York, 1932.
[242] Gonçalo Fonseca, 'Neoclassical Optimal Growth: Golden Rules and the Ramsey Exercise,' *The History of Economic Thought Website,* 2006. <http://cepa.newschool.edu/het/essays/growth/optimal.htm>
[243] Walt Rostow, *The Stages of Economic Growth: a non-Communist Manifesto,* Cambridge University Press, Cambridge, 1961.
[244] Rostow, *The Stages of Economic Growth,* p. 4.
[245] Rostow, *The Stages of Economic Growth,* p. 10.
[246] Harold Barnett and Chandler Morse, *Scarcity and Growth,* John Hopkins Press, Baltimore, 1963, p.11
[247] John K. Galbraith interviewed by Kirsten Garrett, on 'Background Briefing', Australian Broadcasting Corporation (ABC) radio, Sydney, 15 Jan 2006. < http://www.abc.net.au/rn/ta lks/bbing/stories/s1539282.htm>
[248] Taylor Owen and Ben Kiernan, 'Bombs Over Cambodia: New Light on US Air War', *Third World Traveller,* May 12, 2007. <http://www.thirdworldtraveler.com/SouthEast_Asia/US_Bombing_Cambodia.html>
[249] Francis Fukuyama, *The End of History and the Last Man*, 1992, Avon Books p. xv.
[250] Fukuyama, *The End of History and the Last Man,* p. xvii.
[251] Cited in Clive Ponting, *A Green History of the World,* Penguin, London, 1991, p. 158.
[252] Walt Rostow, *The Stages of Economic Growth: a non-Communist Manifesto,* Cambridge University Press, Cambridge, 1961, p. 7, 12.
[253] Heinrich Haussman, *Der Josefpfennig.* Cited in George Monbiot, *The Age of Consent,* Flamingo, London, 2004, p. 239.
[254] Frederick Soddy, *Science and* Life, Dutton, New York, 1920, pp. 27-28.
[255] Hornborg, *The Power of the Machine*, p. 21.
[256] Nicholas Stern, *Stern Review on the Economics of Climate Change*, HM Treasury, 2006. <http://www.hmtreasury.gov.uk/media/8A8/C1/Summary_of_Conclusions.pdf>
[257] John Kenneth Galbraith, 'Power and the Useful Economist', Presidential Address to the American Economic Association, 1972. Cited in Evan Jones, 'Obituary: J.K. Galbraith', *Journal of Australian Political Economy,* vol. 57, no. 12, 2007.
[258] Cohn, *The Pursuit of the Millennium*, p. 69.

## PART III: ECONOMY OF NATURE

# Industrial Apocalypse



*The Cuyahoga River on fire.* [1]

## The Ecosystem: a History of its Constitutional Metaphors

*...anyone will profit from learning how the biosphere functions as an economic system.*

- Richard Bambach [2]

*Hell is truth seen too late.*

- Georg W. Hegel

**The Age of Ecology and the Birth of Biophysics**

On the 22nd of June, 1969, the Cuyahoga River flowing through Cleveland, Ohio caught fire. It is unclear what particular cocktail of industrial and chemical pollution caused the fire, but locals reported that sparks from a passing train ignited an oil slick on the river. Seven years after Rachel Carson's' *Silent Spring* had punctured unqualified enthusiasm for 'better living through chemistry' by demonstrating that US farm chemicals were present even in the bloodstream of Arctic nomads, this event galvanised public outrage at the scandalous liberties taken by the chemical and automotive industries. *Time* magazine described the river in 1969 like this:

> "Chocolate brown, oily, bubbling with sub-surface gases, it oozes rather than flows. [...] The Federal Water Pollution Control Administration dryly notes: 'the lower Cuyahoga has no visible life, not even low forms such as leeches and sludge worms that usually thrive on wastes. It is also, literally, a fire hazard."[3]

Lake Erie, the downstream destination of the Cuyahoga was from the 1960s also dying in full public view; in a state of near ecosystem collapse through what might euphemistically described as 'social eutrophication'. The main culprit was not toxic pollution as such but an extreme accumulation of phosphorus in the lake. Phosphorus is a basic nutrient for biological growth, a building block of life. The initial source was an increasing urban outflow of human excrement, which contains phosphorus. With the domestication, commercialisation and expansion of wartime chemical industries during the 1950s, sewerage carried a sudden abundance of phosphate detergents. Mixed with agricultural runoff, feedlot waste and chemical fertilisers, these generated vast blooms of algae in the lake, which removed much of the dissolved oxygen in the water. The consequences of this were a shift from the remarkable water clarity expected of a Great Lake to a general murkiness, a substantial collapse of aquatic diversity and fisheries, and extensive piles of reeking algae rotting on the shoreline where residents had prime real estate.

A minor cataclysm, this wholly unnatural fire drew its apocalyptic glare from the Promethean furnaces burning at the hidden foundation of Progress. The mastery of fire, as the self-described 'fire ecologist' Stephen Pyne has noted, was the key to the first 'globalisation', the radical Pleistocene expansion in the northward and southward range of human groups from equatorial regions until the extremities of every landmass bar Antarctica was populated by fire users, first Tasmania, then Tierra del Fuego, and then finally New Zealand.[4] Its domestication features prominently in myths all over the world as the moment when humans entered into a competitive rivalry with the gods, and became properly human, cultural, beings; which is to make, as Levi-Strauss suggested, a distinction between the raw and the cooked. Aboriginal Australians used fire to modify their environment to favour the open woodlands and savannahs that favoured both grazing herbivores and long-range nomadism. Tim Flannery argues that the prevalence of sclerophyll forest ecosystems in south-eastern Australia that regenerate through burning (i.e. ecosystems that have internalised fire so that it is not a 'disturbance' but a part of the systems 'regulating' function) suggests a biome-level adaptation to human presence, implying a deep antiquity for indigenous Australians.[5]

Burning rivers, however, signify a historically new intensity to the human ecology of fire: the increasing volume and speed of fossil fuel combustion and the chemical sophistication that the metallurgical mastery of heat has taught. It was not the first time that the Cuyahoga River had caught on fire - fires had been recorded on the river nine times since 1869. In 1969 it came to symbolise for the United States the seriousness of the unregulated dumping of industrial pollutants into the soil, lakes, rivers, atmosphere, aquifers and the sea, and the previously unnoticed accumulation of the battery of synthetic chemicals that had come into existence and use since the second world war. It was this unnatural conflagration, along with the death of Lake Erie and several spectacular oil spills, that catalysed politically an increasing sense that a human-made environmental crisis was imminent. In the same year as the portent of the burning river, *Time* magazine wrote that pollution would "soon replace the Viet Nam war as the nation's major issue of protest" and called 1969 "the year of ecology." The article profiled "the new Jeremiahs", the leading ecologists of the day, who explained "that all nature is interconnected and that any intervention has far-reaching effects". In 1970, *Newsweek* upped the ante and announced the dawn of "the Age of Ecology", in which ecologists would teach society about the "web of life."[6] The same year President Richard Nixon established the Environmental Protection Authority, to the amazement of his opponents in the radical movements and his supporters among corporations such as Dow, Du Pont and Monsanto. While his motives were most likely to do with short term electoral politics, this and subsequent legislation marked the internalisation of the discourse of environmental crisis within the regulatory and normative apparatus of the American state, a state centrally concerned since WWII with facilitating economic growth. The developmental state, committed to specifically to 'growth' only since the invention of national accounts (GDP) in the US during WWII, acquired thirty years later a subsidiary remit to warding off the environmental degradation and risk associated with the very process of economic growth, which has since become the foundational task of national governments.

The social regulation of pollution is not merely the concern of environmental agencies. This concern, perhaps a cultural universal, is replicated in the fundamental taboo structures of the Judaeo-Christian tradition, as the anthropologist Mary Douglas observed in her study of the prohibitions of Leviticus.[7] Douglas defined pollution simply as 'matter out of place', and noted that its proliferation warned of an impending crisis in the social order, manifest in the violation of taboo and threatening the desolation of the landscape. Elaborating on Douglas in her book *The Powers of Horror,* Julia Kristeva writes of taboo and sacredness in patriarchal religion, arguing that waste, the undifferentiated, the slimy - "what disturbs system, order, identity" - are marked out for exclusion from the sacred. The abject is excluded by taboo for its dangerous capacity to overwhelm society through pollution.[8] Uncontrolled pollution, the contradictory mixture of identities that should be separate (fire and water in this case), and the contravention of the sacred balance between the order of society and the order of nature are telltale signs of imminent apocalypse, recognisable in numerous cosmologies.[9] But what exactly is meant by apocalyptic? Several candidate definitions include: "A belief that all history has a single irreversible conclusion [...] A teleological framework for the understanding of evil [...] An attempt to usher in a new era by redefining the rules of the redemptive process [...] A sense that each passing moment stands in significant relation to a beginning and an end [...]" [10] These definitions have been offered by Malcolm Bull, who has presented perhaps the most through account of apocalyptic as a genre to date. His account discusses the classic cases of comparative anthropology, obscure religious and literary texts, and key figures of Western philosophy of history, in a way that "reunites emancipatory political theory with the apocalyptic tradition."[11] Bull ploughs through Hegel, the Weimar Social Democrats, Benjamin, Koheve, Heidegger and Rorty, but avoids what should be the most relevant candidate for analysis of modern politics and the apocalyptic tradition: the modern environmental movement. Since the 1970s, environmentalists have claimed a very real apocalypse, an increasingly detailed and sophisticated account of the 'destruction of nature' backed up by natural science, and have established an urgent political quest for the 'ecological salvation' of nature and society from the wasteful and polluting logic of exponential industrialisation.

In human cultural economies, 'waste' can be taken to mean simply that which is inefficient or 'diseconomic': the loss of opportunity to realise value, or fatigue, or work performed with diminishing returns. Or it can be taboo, like excess bodily fluids or incest, or other situations where matter is out of place. Amidst the crisis of the early 1970s, the mathematical economist Georgescu-Roegen elevated the production of waste to the status of a fundamental law of economics. He reminded economists that the prevention and minimisation of waste is a feature of all sustainable economies, a condition imposed upon all forms of life by the second law of thermodynamics. What this means is that what appears as 'production' and 'accumulation' locally and in the short term, is actually dissipation globally and in the longer term.

> "... the economic process consists of a continuous transformation of low entropy into high entropy, that is into *irrevocable waste* or, with a topical term, into pollution." [12]

The entropy law might be read as giving a rigorous definition of 'waste' as the objective measure of the unavailability of energy in a system to do 'work.' By contrast, Douglas' definition implies that what counts as pollution is subjective, and what constitutes dangerous levels of exposure is the result of culturally determined value judgements. If pollution is matter out of place, then who is to say where things should and shouldn't be? Industrial waste, however, is not merely spilt milk (irredeemable value) but can itself lay waste. What counts as an acceptable level of risk in exposure to pollution is certainly politically and culturally determined, but the presence of radioactivity, dioxin, endocrine disrupters, synthetic hormones or even Teflon™ in the cord blood of newborns is a measurable physiological reality, even if these kinds of measurements are rarely made.

As environmentalists have long argued, the valuation on living systems imposed by the market is entirely self-referential. Visit a firebombed industrial clearcut and note the silence. The desolation of once living landscapes is an indelible mark of the economy of the machine. Concerned only with relationships of supply and demand internal to the economy and its value creation, the old growth forests of East Gippsland (for example) are valued more or less at zero by the market until a sale of a quantity of cubic feet of woodchip is arranged. Once the biodiverse, ancient forest has been shredded and its value realized, the desolate landscape is worth more or less zero until it is replaced with an industrial monoculture of fast growing radiata pine and harvested every couple of decades. Meanwhile the thermal fax paper made from the pulp in Japan circulates at a much higher value, until, consumed and unrecyclable, it arrives at a municipal dump. There its value is negative, less than zero. While ecology itself has little to say about 'value', the environmental politics of the 1970s was, in the broadest sense, about the redemption of both the intrinsic and utilitarian value of intact and ancient living systems, and the restoration of the lost balance of the economy of life.

In economies of nature, the metabolic transfer of matter and energy through living and dead organisms favours tight, adaptive evolutionary integration and occasional bursts of risky innovation between a multitude of species. While the biosphere of our time is a nearly perfect material recycling system this has not always been the case and did not happen overnight. (Depending on your species perspective: the vast majority of lifeforms are extinct!). Evolution has had some billions of years at its disposal to develop a sustainable economy. In an example of what might be called 'natural pollution', the biologist Geerat Vermeij writes that:

> "The plants living 320 to 290 million years ago (Ma) in Carboniferous equatorial forests were so laden with lignins, tannins and other decay-resistant compounds that their remains ultimately accumulated like so much un-biodegradable plastic debris. As a result,

most of the carbon in these plants was lost to the living ecosystem, to be recycled back to the biosphere only when humans retrieved it and burned it as coal."[13]

Such analogies ought not be pushed too far; 30 million years worth of slow lignite accumulation on the forest floor is hardly comparable to the rapidity, novelty and intensity of human generated pollution and the multiplicity of forms it takes. For example, the European Commission has only recently begun to establish a centralised database to store information about the basic properties of synthetic chemicals and polymers annually released into the environment in volumes exceeding one tonne, of which there are thought to be at least thirty thousand. [14] The majority of these chemicals have only existed since the WWII. Few of these substances have been subject to long-term etiological studies into their travels through open ecosystems. Even less studied is the sheer multitude of possible chemical reactions with one or more other pollutants, and the combinatorial effects these have on the bodies and environments of interacting species that, although perhaps vital in the chain of being, are economically uninteresting and thus unexamined.

Nevertheless it is true that the question of sustainability is not a new one. A topical example might be the carbon cycle. The carbon cycle, which maintains the composition of greenhouse gases in the atmosphere, the seas, and the biosphere in the far-from-equilibrium conditions suitable for life, which regulates the earths surface temperature within the range favourable to carbon-based biochemistry, is itself an emergent feature of microbiological evolution. A result of the contingent biochemical adaptation of early photosynthetic life forms; the first step in the establishment of the carbon cycle was the emergence of a photosynthetic process suited to the early volcanic atmosphere, with its high concentrations of ultra-violet radiation and carbon-dioxide. The free energy of sunlight was harnessed by bacterial organisms to drive a chemical reaction that converted CO2 into glucose, temporarily storing exergy to maintain life. The initially negligible waste product of this process was oxygen, in quantity a lethal toxin to these forms of life. One effect of this increasing availability of oxygen was the transformation of the geological weathering process, as ferric iron deposits in the earth's crust absorbed oxygen and became ferrous. (Thus, the iron ore that is mined today to make bulldozers and battleships is itself of biological origin). This fermentation based economy worked well for at least a billion years. However, this led to the over-accumulation of oxygen, which threatened most existing (anaerobic) life forms. Once the geosphere had reached the limits of its 'waste assimilating capacity' regarding molecular oxygen, cyanobacteria faced an ecological crisis of their own making, with no recourse to legislating against pollution. The emergent 'solution' was a new metabolic process that used oxygen, a process which radically increased the energy efficiency of photosynthesis. Over the deepest timescales, this fundamental biochemical process effectively 'balanced' the cycling of carbon dioxide and oxygen, stabilising the atmospheric conditions favourable to the sustainability of organismic life.[15] Through the emergence of new species, similar cycles later evolved that 'regulated' the cycling of nitrogen and phosphorus. One of the first scientists to recognise that biological life was a profound force in the transformation of the earth's inanimate geochemistry was the physicist Vladimir Vernadsky, who published his theory in a 1926 book entitled *The Biosphere*.[16] The older view of evolutionary history was that life evolved on earth within the limits imposed by a relatively stable lithosphere and atmosphere. As Margulis and Sagan put it, contemporary science increasingly suggests that even the non-living environment is "regulated by life for life."[17]

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Earlier in the this thesis it was argued that the currently dominant ideology of infinite economic growth can be considered as a residual form of secular millennialism centred on the liberatory promise of machine technology. Despite its adherence to the Positivist dream of a social physics stripped of all mythology, metaphor and political subjectivity, economics retains a secular relationship to millennialism in its historical projections of infinite growth and universal prosperity through technology. What secures the future of universal abundance promised by liberal millennialism was the free operation of 'the laws of supply and demand', first revealed in the deistic conceit of Adam Smith's 'invisible hand' and later scientised by neoclassical social physics as the 'market mechanism'. As we have seen, this intuition was rendered 'scientific' by the neoclassicals, who posited the identity of social relations of exchange with nature revealed as a 'Newtonian' perpetual motion machine. In what follows we will now attempt to ask the same questions about the historical context of ecology as it became science, observing the parallel (though not contemporaneous) process of theory development, the hidden moments of mutual influence, the relation of politics to ecology, and finally the narrative contradictions between one discourse promising the industrial millennium and another a post-industrial apocalypse.

In his account of the emergence of secular Progress ideology and of the legitimacy of the 'modern age', the philosopher of history Hans Blumenberg argued against the 'secularisation thesis' that I have used to inform my account of the Industrial Millennium. Blumenberg differentiated the temporal structure of Progress ideology, with its steady progress toward a perpetually deferred goal, from Christian apocalyptic, arguing that "eschatology speaks of an event breaking into history, an event that transcends and is heterogenous to it."[18] Political theory, political economy and social movement ideologies have in general nourished themselves upon a view of human history as elevated and distinct from natural history. What I would suggest is that the 'global ecological crisis' - the unpredicted and unprecedented degradation of the biosphere and associated multiplication of existential hazards – is a total 'event breaking into history' and has just this eschatological structure. Modern environmentalism can thus be defined as that multiplicity of political ideologies organised around what Catherine Keller calls "the eschatological threat to human meaning posed by [the earths'] material devastation..."[19] It is no wonder then that conservative economists have tended to downplay and deny the ecological hazards of economic growth, as for them, environmentalism means the apocalyptic collapse of their millennial view of social relations, undermining both the just equilibrium of the market and their claim to hold the keys to moral and material progress. The grandest aim of environmentalism in the 1970s, it might be said, was to establish the 'age of ecology', to supersede the failed 'age of economics' and restore the 'balance of nature', the precondition for the maximum abundance of life. But which ecology? Anyone with a passing acquaintance with the history of ecology knows that, like other branches of knowledge, it has never achieved permanent internal consensus as regards its methods and models, and its borders with other branches of science are often porous and not well policed. And which balance?

The emergence of modern environmentalism coincides with a particular moment in the internal history of ecology, with the consolidation of the 'ecosystems ecology' that arose with cybernetics and systems theory in the post-war period. The detailed explication of this particular understanding of the 'balance of nature' is the subject of the following pages and need not be dealt with here. Suffice to say that natural systems were described as existing normally in a state of dynamic equilibrium analogous to the homeostatic equilibrium of an organism, able to recover from disturbances and injuries and to maintain their form of organisation and resilience over time. Such equilibrium was also correlated with a tendency toward the maximisation of species diversity (order, information, structure) and of biomass (or energy capture). Implicitly, the identification of the temporal and spatial boundaries of a given 'system' and its level of stability, maturity and diversity involves certain judgements regarding the value of particular systems, suggesting which should be preserved and which sacrificed to progress. Indeed, the historian Sharon Kingsland believes that it was precisely the need to place such decision-making on a scientific footing that led to ecology becoming a science.[20]

No longer an obscure branch of biology, ecology during the 1970s lent its scientific credibility to a social movement that argued for a revolutionary transvaluation of values, where the order of society would be consciously adjusted according to what ecology, a superior account of the order of nature, revealed. In a 1978 report to the Canadian government on energy infrastructure and planning, Gordon Edwards wrote:

> "With the rise of the environmental movement in the late 60's and early 70's, a new metaphor was introduced into the public consciousness -- the metaphor of the ecosystem. Infinitely more complicated than any man-made machine, a living

> ecological system is a marvelously well-organized interactive system that is self-regulating, resilient, and irreplaceable. It represents the culmination of billions of years of evolution. [...] Part of the reason for the vitality of the environmental movement may lie in the fact that it has introduced a powerful new image into people's minds: the image of the ecosystem. Here is another way of organizing complexity that is not machine-like. Here is another model which may be emulated. This image, the image of the ecosystem, has indeed become a new metaphor, which may succeed in transforming our society as thoroughly as the metaphor of the machine has done in the past."[21]

Focussing on the global risks associated with the transformation of the Earth's surface, environmentalists placed the industrial machine as a metaphor, ideological fetish and concrete tool under sustained examination. The 'ecology movement' proposed a new set of constitutional metaphors for social institutions around the concept of the ecosystem. In the early 1970s, 'ecology' was a word that had only very recently come in to common use. In his classical 1971 textbook, E. P. Odum wrote that ecology was rapidly becoming the "indispensable" branch of science, the one "most relevant to the everyday life of every man, woman and child."[22] This necessity of an ecological grounding for the human sciences was clear, for the age of limits was at hand: "[f]or the first time in his short history man is faced with ultimate rather than local limitations."[23] With the benefit of hindsight, it seems that Odum's optimism that the Age of the Ecologist was set to replace that of the Economist was seriously misplaced.

In this chapter, we will historically contextualise the emergence of ecology as a science, in attempt to shed some light on the failure of the 'age of ecology'. Its main object is to historicise the rise of its most basic concept, the 'ecosystem', in much the same way as the previous chapter attempted to do for 'the economy'. We will consider the evolution of the ecosystem concept as the cornerstone of ecology's claim to scientific authority, and some of the complex intellectual pathways that placed the 'ecosystem' at the centre of the critique of the economics of perpetual growth. In doing so we'll advance the thesis that one of the reasons for this failure is that the image of the ecosystem, described by Edwards as "a way of organizing complexity that is not machine-like", was in the final analysis anything but. Without giving too much of the plot away, it is hoped that by the end of the chapter the reader come to share the author's suspicions that the metaphor of the ecosystem did not arise fully formed from the ground like a mushroom, but owes a troubling and unacknowledged debt to economics.

This history of the rise of the ecosystem concept analyses its links to early modern science, to economic thought, to energetics, to ideologies of progress, to the American military-academic complex, and finally to the rejection of the entire post-war political-economic consensus on the standard model of growth by the emerging 'biophysical perspective. Through developing this narrative, we will also consider the theme of what ecology means for 'philosophy of history', by which I mean discourses about the totality, meaning and direction of human history 'as a whole', now that Nature and Society are impossible to separate and are thus thoroughly politicised. This history is presented as a contribution to the critique of the present normalisation of infinite economic growth and the image of the market as an automatic force for social stabilisation, even amidst widespread acknowledgement that the biosphere is undergoing radical destabilisation. Since the 1970s, ecology has been associated with claims of a deepening 'industrial apocalypse.'

The narrative has several major themes, which are dealt with sequentially. First, we discuss the tangled roots of ecology in pre-modern Western knowledge systems, suggesting that it has a much longer-term relationship with the grand historical themes of the West than its very recent rise to public importance belies. Of particular interest are the deep origins of the 'natural law tradition' which, as we have seen, sent the study of economics down the path of aspiring to become a social physics. Second, we look at the relations between ecology and other sciences in the late 19th century, looking at the consistent blurring of the lines between Nature and Society as the context in which ecology staked out its claims to describe the natural order and attempted to discover general 'laws of nature'. Third we look at the drift of ecology away from vitalism and historicism and into energetics and mechanism. At this point, we note the prevalence of machine metaphors in the gestation of the ecosystem concept. Organisms become, in a manner of speaking, 'living motors', while ecosystems were figured as 'energy transforming systems', maximising their complexity and energy storage within the fundamental limits of 'ecological equilibrium'. The fourth section deals with the apocalyptic context of ecology's energetic overdetermination: nuclear risk and projections of ecological meltdown. It is at this time that ecology makes its most strident claims toward the status of social physics, and collides headlong with economics, particularly in the area of value theory.

As we have already discussed, the hetero-zygotic twin sciences of ecology and economics emerged from the Cartesian bifurcation of the theological whole *oeconomia* in the 16th century, reflecting the split world in which the machine metaphor had become constitutive of the very definition of science, and increasingly mediated discourse between the social and the natural sciences, as industrialism increasingly shaped the material environment in which the denizens of modernity dwelt. The chapter aims to provide an account of the broad historical sweep of ecological thought, stressing its historical links to parallel developments in political and economic thought, and the recent collision of the two sciences under the sign of the energy formalism in the 1970s. It was at this time that we see the beginning of discourses of global ecological crisis, if not yet the predicted Age of Ecology.

**Oeconomy of Nature: Providential Ecology and the Balance of Nature**

Throughout Western history, the paradigmatic mode of inquiry that has addressed the question of the nature of human being and selfhood has shifted from theology to philosophy, to natural history and thence to biology.[24] Citing Michel Foucault, Richard Doyle argues that the conditions that allowed the possibility of a conceptual matrix supporting biology as the science of life only emerged in the 18th century.[25] Prior to this, writes Foucault, "all that existed where living beings, which were viewed through a grid of knowledge constituted by natural history."[26] Doyle's' suggestion that bounded organisms, molecular structure, species, genes and ecologies simply did not exist until the 19th century makes sense when we bear in mind that the term 'biology' dates to its coining by the systematising Comte in the 1830s, and that the term 'scientist' only dates from William Whewell in 1845. Following the secularisation of the great metanarrative of Christian apocalyptic by the progressive philosophies of the Enlightenment, the diverse providential and creationist narratives of natural history yielded to a recognisably scientific and materialist biological science only in the latter 19th century. The disorienting and decentering effects of the discovery of deep time by geology and the incorporation of this temporal perspective into Darwin's work, which destablised all previous discourse on human value by portraying humans as animals subject to the violence and vagaries of contingent evolution, was resolved for some by depicting humans as the outcome of a providential process, thus saving the ideology of progress by embedding it in 'evolution'. Given that newly emerging industrial economy provided the material evidence for Progress, it is not surprising that the biological organism *Homo Sapiens* quickly required locating within a thoroughly modern economy of nature.

As is widely reported in the literature, it was the zoologist, Darwinist and populariser of energetics Ernst Haeckel who in 1866 first outlined the contours of the discipline he termed 'Öecologie', in a work entitled *Generelle Morphologie der Organismen.* The term was Anglicised at the Madison International Botanical Congress of 1893. This technical term languished in obscure biology departments until coming into common Anglo-American vernacular a century after it was coined. The 1966 Webster's dictionary defined ecology as the study of the 'totality or patterns of relations between organisms and their environment'. This popular recognition of ecology as a science was inseparable from the increasingly politicised evidence of environmental degradation occurring on the global scale, and from announcements and predictions of an unfolding global ecological crisis. Donald Worster has observed that the "[...] science of ecology has had a popular impact unlike that of any other academic field of research. On several continents we have a philosophical movement termed 'Deep Ecology', but nowhere has anyone announced a movement for 'Deep Entomology' or 'Deep Polish Literature'."[27] It is precisely because ecology at its most ambitious addresses the 'totality' (however embarrassing and even dangerous such a concept appears to post-modern philosophy) that it has acquired such importance. Totalities, such as religious eschatologies or modern versions such as Marxism, 'social energetics', and 'the market', offer an ontology of the order of nature and the order of society and thus place the subject in reference to the whole of space and time, posing the ultimate parameters of social, moral, ethical and indeed strategic action. Neither the study of insects or of Polish writing offers such possibilities.

Theorising the 'totality or patterns of relations between organisms and their environment' is hardly a modern concern. The subject matter of ecology has of course always been of direct interest to human beings. One does not have to invoke Romantic stereotypes of the Noble Ecological Savage, or the generalised *homo economicus* lurking within the Optimal Forager of functionalist anthropology to state the obvious, that detailed empirical knowledge of where best to hunt and gather, when to find medical or edible plants, is survival-relevant information of primary importance for pre-agricultural societies. Detailed knowledge of the interactions between different species and their seasonal distribution across different landscapes was and is the basic survival concern of all human beings to whom agricultural surpluses are unavailable. The idea of ecology, of a comprehensive way of looking at the living earth and the interrelatedness of all its organisms is thus much older than the term we use to describe it.

Despite its emergence from a Darwinian conception of the biological sciences stressing contingency and qualitative change, the fundamental theoretical concept of ecology is, according to Frank Egerton, the general idea of a 'balance of nature'. In his 1973 article, Egerton traced a genealogy of this notion in natural history from the pre-Socratic philosophers through to debates among professional ecologists in the 1960s.[28] Egerton concludes that at no time had this idea of 'balance' in ecology been given critical attention sufficient to elevate it to something approaching a 'law of nature': clarification of the balance-of-nature concept would involve expelling the hidden providential and teleological foundations of the metaphor stretching back to Anaximander and Pythagoras, whose abstract and general explanations of natural phenomena reflected the assumption of Greek mythology that the cosmos was constant and harmonious. This view is fully consonant with the incisive critique of the Comtean view of science (as the search for universal laws of matter) given by the philosopher of science Emile Meyerson; who a century ago argued that the very definition of science in the West has come to be bound up with the 'discovery' and elucidation of invariance principles, assumed to exist *a priori*, of which the first law of thermodynamics – the invariance principle of the conservation of energy – was only the latest version. Conservation principles were recognised in Greek thought at least as far back as the 3rd century BC, when Epicurus wrote:

> "Nothing is created out of that which does not exist, for if it were, everything would be created out of everything with no need of seeds. And again, if that which disappears were destroyed into that which did not exist, all things would have perished since that into which they were dissolved would not exist."[29]

Meyerson argued that conservation principles were residual of a basic human prejudice: exposed to the impermanence and contingency of the Heraclitian flux of life and death, the desire to posit the continuing identity of things in time was only natural, but in many cases remained a metaphysical pre-supposition that could have dangerous consequences for scientific thought.[30] We have already seen how paradoxical the appropriation of the first law in economics was: in asserting the exact equivalence of exchanges of 'utility', the equilibrium analysis of the market came to abolish the what Popper refers to as the 'crux of realism': the 'reality of time and change' [31] by constructing the market as a kind of reversible Laplacean daemon. The effect of this is that neoclassical economics has a thoroughly inadequate conception of growth and the material irreversibility of the economic process. Our task here is to recount the history of the 'balance of nature' and the concept of ecological 'equilibrium' from which the most serious critiques of economics has arisen.

Most cosmologies, Egerton argues, have some notion of the balance of nature. In anthropomorphic worldviews, it is held in the hands of the gods, with humans having a supporting role in maintaining it through the performance of sacrifices to encourage divine benevolence. Egerton argues that that the earliest Western source supporting the idea of an ecological 'balance of nature' is to be found in Herodotus, who argued that Divine Providence had ensured that the world was not overrun by malevolent creatures such as serpents and lions by assigning them a much lower level of fertility than benign species such as hares. Although detectable in the histories of Herodotus, the biological observations of Plato, and the physiological writings of Aristotle, the tendency to focus on the individual traits of organisms among early natural historians meant that an explicit formulation of the concept of balance was not attempted. Later writers who gave attention to questions about the interrelatedness and constancy of animal and plant populations such as Lucretius, Cicero, and Longinus drew upon these earlier accounts, which suggested that the balance of nature was maintained by the different capacities for reproduction of species, certain physical traits that ensured the survival of each species, a pre-ordained position for each creature in the natural order, and specific cases of mutualism. This evidence of natural balance was mobilised to provide support for theological positions, first Stoic and later early Christian that asserted the existence of Divine Providence and the benevolence of the Creator.[32]

Egerton describes this complex of teleological ideas as 'providential ecology'. Noting that discussion of the balance of nature largely disappears from the literature of the medieval period, he attributes this to the universal acceptance of the idea of an omni-surveillant God, continually supervising all the workings of nature. Such a belief required no elaborate theory of in-built mechanisms of balance. It wasn't until the 17th century, with its eruption of schismatic tendencies and new knowledges associated with the challenges of Protestantism and early modern science, that the balance-of-nature concept resurfaces. Again, the balance of nature was rarely itself the direct object of inquiry, but was predominantly invoked in arguments that attempted to safeguard both theology and empirical inquiry into nature from fears that they were antithetical and hostile forms of knowledge. Given that the earliest naturalists were often men of the cloth, as indeed the majority of those who had received a higher education were, there was ample reason to defend the rational study of Creation from the charge that science led to atheism. A good example of this is found in the 1677 work of Sir Matthew Hale, *The Primitive Origination of Mankind*, which provides perhaps the earliest explicit account of the balance of nature as a concert of both physical and animate natural forces.

> "That the vicissitudes of Generation and Corruption are by a kind of standing Law in Nature fixed in things, and the Notions and Qualities of Natural things are so ordered, to keep always that great Wheel in circulation; and therein the Access and Recesses of the Sun, the Influxes of the Heat thereof and of the other Heavenly Bodies, and the mutual and restless Agitation of those two great Engins in Nature, Heat and Cold, are the great Instruments of keeping on foot the Rotation and Circle of Generations and Corruptions, especially of Animals and Vegetables of all sorts. [...] That yet these Motions of Generations and Corruptions, and of the conducibles thereunto, are so wisely and admirably ordered and contemporated, and so continually managed and ordered by the wise Providence of the Rector of all things, that things are kept in a certain due stay and equability; and though the Motions of Generation and Corruptions and the Instruments and Engins thereof are in a continual course, neither the Excess of Generations does oppress and over-charge the World, nor the defect thereof and Corruptions doth put a Period to the *Species* of things, nor work a total Dissolution in Nature."[33]

Notable is the prevalence of machine metaphors in the construction of an argument for a Providential equilibrium, a feature we have already observed at work in the formative debates of early physical theory and resplendent in the rhetorical history of economics. Maintained here from the days of

Herodotus is the permanence and stability of populations, and a conception of species as fixed, immutable and secured from the threat of extinction, although the modernity of the text is evident in the recasting of the Creator as supreme Engineer.

The eighteenth century saw a rapid expansion of the scientific knowledge base, with extensive work published cataloguing the range and distribution of organisms throughout a globe made increasingly accessible to Europeans by maritime technology and conquest. This increasing body of evidence exposed contradictions and sparked conflicts in many areas of knowledge, although the balance-of – nature concept did not come up as a significant subject for debate and was largely preserved intact. It was in this period, with the increasing influence of Enlightenment humanism that the theological context of natural history faded somewhat, although the general belief in Providence meant that the balance of nature remained a complacent background assumption of scientific minds.[34]

Suprisingly few comprehensive histories of ecology have been written given the current political importance of the discipline. One of the fewer still that deal directly with the relationship of ecological thought to economic thought is bequeathed to us in the form of Donald Worster's *Nature's Economy,* published by the Sierra Club in 1977.[35] (Much of the historical research that we encounter in this section is indebted to his survey.) Worster says that the most important early formulation of the ecological point of view can be attributed to Carl von Linné (1707-1778) and his 'economy of nature'. Known by the Latinised name 'Linnaeus' under which he published his prolific scientific works, Linnaeus is most famous for his *Systemae Naturae*, his simple, rational and logical system of botanical taxonomy that revolutionised the classification of plants. The system of binomial classification that he devised relied on very simple principles which were avidly taken up by amateur botanists, one simply counted the pistils and stems of a flower and noted their position and its location in the neatly categorised system of nature was revealed. Prior to this, biological work had been greatly obstructed by the absence of coherent and universal taxonomic principles; every natural historian was more or less obliged to invent their own method. Linnaeus' talent for organisation and arrangement brought an elementary coherence to the work of natural history which was previously unknown, and although the tedious work of organising all species into a single plan often produced erroneous results, it was this very process of organisation that rendered anomalies and contradictions visible, thus paving the way for more coherent general theories of which the theory of evolution was to be the most important result.[36]

It was his 1749 work, *The Oeconomy of Nature*, which offered the first systematic and thus recognisably modern exposition of the ecological world picture, albeit one that never departed from the theological concerns and teleological reasoning of providential proto-ecology. For Linnaeus, the 'economy of nature' appeared as an entirely static cycle of geological and biological interactions, with the "perpetual succession" of life and death expressing the rationality and harmony of a universe suffused with divine intention. All creatures are carefully and wisely designed to fit into an intricate hierarchy, each given its unique source of food, its means of shelter, and its 'clothing'. Both the fertility and appetite of each organism is geared to the maintenance of a "just proportion" of each species. Another early modern usage of economy was in the discussion of 'animal economy', the study of the physiology of the individual organism. As each species is designed to interlink with other select organisms in the hierarchical cycle of eating, excreting, reproducing and dying, each has thus been designated its "allotted place", which is both a location in which to dwell, and a functional role to play in the grand scheme of things. Each species provides support to others even as it goes about earning its own living.[37] "By the Oeconomy of Nature," wrote Linnaeus, "we understand the all-wise disposition of the Creator in relation to natural things, by which they are fitted to produce general ends, and reciprocal uses." Thus arranged by Linnaean ecology, living beings are "so connected, so chained together, that they all aim at the same end, and to this end a vast number of intermediate ends are subservient."[38]

To what end or purpose did the Supreme Economist direct the economy of nature? At this point we may recall that, as mentioned in the previous chapter, among the earliest uses of the term 'oeconomy' was in connection with the anthropological projection of Divine Order into nature, for example in Sir Kenelm Digby's 1658 discussion of the 'oeconomy of nature', by which he meant the grand organisation and government of life on earth. The study of 'ecology', a word that appeared in the 19th century as a more scientific substitute for the older phrase is for Worster "in its very origins a political and economic as well as Christian view of nature; the earth was perceived as a world which must somehow be managed for maximum output."[39] The search for general ends, for an overriding purpose and human agency in nature, was the central impetus to the 'economical' or 'ecological' approach to natural history. Providence guaranteed abundance; Progress meant the maximisation of the abundance of the earths' potential to serve human ends.

This notion of nature's economy was palpably different from the reification of classical energy physics in the Cartesan-Newtonian language of 'economic forces'. As we have seen the 19th century economists sought to exclude the metaphorical, the biological, the social, political, technological and historical factors in their presentation of the abstract Market (the residual term that subsumes wider ideas of 'the economy ' and 'society') as an accessible datum of Nature derived from physical systems. The Linnean model of ecology, by contrast, reified a mingling of a religious terminology of 'dispensations' with a social metaphor of the political organisation of resources for the maximisation of production. This tendency to borrow heavily from politics and economics – absorbing their values along with their metaphors – is a crucial characteristic of the history of ecology. [40]

In its commitment to a Christian and neo-Platonic ontology of species, the Linnean system denied the possibility of the post-Edenic creation of species and the possibility of extinction prior to the End of Days. As much of the world remained to be explored by science in the 18th century, his disciples maintained that fossils were the remnants of animals and plants that must surely exist as living creatures elsewhere on the globe. If this logical explanation did not satisfy, then there was always the possibility that fossils represented antediluvian organisms that had perished in the Flood of Noah. The natural history of ecological organisation remained static in its equilibrium, without birth, change or death at the species level. The economy of nature was neatly bracketed between the time of Creation and the End of Days. Such a schema could even be approved of by the Evangelicals who followed Archbishop Ussher in maintaining, on the basis of calculations the genealogies of the Old Testament, that the age of the earth could be no greater than 5650 years. Published in 1650, his chronology followed quite literally the six-day creationist model of millennial thought, in which 'a day in the eyes of God was as 1000 years in the lives of men'. Thus the creation of the world took place at noon on the 23rd of October 4004 BC, and the End of the World was slated for October 23, 1997, exactly 2000 years after the birth of Christ, and 6000 from the day of creation.[41] The Apocalypse would be followed by the Millennium, the thousand years of blissful life that anchored Christian hope in the justice and meaningfulness of history. With the creation of a new heaven and a new earth, the Redeemer would usher in a new 'dispensation', an age without tears, bodily corruption, or death. Eschatology, economy and ecology remained coherent subjects in relation to one another. In the new economy of nature after the End of Days, the lion lays down with the lamb, and the war in nature ceases, as everyone knows who has seen the pictures in Jehovah's Witness pamphlets.

So what was the proper role and relationship of human beings to other forms of life within the Linnaean economy of nature? For the most part, its ethics were entirely resonant with the increasingly ruthless utilitarianism of the age. The absolute distinction between humans and non-human life remained in place. Possessed of language, reason and purpose, humans dwelt in a world created by God for their use. Every last piece of animate and inanimate nature had been created for the exclusive use of humanity. Although many Linnaeans hesitated to embrace the full program of Cartesian mechanism, for obvious reasons, its view of non-human creatures as biological machines with neither sentience nor feeling certainly resonated with the Christian view of nature as having moral relevance only in terms of Man in relation to his Creator. But so far we have avoided the question of predation, violence and 'war to the death' in nature, the economy of death by which all creatures fill their bellies at the expense of one another, an economy of sovereign violence in which humanity was clearly increasing its dominance. It was clear from the processes of colonisation underway in the Americas that the clearing of forests resulted in the replacement of hundreds of native plants and creatures with the few domesticated species that Europeans relied upon, a process enhanced by the open season on the shooting of native predators, described as 'varmints' or vermin. "The uniform scope of human industry" noted William Smellie enthusiastically, has been to "diminish the noxious animals, and to augment that of the useful animals".[42] Nevertheless, 18th century naturalists found it impossible to conceive that a benevolent God would have built a cosmos in which human activity could diminish the abundance and multiplicity of a Creation lacking in resilience. For example, John Bruckner, a Linnean and Lutheran pastor argued in 1768 that:

> "It is, I say, five thousand years at least that one part of the living substance has waged continual war with the other, yet we do not find that this Law of Nature has to this day occasioned the extinction of any one species. Nay, we may add, it is this which has preserved them in that State of perpetual youth and vigour in which we behold them." [43]

Again, the divine balance of nature metaphor is called upon to justify the permanent and providential nature of ecological diversity and creationist productivity. The religious conceptions of the order and reproduction in the pre-scientific ecology of the 18th century thus operated to justify the aspirations of an evermore-aggressive process of capital accumulation, European imperialism and the transformation of landscapes. Perhaps through the common acceptance of the three-stage dispensational model of time and historical process common to historical eschatology, the proto-ecologists carried the crucial metaphor of balance in a largely unexamined state through to the early 19th century. The shallow time depth of this cyclical model, in tune with the prevailing cultural experience of time, was to be threatened and then overthrown in the 19th century by the revolutionary discovery of deep time. This process set in motion by the contributions of Charles Lyell to the modernisation of geology and of Charles Darwin to biology. The rationalisation of geology gave context to the study of what we now refer to as the 'fossil record'. These mutually reinforcing developments enabled a picture of vast eras in which radically different biological communities came ever so gradually in to being, posing the possibility of destructive large-scale extinctions and the orgiastic diversification of novel life forms over eons of time.

**The Struggle for Existence: Political Economy and Proto-ecology in the 19th Century**

Until Darwin, the progress of natural history was largely the domain of dedicated amateurs, and was the respectable pursuit of country divines who painstakingly collected and documented the life of the fields and forests around them in the Arcadian manner of Gilbert White's *Natural History of Selbourne*. Biology, the discipline first described by Comte in 1842, became increasingly professionalised along with the other natural sciences, and after 1845, when William Whewell gave the name 'scientist' to those trained in empirical and positive method, it was increasingly harder to square their findings with the harmonious moral order of the Christian cosmogony. The 19th century was to dispense entirely with the theological language of the economy of nature and embed it firmly in scientific materialism. The delineation of 'society' as a political, national and scientific question generated an array of sciences whose biopolitical object was the organisation of the labouring population of industrialising societies. The apparent contingency of biological life, the profligacy and waste evident in nature's economy presented difficult challenges to the Victorian mind, with its valorisation of order, discipline, frugality and hard work. It is perhaps not surprising then that the well read English middle-classes, given their long political and moral campaigns against the unproductive, vice-ridden idleness of both the aristocratic and the proletarian classes - a complaint also voiced in racial terms of colonial subjects and slaves - began to explore the twinned subjects of the nature of the national economy and the economy of nature.

Among historians of science, a widely discussed case of mutual influence between the Natural and the Social sciences is the influence upon Darwin of Thomas Robert Malthus. The first holder of a British university chair in political economy, Malthus is mostly famous for the bleak bioeconomics of his *Essay On the Principle of Population* (1798), in which he sought to discover the 'laws of population.' In it, Malthus argued that due to the "fruitfulness of marriages," the tendency of the population was to grow geometrically (1, 2, 4, 8, 16, etc.) was blocked by the limited possibilities for increasing the availability of arable land, which Malthus asserted could at best increase arithmetically (1, 2, 3, 4, 5; and this itself is an infinite series.) For Malthus, it was simply logical that the number of individuals existing at any one time must be closely balanced with the amount of food available to feed them. Therefore, he posited the existence of a continuous, forceful array of natural "checks" to maintain the balance of biological forces at some median level that could be sustained over the longest period of time. 'Positive' checks were accidental death, infant mortality, epidemics, starvation and war. 'Preventative' checks included the savage "unnatural practices" of infanticide and abortion. In the moral civilisation, they took the form of spinsterhood, late marriage and preferably abstinence. Contraception was unthinkable to Malthus, a staunch rural parson who believed that the marital duty of sexual union was the production of offspring to the extent that God would give. With utter conviction, he thus wrote: "all these checks...may be resolved to misery and vice." [44] Increasing population meant increasing demand, which would always outstrip supply, leading to a fall in the level of population.

When contemporary conservative critics of eco-crisis discourse accuse environmentalists of 'Malthusianism', they often confuse the 'positive' or rational empirical content of Malthus with his moral theory and political prescriptions. Using the defence that the context of discovery does not determine the context of justification, the abstract and the concrete sides of the argument can be seen as distinct moments unnecessarily conjoined. Malthus lived during a transformative period of rapid population growth, the enclosure of common land, the proletarianisation of commoners, and the wild throes of an ill-disciplined market society that suffered frequent periods of panicked speculation, unemployment, underproduction, near starvation and the break down of law and order along the lines of class discipline. His social theory and political interventions reflect these pressing concerns, being the prescriptions drawn from his generally descriptive demography. According to Malthus, if a poor man were given five shillings and not the 18 pence he usually received, this extra money would do nothing to increase the production of food. Rather, the price competition of more money chasing the same quantity of meat and bread would simply raise prices to the point where the five shillings were not enough to survive upon. William Pitt's proposal to increase the poor rate would only increase the population beyond the means available for its support. The country could in either case not afford to provide more to paupers; or more accurately, would not give more than the tax-paying salaried classes were willing to extend in parish charity. Notably in this model, expenditure beyond the mere survival of the working class was considered a waste of national product to common vices such as drinking, gambling and irresponsible fornication; expenditure could only be productive as investment in the austere hands of the commercial classes. In 1800, Pitt withdrew his proposal, under pressure from a Malthusian backlash from Parliament. In 1834, a Poor Law Amendment bill passed the House of Lords, which instituted the Victorian solution to the poor question in the disciplinary confinement of the workhouse.[45] In order to maintain the natural law and moral justice of the market price, this juridical law prescribed the warehousing of the many abandoned to penitential penury by the invisible hand and the principle of population.

In contemporary debate, Malthusianism is a derogatory term for the 'zero-sum' critique of unlimited growth; biocentric writers who hold it are held to be misanthropic anti-humanists. Malthus is derided by conservative economists for misunderstanding the generative powers of the capitalist economic system, which turns apparent limits into commercial opportunities for entrepreneurs to overcome with technology.[46] Few neoliberal writers recall that political Malthusianism was originally a free trade argument for the moral value of unbridled competition and self-interest, and a defence of the 'naturalness' of the class divisions and degrading poverty accompanying the emergence of laissez-faire factory production. Whereas Malthus believed that population will expand to the limits of subsistence, contemporary economists believe that continuous growth overcomes productivity limits through technology and market efficiencies, rather than through expanding access to depletable natural capital such as topsoil, fisheries, forests, minerals and fossil fuels.

The invisible hand of the market, the organised division of industrial labour, and the implacable checks and balances imposed upon the fecundity of biological life were clearly conceptually entangled in Victorian political economy, as they were in biology and debates around social reform. All of these streams of thought contributed to the revolutionary reconceptualisation of the 'balance of nature' exemplified by Charles Darwin in the latter 19th century, which occurred occurred in parallel with the professionalisation of the sciences according to a philosophy of scientific materialism.

Darwin's diaries and notebooks of 1838 record his reading of *On Population.* While we know little of what Darwin thought of the human implications of social Malthusianism, his application of Malthus' economy of life and death to the problem of ecological change and speciation led to his breakthrough concept of natural selection, the mechanism underlying his theory of evolution. Until Darwin read Malthus, he had never seriously considered how it was the number of animals and plants stabilised and held themselves in relative proportions to one another. In fact, Malthus gave detailed discussions of vegetable and animate life, in which he asked why it was that the world was not entirely overrun with insects and frogs, given the vast number of eggs generated by every female. A vast overproduction of individual offspring was everywhere to be seen in nature, he asserted. The dismal science taught Darwin to think deeply about the ways in which the increase of animals must be exactly limited to the number that can actually live. This balance of nature evidently arose out of death, or what he called the "warring" of species. Every species in Europe, he mused, "must lose individuals every year to cold, hawks, etc" – even the death of single hawk must therefore effect the numbers of all the rest. Darwin's originality was to argue that this "war" would favour the strong over the weak. If only two puppies of a litter of seven survived to breed, chances were that the strongest, swiftest or most 'adapted' would predominate. In this way, over long periods of time death performed the creative function of 'fixing' favourable adaptations and erasing detrimental traits. Driven along by this adaptive struggle, species must simply change or die. [47] In the earliest expression of what was to become the theory of natural selection, the organising concept of *Origin of Species,* Darwin wrote in his notebook:

> "One may say there is a force like a hundred thousand wedges trying [to] force every kind of adapted structure in the oeconomy of nature, or rather forming gaps by thrusting out

weaker ones. The final cause of all this wedgings [*sic*] must be to sort out proper structure & adapt it to change."[48]

While it is not known what Darwin's opinions were regarding the intricacies of the political and economic debates of his day, there is no doubt that it was Malthus who served as the catalyst for the modernisation of biology embodied in the principle of natural selection. We do know that Darwin witnessed at first hand various moments of the extermination of 'inferior' races on the colonial frontiers in Australia and Paraguay during his journey on the *Beagle,* a trip in which he records his early troubled conclusions as to the centrality of violence within the economy of nature. Armed with the bio-economics of Malthusian population theory, Darwin provided the intellectual means for the final removal of the 'dispensational' millenarian terminology from the study of the economy of nature, placing biology upon a scientific footing. The contribution of the dismal science to ecology was to elevate the 'warring of species' for territory and offspring to its basic principle.

The old idea of the 'balance of nature' was first reinterpreted in evolutionist idiom by Herbert Spencer, who reasoned that the preservation of races implied a stable equilibrium between destructive and conservative forces.[49] In keeping with the Hobbesian view of the mythical pre-juridical past as a *bellum omnium contra omnes*, Spencer's historicist economy of nature mapped the concept of species selection onto the sub-category of 'race', and proposed that these were structured in the manner of 'social organisms'. Death and violence were paradoxically reframed as the ultimate drivers of the evolutionary process, which appeared to Man – the universal subject invented by bourgeois males to unify the murderous encounters with the panoply of racialised Others encountered on the colonial frontier - as the emergence of higher and more complex organisms such as himself. With Spencer, Progress was re-inferred within the order of nature as the history of competitive racial selection. The Darwinian account of speciation radically amplified the time depth of natural history, showing that entire clades of species had no living ancestors, and that the majority of species were long extinct. Biological interaction was red in tooth and claw, but this violence was the secret of the abundant production of diverse species adapted to each other's predatory instincts. In turn, political economists drew from this the lesson that if the ruthless competition evident in capitalist economic behaviour was not a violation of some pie-in-the-sky moral law, neither was it entirely in conformity to the amoral law of Darwinian selection. Rather, the liberal state represented the pragmatic moral progress of liberal market society, which had supposedly replaced the bloody and destructive 'state of nature' of primitive survival with the productive and civilising benefits of commercial competition and self-interested labour under free contract – the basis of the commonwealth.

As Hodgson, Ormerod and many other economic historians have observed, Darwinian theory and free market theory are of similar provenance.[50] The liberal ideology of unbridled competition and self-interest governing through the balancing of the forces of supply and demand by the 'market mechanism' foregrounded by Smith and Malthus was a crucial source of inspiration to the theory of evolution by natural selection, in which competition between self-interested individuals inevitably leads to the survival of the fittest.[51] As has been discussed at length in the previous chapter, free-market theory developed in the wake of industrialisation and the rise of the capitalist economy to a global scale. It was to be mathematically formalised through an analogy with equilibrium thermodynamics and statistical mechanics. Molecular biologist Mae Wan Ho notes the contemporary relevance of this history for contemporary understandings of 'the economy of nature': "Neo-Darwinian theory, expressed mathematically in population and biometrical genetics, is based on the same equilibrium, mechanistic assumptions and has an even closer link to statistics." [52] It was not, however, only liberal economists who sought to integrate natural selection, environmental influence and organic development into a social physics of industrial society.

It is well known that Friedrich Engels declared at Marx's funeral that just as Darwin discovered the law of development of organic nature, so Marx had discovered the law of development of human history. It is also well known that Marx chided Darwin for reproducing English bourgeois social relations in nature, with his emphasis on competition, inheritance and competition. It is perhaps less well known, that he considered Darwin's theory of natural selection as 'the class struggle writ large.' As Guiliano Pancaldi has shown in an intriguing study, a largely under-explored avenue of conceptual and metaphorical exchange between the natural and social sciences is the influence of Darwinian ecology upon the economic thought of Marx. [53] In a note added to the second German edition of *Capital* (1872), Marx described Darwin's study as an inquiry into "the history of natural technology, i.e. the formation of the organs of plants and animals, which serve as the instruments of production for sustaining their life." This unusual characterisation of Darwin's theory was, as Pancaldi demonstrates, a crucial first step in Marx's own original proposal to develop a "critical history of [human] technology," or rather, a "history of the productive organs of man in society, of organs [machines, inventions etc.] that are the material basis of every particular organisation of society." Marx's project to develop a political economy grounded in the material environment of society had much to gain from the rising prestige of Darwin. To Marx's credit he emphasised the social relations profoundly embedded in machinery, whereas the classical tradition merely abstracted technology as a generic and abstract form of capital investment. In an 1867 letter to Engels, concerning a forthcoming review essay of *Capital* that Engels was writing for the German journal *Der Beobachter*, Marx instructed him to emphasize the "positive" achievements of the work in demonstrating that "cooperation, division of labour, the use of machines and the connected social relations develop according to natural laws."

However where the neoclassical 'revolutionaries' of 1871 appropriated the invariance principles of proto-energetics to produce a law-bound, rational, and harmonious Society where floating prices produced the best of all possible worlds, Marx's analysis of the business cycle profoundly emphasised chronic disequilibrium, with speculative investment leading to both overproduction, underemployment and sectoral collapses. These systemic moments of crisis resembled what we would now, in the language of chaos theory, call 'bifurcation points': revolutionary moments where the socio-economic system irreversibly crosses a threshold into a new state. In the letter to Engels, Marx even went so far as to dictate directly parts of the review, suggesting that he write:

> "When he [Marx] shows that, from an economic point of view, present society is pregnant with a new and higher form, he is just showing from a social point of view the same process of transformation established by Darwin in natural history. The liberal theory of progress concurs on this and it is the author's merit to reveal a hidden progress precisely where modern economic relations display discouraging immediate consequences." [54]

Here we see natural selection as the class struggle writ large, although Marx makes the common mistake of seeing evolution as progressive. Darwin sought merely to explain speciation in terms of adaptation to existing conditions, which need not at all imply progress over time. Evolution as conceived by Darwin is non-teleological. Although Darwin was chided by Marx and his successors for projecting what they saw as the social relations of Manchesterism (with its intense focus on competition, inheritance, and the 'struggle for existence') into the natural world at large, Darwin was nevertheless indispensable to the progressive movement for providing a theory of development and an economy of nature that was resoundingly post-theological. Whereas David Hume had provided a refutation of William Paley's popular creationist "argument from design" thesis that was convincing to philosophers, he had not an alternative account of the origin of living creatures. It was Darwin who provided the mechanism by which the economy of nature developed new forms of life, structure and organisation. Darwin's thesis did not require God to supervise or direct nature, and for Darwin, disturbing as it might be to contemplate, there was only one possible conclusion: there was no such God. As we have seen, the death of God led to a profound ontological insecurity, which privileged the material as the site of truth and elevated the physicist's role in generating legitimacy for various forms of social theory, with all the attendant problems of generating a meaningful secular history composed of over-determined 'social forces.' For the neoclassical economists, social order arose ahistorically due to the global effects of fixed individual human natures. For the Eastern European Marxists, Engel's attempts to square historical materialism with thermodynamic concerns yielded an 'energetic dialectics' which maintained Helmholtzian productivism as orthodoxy until a few decades ago. [55] Like the neoclassicals, Engels' attempt to raise his social theory to the status of physical science succeeded only in imported the utopiansim of proto-energetics, with its ignorance of the entropy law and its optimism regarding infinite progress in the perfection of a malleable and indestructible nature.

When Ernst Haeckel defined ecology as "the body of knowledge concerning the economy of nature" he was not merely reflecting a general enthusiasm among late 19th century intellectuals for political economy, or throwing metaphors around for the sake of literary flourish, but repeating the phrase given to the comprehensive study of biological interactions in its earliest forms. For Haeckel, the science of the economy of nature meant:

> "[...] the investigation of the total relations of the animal both to its organic and to it in organic environment; including and above all, its friendly and inimical relation with those animals with which it comes directly or indirectly into contact – in a word, ecology is the study of all the complex relationships referred to by Darwin as the conditions of the struggle for existence." [56]

The new term 'ecology' was intended to seal the economy of nature off from its history of dispensational historicism and invest the new science firmly in the scientific materialism of the late 19th century.

**Superorganisms: American Ecology and National Development**

In this section I offer a very brief sketch of the early history of ecology as a science, whose central concept was that of the 'complex organism', elaborated by the groundbreaking work of Frederick Clements in the first decades of the 20th century. I trace the movement from the organismic metaphor of the 'superorganisam', or the 'successional climax community' under whose flag ecology offered itself as an applied science useful to the problems of national development. This occurred at a time when the United States had well and truly closed the westward drive to unincorporated frontiers. The simultaneous disasters of Wall Street and the Dust Bowl caused people to question the free wheeling practices of frontier individualism and stock market liberalism. Through the work of Clements and his peers, ecology was put forward as part of a more general movement of the natural and social sciences to contribute to the rationalisation of a more communal and nationalist version of the ideology of American exceptionalism.

In developing this narrative about the disciplinary trajectory of ecology, we will attempt to situate its choice of approaches and metaphors in historical context, given its increasingly urgent interventions into the political-economic arena. The most authoritative of sources on this topic is most likely Sharon

Kingsland's recent history, *The Evolution of American Ecology, 1890 – 2000.* [57] This volume does us the service of contextualising important debates around ecology's theoretical status as it sought to rise above its heritage in the field studies of amateur natural historians and become a basic science, useful in regard to pressing questions around land use and social policy. This raised problems for its practitioners, namely a continual ambiguity as to whether ecology ought to be a purely descriptive science of untrammelled nature on the one hand, or on the other, as an applied science dealing primarily with human economic interactions with nature. Kingsland locates these themes within wider historical debates about progress and national development, and argues that the formation of ecology as a distinct discipline, which happened largely in the United States, occurred in an ideological context suffused by the national mythos of American exceptionalism. A variant of liberal millennialism converted into the national ideology of the United States, American exceptionalism might be described as a historical faith that the abundant natural resources, republican institutions and democratic ingenuity of Americans would allow them to escape the historical quagmire of class-conflict ridden Europe and lead the way to a future based on liberal humanism and scientific modernity. Even Hegel, the dialectical philosopher of historical forces, exempted America from his laws of history; as 'the country of the future' he saw in it the possibility of a clean break from 'the historical arsenal of Old Europe.'

From the late 19th century, the US was the chief site of discipline building and innovation in the new science of ecology. Firmly located in the New World, we might pause to note further interesting historical parallels between ecology and economics, which both took firm root in American soil. The roots of ecology were primarily in mid-19th century Darwinism and the Humboldtian science of the Germanic *Naturphilosophie* tradition, which divided inquiry methodologically into *Naturwissenshaft* and *Gesellwissenshaft.* As English speakers, American scientific thinkers were far more inclined to the naturalistic reductionism of social to natural relations and then into mechanical causes, in the tradition of Hobbes, Bacon, Descartes, and Newton. Similarly, neoclassical economics was initially not a predominantly Anglo-American school: in the late nineteenth century, it had solid European roots in the Lausanne School under Walras in France, in Italy in the work of those influenced by Pareto, and in Austria in the group around Carl Menger.[58] In the following generation, the orthodoxy was primarily developed in England due to the prestige and political access of the Marshallian research program. From the late 1920's onwards, as Europe embarked on various socialist, nationalist and Keynesian experiments in the wake of the Great Depression, the neoclassical program crossed the Atlantic and became increasingly embedded in American social science, where its methodological individualism and scientism was in tune with the national mythos and its particular forms of historical consciousness. The historian of science Dorothy Ross has reviewed the vast American social science literature produced up until 1929, and arrived at the following characterisation of the relationship between American social science and the national ideology of American exceptionalism:

> "Hoping first in the Gilded Age to sustain fixed laws of nature and history, social scientists in the Progressive era linked American history to Western liberal history and its modernizing forces to capitalism, democracy and science. But they hastened to subject that history to scientific control and tried to carve out a realm of nature that would perpetuate exceptionalist ideals. By the 1920s, driven to harder versions of technological control, the social sciences had transmuted the dismaying uncertainties of history into controllable natural processes." [59]

Ross attributes the rise of particularly American variants of the social sciences in defence of American exceptionalism to the loss of religious authority brought about by industrialism. Such remarks could equally apply, interestingly enough, to the histories of both economics and ecology, and this dialectic certainly did not disappear in 1929 (the end of Ross's account) but as my account will show, at least as far as ecology is concerned, the exceptionalist optimism regarding the subjection of a realm of nature outside history to technological control reached its apogee in the early 1970's, precisely at the moment when ecological crisis reunited natural history with that of the national-state. Since then, the rise of neoclassical governance at the transnational level has 'ended ideology' and similarly transmuted history into a natural process of free markets in equilibrium. The role of American exceptionalist ideology in the ongoing development of ecological and economic science is not, however the main concern of the following discussion.

It should be obvious to any historically informed reader that, like other disciplines, ecology did not emerge spontaneously as a unified science with a coherent set of concepts and methodologies but struggled to define itself as science and find its place in society. Ecology has always had to grapple with fundamental questions regarding the relationship of Nature to Society. Indeed its efforts to isolate general laws and principles applicable to ecosystem succession and equilibrium *in the absence of human disturbances* were largely inspired by the accelerating disappearance of species rich environments through the increasing reach of modern agricultural, industrial and urban development. Ecology's tendency to construct a pure nature external to social relations was largely the result of early efforts to reconstruct the pre-industrial order of nature (an order in which the role of indigenes was often constructed as Natural in racially deterministic ways) in order to predict and control future transformations of the environment in the interests of scientifically rational 'human' progress.

The extent to which ecology yields insights of critical relevance to questions of philosophical, social, political, and economic change has always remained an urgent question, despite the efforts of some ecologists to confine themselves to purely technical concerns in order to delineate the boundaries within which the discipline can be said to have a purely scientific character. Among those whose definition of 'science' is Comtean – the reduction of explanation to the mathematical rigour of physical chemistry - ecology has often not been considered a true or 'hard' science, insofar as it arises from specific natural histories and the ad hoc character of local field work, or deals with ambitiously large and complex theoretical 'objects', or tends toward holism and organicism. As such it is unsurprising that like their colleagues in the social sciences, ecologists have often developed the advanced symptoms of 'physics envy', as Cohen suggested in 1971.[60]

Against the views of such critics of ecology, which have occasionally pressured its practitioners, Kingsland argues that the questions that the early ecologists identified as comprising the research agenda of their field, as they carved out a disciplinary territory from diverse fields such as evolutionary biology, natural history, biogeography, physiology, were and remain some of the most important questions science has been asked to answer.

> "Ecology cannot have fixed boundaries and ecologists must not shy away from ambitious goals. They grapple with some of the hardest questions in science and cannot afford to feel oppressed by the claim that theirs is a 'soft' science. [...] We are indebted to [the early ecologists] for beginning a research tradition that has grown increasingly important for addressing the problems that beset our overcrowded world." [61]

These questions arose largely on the frontiers of the expanding settler societies of the 19th century, in Southern Africa, Australia, and particularly the United States. Europe had long been a densely populated and profoundly humanised landscape, it was the long frontier of 'wilderness' encountered by European colonists and settlers that provided the impetus for the development of ecology. Ecology might indeed be thought of as a science of the frontier, always looking back to a time before the modernised landscape to construct a reference point for measuring society. The industrialising logic of late colonialism led to the wholesale transformation of continents and biomes through mass immigrations, deforestation, agriculture, river diversions, hunting and mining. Held by the majorities of the time as 'development' itself, this process came to be seen by some prophetic writers as potentially threatening to long-term development. One classic text often cited as a pivotal study in environmental history is *Man and Nature: The Earth as Modified by Human Action*, published in 1874 by George Perkins Marsh.[62] Marsh's work is perhaps the first effort towards the 'long term, global stocktaking' of human interaction with the landscape continued into the present day by the annual publications of the Worldwatch Institute, the UN Millennium Ecosystem Assessment and numerous other monumental efforts to document global environmental change. Marsh's systematic attempts to grapple with the effects of rapid colonisation – i.e. the extinction of large mammals, the proliferation of weeds, desertification and erosion – were made from the perspective of a natural theology that saw such actions as transgressing the natural order laid down by God, with grave consequences for Man.

> "The ravages committed by man subvert the relations and destroy the balance which nature had established between her organised and her inorganic creations; and she avenges herself upon the intruder, by letting loose upon her defaced provinces destructive energies hitherto kept in check by organic forces destined to be his best auxiliaries, but which he has unwisely dispersed and driven from the field of action." [63]

The key insight of Marsh's treatise, according to David Lowenthal, the editor of its most recent edition, is that that the balance of nature was not always automatically self-correcting. Human intervention was necessary to restore what human intervention had destroyed.[64] Careful planning was required to re-construct and restore these vital balances. Modern civilisation had to rise to the challenges created by its current blindness to the loss of nature's resilience, its ability to adjust to external shocks and return to equilibrium. Marsh was pessimistic about the prospects of such a challenge in Europe, whose deeply engrained pattern of land degradation produced flows of millions of impoverished immigrants to the New Worlds of Australasia, the Americas, and a few small Pacific islands. It was in these frontier locations that Marsh saw the prospect of a truer accord with a largely untarnished Nature, although he noted with trepidation the free-wheeling nomadism of the North American settlers, who tended to scour each new frontier location for immediate economic gain and then move westward, rather than settling down to establish mature and long lasting relationships with the bountiful soil of specific locations. In Marsh's global proto-ecology we see already forming the two impulses of ecology as a source of narrative about the future of industrial modernity: fear of its destructive impacts leading to the apocalyptic demise of Western civilisation, and calls to avert such a future with a science capable of anticipating the consequences of human activity and ameliorating them with projects of preservation, re-afforestation, and the scientific engineering and management of the land.[65] In the first instance is an acknowledgement that the 'balance of nature' had been disrupted by (white, technologically superior) humans, and in the second, the conclusion that a new balance between nature and (white, scientifically superior) civilisation must be struck.

As scientists that seek to describe the systematic unity of biological inter-relation and the interdependence of organisms, it would appear only 'natural' for ecologists to be drawn to organicist philosophical positions. Organicism as theory posits that certain complex wholes exhibit the characteristics of organisms, which differ from mere mechanisms or statistical aggregates because of the dependence of the existence of the parts on their position in the whole.[66] A butterfly's wing, for example, is and only remains as such if united to a living body. Organicism has been applied to social institutions by writers such as August Comte, Herbert Spencer and (arguably) by Friedrich von Hayek in his evolutionary theory of the market as 'spontaneous order'. In its most ambitious forms it takes the organism as the model and metaphor for the universe at large, as in the philosophy of Alfred North Whitehead. Organicists assume, as Worster notes, that "the organism possesses qualities that elude physico-chemical analysis, and that these result from the integrated functioning of the whole; in other words the whole is more than the sum of the parts." [67] The organic metaphor implies not only that the parts of the whole are internally unified, but that the whole has a life cycle, a course of development, senescence and reproduction in the manner of typical living organisms. In the application of this principle to ecology, the 'economy of nature' is viewed as a 'complex organism.' Individual plants, insects and animals cannot be completely understood as discrete objects sealed off from their environments, but must be contextualised by their participation in and dependence upon the whole. As the anthropologist and cyberneticist Gregory Bateson once put it, "the basic unit of survival is the organism *plus* its environment." [68]

Speaking generally, in the early years of ecology practitioners tended to be divided into plant ecologists and animal ecologists. A further division of approaches was discerned between autecologists and synecologists, with the former focussing on the population dynamics of a single species and the latter dealing with the relationships in the multi-species 'community'. Observations about how different plant communities change over time have a long history that predates formal science and the formation of ecology as distinct research program. Key early modern studies included work by Alexander von Humboldt (1850) on German landscapes, Henry David Thoreau (1860) a German immigrant to the US who wrote on forest succession after logging, and the work of Eugene Warming who produced the first ecology textbook which included formulations of the 'laws of succession'. Stephen Forbes is another figure often cited in the literature, whose 1887 lecture 'The Lake as Microcosm" forged a synthesis between Darwinism, earlier balance-of-nature concepts and notions of the biotic community. Forbes held the view that the balance of nature held populations at a constant value. "Perhaps no phenomena of life is more remarkable than the steady balance of organic nature which holds each species within the limits of a uniform average number, year after year." [69] As Kim Cuddington points out, this view is difficult to square with Forbes' professional focus on the biological control of pest species, an unwelcome economic problem from the point of view of agriculture. Rapid increases of insect pests to 'plague proportions' are still often regarded as unusual and unnatural events, although they are no longer associated with divine punishment for human contraventions of the order of nature as they were in pre-modern Europe.[70]

The Chicago ecologist Henry Cowles is generally credited with providing the first modern study in plant ecology, in which he gave a detailed study of the successive changes in vegetation associated with the migration of sand dunes on the shores of Lake Michigan.[71] This study introduced the metaphor of the co-operative 'community' into the study of inter-species interaction. Indeed, much late $19^{th}$ and early $20^{th}$ century research in ecology emphasised the 'social' aspect of biological life, or as Mohan Wali puts it, "the communal relationships among distinct assemblages of plants and other organisms in natural systems, as opposed to contemporary linguistic constructs", which will discuss later.[72] Two examples given by Wali are an influential 1928 work by Josius Braun-Blanquet called *Pflanzensociologie* ('plant sociology') which develops a theory of community types or 'plant associations' using concepts such as sociability, gregariousness, and constancy to refer to attributes of inter-species relationships, and Charles Elton's important 1927 work *Animal Ecology,* which was concerned with "the sociology and economics of animals."[73] Elton recommended that ecology be a part of the training of biologists, as it was primarily this branch of science that would be "able to offer immediate practical help in the present parlous state of civilisation."[74]

The coherent fusion of plant and animal ecology can be largely attributed to the work of Frederick Clements, whose early formative years and professional career were spent observing and documenting the historic changes occurring to the Great Plains, the vast prairies of the American Mid-West. As one of the most important early theorists of ecological science, Clements is best known for his attempt to establish general theories of ecological succession. Clements' organicist conception of the 'climax community' derived from his study of the Great Plains notably led to a distinction between the role of human beings in the economy of nature, drawing a sharp line between the Native Americans the modern European colonists who began to decisively alter the ecology of the region from the latter $19^{th}$ century.

The ancestors of both the Plains Indians who inhabited the prairies and the wild herds of bison that formed the basis of their subsistence economy are thought to have arrived relatively recently in the North American biota, crossing the Bering Strait from Eurasia between 17 000 and 10 000 years ago. As the United States expanded westward, the government encouraged the slaughter of the buffalo herds as a form of ecological (i.e. economic) warfare against the resistant Sioux, Cheyenne, Crow, Blackfoot, Comanche, and Pawnee peoples. As railway networks expanded through the mid-West, the vast herds of bison, thought to have numbered over 60 million at mid-century, came under enormous pressure from thousands of sporting shooters and commercial hunters. By 1876, enforcing a presidential order that all Indians be confined to reservations, the US Army had effectively rid the

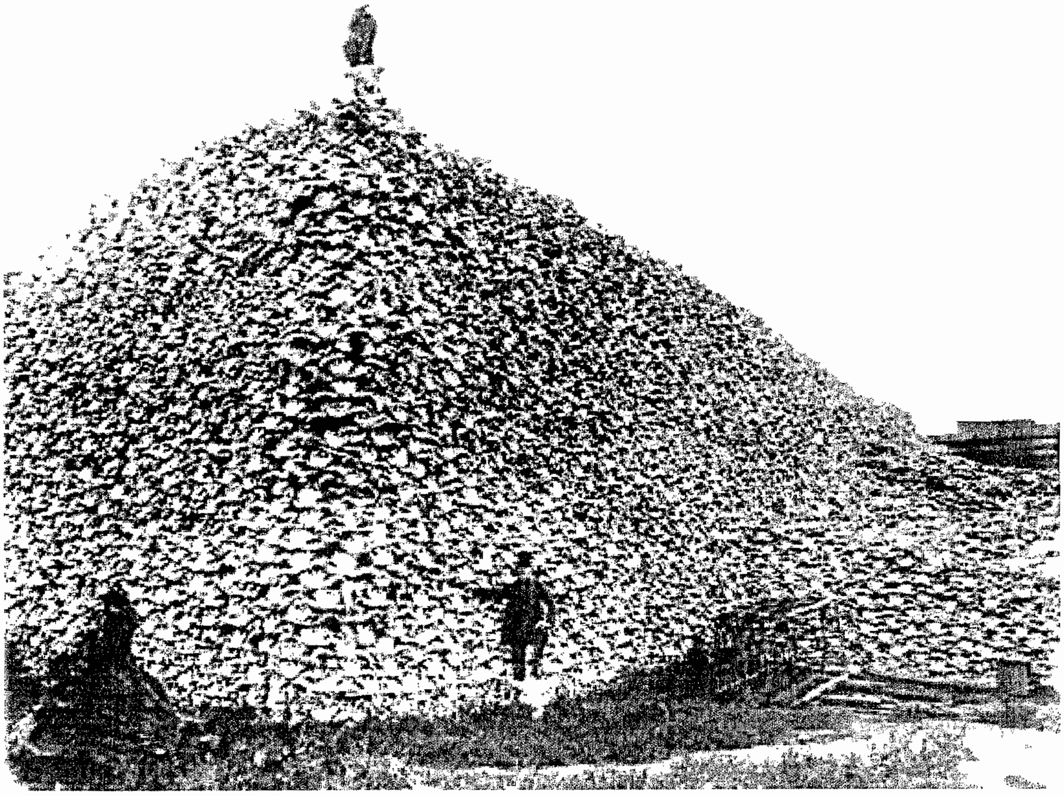

**Figure 4. A pile of American bison skulls waiting to be ground into fertilizer, c.1875.** Source: Burton Historical Collection, Detroit Public Library. <wikipedia.org/wiki/Image:Bison_skull_pile%2C_ca1870.png>

Great Plains of its indigenous population. By the mid-1890s, the bison was on the verge of extinction, reduced to a population of around 300.

The period 1875 – 1886 was one of unusually high rainfall, and this attracted huge numbers of settlers, who fenced off sections of the prairies for intensive grazing and agriculture. A severe drought during 1893-1896 led to an equally rapid depopulation, as about half a million people abandoned the frontier regions and turned their wagons eastward. It was in these years that Clements began his early study as a botanist, as part of a project to discover which grazing and farming practices might be viable in the region. Destruction of the native grasslands was well underway by this time. In areas that had not been farmed, perhaps fifty species of grass could be found per square mile, in many areas this diversity was rapidly dwindling, leading to reduced yields, falling carrying capacity for cattle, and the destruction of soil. The studies of Clements and his colleagues noted that in areas that retained an unbroken line of seed, the prairie vegetation could over fairly short periods of time make a more or less complete recovery, arriving at a stable equilibrium or 'climax' state of maximum diversity and biomass after passing through various 'stages' of development.[75] Ironically, while it was the expansion of the railways and the locomotives power to transfer large volumes of immigrants and bulk goods that had led to the precipitous transformation of the prairies, the fact that the tracks were fenced off meant that often these unbroken corridors were often the only places where 'nature' was able to recover from the disturbances of modern economic usage.

Numerous field observations in frontier regions of the American West led Clements to formulate general principles of succession, applicable to widely different climactic environments and the different species that were adapted to them. Noting the functional interdependence of associated species in the process of succession, Clements designated the most important analytical unit of ecology as the 'complex organism'. In a state of maturity and health, the complex organism manifested as a 'climax community', as the final equilibrium state of nature to which living systems tend to return after a disturbance. The climax community manifested the highest levels of species diversity, biomass and population stability. Adopting the then common metaphors of organicism, Clements wrote:

> "The unit of vegetation, the climax formation, is an organic entity. As an organism, the formation arises, grows, matures, and dies. Its response to the habitat is shown in processes or functions and in the structures which are the record as well as the result of these functions. Furthermore, each climax formation is able to reproduce, repeating with essential fidelity the stages of development. The life history of a formation is a complex but definite process, comparable in its chief features with the life-history of an individual plant. The climax formation is the adult organism, the fully developed community, of which all initial and medial stages are but stages of development. Succession is the process of the reproduction of a formation, and this process can no more fail to terminate in the adult form of vegetation than it can in the case of the individual plant." [76]

Clements was the first to provide a comprehensive theory of plant succession with a scientific methodology that was convincing in its order and logic. Despite the numerous criticisms levelled at him by his successors, "at the simplest level, the mechanisms outlined by Clements in 1919 remain valid today."[77] For Clements, organicism was no mere metaphor, and he was criticised by many for insisting on the deterministic sequence of succession, which he thought of as the central fact of ecological study. Due to the organisational and self-equilibrating properties of plant associations, Clements argued that it was valid to describe them as a kind of higher order organism, or 'complex organism,' which, like individual organisms, exhibited a fixed developmental sequence that could be predicted. Within the limits dictated by climate and landscape, general principles of ecological succession for the evolving structure of the 'complex organism', Clements thought, could be ascertained. Although these principles could only be derived from careful study in the field, without the possibility of a general theory and a coherent, accepted methodology, ecology would not be justified as a systematic science with its own research program. It would rather remain a collection of localised natural histories, each idiosyncratically couched in its authors' own notions of relevance. Unless ecology could provide an objective, systematic account of how nature actually worked it would remain nothing more than an ill-defined 'point of view'.

By the mid-1930s, Clements began writing of his ambitions regarding the social role of ecological science, reflecting on an unfolding ecological disaster of unprecedented national importance, the creation of the Dust Bowl. Following the eradication of Indian resistance and the herds of buffalo, millions of wheat croppers had been encouraged to migrate and establish farms on the prairies of the Great Plains. During periods of relatively constant rainfall, Midwestern politicians and science professors had encouraged this migration to what was at best marginal farmland, under the optimistic belief that climate responded positively to agriculture. "Rain follows the plough" was the common slogan, reflecting perhaps less the results of empirical climatological study than the exceptionalist confidence that American expansion was blessed by Divine Providence. Even in the short history of European occupation, the area had been known to be prone to extended drought. Against the evidence of experience (and all ecological principles) the US Bureau of Soils proclaimed in 1909 that "the soil is the one indestructible, immutable asset that the nation possesses. It is the one resource that cannot be exhausted: it can not be used up."[78] Between 1889 and 1930, 'virgin' prairie, with it fragile soils formed slowly over hundreds of years by the complex interactions of native ecosystems, was ploughed into wheat farms at an average rate of over 1 million acres per year, with little regard for techniques of soil conservation. From around 1934 to 1939, an expanding area of severely eroded land generated increasingly intense dust storms as the loose and fragile soil was swept across the country. The destruction of vegetation through land clearing, overgrazing, and deep ploughing of soil was amplified in a self-reinforcing process by severe dust storms, which stripped topsoil and destroyed millions of acres of standing crops. In May 1934, the first of a long sequence of major storms picked up 350 million tons of topsoil and deposited it all over the eastern US. Twelve million tons fell on Chicago alone and dust landed on ships 300 miles off the Atlantic coast. The destruction of the grasslands led to the partial collapse and depopulation of farming economies in west Kansas, south-east Colorado, north-west Oklahoma, north Texas, north-east New Mexico, and parts of Nebraska and the Dakotas. Impoverished environmental refugees, a quarter of whom suffered from respiratory illness, abandoned their broken farms in a mass exodus of 3.5 million people.[79]

This catastrophe opened up a niche for the upstart science. By this time, Clements was inclined to think of ecology not just as a minor branch of biology, but as a coherent scientific approach to the entire range of problems regarding life and the environment.[80] In particular he argued that the events of the Dust Bowl showed the future necessity of the role of the ecologist as an impartial source of knowledge on what forms of agriculture and settlement were viable in terms of the long-term resilience of the as yet ill-understood ecological communities of the New World. The myopic individualism of farmers, lenders and land speculators, each seeking to maximise profits in the boom periods accompanying high prices or high rainfall, led to the widespread adoption of farming practices which damaged the long term resilience of the 'complex organism'. The Dust Bowl disaster showed that without careful ecological planning, the cycles of boom and bust driven by the corrupting logics of politics and profit seeking would result in the 'ruin of the countryside,' with a corresponding slide into moral degeneracy such as the cattle-rustling and vigilante justice that he recalled from the less degraded landscapes of his youth.[81] As Bowler has noted, Clements was positioned to exert considerable influence on land use policies after the disaster of the Dust Bowl, and urged administrators to discourage cropping in the drier areas of the plains, which would be more suitable for grazing. Ecology thus gained a vocation for assisting society to make the best economic use of land by demonstrating which modes of exploitation would be most in tune with what was 'natural' for that region.[82]

Donald Worster notes that Clements' notion of the climax community posits a stable external nature devoid of humans and suggests that this reflects a nostalgia for the (spuriously?) 'virgin' expanses of native prairie that he encountered as a young man growing up on the uncrowded frontier of settlement. Kingsland proposes otherwise; for her the attempt to discover how natural systems developed in the absence of modern disturbances was more likely motivated by a concern for the social consequences of land degradation. In addition, Kingsland argues convincingly that Clements' hardcore insistence upon the organismic metaphor at the heart of his ecology – which he asserted as an objective fact rather than a heuristic concept - was crucial to the role he envisioned for ecology as an objective managerial science of civilised development. The organismic structure of the complex community, with each species and population functionally integrated into the whole, meant that its development followed a historical process with a definite direction toward diversification and equilibrium, a path that could be predicted with the certainty of the stages of growth of an embryo. Clements' organismic determinism notably assumed two things: humans were not (or were no longer) part of nature; also, it was possible to detect which changes in the environment were 'natural' and which were not even after humans had arrived on the scene. Without knowledge of how nature functioned in the absence of human intervention, how could ecologists offer any advice on which kinds of development were more likely to be viable in the long term? With the ability to make predictions came the possibility of control. Subject to the limitations of climate, which Clements assumed would forever remain beyond control, the ecologist armed with the knowledge of the process of succession would not only be able to accurately observe nature but achieve commanding power over it. "In short," he argued, "as an instrument for the control of the entire range of human uses of vegetation and the land, succession is wholly unrivalled." [83] This did not mean passively living in harmony with nature, but implied all sorts of interventions. As Kingsland writes, Clementsian ecology was entirely in tune with the scientific optimism of the Progressive Era:

> "Once understood the natural process could be retarded, accelerated, telescoped, held in one stage indefinitely, or deflected along another course, perhaps even destroyed in order to allow the process to start again. It could be modified by the introduction of new species." [84]

Clements was no different from other early ecologists and proto-environmentalist thinkers in preferring organismic, historicist and holistic accounts of nature. Indeed, such models were widely popular in reformist politics and their associated social sciences in the 1930s, and despite the fact that 'Modern Man' and Nature were separated in Clements model, it is possible to argue that a social climate more accepting of his ideas had begun to arrive by the middle of that decade. As Alice Ingerson suggests, ecologists were also engaged in debates about human society and hoped to influence public policy, and despite the claims that theory followed objective observation, it is plausible to suggest that prevalent images of society may have been projected back into models of nature.[85] (The following examples are drawn from her work.) Writing of the changes of policy inspired by Clements after the Dust Bowl, Bowler suggests that the possibility of regional management of in the interests of the long-term health of the complex organism could only be conceived of given a government that was willing and able to over-ride individual gain for the public good. The super-organism fitted well with reformist models of society that saw society as a unified whole, with the government as the brain.[86] Similarly, Mittman notes that the narrative historicism of the ecological climax community resembled historicist stage theories of social progress, in that both detected a movement toward increasing interdependence, specialisation, and 'cooperation'.[87] Linking the acceptance of ecology as a science of holistic management to economic thought, Worster suggests that because the disaster of the Dust Bowl followed the collapse of Wall Street and the entire economic system, people were predisposed to accept the ecologists' concern for maintaining the community of life in a planned equilibrium, as the difficulties of the decade had inspired a mood of communalism over individualism.[88] Notably, contemporary liberal critics of ecological holism as a philosophy of government were able to link its claim to provide society with a governmental science applicable to the whole of society and its natural environment to the profoundly anti-democratic tendencies of the totalitarian and utopian European technocratic elites of the 1930s. The conservative French philosopher Luc Ferry has revived this critique more recently in an offhanded dismissal of environmentalist narratives.[89]

Ecology's undramatic entry into the political realm in the 1930s nevertheless raised a now familiar dilemma with regard to its social function. Was it a 'pure' scientific profession that ought merely to accurately describe encounters with 'virgin' nature in the field, carefully building theory and providing objective, value-free information to hand over without opinion to policy makers? Or was ecology an applied science with which to manage the entire agricultural and industrial economy's interface with nature, providing insight into the most efficient forms of exploitation, by keeping 'production' within the limits decreed by the fragile regenerative capacity of the complex-organism? In either case, most ecologists felt largely ignored as their expert analyses of destructive agricultural practices (such as those that led to the desertification of the Dust Bowl) remained internal to the limited spaces available to ecologists in the ivory tower. Few universities taught ecology as a subject, and even as late as 1964, Sears lamented the low status of ecology, which was generally perceived as of "limited interest and utility".[90]

Another possibility is that in its engagement with the productivist ethic and historicist discourse of national development, ecology itself became transfigured by its claim to provide a new way of perceiving the world as a totality. By exposing the general blindness to the potentially apocalyptic consequences of environmental destruction, ecologists hoped to forge a new language of natural law and thus to foster a transformative social ethic with which to transcend the destructive and socially undesirable consequences of short-sighted industrial modernisation.

In summary, we can note that the reigning metaphor that brought ecology into the realm of the useful sciences was, quite naturally an organicist one. However apt the idea of the 'super-organism' would seem, it is notably difficult to measure and quantify the specific qualities and identities implied by the metaphor. When is a forest 'senescent' for example? If it true, as some would say, that the essence of science is measurement, then the organicist account will always have problems claiming its rank among the sciences.

In the following section, we will explore further the parallel between neoclassical economics in the 1870s and the trajectory of ecology in the post-WWII period, as it sought to incorporate energetics: the mode of inquiry that promised the key to the formal modelling of the formidable complexity of ecological interaction, and thus to the halls of Science. This process was a continuation of the search for a scientific idiom to represent the economy of nature as law-bound within the overarching metaphor of 'the balance of nature.' The decline of the organic meta-theory in favour of a rising mechanism was to have profound effects on the development of ecology as a science and in its applied form as tool of social technology.

**Ecological Mechanics: Energetics, Ecology and the Great World Engine.**

In this section we will examine the route by which ecology arrived 'in the lobby of the energy hotel.'[91] A century after this complex metaphorical transfer had been attempted by economists for 'the market' or 'the economy' in the publication of Jevon's *Theory of Political Economy,* Walras' *Elements of Pure Economics* and subsequent works of Pareto and Edgeware, ecologists had developed their own far more thorough energetic conception of the ecosystem, of which we can take the 1971 edition of E. P. Odum's *Fundamentals of Ecology* as paradigmatic. Notably, the very notion of 'energy' had changed significantly since the pre-entropic sources borrowed abstractly by the marginalist revolutionaries: theoretical ecologists were fully aware of the second law and attempted to incorporate it into the models driving empirical field work. For ecology, this meant the shift from the relevant unit of analysis being a localised 'superorganism' or 'biotic community' (this grassland, that tundra) to a general theory of the 'ecosystem' as a system of energy conversion. In line with the Law of the Conservation of Energy, the ecosystem concept promised general modelling and precise quantification on the basis of the circulation of matter and energy (although accurate prediction is perhaps another issue) through anything identifiable as a 'system', which could be microbes in a single drop of water or the biosphere as a whole, including its humans and their machines.

The process of succession and its corollary concept of the climax community began to be displaced as the most important concept in professional ecology from 1935, when Cambridge botanist Arthur Tansley introduced the concept of the 'eco-system'. While the comprehensively organicist approach could still be found, for example, as late as 1949 in Alee and Park's widely read text book on animal ecology, by the mid 1950s the ecosystem had replaced the super-organism as the central object of ecological study.[92] Tansley coined the term in an article, which specifically sought to address the 'use and abuse of vegetational concepts and terms.' Tansley's concept of the ecosystem was intended to take ecology in a direction away from organicism, and was developed in reaction to the rigidity of Clements' description of succession and the ambitious metaphysical holism of generalists such as General Jans Smuts.[93] By the late 1960s, largely due to the educational and public careers of Howard and Eugene Odum, the ecosystem had become popularly recognised as the central concept not only of ecology as science, but as the political message and medium of economic analysis of the modern environmental movement. If the move away from organicism that ecosystem thinking signified accomplished a revolutionary change in the idiom of ecology, its becoming-mechanistic anchored its critique of society and economics within a model of industrial intensification and expansion derived from systems biology and informed by information theory and thermodynamics.

To flesh out this narrative we now return to Tansley, who reframed and directed the study of economy of nature into the analysis of biophysical structures and systems combining both living and non-living elements. Against the ultimate focus of Clementsian super-organism theory on the 'communitarian' structure of inter-biological relations, Tansley proposed that:

> "[...] the more fundamental conception is, it seems to me, the whole system (in the sense of physics), including not only the organism complex, but also the whole complex of physical factors forming what we call the environment of the biome. Though the organisms claim our primary interest, when we are trying to think fundamentally we cannot separate them from their special environment, with which they form one physical system. [...] Our natural human prejudices force us to consider organisms (in the sense of the biologist) as the most important parts of these systems, but certainly the inorganic 'factors' are also parts – there could be no systems without them, and there is constant interchange not only between the organisms but between the organic and the inorganic. These ecosystems, as we may call them, are of the most various kinds and sizes. They form one category of the universe as whole down to the atom."[94]

> "The fundamental concept is the ecosystem, which is a particular category among the physical systems that make up the universe. In an ecosystem the organisms and the inorganic factors alike are components which are in relatively stable dynamic equilibrium."[95]

Where Clements had insisted that the super-organism was not a metaphor but an identity, Tansley saw that the underlying systemic reality was not in the morphological integration and functional adaptation of interdependent communities of species, but was bounded within the measurable totality of physico-chemical and energetic flows.

The ecosystem concept was remarkable in the way that it opened up the scope of ecology as a scientific methodology and a potentially applied science. In his concept of the ecosystem, Tansley developed a dynamic interaction between the 'biocoenosis', a notion similar to that of 'the community' in that it describes a group of living creatures, with that of the 'biotope', the inorganic environment that sets the material limits to which life adapts and which is in turn affected by life. Tansleys critique of

Clementsian ecology included a suggestion that its dogmatically organismic model of the 'biotic community' and the 'complex organism' bracketed living nature from non-living nature in a way that limited inquiry to established areas of biology – zoology, morphology, taxonomy, biogeography. The way to open up a research agenda that might lead to the formalisation of general ecological principles, Tansley proposes, is through extension of its inquiry into geology and climatology and finally, through the grounding of ecology in modern thermodynamics. With Tansley, ecology began to travel down the path that would lead to it becoming by definition the science of ecosystems. By including the inorganic sphere and blurring the distinction between living and non-living nature, the concept could be readily scaled, which eliminated some of the difficulties of defining the boundaries of different types of climax community under tags such as 'grassland', 'forest' etc. All that was required was one or more species and its environment. An ecosystem could thus be defined according to the interests of the researcher- an ecosystem could be a puddle, a lake, a watershed, or the entire planet. As Mirowski has noted, the assertion of the ecosystem concept as an escape route from holism and organiscism was more than a little ironic.[96] The 'ecosystem' was still a living, functionally integrated and bounded whole accessible in totality to theory. In replacing the organism analogy with the machinic analogy of systems theory, ecologists were able to disassociate themselves from the embarrassing vitalism of their earlier progenitors, while the move into physico-mathematical analysis if anything increased the strength of ecology's claims to gain an objective perspective on 'the system as a whole', at the risk of sacrificing meticulous local natural histories and taxonomic detail for an increasingly distant and abstract analysis.

The development of the ecosystem concept was not of course merely the exchange of old metaphors for new, or of a change in stylistic conventions among texts describing nature, but was crucial to the development of ecology as a science of environmental management. By shifting the perspective from the 'communal' relations between organisms in the state of nature to (eventually) the biogeochemical cycling of nutrients and matter/energy through biophysical systems, the ecosystem concept opened the way to the analysis of landscapes that included significant human presences. [97]

As the historian of science Sharon Kingsland has noted, ecosystem ecology was the fruit of a movement among ecologists in the post-WWII period seeking to convert the 'soft' science of ecology into a 'hard' science that could command intellectual respect. According to the Cartesian-Newtonian criteria of 'hardness', this meant rigorous reduction to physical-chemistry, with the attendant possibility of sophisticated mathematical modelling. Ecologists sought to lose their image as 'glorified birdwatcher and bugcatchers', field enthusiasts whose works were lovingly filled with pictures of plants and landscapes, but were empty of models, diagrams and strings of equations. Kingsland writes:

> "Ecosystem ecology sought to move beyond general conceptions of ecological processes by adding exact measurements, experiments, and tests of hypotheses. It welcomed application to new techniques in applied mathematics, looked to physics to provide basic principles for ecology, and pushed ecology into the computer age with enthusiasm. It was cautiously optimistic about the possibilities of environmental engineering. And it too sought a way to incorporate human activity into the analysis of ecological process, both on the local level and in the biosphere." [98]

In developing this biophysical approach, ecology entered decisively into the policy arena, in the context of the rise or the modern environmental movement. Just as mathematical axiomatisation had for political economy, the institution of ecology as respectably 'physical' systems biology, I would argue, conferred upon it the paradigmatic status of a candidate social physics. Simultaneously, its consequently dire revelations in the public sphere conferred a prophetic role upon the ecologist in the broad and speculative narratives of secular millennialism, just as had occurred for the post-political economists in the heyday of British liberalism. In becoming public figures by virtue of their increasing scientific authority, ecologists made a radical intervention, providing an analysis of the future of industrial society that was a polar opposite to that provided by economists, at a time when the neoclassical variant of the discipline was again achieving political importance in the context of the post-war preoccupation with economic growth in modernisation theory and development studies.

This impulse to link ecology to a general theory of the physical universe was perhaps latent in the mind of the German scientist Ernst Haeckel, who as we have seen replaced the old descriptor 'economy of nature' with modern term 'ecology'. In addition to his work as a biologist, Haeckel was also a key populariser of the doctrines of energetics and the German productivist movement of the late 19th century, which linked the capture and conversion of solar energy by the biosphere to the dynamic forcefulness of modern industrial society in an unbroken chain of energy transformation and productivity:

> "The sum of force, which is at work in infinite space and produces all phenomena, is unchangeable. When the locomotive rushes along the line, the potential energy of the steam is transformed into movement [...] The whole marvellous panorama of life that spreads over the surface of our globe is, in the last analysis, transformed sunlight. It is well known how the remarkable progress of the technical sciences has made it possible for us to convert the different physical forces from one form to another [...] Accurate measurement of the quantity of force which is used in this metamorphosis has shown that

it is constant or unchanged. No particle of living energy is ever extinguished; no particle is ever created anew."[99]

Notable in Haeckel's implied bioeconomics of *vis viva* as 'living energy' is the productivist model of nature as *Arbeitskraft,* labour power as a vast reservoir of energy awaiting conversion to mechanical force or 'work'. Here we recognise the optimistic pre-entropic account of nature according to the first law of thermodynamics, the law of the conservation of force formalised and popularised by Helmholtz. The First Law translates nature as energy, and discovers energy as inexhaustible and (potentially) universally convertible. This was a dramatic departure from the Newtonian account of the laws of mechanics. For the energetics movement, nature was a "force beyond matter and motion" powering the "work" of the cosmos. As Rabinbach explains, energy conservation was claimed as a transcendental principal, and was "productivist" insofar "as it placed the metaphor of the machine at the centre of scientific explanation and the energy of the universe in the service of an order dedicated to the production of work." [100] It is indeed ironic that the elaboration of the principle of the conservation of energy led to the ideology of productivism, which in the form of the contemporary fetish for unlimited economic growth routinely evades the increasingly important question of the limited supplies of available energy required to slake the thirst of the exponentially expanding reserve army of industrial machines (or in environmentalists' terms, the need to conserve energy to increase the temporal sustainability of industrial society). To compound the irony further, we need only note that the legitimacy of ecology as a science required that the mastery of the language of energetics by its practitioners and this consequently saw the import of the machine metaphor from economics in replacement of the naturally occurring organismic metaphors of Clementsian ecology.

As Ingerson notes, some historians and ecologists saw the 'ecosystem' concept as simply a revision of Clements notion of the successional community, with the organic and social metaphors replaced with an image of nature as a "well oiled machine". What were the attractions of the machine metaphor for ecology, and what were its implications? In what follows, we shall consider another of the ironic aspects of physics envy in the parallels and contretemps between ecology and economics: the metaphorical conversion of ecological systems into machines through the introduction of energetics. What this energetic turn meant for the claims of ecologists in the sphere of political economy is a key consideration given the emergence and subsequent institutionalisation of the environment movement in from the 1970s onward. Searching for explanations for the paradigmatic change toward ecosystems ecology in post-war American ecology, Ingerson cites the laudably concise explanation of Golley, who says that:

"In America…the ecosystem system concept appeared modern and up to date. In short it was a machine theory applied to nature." [101]

Bowler, on the other hand, elaborates on this idea in a way that resonates well with both the DMDM thesis and our own discussion about the ramifications of the physics envy displayed by ecology for its potential social functions:

"Where Clements once justified government control of the environment by appealing to the image of society as a super-organism, the new systems theory offered the prospect of social control through the setting up of stable feedback loops of human interactions. In an atmosphere of post-war optimism, science seemed to offer the prospect of creating a safer and more secure world." [102]

It seems that the attractions of this route for ecologists were similar to those experienced by the economists who had taken it a hundred years earlier. Both 19th century economists and 20th century ecologist saw the way out of the politicised subject matter of the discipline in the cool rationality of mathematics derived from the *prima materia* of energy physics. They thus hoped to provide objective foundations for the management of human interactions with their environments, bypassing politics and cultural specificities by accessing a pure nature potentially available for direct manipulation by experts.

The historical importance of ecosystems ecology to the modern 'biophysical' critique of economics, and its occasionally proposed candidature as an alternate 'social physics' for the new era of ecological risk, justifies some discussion its background. Again we return to the difficult subject of thermodynamics, which as Georgescu-Roegen once pointed out, is "the only branch of physical chemistry in which life matters." [103]

The origin of the biophysical perspective and thus of ecological economics, has been traced by Tim Jackson to an 1886 lecture given by the Austrian physicist Ludwig Boltzmann to the Imperial Academy of Science in Vienna.[104] In this lecture Boltzmann presented his probabilistic interpretation of the second law of thermodynamics, around twenty years after it had been first proposed. At one point, Boltzmann argued that the "struggle for existence" of animate life was essentially a struggle for "available energy", captured for use by photosynthesis and ultimately deriving from the sun. In so doing, Jackson argues, he created a 'metaphorical bridge' between Darwinian evolution and the emerging physics of statistical mechanics and thermodynamics. At the same time, he provided the foundation for reasoning about the environmental limits to industrial development which is increasingly relevant in our own time. Boltzmann's probabilistic interpretation of the concept of entropy held that in the evolution of physical systems, there was a general and movement toward less ordered (and more probable) states from more ordered (and less probable) states. The tendency was thus for the universe to move toward maximum entropy, toward an entirely random distribution of matter in which "all tensions which might perform work and all visible motions in the universe would have to cease." [105] Helmholtz called this static equilibrium the 'heat death' of the universe. Inevitably, the great world engine would run down and succumb to entropic degradation.

This pessimistic cosmology of universal heat-death pervaded fin-de-siecle European culture, filtering into discussions of such Spenglerian subjects as the decline of the West. As William Butler Yeats wrote, "things fall apart, the centre cannot hold." This re-visioning of universal history as a slow apocalypse of ennui, waste and exhaustion was also to found in T.S. Eliot's poem *The Hollow Men*, which concluded with the line: "this is the way the world ends: not with a bang but a whimper". In an essay written in 1903, Bertrand Russell wrote of the challenge the scientific view of the world presented to optimistic eschatologies of progress:

> "[...] that all the labours of the ages, all the devotion, all the inspiration, all the noonday brightness of human genius, are destined to extinction in the vast death of the solar system, and that the whole temple of Man's achievement must inevitably be buried beneath the debris of a universe in ruins- all these things, if not quite beyond dispute, are yet so nearly certain that no philosophy which rejects them can hope to stand. Only within the scaffolding of these truths, only on the firm foundation of unyielding despair, can the soul's habitation henceforth be safely built." [106]

More optimistic voices (perhaps less schooled in the rigours of the entropy law) were to be found across the Atlantic, where the immediate future of America is a rising industrial power may have led to a more optimistic view of the great world engine. Writing in *Atlantic Monthly* in 1901, Brooks Adams foresaw a progressive future society driven by an increasingly efficient mastery of increasingly vast flows of energy. This future society would be run by rulers capable of administering "masses vaster than anything now existing in the world"; institutions and law would "take the shape best adapted to the needs of the mighty engines which men shall control." [107] Here, energy and evolution were yoked to Progressive ideology.

It is Boltzmann's crucial linking of Darwinian selection and resource appropriation that is the most relevant to our narrative of the development of ecology, and of the biophysical perspective of 'ecological economics'. Entropy as an inevitable winding down of structure and process was seen by many to be in contradiction to the account of Darwin, which convincingly argued that the "struggle for existence", the central metaphor of his theory of natural selection, evolved 'higher', more complex forms of biological organisation. Life itself appeared to locally resist the predicted movement toward stasis and chaos, with each organism cheating predation or its own inevitable decay by passing on genetic information to subsequent generations. It was Boltzmann's most admiring student, Ervin Schrödinger, who in his 1944 work *What is Life?* first set out clearly the relationship of biological life and entropy.[108] This essay was to have great influence over the subsequent generation of molecular biologists and is credited in leading to the discovery of DNA. It was also crucial to accommodating the problem of life and evolution within the rigorous limits of the entropy law. In it, he foreshadows Ilya Prigogine's concept of 'dissipative structures', crucial to the thesis developed here, by suggesting that "the device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists in sucking orderliness from its environment." [109] Organisms maintain their existence and 'order' by importing what Schrödinger referred to as 'negentropy' (negative entropy) from the environment and exporting or externalising back to it waste, disorderliness and heat (entropy).

From the perspective of our current analysis of the shared discourses of economics and ecology, and the prospects of these discourses for contributing to a science of human sustainability, it is Boltzmanns link between Darwinian selection and resource appropriation, taken up by Lotka, that is of most relevance. In Lotka the biophysical parallels between population growth, industrial 'growth' and ecosystem dynamics are first made in the context of a rigorous, though speculative, discussion of the evolutionary development of the biophysical economy of nature. It is here that neoclassical economics intersects directly with ecology perhaps for the first time, and neither discipline would be left unchanged by the encounter. Lotka was the first, as early as 1914, to apply mathematical models from economics to ecological questions, attempting to mathematise ecology in a way that could in turn yield 'An Objective Standard of Value Derived from the Principle of Evolution.'[110] In conceiving of this ambitious research project to ground evolution in thermodynamics (and value theory in evolution) Lotka was inspired directly by social theory. He had been impressed by Herbert Spencer and his efforts to formulate a general law of evolution that could unify all historical processes. Spencer's work proposed an entirely different vision of evolution to that of Darwin, deriving less from painstaking analysis of empirical fieldwork, but from the armchair application of analogies. William Stanley Jevon's *Theory of Political Economy*, which advanced the neoclassical price theory and also proposed a universally applicable economic mechanics, provided a direct model for the physical analysis of statics and equilibrium. Vilfredo Pareto, who perhaps most strongly asserted the identity of economic and physical 'laws', provided the mathematical approach to equilibrium and distribution with the concept of marginal ophelimity or 'optimality'.[111] Lotka was also influenced by his teacher Friedrich

Wilhelm Ostwald. With Ernst Solvay a key founder of the 'social energetics' movement, Ostwald was a keen writer on questions of industrial organisation. Ostwald saw the entire universe as pure labour power governed by the laws of energy. The whole purposeful activity of civilisation was converting raw energy into available energy, redeeming energy that would otherwise be dissipated by making it socially useful.[112] Progress could be measured by the increasing efficiency of energy conversion and the elimination of waste. Lotka was the first to pursue this vision into general biology. As Kingsland reports:

> "Physical chemistry emphasised thermodynamic principles and mathematical analyses, so Lotka imagined that physical biology must treat the organic world as a giant energy transformer. [...] Lotka believed it would be profitable to analyse the evolution of the entire world system as a whole. He compared the world to a giant engine or, using an image familiar to thermodynamics, to a giant mill wheel." [113]

Reflecting on the link between evolution and energy appropriation, Lotka conceptualised his ecology in terms of the "selfish effort of each organism and species to divert to itself as much as possible of the stream of available energy".[114] This competition for available energy could provide a rigourous point of analysis for the mathematical treatment of oscillations in populations. Relating evolution to energy transformation (in Spencer's sense of the macro-evolution of the social organism, as distinct from Darwin's focussed account of the 'micro-economics' of speciation), Lotka made a heroic attempt to derive a general law of evolution from a single extremum principle. Through a series of theoretical moves, he freshly interpreted evolution as a way of increasing energy flow and efficiency. Thermodynamic principles, he believed, supported his view that natural selection would not only increase the total mass of biological systems, but also the energy flow through the system, an explanation which linked the directionality of evolution to the irreversibility of the second law of thermodynamics.

Drawing on later works that sought to elaborate what this meant for human societies on the verge of massive technological transformations, Kingsland argues that Lotka's work was intended to show the unity of 'man' and nature, by intimately tying human action to the operation of the vast world engine. In Lotkas's view, the species most successful at diverting available energy would "tend to grow in extent (numbers) and this growth will further increase the flux of energy through the system."[115] He admitted the possibility that sparing use of the energy flow and a more careful husbandry of resources might "work to the advantage of a species talented in that direction", but continued to insist that the general tendency in such systems is to appropriate the "*maximum possible share of the available energy resources*." [my italics][116] Lotka's maverick attempt to unify the Natural and the Social sciences within the medium of energetics poses the usual chicken and egg questions: while a full analysis of Lotka's thought is outside the scope of this thesis, it would appear that the universal psychology of *Homo Economicus*, the algorithmic unit of microeconomics whose rationality is defined exclusively in terms of a natural propensity for utility maximisation, is here writ large into population ecology and ecosystem evolution, and then reprojected back into industrial society. While the substantive elements of Lotka's evolutionary physical biology and the formally static abstractions of neoclassical social physics are worlds apart, the equation of utility with energy is remarkably similar. The irony of such resonances is that while Lotka shared the industrial millennialism of the social physicists, his approach was crucial for the development of the ecosystem perspective and the inseparable biophysical critique of the ideology of unlimited economic growth, a position associated primarily with neoclassical growth economists such as Robert Solow, and right-populist libertarian 'doomslayers' such as Julian Simon.

For Lotka, writing in times innocent of multiform and systematic environmental degradation, economic growth was no mere metaphor for industrialisation, but the world historic evolution of humanity as a species, including the extra-somatic prostheses (machines) that were the logical extension of the (decidedly Lamarckian) evolutionary process. This again indicates the influence of Ostwald, who often compared the evolution of machinery to organic evolution. In a curious intermingling of organismic and machinic metaphors, Lotka rendered technology as the sensory organs and motor organs of the 'the social organism', or 'body politic'. "Man and machines", he wrote, "today form one working unit, one industrial system. The body politic has its organs of sight and hearing, its motive energies, its moving members, in close copy of the primitive body of man, of which it is a magnificent and intensified version." [117] His viewpoint on the thermodynamic harnessing of the worlds energies to an ever more powerful social machine was progressive and optimistic. As Kingsland puts it, "Lotka's notion of the body politic was intended to show that the evolution of the social organism through technological expansion was part of a natural process that contributed to the individual's unity with nature." [118] As his physico-mathematical ecology implied, modern civilisations' harnessing of the maximum available energy was merely an extension of the laws of nature that operated on each species and drove the evolutionary process. In rising above selfish individualism and becoming 'collaborators with nature', people could embrace modernity and contribute to an orderly and rational industrial expansion of the social organism. Drawing on the previously mentioned argument of Dorothy Ross that American social science responded to industrialisation by elevating the United States out of history through devising a means to engineer the future, Kingsland argues that Lotka was advocating a kind of secular millennialism, the response of the educated middle-classes to the anxieties of the interwar period. Though some blamed the racial and class antagonisms of modernity on industrial technology, Lotka was keen to show that more science and technology, not less, was the guarantee of progress. His vision of the new industrial society was one of transcendent efficiency and social harmony, as the body politic was steered ever onward by an elite intelligentsia that actively fulfilled “the Great World Purpose”.[119]

In this millennial vision, Lotka seems to share some of the vision of the Technocracy movement, a movement that shone briefly as a popular discourse proposing to deal with the social crises of the Great Depression. For Howard Scott, the founding Technocrat of the movement, society faced a stark choice between ‘Science or Chaos.’ Writing in 1933, he pointed out to his readers that:

> “I have not enquired as to whether you do or do not like the idea [of Technocracy].The events that are going to occur in the very near future are not going to be respecters of human likes and dislikes. The problem of operating any existing complex of industrial equipment is not and cannot be solved by a democratic social organization....[It] is a technical problem so far transcending any other technical problem man has yet solved that many individuals would probably never understand why most of the details must be one way and not another; yet the services of everyone...will be needed.” [120]

Technocracy represents another divergent path in the story of social physics. Its exponents were clearly social physicists in that their industrial millennialism was firmly grounded in a monolithic energy theory of value and a view of science as a universal truth machine, whose methods and problem solving techniques were the only ones capable of generating Progress as far as industrial society was concerned. Although they would probably have accepted the <utility=energy> metaphor at the heart of neoclassical economics, the events of the Depression had everywhere cast faith in the automatic equilibrium of the Walrasian ‘price-mechanism’ into disrepute. After the speculation-induced stock market crash of 1929, the market mechanism beloved of neoclassical orthodoxy was viewed by many as wasteful and chronically unstable. As the principal site of decision making regarding production, distribution and the division of social labour, it was seen as ultimately captive to the vagaries of what Keynes would have called the ‘animal spirits’ of the investor class, individual egos driven in turn by fear, greed, rumour, unwarranted optimism and the madness of crowds. For the Technocrats, the global ‘market failure’ of the Great Depression indicated the irrationality of lassez-faire economic liberalism: the choice of futures facing modernity was framed simply by Scott as a case of ‘Science versus Chaos.”[121] Social engineers would henceforth be required to adapt social institutions, beliefs and practices to the technical requirements of increasingly complex and powerful industrial megatechnics. Seeking to place the future organisation and development of industrial society on firmer rational ground than the skittish whims of speculative investment or populist electoral politics, they sought to replace the crisis-riven “price system”, seen as a dispensable and irrational form of value calculation, with equal allocations of energy certificates that could not be accumulated. Material inputs, labour and commodities would be measured in energy units. Engineers, distanced by their technical expertise from the ideology-driven fields of politics and economics would generate the most logical means of organising society, restoring order to a world on the verge of crisis. Their industrial utopia was, as Peter Taylor has put it, based upon the reduction of society, politics and economics to natural forces "controlled by a single energy dial that could be adjusted according to objective conditions as determined by social engineers."[122] As a popular movement, Technocracy ultimately met the same fate as the Positivist religion proposed by August Comte a century earlier: the vision of a society controlled by scientific elites only had lasting appeal for scientific elites.

We are no in a position to return to the development of ecosystem theory and its adaptation of biophysics. Evelyn Hutchinson, the mentor of H.T. Odum, was a highly influential figure in the development of post-war ecology. While his influence extended to many areas of ecology, his place in this narrative is as a contributor to systems ecology and the biophysical perspective on the energetic economy of nature. One genealogical point of reference for this perspective, indispensable to the critique of what Mishan once called the 'growth-mania' of applied economics since World War II,[123] can be traced to a comment that Hutchinson had made in 1940, reviewing *Bio-Ecology*, a textbook produced by Frederic Clements and Victor Shelford.[124] Attempting to transcend the then contemporary debate around whether or not communities could be legitimately identified as higher-level superorganisms, Hutchinson argued that "general principles are largely classificatory. [...] if the community is an organism it should be possible to study its metabolism."[125] If biotic communities were organisms, then by analogy one could look at the 'physiology' of ecosystems and thus analyse the successional process by which a homeostatic 'equilibrium' consonant with the long term maintenance, coherence and stability of organisms was achieved.

Hutchinson encouraged this approach in the promising research of a young graduate student by the name of Raymond Lindemann who died before the 1942 publication of his study of a Minnesota lake, 'The Trophic-dynamic Aspect of Ecology.'[126] The essential achievement of this paper was in its presentation of an analysis of the food cycle of an entire ecosystem, focussing on the way in which the relatively simple and bounded ecosystem of Cedar Bog Lake exemplified the capture of solar energy and its conversion into living material, or biomass. And it was also, as Worsters' discussion of the paper makes clear, the point at which a new scientific paradigm in ecology emerged, one that explicitly deployed energy as an economic concept. In reviewing this paper, Hutchinson himself deployed economic terms, explaining that Lindeman came to realise "that the most profitable method of analysis lay in the reduction of all the interrelated biological events to energetic terms."[127] "Here for the first time" Hutchinson noted, "we have the interrelated dynamics of a biocoenosis [the older term for a community or ecosystem] presented in a form that is amenable to a productive abstract analysis."[128]

Lindemann's paper grouped all the different species into 'trophic levels', characterised by their function within nature's economy as primary producers, primary and secondary consumers, and decomposers (or recyclers). Alternative terms can be used here: 'autotrophs' for plants, which produce their food internally by converting sunlight and atmospheric carbon to sugars by photosynthesis; and 'heterotrophs', animals and bacteria which feed on other organic tissues. The most important realisation of Lindemann's study was that at each level of the trophic pyramid, much of the energy embodied in the previous level was lost as heat to the atmosphere. Only a fraction of the solar energy arriving in an area was converted into plant matter, only a part of the energy incorporated into plant biomass was converted into the bodies of herbivores when eaten, and carnivores at the top of the food chain were similarly limited in number and weight by the efficiency of energy transfers below them in the pyramid and the fact that consumption was limited. If too great a proportion of prey species was eaten by a predator species, the prey species would not be able to regenerate and reproduce, and the predators own local extinction was ensured. By quantifying these losses, the ecologist could measure the 'productivity' of each trophic level in terms of the energy embodied as biomass (minus the energy expended in respiration, digestion or hunting) and also the 'efficiency' of transfers of matter/energy between trophic levels.[129] The ecologist could then calculate Gross Primary Productivity for her chosen ecosystem - the rate at which it accumulated biomass, including the energy it uses for the process of respiration - and then subtracting the high proportion of matter/energy used up in the metabolic process, arrive at a figure for Net Primary Productivity. Each organism is treated as a kind of biological factory receiving raw inputs of light, carbon dioxide, water and nutrients into goods and services useful to other sectors of the economy of nature. It is with Lindemann that we see the 'economy of nature' metaphor fulfilled for the modern period, with the natural environment fully realised in discourse as a modern economy through the medium of the energy metaphor and the statistical analysis of productivity.[130]

Lindemann's paper was a major catalyst of one of the biggest projects ever organised in biology, the International Biological Programme (IBP) which ran between 1964 and 1974. Set up after years of negotiation between the presidents of the International Council for Scientific Unions and the International Union of Biological Sciences, the IBP organised several thousand biologists, their universities and national academies to measure the 'The Biological Basis of Productivity and Human Welfare', that is to measure the energetic 'productivity' of as many different ecosystem types as possible, from arctic tundra, to deep ocean floors, to peasant agrosystems and modern industrial monocropping. This project gave a huge boost to the nascent science of systems ecology, although molecular and evolutionary biologists, sceptical of the systems approach itself, were critical of its hierarchichal forms of organisation, and thought its problem definition too vague to justify the vast research funding it soaked up.

It is with Lindemann that Worster concluded his still highly relevant 1977 study of ecology, offering the following reflections:

> "[...] to a great extent, ecology today has become 'bioeconomics': a cognate, or perhaps even subordinate, division of economics. [...] The metaphors used [in a 1967 text – biological capital, energy, efficiency, productivity] are more than casual or incidental; they express the dominant tendency in the scientific ecology of our time. In their most recent historical models, ecologists have transformed nature into a reflection of the modern corporate industrial system." [131]

That this transformation of nature into a reflection of the modern corporate industrial system occurred through an appropriation of an economic conception of energy is vitally important to note, although Worster's history does not deal in any depth with the history of economic concepts and most importantly, not at all with the little known history of the pretensions of economists in appropriating the legitimacy of physics through the selective appropriation and application of physical metaphor.[132] While the possibility of a mechanistic determination of the ecosystem concept is certainly not universally accepted among professional ecologists, a look at contemporary introductory textbooks confirms that this shared language has remained a lasting feature of ecology. Ricklefs begins his *Economy of Nature: A Textbook in Basic Ecology* (1997) by simply stating that problem of describing the incredible complexity of assemblages of species at the ecosystem level of organisation is dealt with in the systems approach by speaking of 'common currencies'; 'budgets' of energy and chemical elements, by which the activities of organisms as different as bacteria and birds can be compared.[133] While this is a textbook and not a critical history, it seems a little odd that the book has no reflection on the implications of the use of economic metaphor, not even in the final chapter which introduces the themes of global ecological destruction through the continued conversion of the biosphere into 'the economy'. This is more than a little ironic, given the current mainstream economic faith that continued economic growth through the 'self-regulating market' is vital to the achievement of such Sisyphean tasks as 'sustainable growth' and 'ecological modernisation', even though the oil reserves that have 'funded' modern economies may already have peaked. Why not attempt a national estimation of ecological Gross 'Natural' Product and compare it on the same chart as the standard Gross National Product figures? Much would be revealed by such an exercise, not least the colliding ontological foundations of universal measurement in the two polar opposite versions of the economy of nature.

Such an exercise might reveal what both faces of the 'economy of nature' lack: a concrete analysis of 'industrial technomass'. The facticity of industrial infrastructure been obscured in both disciplines by selective appropriations of the machine metaphor to 'pure' realms of nature, such that we do not study the inter-relations of modern economies with nature via their material requirements and effects.

The legitimate role of metaphor in science is arguably to suggest novel approaches and to facilitate exchange of methods developed in one discipline into often counter-intuitive research settings. Thus while metaphors may enable new creative thinking, they also competitively exclude other approaches as the metaphor is reified as core dogma and the contradictory or unworkable implications of the metaphor are glossed over in a defensive action to maintain the core hypothesis. Twenty years before Lindemann's empirical study had opened the gate to a quantitative energetic approach in ecological method, Lotka's general, speculative work on the energetics and evolution of organisms led him to proposal a general law of evolution derived from a single physical extremum principle.

> "[...] the operation of natural selection tends to increase the biomass and embodied free energy in the biosphere. It also tends to increase the rate of circulation of both matter and energy flux through the system."[134]

Using the key provided by Lotka, Lindemann synthesised the pre-existing set of ecological methods. Nature (ecosystems) and Society (economies), though confined to distinct ontological domains each exhibit similar hierarchies and structural processes, obey the same laws, and are amenable to the similar forms of analysis. Nature and Society are organised in such a way that individuals adapting their behaviour to solve 'maximisation' problems subject to thermodynamic constraints follow an energetic pathway toward a stable maximum characterised by an increasingly complex division of labour. And while both economies and ecosystems are viewed as machines, machines are abstracted from the analysis, both as material biophysical forms, and as 'solidified' social relations Here we are reminded of the Durkheimian thesis, which has been summarised well by Jeremy Rifkin:

> "Every major economic and social revolution in history has been accompanied by a new explanation of the creation of life and the workings of nature. The new concept of nature is always the most important strand of the matrix that makes up the new social order. In each instance the new cosmology serves to justify the rightness and inevitability of the new way human beings are organising their world by suggesting that nature itself is organised along similar lines. Thus, every society can feel comfortable that the way it is conducting its activities is compatible with the natural order of things, and therefore, a legitimate reflection of nature's grand design."[135]

As we have seen, Lotka saw the 'evolution' of industrial technology and the phenomena of economic growth as an extension of the fundamental principles of the economy of nature. Parsing Lotka's formulation of his law of biophysical evolution, we can speculate as to how this principle might be expressed by a neoclassical economist (albeit one with an unusual curiosity about the substantive dimension of 'the economy') for modern human social systems by substituting some of the Natural terms for Social ones. This would yield the following: the operation of the market mechanism [natural selection] tends to increase technomass [biomass] and capital value [embodied free energy] in the anthroposphere [biosphere]. In Lotka's day, as we have seen, such a thought experiment would merely have confirmed the industrial optimism of whichever mainstream political ideology one adhered to, although Marxists would perhaps have replaced 'the market mechanism' with 'co-operation' or 'the class struggle' depending on their preferred evolutionary metaphor. In any case, techno-industrial accumulation could simply be seen as the extension of evolutionary principles of increasingly efficient energy capture and growth, providing a Natural foundation to reflect the cosmology of the industrial Social order. Despite its overheating through the frequency of its use as metaphorical power switch, its discursive role in rationalising the Social in Natural terms and vice versa, the machine metaphor and the 'image of unlimited good' Western culture attaches to industrial technology at this point could continue to exist unchallenged. As nature became more machinelike, modern industrial organisation remained the yardstick with which to measure the Natural. Meanwhile, while industrial technomass remained outside the analysis, both materially as a 'dissipative structure' (dissipating oil reserves and more or less 'natural' ecosystems) and as a socially distributed phenomenon (industrial infrastructure is not evenly distributed across the surface of the earth, and the benefits of industrial civilisation are largely achieved for some populations at the expanse of others). The patent fact that economies are embedded in ecosystems and depend upon them was overlooked, any limit on natural resource consumption at that time appeared purely as a problem of engineering: more and better roads, drilling rigs, oil platforms etc.

In the following section we will discuss the paradoxical route by which ecology arrived as a 'subversive science', with a radical critique of the industrial optimism manifest in the post WWII pre-occupation of economists and development planners with engineering economic growth. As we shall see, the mainstream tradition of environmentalism has its roots in the funding and intellectual environments of the modernising state and thus to the attendant ideologies of industrial development. Under the influence of Lotka, the adoption of energetic analysis of ecosystems led to the development of an ecology framed in the idiom of physics, and just as it had for economics in the 1870s, this gave it a greater authority and purchase on public discourse. However, unlike Lotka's holistic and millennial view of industrialisation as the evolutionary extension of 'the Great World Purpose', the complete realisation of his approach in ecology led to a vision of apocalypse and a major confrontation with the economics of equilibrium and perpetual growth.

### Ecologist as Cyborg: The Military Origins of the Subversive Science

*Cybernetics extends and widens the circle of processes which can be controlled – this is its special property and merit.*

- Norbert Weiner [136]

*I thought it would be good to have a new concept, a concept of persons who can free themselves from the constraints of the environment to the extent they wished. And I coined this word cyborg.*

- Manfred Clynes [137]

In the early 20th century, the sciences of ecology and economics were properly and safely demarcated around ontologically distinct research objects: the pure Nature of the successional climax community devoid of humans, and the self-equilibrating Nature of exchange in Walrasian markets. Despite the frowned upon boundary riding of polymaths like Lotka, the genteel practitioners of these arcane arts had little cause for contact, let alone fistfights. This cosy situation was to remain so until the 1960s. From this time on widespread fears of nuclear annihilation and announcements of impending ecological meltdown began to bring the dreams of the industrial millennium into crisis. The dawning awareness of ecological risk on a biospheric scale emerged in the post-WWII period, with the rapid expansion of investment in the chemical, nuclear and genetic industries. This transition marked the end of what Ulrich Beck has referred to as 'simple modernity' and the beginning of what he calls *riskgesselschaft* or 'risk society', a new social order shot through with the spectre of incalculable and thus uninsurable ecological hazards, a social order in which the epistemological authority of the scientist, once as unquestionable as the permanence of the Nature she studied, has been undermined by the scientific creation of unforeseen hazards. The pervasiveness of global ecological risk has undermined the very idea of an external nature independent of human activity. This has led, so Beck says, to the pitting of science against science. [138] Under these conditions we can expect great stresses to have been placed on ecology and economics as distinct fields dealing with distinct realms of Nature and Society.

The reader will recall that earlier we proposed to follow Mirowski's suggestion that in Western culture the Natural and the Social exist as amorphous domains until some kind of crisis emerges. The unprecedented emergence of novel and disquieting accidents requires an inquiry into whether the crisis has Natural or Social causes, followed by the judicial determination of guilt, a decision which renegotiates the boundary between nature and culture and restores order to both domains. In this section it will be argued that the scientific and technological milieu that engendered the first truly global crisis of technologically generated ecological risk – the possibility of nuclear annihilation during the Cold War arms race – also engendered the conditions for the development and institutionalisation of the ecosystem concept at the core of systems ecology, which redefinition of nature was to have profound consequences for social knowledge.

A watershed moment in the formulation of systems ecology and was the delivery of a paper by G. Evelyn Hutchinson to the New York Academy of Sciences, entitled 'Circular Causal Systems in Ecology.'[139] In this paper, Hutchinson outlined the 'biogeochemical approach' to ecology, which interfaced biology and the study of the global distribution of chemical elements. Drawing on the work of Vernadsky, Lotka, Volterra and Gause, Hutchinson developed a carbon budget for the biosphere, and attempted to balance it. Because biological and physical processes were tightly coupled, it was clear that the activities of living organisms had a balancing effect on the cycling of chemicals through ecological communities, oceans, the lithosphere and the atmosphere [Fig. 5].

This paper was to have deeply prophetic significance for our own time. His diagram of the carbon cycle notably included industrial civilisation; at the right hand side of the 'circular system' we see the combustion of buried organic carbon returned to the atmosphere as carbon dioxide in fuel exhaust. The first paper to attempt to model the global 'biogeochemical' cycles of carbon, it was also the first to speculate on truly global environmental change due to local human activities, as it was known in the early 20$^{th}$ century that the atmospheric concentration of carbon dioxide was increasing. Hutchinson suspected that the main reason might not be industrial emissions but deforestation, as land clearing limited the biospheres ability to reabsorb the carbon once stored in climax forests. (Currently, deforestation is thought to account for between a quarter and a third of anthropogenic transfers of carbon to the atmosphere.

Hutchinson surmised that perhaps the regulatory mechanisms that the history of life had evolved to stabilise the atmosphere had been damaged, potentially throwing the cycle 'out of balance.' Not only was this one of the earliest attempts to apply a systematic chemico-physical analysis of a global system within the framework of the ecosystem concept, it was also perhaps the moment when ecology became a genuine social physics, through the first global quantification of the physical impact of the 'world industrial organism' on the biosphere

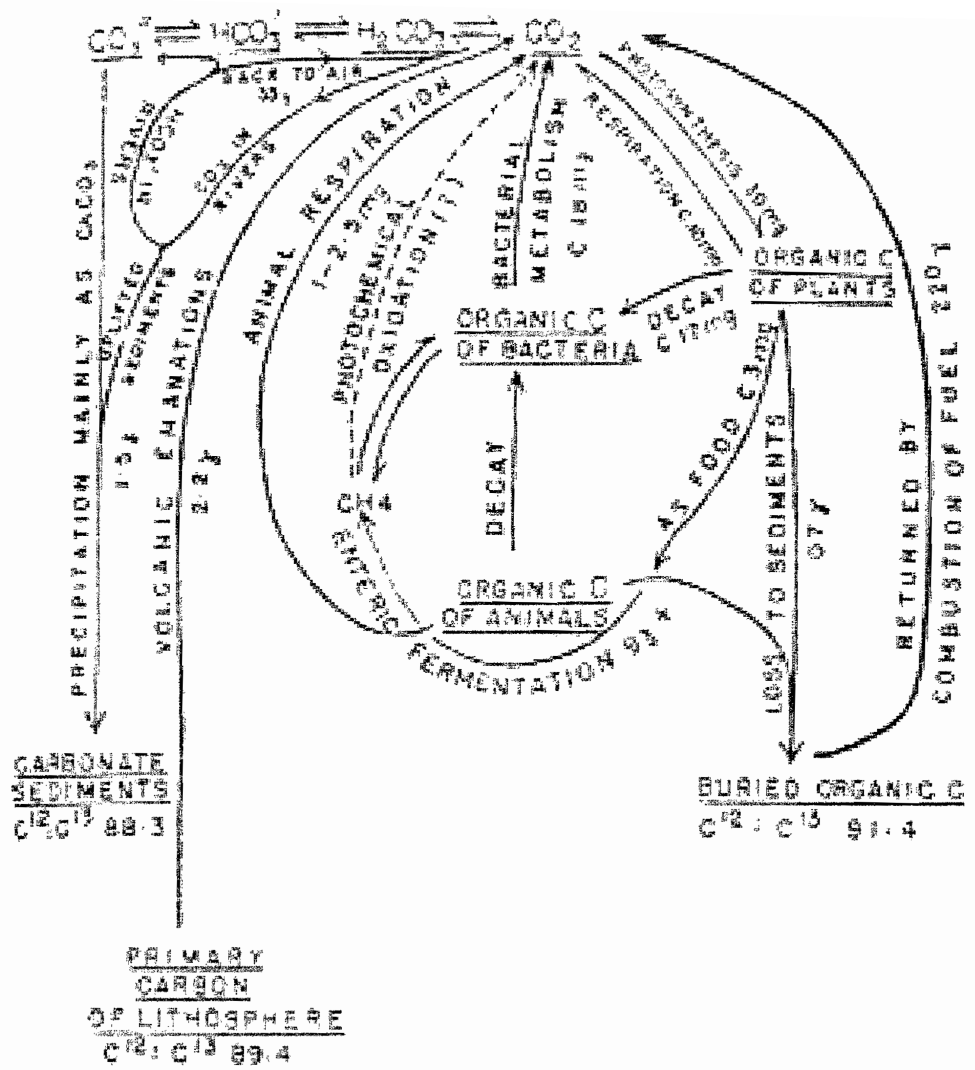


**Figure 5. The global biogeochemical cycle of carbon.**
Source: G. E Hutchinson, 'Circular Causal Systems in Ecology,'
*Annual of the New York Academy of Sciences*, vol. 50, 1948, p. 223.
<www.wku.edu/~smithch/biogeog/HUTC1948.htm>

Anxiety about the hazard of runaway global warming did not become widely shared and acknowledged until the development of an overwhelming body of research modelling the relations between observed warming and rising CO2 concentrations. Climate change as a decidedly social and economic problem is only now beginning to be openly accepted as an ecologist's dark revelation come true, overriding all other social discourse on forms of environmental crisis. If people spoke of DDT and population bombs in the sixties, pollution and energy depletion in the seventies, of acid rain, ozone depletion and Chernobyl in the eighties, of rainforest destruction and biodiversity loss in the nineties, the first decade of the third millennium has been dominated by the discussion of rapid climate change, a truly global crisis that seems to intensify all locally or regionally circumscribed ecological crises. The Kyoto treaty founders, oil wars stagnate and energy demand soars, amid evidence that the climactic phase transitions may be more rapid, random and severe than was generally supposed ten or twenty years ago. If the methodology employed by science to move from historical prophecy to prediction (in the sense outlined by Karl Popper in *The Poverty of Historicism,* that only accurate metrics generate accurate predictions),[140] then it is at this point that ecology became a social physics in the biophysical sense of measuring the physicality of human ecological flows generated by machinery. But it was also the moment in which ecology decisively plugged in to the eschatological totality of secular Western metahistory. Though initially optimistic about the possibility of global control of the 'system of Man and nature', the findings of systems ecology ensured it entered the drama of universal history on the side of apocalypse.

Hutchinson's paper raised the profile of ecology, by showing it to be an exciting discipline capable of providing important insights into the problems of basic science and also of addressing the relationship between the human species and the biosphere as a whole. It was also unique in that it was one of the first papers in ecology to incorporate the new metascience of cybernetics. Hutchinson was a key participant in the now famous Macy conferences between 1946 and 1953. The Macy conferences, which led to the wide discussion of systems theory, were exemplary of post-war optimism. From the beginning, an interdisciplinary open-house gathering of academic luminaries attended these conferences, whose purpose was to discuss 'Circular Causal and Feed-Back Mechanisms in Biological and Social Systems', a term later condensed to 'cybernetics'.[141]

Numerous histories relate how theoretically influential these conferences were across a wide array of disciplines.[142] It was under this term cybernetics (which we might define as the study of communications and control in machines and organic systems) that the hope for a unified science that could promote orderly, peaceful economic development and for the development of "non-political" technologies of rule was carried forward in the anxious first decades of the nuclear arms race. Machines able to perform rapid computation not only offered to radically extend the epistemological reach of interdisciplinary research but to revolutionise the structure of business corporations, economic management, war, and human-environment relations. In a keynote speech, one of the convenors of the Macy conferences, the social scientist Lawrence Frank, declared: "[W]e are engaged, today, in one of the major transitions or upheavals in the history of ideas. When the social sciences accept these newer conceptions... and learn to think in terms of circular causal processes, they will probably make amazing advances."[143] In a 1948 paper that applied 'physical thinking' to social problems, Gregory Bateson expressed hope that the new systems theory might unify the physical, biological and social sciences by allowing the success of physics flow into other fields.[144] In a paper tellingly entitled 'Social Theory and Social Engineering', Hutchinson also expressed similar sentiments.[145]

As Taylor notes, ecology reprocessed by cybernetics meant the death of one metaphor and the victory of another:

> "Although vitalism was a defeated force in biology, it was nevertheless a radical step to unify the study of living and non living systems. The new theorists of feedback systems conceived of nature as a machine, and the same time acknowledged the purposive and regulatory character of the nature-machine. A theory of 'teleological mechanisms' could not only abolish vitalism but also the old cause and effect determinism. Furthermore the same terms could be applied to all systems, whatever their components; living and non-living could be intermeshed, eliminating the biological relations from physical factors. ...It would not be long... before purely physical theories, such as those of thermodynamics – or, even more abstractly, of information theory – would be taken up as organising principles for ecology." [146]

Just as cybernetics vigorously broke down the Nature-Society dichotomy with its metaphorical conflation of machines and organisms, so to did it blur the lines between the Social and Natural sciences. Exemplifying the final shift in American sociology from the organicist or communitarian historical approach to the quantitative behaviourism enabled by high-speed computer analysis of data, Warren McCulloch was of the confessedly utopian view that a cybernetic social science would allow 'Man' to "learn to construct for the whole world a society with sufficient inverse feedback to prevent another and perhaps last holocaust."[147] To this purpose, the powerful data storage and analytic capabilities of the digital computer suggested that long-range data sets would allow scientists to determine which mechanisms of negative feedback could account for the stability and purposive aspects of the behaviour of groups. This would allow an all-encompassing system of feedback to be constructed. As Taylor suggests, the instrumental systems approach to understanding nature and machinery was easily translatable to a systems theory for control-engineering society.[148] But who would run such a society? In what follows we shall trace the rise of cyborg ecology to the point where the systems ecologist was put forward as a candidate social physicist, capable of replacing the economist as the engineer of society by managing its total interaction with the environment.

As Bill Bryant has written, the 1950s convergence of ecology and cybernetics in the ecosystem concept was to have a profound effect on the general understanding of the natural and the social order, or at least in the United States and other places influenced by its political culture. The ecosystem, Bryant writes:

> " [...] was a comprehensive model of nature that integrated humans into the environment and accounted for the ecological effects of technologies, a model that could be employed to evaluate the relationships among people, nature and machines."[149]

Bryant argues that the ecosystem concept enabled the distinction between two levels of technological interaction between nature and society, the physical and the informational.

> "In the first case, critics of modern technologies used the ecosystem concept to make comprehensible, and to legitimate alarm over, the environmental threats posed by the Bomb, chemical pesticides and other technologies characterised by the physical force they exerted on the world. [...] At the same time, the ecosystem concept served as a model of nature compatible with, even necessary to, the cybernetic technologies of the information age. These technologies were characterized by their ability to monitor their own internal and external states and adapt in response to changing conditions. They exhibited self-regulation through information feedback, a capability held to be fundamental to all complex self-organizing systems, natural or artificial. The ecosystem concept naturalized the features of cybernetic system-ness characteristic of post-war information technologies and attributed them to nature on a macro scale."[150]

We have shown so far how intertwined the development of ecology was with both prevailing economic metaphor and questions of national development and economic growth. Ecosystems ecology sits in an ambiguous position with regard to this historical theme. While its designation as the 'subversive science' is coterminous with the arrival of an energetic approach to ecosystem theory, it is not often recognised that ecosystems ecology would not have gained its initial funding or paradigmatic methods without the centralisation of scientific research accomplished by the imperatives of national security, in a research environment dominated by military funding.[151] In its full energetic determination, the ecosystem as the foremost analytical unit of the order of living nature was derived from the wartime study of control and information in human-machine interfaces. From its chthonic origins in the closed intellectual workshops of the US total war effort and the Cold War national security state, cybernetics produced an ambitious research agenda that, while unsuccessful in providing a unifying metascience capable of overcoming disciplinary methodological differences, was nonetheless highly influential in the heterogenous cyborg sciences spawned by the approach: operations research, communication and computer engineering, artificial intelligence, socio-biology, robotics, to name the obvious. Cybernetics was applied as a form of systems analysis and control theory in numerous spheres: anthropology, the behavioural social sciences, communication engineering, and also to strategic questions of industrial and military organization. In the postwar period, both economics and ecology underwent profound transformation as a result of exposure to the cyborg hive mind of post-war systems thinking. As this 'paradigm shift' is crucial to our thesis, we will now selectively recall some of the history of the cyborg sciences.

The MIT mathematician Norbert Wiener is usually written up as the key figure in the origin stories of cybernetics, and indeed his 1948 book, *Cybernetics: or Control and Communication in the Animal and the Machine* represents the first explication of cyborg themes under that term.[152] For reasons of narrative economy, we will provisionally attribute the birth of cybernetics to Norbert Wiener, forgoing a discussion of other key figures such as John von Neumann, Claude Shannon, and Allan Turing. During WWII, Wiener worked on problems of gun aiming for antiaircraft artillery. Out of this research came a paper titled 'Behaviour, Purpose, and Teleology,' which Wiener published with Arturo Rosenblueth and Julian Bigelow in 1943.[153] The paper defined "purposeful behavior" in both machines and living organisms in terms of information feedback. Bryant explains well the fertile metaphor posited in this paper, which was to outline the parameters of a new metascience:

> "Certain machines were like organisms in that they received inputs and produced behaviour or output in turn. When a portion of that output circled around to become input again, the machine acquired a means for responding to the effects of its own behavior. Its behavior became purposeful when this circuit of information feedback guided the machine toward a goal. A torpedo with a target-seeking mechanism exhibited purposeful behaviour, for example, whereas a bomb that simply fell to earth from an airplane did not. Structurally, organisms and self-directed machines were far different, but in terms of behaviour they could be classified together, as an order of things that were purposeful and predictive. 'The broad classes of behaviour', the authors argued, 'are the same in machines and in living organisms.' Such behaviour, whether exhibited by an organism or a machine, depended upon the circular feedback of information. Structurally, organisms and self-directed machines were far different, but in terms of behaviour they could be classified together, as an order of things that were purposeful and predictive. Such behaviour, whether exhibited by an organism or a machine, depended upon the circular feedback of information."[154]

A full genealogy of cybernetic concerns – involving the study of self-regulating systems and interactions between human labourers and industrial machines, a fascination with the formal and analogical similarities machines and organisms to the point of outright conflation, with attempted construction of automatons to the building of computing machines, could be taken back at least as far as Charles Babbages' attempt to build his Analytical Engine, and to his lesser known work *The Economy of Machines and Manufactures* (1832). Cybernetics was certainly not the first field with an ambition to formalise general principles that would unify the analysis of and provide engineering control over phenomena such as these. More pertinently, this history of fascination with 'thinking' machines is intimately connected to the historical debate around the second law of thermodynamics, which after 1865 revolutionised the Laplacian determinism of prior physical theory.[155] The relationship of entropy to 'information' conceived of by cyberneticists in rigorously physical terms is crucial to the current fashion for speaking of 'the information society' or 'the knowledge economy' as if we are living 'after industrialism', and as if the evolutionary trajectory of modern industrialism is one of transcendent dematerialisation and not exponential growth in its material scale. Again, this debate requires more contextualisation than we can provide here. Suffice to say, that the original vision of the 'postindustrial' was conceived around the hope that computing machines would lead to the realisation of a new age and a new social physics.

In his 1973 'venture in social forecasting', *The Coming of Postindustrial Society,* Daniel Bell argued that the seeds of the 'postindustrial' society whose contours he described in this bestseller, were already in place by 1950:

> "The period since the end of World War II has produced a new consciousness about time and social change. One might say that 1945 to 1950 were the birth years, symbolically, of the post-industrial society. To begin with, the transformation of matter into energy by the creation of the atom bomb in 1945 made the world dramatically aware of the power of science. [...] In 1946, the first digital computer, the ENIAC, was completed at the government proving grounds in Aberdeen, Maryland, and it was soon followed by the MANIAC, the JOHNNIAC, and within a decade ten thousand more. Never in the history of invention has a new discovery taken hold so quickly and spread into so many areas as the computer. [...] In 1947, Norbert Wiener published his *Cybernetics*, which spelled out the principles of self-regulating mechanisms and self-adjusting systems. If the atom bomb proved the power of pure physics, the combination of the computer and cybernetics has opened the way to a new '*social physics*' – a set of techniques, through social and communications theory, to construct a *tableau entière* for the arrangement of decisions and choices." [italics in original] [156]

This quote from Bell is of interest to our narrative here, and not merely because he is an advocate of 'social physics'. The social physics project of the post-war years were informed by the prioritising of the question of engineering economic growth and national development in the face of anti-colonial rebellions abroad and dramatic internal strife. Its proponents foresaw an exciting future for productive enterprise, based on cooperation of employer and employee, on improving technology, and continued population growth. Also intriguing is his non-recognition of what this thesis argues are the most influential and important (if contradictory) forms of social physics in the 'postindustrial' era: neoclassical economics and systems ecology (although most authors do not recognise them as such.

Elsewhere in the book, Bell took dismissive note of the nascent environmental movement:

> "[...] ecological reformers like Rachel Carson and Barry Commoner, [...] invoke the institutional charisma of science in making moral or political judgments. What we have here is the resumption of the prophetic claims of science in setting forth truth as against self-interest. [...] Paradoxically, the vision of Utopia - a fully automated production economy with an endless capacity to turn out goods - was suddenly replaced by the spectre of Doomsday. In place of the early-sixties theme of endless plenty, the picture by the end of the decade was one of a fragile planet of limited resources whose finite stocks were rapidly being depleted, and whose wastes from soaring industrial production were polluting the air and waters. Now the only way of saving the world was zero growth. What was striking in this change is the shift in attention from machinery to resources, from man's mastery of nature to his dependence on its bounty, from Harrod-Domar-Solow growth economics to Malthusian-Ricardian scarcity economics. And the principle of diminishing returns, rather than increasing returns to scale, becomes the analytical motif" [157]

Interestingly enough, for someone so optimistic about possibility of constructing a social physics, Bells' defence of the Harrod-Domar-Solow growth model dealt not with physicality but subjectivity. For Bell, the economic process was driven by the need of 'men' for status, and as 'status' by definition requires inequality, 'growth' is ultimately a psychological arms race involving the conspicuous consumption of subjective utility, which, due to the insatiability of desire, can never be completed.[158] This Hegelian subjectivism merely confirms the underlying creationist ontology of the neoclassical growth model, which in its multiplicative 'production function', only includes specified combinations of *K* and *L,* capital and labour, and essentially denies any necessary role for natural resources in the production process. Outputs were all combinations of money, work and machines, which all reproduced and expanded one another, all the while producing a stream of commodities *ex nihilo.*

One can search high and low for contemporary references to the obscure phrase 'social physics', which strikes contemporary observers as a hopelessly deterministic and positivist. The only writer I have been able to find between the neoclassicals of the 1870s and Daniel Bell in the 1970s who directly proposes such a grounding of sociology in the methods of physics is an obscure Princeton university physicist by the name of John Stewart. In an article published in 1950 in the *American Journal of Physics,* Stewart traces the project of the mathematical unity of the sciences from Adolphe Quetelet through to Norbert Wiener, exposing the absolute lack of philosophical subtlety of the social physics genre by defining it thus: "the distinction between social physics and sociology is the avoidance of subjective descriptions in the former."[159] Stewart's own contribution to the development of a social physics based on empirical measurement, mathematical analysis and the search for objective "laws" of society analogous to physical laws, is a discussion of economic geography. Beginning with a review of Thomas Malthus' bioeconomics and the equilibrium sociology of Vilfredo Pareto, he proposes an axiomatic principle of 'demographic gravitation' to explain patterns of settlement and urbanisation, suggesting for instance that 'the rural population can be treated as a gas, and cities as condensations of 'human molecules'. Having produced a series of equations based on similar analogies as applied to government statistics, Stewart continues in the worst traditions of Paretian sociology. First he reduces the observed and objective 'natural' distributions of income and settlement to axiomatics. Then without signalling a shift from positive description to normative prescription, he suggests that the tentatively offered 'law' of demographic gravitation could be used by central planners: if the gravitational population trajectory of a given rural region could be calculated as leading to a dampening in the rate of national economic development, officials could (should?) withhold state funding to rural schools. Notably, national 'economic growth' is the over-riding 'objective' point of reference for value questions, and the ultimate objective of social engineering.

Attending the conferences held by Stewart to resuscitate the social physics project, were the theorist of games and economic behaviour Oskar Morgenstern, and Frank Hahn, one of the few ardent Walrasians left in an American academy then dominated by American Keynesians. Also attending was the unacknowledged grandfather of bioenergetics, Alfred Lotka, who died shortly after, although the correlation of these events should not indicate causation. Tellingly for our current purposes, Stewart is careful to advance the newer term 'cybernetics' as a direct synonym for 'social physics'. This approach was to thoroughly eclipse his own now forgotten program to make social science 'real science'.

Nailing down exactly what cybernetics is a difficult question, but perhaps the simplest way to think of it is in the way its post-war practitioners did: as a kind of cutting edge metascience that had the potential to bring a whole gamut of technical and scientific problems within the range of mathematical analysis by rephrasing them as problems of input and output in dynamic systems regulated by positive or negative feedback. Numerous projects were gathered together under the concentrated reorganisation of research for the 1941 – 1945 war effort under such figures such as Vannevar Bush and Warren Weaver. Under the general ambit of 'operations research', which involved the development and application of mathematical techniques to the prerogatives of the large-scale organisation of the total war effort, social scientists, economists and physicists worked together in a centralised, well-funded environment that accorded scientists with a new importance and respect. Numerous advances occurred due to the cross-fertilisation of interdisciplinary work required to solve the many logistical problems of the total war economy: i.e. the need for the rapid development of new military prototypes, of a means for selection among different weapons platforms for mass production and deployment, the importance of intercepting and decoding enemy signals, and the need for highly sophisticated strategic deception once the enemies' communications had been penetrated.

The historical literature on the cybernetic 'paradigm' often divides its avatars into two camps. The first, exemplified by John von Neumann, were consummate insiders within what Eisenhower termed the 'military-industrial complex', with access to academic prestige, high-level government committees, and substantial military funding. These men were embedded in the military mindset of RAND think tanks and Airforce strategic command. They were the engineers of the Cold War, engaged in the intensity of a hairtrigger nuclear confrontation with a formidable and inscrutable enemy, in a bunker atmosphere "slick with dread and heavy with doom."[160] The intense demands of working within the wartime environment ended for many scientists with the demobilisations of 1945, and those that returned to civilian research applied the technological optimism of the military engineer to the problems of peacetime. It is among this second camp that we find such characters as Norbert Wiener, Gregory Bateson and (despite his technocratic inclinations) Tom Odum; figures optimistic about the expansion of knowledge, technology and the application of rational systems of governance in the long-term service of civilisation. As time wore on some of these voices became increasingly critical of the irrationalities arising from hardcore rational abstraction of the status quo (i.e. the Strangelove strategy of MAD), and the vast absorption of American scientists and research funding in the development of weapons of mass destruction. This pattern of Cold War science was evident as early as 1946 to Norbert Wiener, who attempted to have his own wartime papers on the subject of missile control removed from libraries in protest at the "tragic insolence of the military mind".[161]

As Bell says, the most important technical developments for the post war period were nuclear weapons and the digital computer. These were not at all separate projects: the computer was but a subordinate daemon whose development served to release a more awesome djinn from its bottle, the thermonuclear bomb. One of the key objectives driving the design of early punch card computing machines was the need to perform the thousands of complex calculations that went into the design of atomic weapons. The first program run on the ENIAC was run for the Los Alamos scientists.[162] Edward Teller was already demanding funds for research into the development of a hydrogen bomb well before the Manhattan Project was in sight of completion, and the first priority of this project was the improvement of computation. As Mackenzie reports, "[t]he complex calculations of hydrogen-bomb simulation exceeded the capabilities of the punched card machine operation" used for the design of the atom bomb.[163] In 1945 John von Neumann, a seminal cyborg figure and consummate military insider (who not incidentally redirected the search for neoclassical foundations into game theory in a work published the previous year),[164] arranged for the use of the ENIAC to begin the simulation. One million IBM cards were produced, each carrying one of the initial values for each point in the computational mesh, and "the computations to be performed required the punching of intermediate output cards which were then resubmitted as input."[165] From the outset, digital information technologies were engaged with the quantification of technological hazards at the biospheric scale. Prior to the detonation of the first A-bomb at Alamogordo, a question arose regarding the rate at which deuterium would decay in an atomic reaction. There was a fear that if this chain reaction gained too much momentum it might set the whole of the Earth's atmosphere on fire, a risk which the Los Alamos IBM punchcard computer was able to calculate down to a probability which was deemed by Teller as acceptably remote for the test to proceed.

Neoclassical theory's description of competitive general equilibrium underwent some major rethinking during the early Cold War, as a direct effect of the interdisciplinary efforts of influential American thinkers employed in highly covert military research. In his most recent history of economics, *Machine Dreams*, Mirowski recounts the historical transformation of neo-classical economics through intellectual contact with cyborg scientists mobilised for the war effort by the RAND Corporation.[166] He describes RAND as a strangely hybrid institution: part military strategy research unit, part university, part private corporation. With no clear commitment to any specific branch of the social or the physical sciences, RAND was contracted to advise on the rationalisation of scientific research into strategic thermonuclear command structures and man-machine interfaces, organised around the prerogatives of 'C3I' – communication, command, control and information.[167]

Both ecology and economics were to be profoundly transformed by the intellectual environment of the early cold war, as science funding and the organisation of research was restructured from the top-down by the national security state to meet the formidable scientific challenges of the of the arms race against the Soviets. These intellectuals were continually exposed to the pressure of extreme consciousness of risk to the future of the globe, which was met by a similarly extreme confidence in the power of rationality:

> "[RAND] was supposed to be a haven for steely eyed technocrats with ice in their veins, pursuing the mandate to think through a real apocalyptic conflict, one fought with unimaginably devastating nuclear weapons. These layers of looming apocalypse upon apocalypse... had the effect of escalating the drive for an abstract rationality well beyond that expounded in any previous social theory. It sought reassurances that could not rest satisfied with a mechanism for giving people whatever it was they thought they wanted, as with some pie-in-the-sky Pareto optimality; neither would it accept that the consequences of present actions could be extrapolated into the future using some mechanical inductive procedure. In an inherently unstable situation fraught with extremes, where meanings were elusive and one slip might mean the catastrophic loss of everything that ever mattered for humanity, what was required was ironclad standard of rationality imposed upon the threatening chaos by means of some external governor. The establishment of control was the essential precept in a nuclear world: passive resignation would never suffice, laissez-faire was out of the question." [168]

Incorporated into the military re-organisation and funding of scientific research, American social science and especially economics subsequently underwent profound reconfiguration around cyborg themes. As various commentators have suggested, though the 1870s provided the original interest in social physics, the 1940s was a period in which American neoclassical economics assumed its current format and scientific pretensions. Economics became less interested in theories of collective action, welfare and institutions and more fascinated by formality, abstraction, statistical inference and algorithmic representations of 'rationality.' Mirowski refers to this moment as the second stabilisation of the conceptual orthodoxy, like the first occurring through an oblique historical connection with physics, mediated by the most up-to-date machine metaphors.[169]

The theoretical outcomes were the hyper-rational, behaviourist models of information processing produced within decision theory and game theory, which sought to codify and mathematise the logical structure of decision-making under conditions of risk and uncertainty. The work of the mathematical economist John Nash consolidated the reconstitution of the microfoundations of economic 'rationality' in game theory. The Nash equilibrium replaced the ageing Walrasian equilibrium as the basis of general equilibrium theory. Unlike the 'rationality' of *Homo Economicus* in the earlier formulations of neoclassical economics, where the assumptions of perfect rationality, perfect information, and frictionless markets leads to a global equilibrium with a serendipitous welfare function reminiscent of Smith's invisible hand, game theory rather internalised a decidedly paranoid 'hermeneutics of suspicion' into economics that reflected the problem of the military strategist in the atomic era. Game theoretic models of rational choice attempted to bring into the same sphere of analysis the choices faced by executive Cold War nuclear strategists with those made by the atomised rational economic man of neoclassical economics, in his struggle to maximise 'utility' at the direct expense (to the point of annihilation) of other competitive units. Nash's economic agents are engaged in competition with an inscrutable and deceptive market opponent, a competition carried to the point of annihilation. As is dramatised in the recent film *A Beautiful Mind*, Nash was awarded the 1994 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel. (Contrary to the popular misconception, this is not the same as a 'Nobel Prize in economics'. In establishing the trust to fund the award, Alfred Nobel did not include economics among the natural sciences that he saw is beneficial to the human condition, nor was it classified with literature and 'peace' as deserving a prize. As Ravenscroft and Williams have argued, the creation of the prize by banking interests was a strategy intended to elevate economics into a science and help to naturalize a political ideology.[170]) While this says nothing about the quality or content of Nash's mathematical achievement, it is surely ironic that the man who redefined 'rationality' for economics was plagued by a tragic and serious mental illness for most of his life.

The recent wisdom justifying the revival of neoclassical economics and its neoliberal politics is technological, i.e. because *it works*. Mirowskis' account seems to suggest an alternative reading to the view that the neoclassical revival is a result of it presenting the most scientific description of a free society, to the exclusion of all other approaches. Rather than the re-discovery of the inherently generative effects of deregulated markets as against the 'dead handed' regulatory approaches of the post-war welfare state, the return to political pre-eminence of American neoclassical mathematical economics, was in many respects an epiphenomenen of its theoretical re-invigoration as an ideologically acceptable control theory within the decidedly apocalyptic Cold War research program of 'maintaining the delicate balance of terror'. Notably, this notion of equilibrium in thermonuclear politics (first formulated in 1959 as strategic doctrine by Alfred Wohlstetter in *Foreign Affairs*[171]), led not to a 'balance of forces', a 'steady state', or an 'optimal' level of expenditure on nuclear security but to runaway positive feedback in the potlatch of the arms race.

Up until the mid-1960s, when images of the 'mad scientist' such as Stanley Kubrick's military sociopath *Dr. Strangelove* (1965) began to penetrate the popular lexicon, physicists commanded an unqualified public respect and prestige over other scientists. (Debate still goes on as to whether

Strangelove was modelled on von Neumann, RAND theorist Herman Kahn or Edward Teller, with the smart money on Teller according to a recent book.[172]) In the wake of the Manhattan project, nuclear engineers were proof of the incredible success of scientific knowledge. Although this effort was doomed to failure, much government propaganda was developed in order to redirect public anxiety about atomic war toward the hope that their efforts would soon harness 'the peaceful atom' to the great benefit of all, as the following examples drawn from David Nye's history of the 'technological sublime' show. In the 1950s, the Atomic Energy Commission was established by the government to direct this process of domestication and public relations. With a mandate to plan the construction of civil atomic infrastructure, the AEC also produced a sizable volume of 'educational' materials on the subject of 'Our Friend the Atom'. The Atomic Energy Commission promoted the viewing of a nuclear test as an exciting event. Nevada local government assisted a roaring local tourist trade by publishing road maps giving directions to the best view points for watching atmospheric tests of hydrogen bombs.

Proponents of the atomic millennium proclaimed that energy would soon be too cheap to meter, and that this would massively increase productivity. Unlimited energy would even allow Americans to control the weather and to realise a social utopia. In a series of articles, David Dietz, the science editor of a widely read syndicate of American newspapers, explored the possibilities of atomic energy in the coming era. People would run their Cadillacs for a year on "a pellet of energy the size of a vitamin pill"; "summer resorts would be able to guarantee the weather", and "artificial suns will make it as easy to grow corn and potatoes indoors as on the farm." Nuclear powered mechanical hearts were proposed by some medical visionaries. Boundless free and clean energy was promised by future techniques of nuclear fusion, where 'self-regenerating' breeder reactors would produce no pollution apart from hot water. Also on the drawing board of policy-makers were the uses of specifically designed nuclear bombs for large-scale environmental engineering in the interests of national economic growth - for the excavation of harbours, dams, canals or for surface mining. Feasibility studies were drawn up by the US government for a 'Panatomic Canal' that would join the Atlantic and the Pacific at sea level, obviating the need for locks. Instead of cutting through the mountain ranges that traversed the Isthmus of Panama with ordinary equipment, nuclear row charges would cut huge incisions through bedrock to 200 feet below sea level in less than a minute.[173] This project was scrapped largely because of the Test Ban Treaty of 1962, which banned atmospheric testing. Significant opposition to the Panatomic Canal was also given for ecological reasons, as the effects of exposing the separately evolved biota of the two oceans to one another were entirely unpredictable. One wonders what local residents thought of the plan.

This hyper-optimistic form of geoengineering was actually attempted by Communist agencies of economic development. In 1965 the Soviets detonated an atomic charge under a riverbed in Kazakhstan. The resulting crater formed a reservoir, which was intended to bring irrigated agriculture to the arid surrounding plains.[174] In addition to the diversion of rivers and the effects of radioactive fallout, the mass use of chemical fertilisers, herbicides and insectides and heavy agricultural machinery destroyed of much of the regions fragile soil, its insect pollinators, and its aquatic life. Ultimately, this has led to the near total ecological and hydrological collapse of the Aral Sea, once a huge lake bustling with fishing boats and merchant haulage. Today, aestheticians of the industrial sublime can view the surreal spectacle of hundreds of rusting ships stranded on sand dunes that for decades have been becoming ever more remote from the receding waters.

The systems theories that accompanied the development of the digital computer led some to an incredible optimism regarding the ability to produce models of complex and stochastic phenomena that were more or less isomorphic with the natural (or social) phenomena in question. It was hoped that computer models simulating open environmental (or social) systems could lead to the development of instruments of control from the predictions of the model. Cybernetics was key to all of this by virtue of its ambition to provide a universal key to all the other sciences. Chunglin Kwa has described the period from the mid-1950s to 1973 as the 'heyday of macromodelling', when the computer modelling of complex systems – even though the computing power and mathematical complexity invested in these models was incredibly simple by today's standards – was thought to confer almost unlimited potential for control over the phenomena being modelled.[175] Kwa cites as an example John von Neumann's project for controlling the weather. As James Gleick reports of the optimistic faith in models of the period,

> "He [Von Neumann] recognised that a complicated dynamical system could have points of instability – critical points where a small push can have large consequences, as with a ball balanced on top of a hill. With the computer up and running, Von Neumann imagined that scientists could calculate the equations of fluid motion for the next few days. Then a central committee of meteorologists would send up airplanes to lay down smokescreens or seed clouds to push the weather into the desired mode." [176]

In a more spectacular example not discussed by Gleick, Kwa reports that Von Neumann once proposed that the famines associate with the endemic drought conditions of the Sahel could be fixed by the judicious seasonal detonation of atomic bombs off the coast of Africa.

While the sheer radiant force of nuclear technology briefly widened the horizon of millennial expectation, yielding machine dreams of infinite growth in energy output coupled with complete technical power and control, the terrifying reality of its hair-trigger deployment for global warfare and the emerging account of the longevity of harmful radiation after accidents like Three Mile Island and Chernobyl meant that the 'peaceful atom' was never really been trusted or welcomed into civilian life. The visceral awe and spiritual inspiration at human achievement witnesses reported at the contemplation of the mushroom cloud too quickly collapsed into terror.[177] (That said, the 'peaceful atom' may be on the verge of a comeback. In the last few years civilian nuclear energy has gained an unprecedented new respectability among some environmentalists as predictions of global warming disaster due to mounting industrial emissions of carbon dioxide and methane have become increasingly dire and more widely accepted by mainstream political parties.)

The emergence of the 'nuclear sublime' was accompanied by a sense of the permanent technological violation of nature through military hubris. With 'balance of power' politics stalemated in the bipolar logic of 'mutual deterrence', with its destructive potlatch of increasing 'throw-weight', for the first time in the history of the earth, the continuing stability of the conditions of earthly life as a whole were linked to an executive political decision. Moreover, the automation of the decision gave the commander-in-chief less than 15 minutes to consider whether to irreversibly put the entirety of the nuclear war machine into simultaneous action. In the age of mutually assured destruction, the balance of nature became dependent upon a bipolar ideological conflict conducted under the strategic simplification of geopolitics to a 'balance of power'. The continuity of life on earth came to be contingent upon the decisionism of sovereign power. The biopolitical reach of modern sovereignty had come to encompass the totality of planetary life.

Against the energetic optimism of government accounts of the 'peaceful atom', ecologists were crucial in countering the common view that atomic weapons were simply extra-large sticks of dynamite, by publicising the utterly catastrophic effects of radiation and rapid climate change in the 'nuclear winter' that would follow a war. Not only would vast numbers of humans perish in a full-scale nuclear exchange, but the biosphere itself could be threatened with collapse and mass extinction. Wallace Arthur notes a hypothetical situation in which all organisms were exposed to a million rads of radiation: this would result in the extinction of every species but the hardiest of bacteria, wiping out more than a billion years of evolution and returning the Earth to the 'green-slime' ecosphere of the very distant past.[178] Even relatively low doses of radiation, for example the strontium-90 and caesium-137 finely dispersed throughout the Earth's stratosphere by the multi-megaton airbursts of the late 1950s and early 1960s, were shown to threaten human beings directly. As studies of Innuit and Lapp nomads far removed from test sites showed, radionuclides tended to bioaccumulate in body tissues, increasing their concentration as they moved up the food chain.[179]

The consequences of the Cold War turning hot, communicated to publics by ecologists and popularised by the nascent environmental movement, effectively arrested the simple technological millennialism of unending Progress. As humanity became godlike in its partial mastery of the protean energies of physical nature, living nature, which had in Western culture since the Old Testament laid claim to 'a certain ferocious inexhaustibility'[180] was revealed as utterly fragile and contingent. In his diary, Harry Truman noted the end of the innocence of the myth of perpetual human progress through the war on nature. "The human animal and his emotions change not much from age to age. He must change now or he faces absolute and complete destruction and maybe the insect age or an atmosphereless planet may succeed him." Characteristically, Josef Stalin was more circumspect. "Atomic weapons", he once said, "can hardly be used without spelling the end of the world." [181] By this time, the unambiguous optimism of the industrial millennium was widely discredited for many as the technological imperatives of security introduced the daily possibility of nuclear annihilation to the psychic terrain of people everywhere.

At this time, ecologists thus took on a public role as the 'sane scientist' speaking in the public interest and warning of the destructive potential of technological hubris. If ecologists first rebelled against military discourses of omnicompetence, it was to economic millennialism that they were to give their most profound and as yet largely unrealised challenge. Out of the fear of a nuclear war arose a more insidious set of warnings regarding the prospects of perpetual economic growth. Through the depletion of forests, soils, biodiversity, minerals and energy resources at one end of the economy and the accumulation of chemical pollution at the other, the very 'success' of the industrial apparatus and the economic process threatened the stability of the biosphere, and in some accounts, the survival of the human civilisation.

**Power and the World System: Odum's Economy of Energy**

Despite the popular association of 'ecology' with 1970s counter-cultural radicalism, back-to-the-land Arcadianism, a pessimistic view of science and technology, the critique of 'development', a revaluation of peasant and hunter-gatherer economies and a quest for the preservation and re-enchantment of wild nature, the reality is that ecology as a 'hard' science was anything but subversive. The formative history of systems ecology – from which the radical environmentalist critique of mainstream Western culture claimed its validity and drew its paradigmatic metaphors – was characterised by individual and institutional accommodations to military funding. Like cybernetics, digital computation, game theory and behavioural microeconomics, early forms of the internet, artificial intelligence, and importantly the consciousness of the possibility of human induced biospheric meltdown, 'the ecosystem' as a fully realized scientific object is ultimately an artefact of the Manhattan Project and the subsequent expansion and re-organisation of Big Science in the United States around the linked imperatives of national security and national development. The social and political history of the 'ecosystem' is inextricably linked to an era whose essential characteristic seemed to be the mastery and control of the vast energies stored within the atom. Like the demons of mythology, nuclear technology promised an infinite number of free lunches to the wizard able to master the occult symbolism required conjure it up, but at the price of an intensely dichotomous struggle for dominance and submission that if lost, threatened utterly unnatural levels of destruction.

In the introduction to this conceptual history, we noted that the coming 'age of ecology' mooted by some observers in the 1970s meant that the metaphor of the machine would be confined to the dustbin of history and replaced by the metaphor of the ecosystem. To refresh the readers memory:

> "Infinitely more complicated than any man-made machine, a living ecological system is a marvellously well-organized interactive system which is self-regulating, resilient, and irreplaceable. It represents the culmination of billions of years of evolution. [...] Part of the reason for the vitality of the environmental movement may lie in the fact that it has introduced a powerful new image into people's minds: the image of the ecosystem. Here is another way of organizing complexity that is not machine-like. Here is another model which may be emulated. This image, the image of the ecosystem, has indeed become a new metaphor, which may succeed in transforming our society as thoroughly as the metaphor of the machine has done in the past."[182]

It seems to this author quite clear that while the scientific and popular discourses of environmental crisis have proliferated, adapted, matured and modernised (i.e. nobody now advocates mass sterilization of the 'third world' or the 'triage ethics' of cutting off immigration and development aid to the South for the benefit of 'humanity as a whole'), the ecosystem metaphor *has not* won out in the 'market place of ideas', or at least not the version of it that the above author uses, stressing as it does the irreducible and irreplaceable complexity of living organismic interactions. Perhaps one reason for this is that ecology became socially relevant as an incidental effect of its reconstruction as a general cyborg science, with all that that implies about the conflation of machines and organisms, and the reduction of complexity to computable algorithms and binary code. It is only when ecology ceased to confine itself to describing an ontologically distinct and pristine wilderness composed of organisms in communities, and began to abstractly analyse large, hybrid 'systems' containing cities, machines and industrial agriculture as well as 'wild' estuaries and grasslands, that it began to transform the terms of modern political discourse and undermine the naïve progress ideology associated with the machine metaphor. Quite ironically, it was largely through taking the same route that economics did in the 1870s – by attempting to find invariance principles (laws of nature) derived from energy physics and reducing kaleidoscopic complexity to a single medium of exchange – that ecology itself became a respectable new source of metaphors potentially transforming established social, political and economic discourse. In other words, it was through the work of Howard T. Odum and others in expunging organicism and communitarianism from its conceptual lexicon and implicitly embracing the metaphor of machinery that ecology made its (now forgotten) bid to replace economics as the *tableau entière* of decision theory *par excellence.*

Taking H.T. Odum as archetypal and indicative, this section outlines his important contribution to the renovation of the ecosystem concept between the early 1950s and the early 1970s, and seeks to place systems ecology in the historical context of the cyborg sciences. We then consider his subsequent 'subversion': the enunciation of an ecological critique of prevailing economic ideology. Finally, we look at Odum's 1971 attempt to construct an energy theory of value and to derive a social physics from ecology as a tool to ward off the catastrophic risk of ecological meltdown, and his vision of global cybernetic control over the interactions between large-scale technological systems and a biosphere conceived of in energetic terms. We then finish by comparing Odum's progressively mechanistic blurring of the lines between Nature and Society with the internal critique of mathematical economics given by Georgescu-Roegen, who in the same year devoted a classic text to the ignorance of economics regarding the entropy law. As I will argue, 1971 represents the moment when the long journeys of the alienated twin sciences of 'economy of nature' came full circle, arriving at the same cross roads, although without recognizing each other as intimate blood relations.

While economics has since its inception been a topic of intense public debate, this is not the case with ecology. As we have seen, ecology entered into public importance in the mid- to late 1960s, at a time when the concept of the ecosystem became central to its scientific legitimacy and social role. The ecosystems ecology developed by the brothers Eugene and Howard T. Odum separately and together from the mid 1950s redefined the discipline at a time when ecology was gathering attention and importance. It was from this point that ecological science 'came of age' in its new social role as analyst of humanity's home. Eugene Odum's textbook *Fundamentals of Ecology* ran to many editions and was the staple text between its first edition in 1953 the late 1970s. Eugene is still primarily remembered as an educator, but it was his brother Howard who brought ecology boldly into the analysis of the causes of and solutions to the global environmental crisis. Despite numerous collaborations in fieldwork and publication, the brothers tended to favour different metaphors. As Kingsland says, "Eugene thought of the ecosystem in organic terms as though it were an organism in a state of homeostasis, Tom deviated from this organic analogy and increasingly thought of the ecosystem as a machine governed by feedback mechanisms."[183]

Both the brothers were influenced by the biogeochemical approach taken by Hutchinson on their way to becoming prominent ecologists. Eugene studied physiological ecology under Hutchinson, and Howard wrote his doctoral thesis on the global cycle of naturally occurring strontium.[184] This latter subject was timely: the dispersal and activity of radionuclides in the environment later become an imminently relevant concern due to the *unnatural* amount of strontium–90 circulating the globe after atmospheric nuclear tests carried out in the 1950s, and as the civilian nuclear industry expanded in the US. The high importance placed upon the technological domestication of nuclear power in the upper-echelons of national security and planning institutions opened a series of professional opportunities for ecologists.

Ecosystems ecology enjoyed the continued support of research funding from the Office of Naval Research and the Atomic Energy Commission, as key academics pitched ecology to military funders as an indispensable part of the emerging literature on 'health physics', or the effects of radiological pollution on human physiology. This area of research was crucial to the question of safety and thus to the advanced utilisation of the technology. As humans could absorb contamination indirectly from is diffusion in the environment, ecology could assist in determining the levels of tolerance and thus the maximum 'safe' load of radiation for whole ecosystems. 'Radiation ecology' played an important part in the elaboration of systems ecology, as ecologists were employed by the state to research atomic test sites, to study the discharge of effluent from plutonium reactors, to research the process of forest succession in the hundreds of abandoned farms compulsorily resumed as buffer zones around experimental nuclear facilities, and to analyse food-chains by mapping the vectors taken by radionuclide tracers inserted into various points of the ecosystem.[185] Eugene had worked with AEC directed Oak Ridge National Laboratory, which under the ambit of 'health physics' became a major research center for systems ecology, and with Howard on the Eniawatak Atoll H-bomb test sites. Here they employed a biogeochemical method to analyse the processes of ecosystem succession on the islands and reefs as the sites began to recover from the blast, although these studies also contributed to the knowledge of how certain forms of radiation became concentrated at higher trophic levels (the top of the food chain, where humans dominate). Using the organismic idea that the biotic community as a whole had a metabolism, the presence of slowly fading radioactive isotopes allowed the tracing and mapping of energy and nutrient flows through the ecosystem as it approached the climax stage over the long term, providing that 'excessive' radiation did not retard 'normal' growth altogether. This metabolic analysis conducted through the mass-balance accounting of material flows became the essence of systems ecology. Another AEC project undertaken in the rainforests of Guatemala involved the meticulous classification of biota in a set acreage, the measurement of respiration, the removal of everything living from the site, and then a physico-chemical quantification of 'biomass' through the measurement of specific nutrients and of embodied energy. A barrel of radioactive material giving off 10 000 curies was then placed in the centre of the fenced off area and left for three months. Radioecologists were then brought in to analyse the effect of the surge of radiant energy on the early stages of forest succession.[186]

From this period, Odum took the ecosystem in a more mechanistic direction, first developing a hydraulic model of ecosystem function and then in 1960 introducing symbols from electrical engineering to depict the main functions within the system using energy circuit diagrams. A crucial point of inspiration for the thermodynamic ecology of H.T. Odum in these and other studies was Lotka's *Elements of Physical Biology*, which as we have seen for the first time attempted to develop a mathematically rigorous 'economy of nature', through joining thermodynamics to evolution through the analysis of predator-prey oscillations. With his undergraduate training in electrical engineering, the systems approach was appealing to Odum, who later made it the framework of his research. Where Darwin had provided the key evolutionary principle of natural selection, Odum argued that Lotka had raised natural selection to the status of a general energy law, which he proposed as a candidate third law of thermodynamics. As Neufeld reports,

> "Odum ... attempted to incorporate evolutionary thinking into his research, looking for patterns that may have arisen by natural selection, but at the ecosystem level. According to Lotka, evolution was not just species changing through time, it was an *overall accumulation and distribution of energy within a system* [my italics] Natural selection tended to maximize the flow of energy and matter through a system, a concept little dealt with by traditional evolutionary ecologists, perhaps because most of them work at the level of the individual and population, and not the ecosystem. Odum took Lotka's idea and called

it the *'maximum power principle'*, and it became the cornerstone of the bulk of his research." [italics in original][187]

Thus Odum provides a means for conceptualising 'economic growth' as the 'overall accumulation and distribution of energy within a system' according to dynamism of the 'maximum power principle'. Industrialisation appears as a blind, self-reinforcing material process.

As has been suggested, economics hardened and thoroughly robotised its account of rationality through its Cold War contact with the cyborg sciences in the military–academic complex. Mirowski has argued that the institutionalisation of machine rationality in economics was a controlling response to the apocalyptic tensions and looming chaos of MAD. I would argue that Odum's hardcore instrumentalisation of ecology, derived from similar intellectual and funding environments and from actual field studies of the Bomb's effects, followed an identical pattern. The affective dimensions of nuclear catastrophism were not the only source of his drive to subject the world to an 'iron-clad standard of rationality'; he increasingly saw another apocalypse emerging from the ordinary activities of peaceful economic development. His development of an energetic language for ecology was, I would argue, an attempt to situate ecology between economics and physics in such a way as to provide a conceptual language and a set of engineering tools for the management and stabilisation of the interface between complex technological and ecological systems. To H.T. Odum, the linking of control theory and thermodynamics promised to lead to a 'consilient' cybernetic ecology inclusive of both living and technological systems.

Cyborg metascience had opposite effects on the different 'economies of nature'. As a result of its reprocessing by the cyborg sciences, the neoclassical orthodoxy further entrenched itself as part of the order of society that must be defended at all costs. By contrast, the consequence for ecology was to become 'subversive'. By 1970, Odum was forming direct connections between his ecology and the environmental movement, specifically to address the contradictions and scientific inadequacies of modernisation theory which considered economic growth to be the 'permanent and normal condition' of industrial modernity, applying his cybernetic ecology to the analysis of the metabolism of industrial society as a global ecosystem of industrial technomass. Cybernetics, wrote Odum in a popular collection of environmentalist essays called *The Crisis of Survival*, "provides a convenient way of viewing the environmental problem as a whole." Arguing that economies and ecosystems, like machines and organisms, are functioning systems of dependent parts, he argued that such systems:

"[...] can exist in two general states: (1) a "transient" state in which the whole is growing or otherwise changing in time; and (2) a "steady state" in which the system is maintained in *equilibrium*, a system of inputs and outputs... A growth, or youthful stage is under the influence of what is called "positive feedback" in that each increase accelerates another increase, often in geometric progression (a doubling followed by a doubling, etc.) For the individual or the population, as for a new business, growth and positive feedback are necessary for survival. [...] However, growth does not and cannot continue unrestricted because "negative feedback control" also comes into play, either due to some limitation imposed by the external environment or due to the action of an internal "governor" that brings about an orderly slowdown and establishes a "set point" at which growth stops. As a living system becomes larger and more complex more of the energy that it transforms must be "fed back" to maintain and control the intricate structure; quality maintenance replaces mere quantitative growth as the strategy of survival in the mature system." [188]

In his fascinating though highly idiosyncratic *Environment, Power and Society* (1971), Odum directly takes up the problem of energy with regard to what Marshall referred to as 'the world industrial organism'. In this work, he laments the lack of an historical and evolutionary perspective among economists.

"Ecologists are familiar with both growth states and steady state, and observe both in natural systems in their work routinely, but economists were all trained in their subject during rapid growth and most don't even know there is such a thing as steady state. Most economic advisors have never seen a steady state even though most of man's million year history was close to steady state. Only the last two centuries have seen a burst of temporary growth because of temporary use of special energy supplies that accumulated over long periods of geologic time." [189]

In this book he analyses the fossil-fuel based 'system of Man' and its interaction with the global ecosystem revealed by the macroscopic 'maximum power principle' derived from the study of ecological energetics. He argues that what we might for the sake of argument call 'laws of ecology' can be expressly observed in mutual relations of feedback within and between socio-economic systems and the broader economy of nature. The biosphere and the 'system of man' can by measured and represented with pathways of 'power', which form systems of energy flow. In a classic piece of scientism, he conflates 'power' as 'energy available to do work' with a sociological meaning of power, arguing that the "economic, political and social power flows are just as measurable as those of the simple physical and chemical systems."[190] After describing the biosphere in energetic terms Odum gives a wide-ranging account of power, social order, agriculture, solar-based Roman imperialism, global economic structure in the age of fossil fuels, democracy, religion, ethics, and the forces of history and the soul, all liberally illustrated with his unique energy circuit diagrams (Fig. 6). Analysis of the contemporary 'system of man and nature', shows that the unbalanced energetic flows associated with human activity has manifested from the point of view of the biosphere as "cancer at many levels." For Odum, this planetary dilemma requires not merely that ecology should come to exert some influence on political and economic practice, but should entirely subsume it. He gives almost no discussion of prior anthropological, economic or social theory, all the while proposing to produce a unified science from a universal energetic language of his own design.

Each of these diagrams shows the linear flow of available high quality energy from a source (i.e. the sun) throughout a system of 'work gates' and ultimately to an entropic sink. These energy diagrams, argues Odum, allow the common concepts of economics that are meaningful in ecological systems to be translated into a unified technical language. In reciprocal manner the concepts of ecology, usually expressed in energetic terms, can be made available to economic analysis. The equilibrium analysis of prices as balances of supply and demand is thus subsumed entirely within ecology.

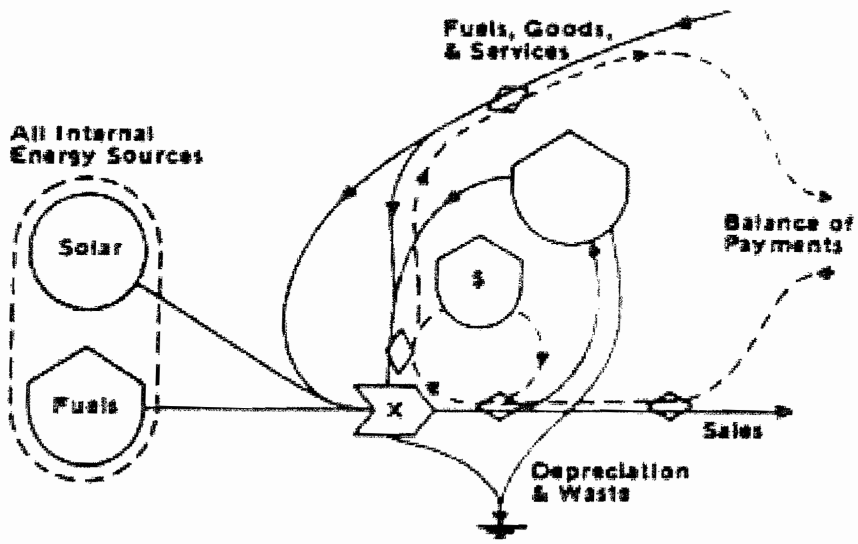


**Figure 6. Diagram of a national economy showing how the cyclical flow of monetary payments travels in the opposite direction to unidirectional flows of energy.**
Source: H. T. Odum, 'Energy, Ecology, & Economics', *Ambio*, no. 6, 1974.
<www.mnforsustain.org/energy_ecology_economics_odum_ht_1973.htm>

H.T. Odum challenged the role of monetary calculation of economic value with a different calculus, that of available energy. Odum noticed that the flow of conventional economic value represented by money seems to run in the opposite direction to the expenditure of potential or embodied 'energy' [Fig. 6.] This linear flow enters and leaves the circular flow of money (the economy) in the form wastes. The most important 'input power flows' to the economy in energetic terms – sunlight falling on crops, rivers turning waterwheels, or the gathering of coal – are considered to be free, and are priced not in terms of an essential "energetic value" but as in the case of oil, only in terms of the difficulty of extracting, refining and transporting it. Thus in monetary terms, the vital "free energy" of low entropy sources has an equivalent intrinsic value as the useless exhaust ('high entropy') of the economic process. As Georgescu-Roegen crucially observed in his seminal work, published in the same year, industrialism is "completely tributary" to mining and agriculture, "it is the pace at which low entropy is pumped from the environment into the economic process that limits the pace of this process". In the end, "the issue of returns boils down to that of returns to mining and agriculture."[191] From Odum's macroscopic point of view, this meant that money was a communicative disorder, sending erroneous signals to 'Man' and accelerating the cancer of the biosphere.

Odum can be considered to have laid down some first principles of a calculable ecological economics. Indeed, he devoted many years to producing a technical theory of value derived from thermodynamics. The basis of his theory is the proposal that economic value is equivalent to what he termed '*em*ergy' or embodied energy. (The attentive reader will note the similarity with Jevon's assertion a century earlier!) This idea goes back as far as Lindeman's foundational paper on the ecological energetics of the food chain, which suggested that predators inhabiting the highest 'trophic levels' of the ecosystem such as eagles, bears and sharks, represented the embodied energy of all the lower levels going down to the primary production of photosynthesis. As every metabolic conversion entailed the dissipation of much of the 'embodied energy', this analysis showed the numbers of organisms at the higher levels was strictly limited by the number of those beneath.

The concept of 'emergy' in ecology was devised to theorise the relationship of structure and function in ecological systems (i.e. 'orderliness', negentropy, information or low entropy), on the basis of the biophysical properties with which plants accumulate and transform radiant energy into a structural form useable by other organisms.[192] Odum transferred this metaphor of the 'trophic-levels' of a food pyramid to the analysis of machinery and industrial processes. He argued that as the economic system transformed and 'embodied' the energy previously embodied in fuels, ores, biomass and food for workers into industrial infrastructure and sophisticated capital goods, in a self-reinforcing cycle of positive feedback, it increased the flows of energy required to maintain the structure, in turn further expanding its capacity to access and dissipate more 'emergy.' According to the entropy law, the increasing 'orderliness' of the industrial heartlands was matched by a greater increase in 'disorder' elsewhere, in the degradation of ecosystems in the supply hinterlands from which 'emergy' was appropriated and transferred to the cities. Odum's general energy theory of value was thus developed to counter the environmentally destructive tendencies of classical economic value calculation by bringing ecosystems and economies into the same framework of objective analysis. Moving from 'natural law' to legislation, he argued that dollar/energy ratios should be applied as the basis for the re-engineering of social institutions away from growth into the maturity of the steady state, by ensuring that nature is 'paid' (whatever that might mean) for its services, in terms of inputs of human economic effort to maintain the integrity of the systems total function.

It is appropriate here to again widen our focus, and draw the reader's attention to the ironies inherent in the parallel with economics, as the ironies of physics envy here are rich. In both neoclassical economics and systems ecology, the value substance is potential energy. Unaware of the history of value theory and without even a nod to conventional economic theory or other social sciences, Odum replaces one energy theory of value, the neoclassical economic mechanics under which 'value is always conserved', with one updated by the second law, under which it might be said that 'value is always dissipating'. As we have seen, in dealing with the complexity of industrial capitalist society, the economists of the 1870s reduced social reproduction to the problem of production, and production to exchange value by representing market prices as a non-entropic realm of "energy/utility" in motion. Although professional economists would disdain to assert that 'utility' or 'value' is equivalent to something as base as money, in practice, economists, accountants, and politicians accept that money is the most convenient way to represent mathematically and thus render calculable the vast complexities of modern social activity in interaction with nature. The neoclassicals metaphorically equated pre-thermodyamic 'energy' with 'utility' in order to completely sidestep value theory and concentrate on prices – abstract and symbolic aggregations of subjective value. H.T. Odum's energy theory accomplishes the reverse, aiming to re-engineer the information signals given by the 'price-system' so that it reflects not subjective exchange values but the 'real value' of the underlying energetic flows, re-orienting value to the 'real' expenditures and losses embodied in the dissipative transformation of natural ecosystems into socio-economic systems. These natural flows, incorporated by farms, human labour and machines into integrated technomass, increase the order of the system locally, while exporting a greater quantity of 'disorder' to the great multiplicity of ecosystems whose sum is the biosphere.

Peter Taylor has rightly argued that the themes of the 1930s Technocracy movement would re-occur later in the systems ecology of H.T. Odum.[193] In contrast to the 1930s, however, Odum's 'technocratic optimism', was a response to a very different articulation of crisis. Whereas the Hoover-era

Technocrats were reacting to market irrationalities blamed for halting the onward march of industrialisation, Odum's ecology was intended to reveal the crisis of industrialism as a result of its excess of success in maximising energy consumption, in order to provide an objective science capable of ensuring the survival of humanity from the risks of network disintegration as energy flows are expended, cut off and degraded. While his conception of the relationship between physics and governance was in the 'optimistic' tradition of the earlier versions of social physics that we have already encountered, when mediated by his biophysical approach, the millennial view of industrialism typical of the social physics genre was replaced by a deepening preoccupation with the apocalyptic dimensions of risk in post-industrial modernity. In Odum's works we find a prophecy regarding the destructive tendency of the technological high-energy inputs through the economy: oil-dependent exponential growth and atomic technologies in the long term view impose serious costs on future generations because of the inexorable consequences of depletion and of waste. "To maintain order in an ecosystem, energy must be expended to pump out the disorder; both pollution and harvest are stresses that increase the cost of maintenance. The more we demand from nature, the less energy nature has for maintenance, and therefore the more it costs man to prevent disorder." [194] Despite his dissent with the orthodoxy of his time, his 'subversion' was tempered by a high positive technocratic optimism regarding the ability of science to cut through ignorance, to provide objective knowledge and solutions for the restructure of society needed to restore of some kind of semi-engineered global equilibrium. Catastrophic risk was the background against which ecosystems ecology went global.

If the macroscopic view of the world provided by systems ecology revealed the fundamental energetic dimensions of the environmental crisis, Odum did not despair. He devoted the latter section of his book to the re-design of the anthroposphere to make it consistent with the limits imposed by the tightening global energy budget. An effective global political organisation is needed, he argued, to urgently to redesign the structural couplings between wilderness, agricultural and industrial zones on a global scale, and in order to ease the transition to the steady state, which will come either through democratic economic restraint of energy use, or through the inexorable logic of depletion. Indeed, in the paradoxically millennial tradition of the social physicists, Odum advocates that if the United Nations could be re-engineered in a manner consistent with energetic principles, world peace could be the result. However, Odum's version of global democracy looks a lot like gerrymandering. Votes in UN forums, he says, ought to reflect "the power budget of a country", which is

> "[...] readily computed and could be determined annually. Instead of yearly votes in proportion to population they could be assigned in proportion to the energy budget of the previous year. Thus the voting power would always correspond to real ability to influence the world."[195]

Here the potential for deep political conservatism of cyborg ecology is revealed, as Odum proposes an energetic apartheid that would maintain the stratified privileges of the globes energy consuming elites, who in his version of the global industrial organism, hold the position of world brain in the division of labour, selflessly doing research and finding technical solutions to the worlds problems for 'our common future'. In what appears to be a veiled reference to the brief hope for a New International Economic Order, he warns "for the rich countries to give up their present power control to a system of untried capabilities may be very risky for the whole world's progress."[196]

In another of the ironies of social physics, it is worth noting that the neoliberal order of market privatisation and deregulation, the very opposite of Odum's political ideal, has since the 1970s been convincingly maintained. The stratified correlation of political and economic power with energy consumption, through the socially constructed market determination of value, a process Hornborg has convincingly analysed as the 'thermodynamics of imperialism.'[197] In 1984, for example, the dollar denominated statistics of the General Agreement on Tariffs and Trade indicated that fuels formed 46.8% of the value of exports from the South to the North. Conversely the dollar value of energy exported from North to South was only 7.8% of trade in that direction.[198] Emissions of carbon dioxide are 50 times higher for the average American than for the average citizen of India. Hornborg argues that it is the wide differentials in the market value of human labour as opposed to the uniformity of commodity prices (especially energy) on world markets that, when combined with the structure of intergovernmental debt, facilitates the continuous asymmetric transfer of natural resources from South to North. This situation has effectively been normalised since the Brundtland Report (1987) and the compromise of liberal environmentalism, which traded acknowledgement of environmental crisis for agreement on the centrality of free-market economic growth as the solution. Despite major efficiency gains since the oil shocks, 'postindustrial' centres are continuously increasing their energy consumption. Even though denying zero-sum arguments for ecological limits to perpetual growth, the modest institutionalised norms of liberal environmentalism have since 2004 been undermined by the culturally relativist arguments of George W. Bush, who famously rejected the Kyoto Protocol on the eve of the Johannesburg Earth Summit on the grounds that 'the American way of life is not negotiable'.

Although it seems impossibly remote from our own time, in 1970 Odum believed that most people would soon accept the necessity of ecological engineering:

> "General realisation that the supply depot and the living space functions of one's environment are interrelated, mutually restricted and not unlimited in capacity has

amounted to a historic 'attitude revolution' that is a promising sign that man may be ready to apply the principles of ecological control on a large scale.[199]

This does not mean merely conservation, fencing off of wilderness and applying ecological controls to industry, but redesigning the entire interface of social and environmental exchanges. He expresses a great confidence in the future of molecular biology and systems engineering, from which comprehensive methods must be derived in order to impose control upon the rising chaos of destabilised ecosystems.

> "The millions of species of plants, animals and micro-organisms are the functional units of the existing network of nature, but the exciting possibilities for great future progress lie in manipulating natural systems into entirely new design for the good of man and nature. The inventory of the species of the earth is really an immense bin of parts for the ecological engineer."[200]

Not content to redesign the world's ecosystems, economies and political systems, Odum also proposes an energetic basis for religious values. Posing as Moses, he replaces the Ten Commandments with another ten more suited to the age of depletion, which include the following:

1. Thou shalt not waste potential energy
6. Thou shalt judge value by the energies spent, the energies stored, and the energy flow which is possible, turning not to the incomplete measure of money.
7. Thou shalt not take from man or nature without returning service of equal value. [201]

Here the ironies of 'physics envy' reach their logical extreme. Claiming to stand outside of both society and nature and deal only with objective energy flows, Odum's biophysical ethics highlights the paradoxes built into the metaphor 'the laws of nature.' The intimate cultural relationship of physics to theology, and of economics and ecology to the millennium, is perhaps best illustrated with a visual metaphor. In the most fascinating circuit diagram of Odum's book, thermodynamics and eschatology are converted to a single image through a single theory of value [Fig. 7].

Falling victim to the naturalistic fallacy, Odum attempts to bring the moral laws of society into isomorphic conformity with the physical laws of thermodynamics. There is some irony here, in that the long historical intertwining of secular millennialism and attempts to construct a social physics, which as we saw in the case of economics engendered a belief in the justice of the market, the generative powers of machines, and finally infinite growth, has here in ecology manifested itself as a religious scheme to restrain the machines and ward off the apocalypse of chaotic depletion. As this thesis has argued, the history of attempts to construct a social physics with which to bypass all metaphors, subjective values, historical contingency and metaphysical questions is doomed to failure, because as Nietzsche argued, the faith in science is itself metaphysical, metaphorical and embedded in metanarrative.

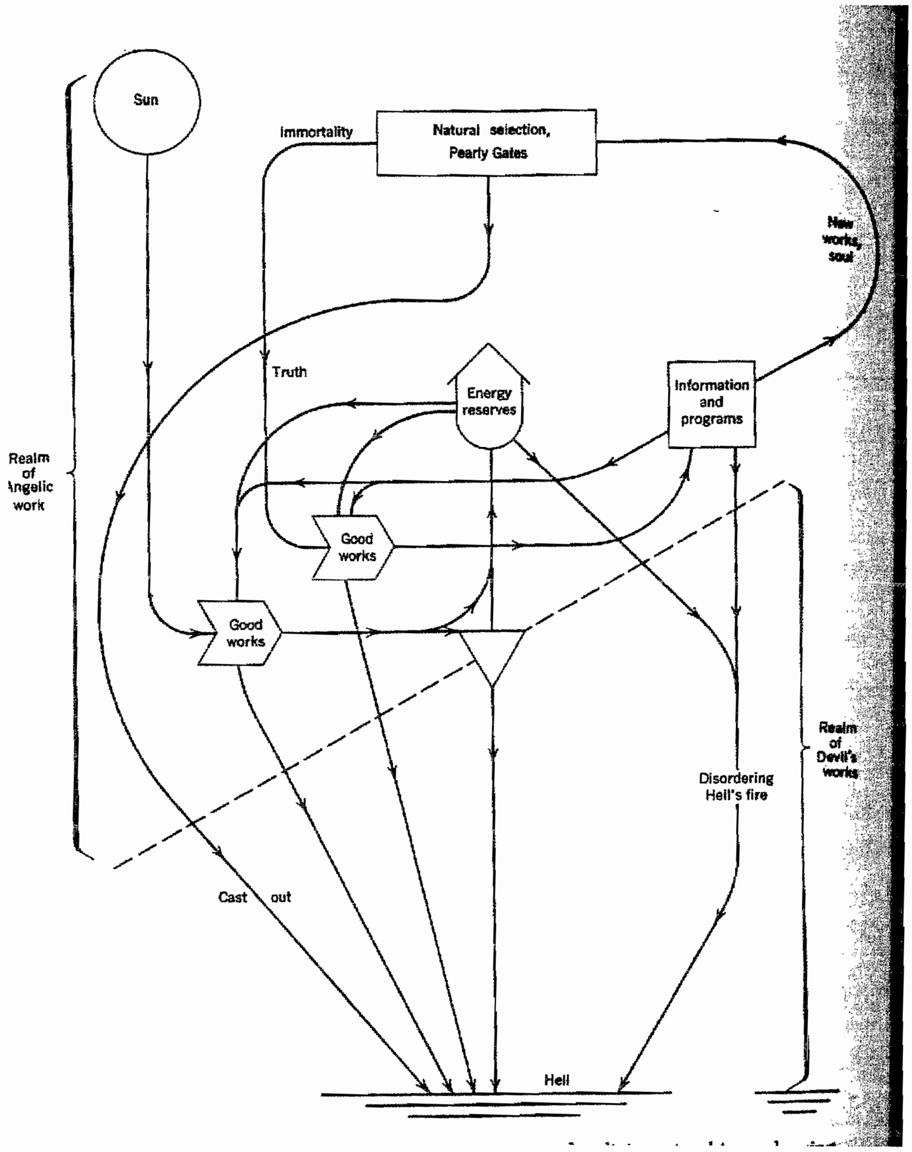


**Figure 7: Odum's Theology of Energy.**

A diagram showing "angelic operations of order, evolution and selection of information above and the evil processes of disorder, dissipation and heat death below." Source: H.T. Odum, *Environment, Power and Society*, Wiley Interscience, Sydney, 1971, p. 252.

**Conclusion: Odum and Georgescu-Roegen as Epistemological Twins**

In this chapter I have tried to generate a little bit more light than heat, so that we might glimpse economics more plainly in the mirror of ecology. As the mathematical economist Georgescu-Roegen initiated the critique of the neoclassical syntheses that underlies my earlier account of the Nature of Economy it seems appropriate to mention him here again with his non-identical epistemological twin. H.T. Odum and Georgescu-Roegen make a fascinating pair, gazing at us from either side of the dialectical interplay between the Natural and the Social sciences. Separated at birth, economics and ecology were momentarily re-united by the crisis of the 1970s in the apocalyptic collision of hidden machine metaphors, a crash that took place as result of the historically specific appropriation of different moments of energetics that established them both as 'real' sciences.

Odum and Georgescu-Roegen take very differing positions in the canoninical history of ecological economics. As an economist Georgescu-Roegen has had a mixed reception. His public resignation from the American Economics Association over the scientific value of mouse torture, and his deeply critical work on the scientific pretensions of neoclassical economics, have meant that neoclassical economists praise his early mathematical work on consumer theory but ignore his mature work on agrarian development and bioeconomics. These latter works have gone unanswered and ignored by the hagiographic purveyors of standard Arrow-Debreu 'general equilibrium', and Solow-Stiglitz 'economic growth' because they strip economics of its claims to be scientific, and in doing so, reveal the current neoliberal order as the creation of powerful interests and well marketed ideology.

Both of these figures approach the critique of mainstream growth ideology by observing that just like organisms, machines and commodities, the 'economy' is not a bounded scientific object, but a nexus of overlapping fields of energy, information, work, ideas about value and flows of natural materials of biological origin that sustain their existence. The ultimate referent to this critique from both is energetics, or with entropy, strictly the measurable quality of the relationships between different states of energy. Both point to the illogicality of the machine dream of perpetual growth. Dealing directly with the orthodox economic theory of 'production' and the consequences of its ignorance of the second law, Georgescu-Roegen is content to theoretically demonstrate that the biological capture of solar energy is the ultimate limit and basis of industrial 'production', which is thus not generative as the metaphor of growth suggests, term but ultimately dissipative. Georgescu-Roegen draws from authorities across the academy and arrives at an anti-mechanistic conclusion. Unlike Odum, he resists the technocratic temptations of engaging in social physics and succumbing to the dark side of the force. Brilliantly critiquing mathematical economics from within in a rigorous analysis according to biological consequences of the entropy law, Georgescu-Roegen establishes a philosophically sophisticated bioeconomics of fundamental limits that secures his place as the father of contemporary ecological economics. While providing few predictions and no solutions, he ends with a comprehensive denunciation of arithomorphism, behaviourism, positivism, mechanism and all other deterministic schemes of improvement, and a plea for the irreducible and untranslatable value of human cultural and social experience, which unlike 'fitness' or 'utility maximisation' or 'maximum power', is the ultimate goal of the economic process. Georgescu-Roegen refuses to be a social engineer and remains an anti-deterministic humanist, a gentle pessimist that sees the goal, the telos, and the output of the economic process as the ineffable *enjoyment of life*.

It is either worrying or a tribute to the sophistication of this volume, that even though *The Entropy Law and Economic Process* (1971) is considered the founding document of 'ecological economics', the index of Georgescu-Roegen's opus contains not a single reference to ecology or an ecologist, although there are many useful discussions of the questions of the molecular biology of the day. The plot thickens when one refers back to the index of Odum's *Environment, Power and Society* (1971), which reveals virtually no reference to the human or social sciences or to any economists other than Wassily Leontif, who was engaged in a similar analysis of intersectoral inputs and outputs according to a mass balance approach. These striking omissions in coterminous works treating essentially the same questions are plainly indicative of the deep academic estrangement of the twin 'economies of nature' across the Natural and Social divide, despite the mirroring of key metaphors, concepts and terms. It is also reflective of very different temperaments, with Georgescu-Roegen the playing the lucid and critical humanist intellectual and Odum as nature's cyborg, decoding, recoding and overcoding a monistic universe of 'power' with his arcane circuitry of work, energy and information flows. Despite mutual disinterest in the details of the each others fields, both make the powerful shared claim that economic theory and practice should reflect biophysical reality, and the proper parameter for the discussion of production, growth and distribution is not statistical mechanics, but the second law, the domain of natural law in which 'life matters' and history happens. Both call for a transvaluation of values such that decisions are made on the basis that the earths supply of natural capital is humankind's dowry and should be conserved to the greatest extent possible.[202] Both point out in their own way that what counts as 'production' for economics, is from a biophysical perspective, strictly consumption. From this unacknowledged historical meeting point, Odum and Georgescu-Roegen part company. It would be an interesting project for another day to review the entire literature and see if either of these scholars every referred to each other's work, which was on the same topic but approached in irreconcilable directions.

Georgescu-Roegen, who described his approach to social science as bioeconomics, is still one of the most cited authors of the journal *Ecological Economics*. While this intellectual enterprise does little to awaken the slumber of the orthodoxy, it is far more promising than rival approaches such as 'environmental economics', an approach entirely consonant with neoliberal 'free-market environmentalism' and its conclusion that more markets and more growth are the *solutions* to the environmental crisis. In contrast, Odum's attempt to unify the 'system of man and nature' through ecological energetics is rarely referred to in any detail, either in economics or ecology. Neither of these crucial 1971 books are mentioned in standard economic or ecology textbooks.

Some tentative explications of these differing fates are worth considering. Georgescu-Roegen, for his part was a long time and relentless critique of the American professions enthusiasm for Arrow and Debreu's new proof of general equilibrium (which he ridiculed for its initial assumption that all economic actors have a guaranteed lifetime income) and Robert Solow's standard model of growth, for obvious reasons. Both of these achievements were recognised in Bank of Sweden 'Nobel Prizes', while his own imminently relevant work on the substantive historical, ecological and thermodynamic aspects of the economic process went ignored by all and sundry. A perennial candidate for the Prize himself, Georgescu-Roegen became embittered and unco-operative in his later career, believing himself to be the victim of a reflexive institutional lockout. This meant the explication of his work and its exfoliation through the academy had to wait for the later generation of organizers and networkers such as Herman Daly and Robert Costanza.[203]

Odum for his, part suffered the standard fate of the out-and-out social physicist: failing to gain political support for a total program of control derived from a value calculus derived in turn from forbiddingly opaque regions of physical theory inaccessible to laymen. Enthusiasm for this particular form of cyborg millennialism went out of fashion with von Neumann's weather control and the Panatomic canal. As the sociologist Chunglin Kwa reports, explicit programs of social and ecological engineering went underground in the 'decade of crisis':

> "Modelling projects which aimed at large-scale control were abandoned in meteorology, economics and ecology at about the same time [1973]. The search for models that would convey power converging on omnipotence stopped. Concepts that had informed the search for global control, such as equilibrium and stability, lost much of their intuitive plausibility. [...] The relinquishment of the projects mentioned set in motion a redefinition of the idea of control, involving both the scale and the technologies of power."[204]

Despite this, Odum continued to work on the thousands of calculations needed to apply his emergy synthesis to specific situations. While he influenced an international coterie of environmentalists and energy policy analysts, even economists, by the 1980s evolutionary biologists and ecologists had largely turned away from the analysis of group dynamics as systems of feedback and coordination and instead shifted theoretical inquiry onto the individual pursuit of self-interest, completing the takeover of ecology by the Walrasian social physics.[205] For our narrative, the most fatal problem of Odum's heroic unification of science and society through a general 'emergy synthesis' has been hinted at in a more recent critique of his ecology. With a telling metaphor, Manssen and McGlade's analysis speaks volumes to our discussion of the economy of nature.

> "We conclude that the various forms and uses of energy bound up in essential ecosystem processes present a formidable obstacle to obtaining an operational definition of a general, aggregated available-work concept, a prerequisite for the systems approach of Odum and others. We also show that the prototypical derivations of the maximum power principle, and its interpretation, are contradicted on many scales both by empirical data and models, thereby invalidating the maximum power principle as a general principle of ecological evolution. *The conclusions point to the fundamental problem of trying to describe ecosystems in a framework which has a one-dimensional currency*." [my italics][206]

Their paper gives no discussion of the relationship with economics despite the metaphorical reference to energy as currency. Similarly, Peter Taylor concludes his otherwise illuminating study of Odum's transformation of the ecological metaphor with the following remarks, which follow an attempt to explain Odum's control mania psychologically, as over-compensation for the loss of the genteel and convivial Old South of his childhood, when everyone and everything was in its place:

> "...the individual is [now] more vulnerable to decisions about social organization that are increasingly made on a scale that eliminates the details of local interests, and at a distance that removes the decisions from the individual's influence. In fact, in feedback systems of energy or information the individual is potentially obsolete – all processes, whether physical or biological are *substitutable*." [my italics][207]

Are they really? Or is this just further evidence of the technological faith of the neoliberal era? As the patient reader will no doubt begin to suspect, the reified proto-energetics metaphor has inclined economists to believe that 'the market' enables the perfect substitution of all factor inputs, leading to a simple faith in entrepreneurial technological innovation as an automatic solution to the problem of peak oil and the need to reduce carbon emissions. The neoclassical matrix of calculation, imprisoned as it is in the unacknowledged metaphor <energy=utility=value>, essentially denies the specificity and centrality of depletable energy to economic growth. In one of the many ironies of physics envy, it is this very one-dimensionality that allows money to be a measure of all things. Such comments unwittingly go to the heart of the dilemma we face in our time of eco-social crisis: abstract exchange value (money) renders all things *exchangeable*, but this does not mean that they are *substitutable*, as economic models assume, and economists then believe to be a fact about the world. Oil is irreplaceable, as are extinct species and destroyed old growth forests.

Georgescu-Roegen, for his part maintained a fierce epistemological critique of economics and mechanistic philosophy, and particularly of the mathematisation of value theory, continuing to argue as he had done since 1930 that social phenomena could never be grasped by the mechanical methods of classical statistics. After studying economics at the Sorbonne, he concluded that "economic phenomena cannot be described by a mathematical system, a faith I have never renounced."[208] Georgescu-Roegen shared the view of his mentor Schumpeter that the most important vectors of the economy were qualitative and not quantitative, and this meant that economic theory must be open, dialectical and self-reflexive in its relationship to the institutional and biophysical effects of policies derived from the models. That is, he believed that social and historical context was indispensable, and that economics must remain open to other disciplines to retain legitimacy. Here, he is especially critical of the Walrasian brand of equilibrium. "Time and time again," he writes, "we can see the drawback of importing a gospel from physics and interpreting it in a more catholic way than the consistory of physicists."[209] Despite hammering home the inadequacies of a social physics ignorant of the Entropy Law a century after it revolutionised science, Georgescu-Roegen avoids a reduction of economic value to measurable ratios of 'low entropy'. Low entropy is, he insists, a *necessary* but not *sufficient* condition of economic value. A poisonous mushroom has the same degree of low entropy as a rare species renowned as a delicacy, but one has negative and the other positive *utility* from the perspective of the human enjoyment of life. Similarly, an object with no economic value never has a price, but an object that does have economic value (i.e. the sun) may never enter into the circulation of property exchange and thus never attract a price.[210] Thus, despite his long-term fascination with questions of value theory, Georgescu-Roegen utterly refuses to contemplate a single measure of economic value and thus, to construct a social physics. In a paragraph that could be taken as a direct rebuttal of Odum's entire approach, he insists that:

> "It would be utterly wrong to equate the economic process with a vast thermodynamic system and, as a result, to claim that it can be described by an equally vast number of equations patterned after those of thermodynamics which allow no discrimination between the economic value of an edible mushroom and a poisonous one. [...] All this, however, does not affect the thesis I have endeavoured to develop in this book,

namely that the basic nature of the economic process is entropic and that the Entropy Law reigns supreme over this process and over its evolution." [211]

Picking up a standard text, Begon, Harper and Townend's *Ecology* (1995), we turn to the section on 'The Flux of Energy through Communities' which introduces the analysis of ecosystem 'productivity'. We there learn first that what distinguishes the human species from others is the wide range of 'resources' that can be 'substituted' for one another: gold for housing, food for work, even cattle for wives![212] These elementary forms of barter are profoundly unimaginative, and do little justice to our present predicament: in the present it is possible to exchange financial derivatives speculatively hedging against the risk of investment in carbon emission permits for a top-of the range leafblower, a tank of two-stroke fuel and a pair of plastic earmuffs. Elsewhere, 'developing' countries can trade their unpayable dollar-denominated debts incurred to Northern capital for high conservation value rainforest, as has happened between the International Bank and Costa Rica. These forests might then be claimed as investment in 'carbon sinks' by their new proprietors, sold on as a 'carbon credit' and then used to secure additional licenses to emit carbon dioxide by industrial corporate investors in the North, completing an arbitrarily drawn circle of thoroughly incommensurable activities through the universal acid of commodification. Not bothering to open the Pandora's Box of what is actually meant by 'substitution', Begon et.al. then go on to note briefly with evident bemusement that what elevates Society up and out of the realm of Nature is the phenomena of exchange:

"[...] in effect, dollars and pounds have come to be surrogates for resources."[213]

As the perceptive reader will have gathered, this goes to the heart of our thesis, because this is exactly the ontology of nature embedded in the 'frictionless machine' of the Walrasian market and inherited by its illegitimate child, the neoclassical theory of growth. The assumption of the frictionless and timeless exchange of equivalent values needed to conjure 'equilibrium', turned into the assumed (and then believed) perfect substitution of capital for nature in model of growth, which was added later as an afterthought. This is why economists believe in infinite growth. And while the phenomena of money is entirely built into the 'flux of energy' through industrial 'communities', in the final analysis, dollars and pounds are not really 'surrogates for resources', as they are rather symbolic claims on someone else's resources or labour.

Casting a dissenting backward glance at systems ecology the 'dialectical biologist' Richard Levins has suggested that:

> "The notion of energy as the fundamental thing to look at as the universal medium of exchange is clearly brought into biology by analogy with economic exchange...There was a hope...that we could ignore all the complexity of interacting species, the heterogeneity of populations, the complexities of competition and symbiosis, of mutation and predation, and reduce everything to a single medium of ecological exchange, which was designated as 'energy' ".[214]

Although some of his more conservative colleagues discount his opinions as those of a 'Marxist', Levins is as an ecologist justly wary of the metaphors and methods imported from the Walrasian branch of social physics. It is this passage that is perhaps at the core of the problematic investigated in this thesis, leading as it did this unwary doctoral student into the labyrinthine 'Library of Babel' that has accrued around to the venerable term *oikonomia* and the innocent looking phrase 'economy of nature'. While this author is inclined to similar skepticism as that of Levins regarding the prospects of Unified Science, it is easy enough to find examples of those who feel that the parallel problematic of ecology and economics can be resolved, either by subsuming them within some master metaphor or (in what might amount to the same thing) claiming to eliminate all the metaphorical obstructions to clear vision on appeal to the direct truths of science, through ratiocination and mathesis.

Exemplary of the mathematical approach to unification is the work of the economist John Tschirhart, the only author I know of to attempt to found an explicitly neoclassical model of ecology. In a paper wonderfully entitled 'Ecological Transfers in Non-Human Communities Parallel Economic Markets in a General Equilibrium Model', organisms engage in perfect competition for scarce 'energy' expenditures. While the author bends over backwards to point out distinctions between predation and 'economic markets' (eg. unlike predation, where one actor exploits its involuntary prey to the point of death by consuming its actual body, he naively believes that in 'economic markets' all exchanges are voluntary and mutually beneficial), the similarities are such that he is then able to invoke a neoclassical general equilibrium model as ideal for population ecology. This after he argues that its microeconomic foundations are applicable to ecological behaviour, by assuming that "individual plants and animals make decisions" motivated by the "maximisation of net energy per unit time", calculating their optimal foraging strategies through solving differential equations of "energy prices".[215] In an understatement delivered without a shred of irony, Tschirhart notes that "economic modelling has proved very useful in formulating policy", and thus his three-good Walrasian model of a North Pacific ecosystem consisting of pollock, sea lions and orca is finally offered for its usefulness in shaping public policy. One wonders what would happen to his carefully constructed equilibrium of 'energy prices' were his model to include the über-dominant predator of the worlds oceans: human beings in fossil-fuelled, refrigerated ships that spend months at a time scouring the bottom of the sea around the clock with mile-wide driftnets. Would 'the predator' be the ships crew, the holding company that comes to 'own' the fish, the sum of capital invested seeking a return, the ship itself, or 'the market' which mediates through prices the 'demand' of all the landlocked humans and their cats that end up eating the fish? Like the equilibrium model he uses, Tshcirhart's ecology is a zero-sum game, yet nowhere does he discuss how the idea of 'economic growth' might translate into ecology, nor does his discussion of equilibrium consider the question of entropy. None of the conceptual history of either discipline, nor the questions about representation developed in this thesis trouble Tshirhart. Here, we can see that the analogical configuration within which economists work has become an end in itself.

The vast mountain of conceptual excess and analogical wreckage generated by the ebb and flow of terminology between the Natural and the Social, in particular by the metaphorical complex <energy=utility=value> is invisible to Tschirhart, even though it is the ground upon which his economic science rests. Unaware of the proto-energetics metaphor at the heart of his epistemology, his attempt to subsume ecology nevertheless continues to work entirely within models built upon the original metaphor. As Klamer and Leonard would say, the primary metaphor remains, but the very incongruities that once alerted us to the presence of a metaphor have been eroded by its 'currency'. [216] Familiarity and overuse has drained the metaphor of its merely figurative sense, such that it appears to be a feature of the world and not merely a theoretical prop to make the model 'work'.

## Part III Endnotes


[1] Cuyahoga River Online Exhibition, 'Fires on the Cuyahoga River', Cleveland Press Collection, Cleveland State University Library, 1999. <http://web.ulib.csuohio.edu/SpecColl/croe/accfire.html>
[2] Richard Bambach, 'Ecology as an Economy', [review of *Nature: an Economic History* by G. J Vermeij, 2004], *American Scientist,* vol. 93, no. 2, 2005, p. 185.
[3]Cited in Betty Jean Craige, *Eugene Odum: Ecosystem Ecologist & Environmentalist*, University of Georgia Press, 2002, Chapter 6.
[4] Stephen Pyne, *Burning Bush: A Fire History of Australia*, Henry Holt, New York, 1991.
[5] Tim Flannery, *The Future Eaters: An Ecological History of the Australasian Lands and People*, Martin Secker & Warburg Limited, 1996
[6]Craige, *Eugene Odum: Ecosystem Ecologist & Environmentalist*, 2002.
[7] Mary Douglas, *Purity and Danger: An Analysis of the Concepts of Pollution and Taboo,* Routledge, London, New York, 1991.
[8] Kristeva cited in Malcolm Bull, *Seeing Things Hidden Apocalypse, Vision and Totality,* Verso, London, 1999, p. 61.
[9] Bull, *Seeing Things Hidden,* Chap. 2.
[10] Bull, *Seeing Things Hidden,* p. 47.
[11] Bull, *Seeing Things Hidden*, dustjacket.
[12] Nicholas, Georgescu-Roegen, *The Entropy Law and the Economic Process,* Harvard University Press, 1971, p. 281.
[13] Geerat J. Vermeij, *Nature: an Economic History*, Princeton University Press, Princeton and Oxford, 2004, p. 50.
[14] The European Commission, 'European Commission 2001 White Paper on Strategy for a Future Chemicals Policy, COM (2001) 88, Brussels, 2001.

[15] Robert U. Ayres, *Information, Entropy and Progress,* American Institute of Physics, Woodbury, NY, 1994, p. 283.
[16] Vladimir Vernadsky, *The Biosphere*, trans. David Langmuir, Copernicus, New York, 1998.
[17] Lynn Margulis & Dorion Sagan, *Microcosmos: Four Billion Years of Microbial Evolution,* University of California Press, Berkeley and Los Angeles, 1997, p. 94.
[18] Hans Blumenberg, *The Legitimacy of the Modern Age,* Cambridge, MIT Press. 1983, p. 30.
[19] Carol Keller, 'Talking about the Weather: the Greening of Eschatology' in *Ecofeminism and the Sacred,* (ed.) Carol Adams, Continuum, New York, 1993.
[20] Sharon Kingsland, *The Evolution of American Ecology: 1890-2000,* John Hopkins University Press, Baltimore, 2005, p. 208.
[21] Gordon Edwards, 'A Metaphorical Framework: the Ecosystem versus The Machine', Part One of the *CCNR Final Submission to the Ontario Royal Commission on Electric Power Planning,* June 1978.
[22] Eugene P. Odum, *Fundamentals of Ecology,* W.B. Saunders, Philadelphia, 1971, p. 3.
[23] Odum, *Fundamentals of Ecology.* p. 4.
[24] Adam Swift, *Mapping Posthuman Discourse and the Evolution of Living Informatics,* Doctoral Thesis, Queensland University of Technology, 2006, p.11.
[25] Richard Doyle, *On Beyond Living: Rhetorical Transformations of the Life Sciences,* Stanford University Press, Stanford, 1997, p.10.
[26] Michel Foucault, *The Order of Things, An Archaeology of the Human Sciences,* Pantheon, London, 1970, p. 127
[27] Donald Worster, *The Wealth of Nature: Environmental History and the Ecological Imagination,* Oxford University Press, New York, 1993, p. 156.
[28] Frank Egerton, 'Changing Concepts of the Balance of Nature,' *Quarterly Review of Biology,* vol. 48, June 1973, pp. 323-350.
[29] Cited in Garret Hardin, 'Perpetual Growth: the Next Dragon Facing Biology Teachers', address to the National Association of Biology Teachers, Houston, Texas, November 1990.
[30] Emile Meyerson, *Identity and Reality,* trans. Kate Loewenberg, Routledge, [1908] 2002.
[31] Karl Popper, *The Open Universe: An Argument for Indeterminism,* Routledge, 1992.
[32] Egerton, 'Changing Concepts of the Balance of Nature', p.330.
[33] Matthew Hale, *The primitive origination of mankind, considered and examined in the light of nature,* Shrowsberry, London, 1677..p. 211. Cited in Egerton, 'Changing Concepts of the Balance of Nature', p. 336.
[34] Egerton, 'Changing Concepts of the Balance of Nature', p.333.
[35] Donald Worster, *Nature's Economy: the Roots of Ecology,* Cambridge University Press, New York, 1977.
[36] Worster, *Nature's Economy*, p. 33.
[37] Worster, *Nature's Economy*, p.34 - 35
[38] Cited in Worster, *Nature's Economy*, p. 37.
[39] Worster, *Nature's Economy*, p. 37.
[40] Likewise, ecological ideas in the broad sense are also capable of being injected back into economics, although crucially this process only really gets underway from the 1970s and remains marginal to the decade in which coincided the rise of a physicalist 'cybernetic' ecology and a highly politicised critique of the latent ideology of infinite growth. Growth areas such as 'ecological economics', 'evolutionary economics' and 'sustainability studies' remain poorly attended sideshows in the *grande casino* of the neoclassical intellectual hegemony.
[41] Eco, U, Gould, S.J, Carriere, J-C and Delumeau, J-C , *Conversations About the End of Time,* Penguin, 1999, p.11.
[42] Cited in Worster, *Nature's Economy*, p. 353.
[43] John Bruckner, *A Philosophical Survey of the Animal Creation,* London, 1768, pp. 76-77. See Worster, *Nature's Economy*, p. 37.
[44] Thomas Rorbert Malthus, *An Essay on the Principle of Population,* (ed.) Anthony Flew, Hammondsworth, Penguin 1970.
[45] Janet Browne, *Charles Darwin: Voyaging,* Random House, London, 1995, p. 387.
[46] Robert Ayres, *The Turning Point: The End of the Growth Paradigm,* Earthscan, London, p. 134.
[47] Browne, *Charles Darwin*, p. 387-388.
[48] Cited in Browne, *Charles Darwin*, p. 387-388.
[49] Sharon Kingsland, *Modelling Nature: Episodes in the History of Population Ecology*, University of Chicago Press, Chicago, 1985.
[50] Geoff Hodgson, *Economics and Evolution: Bringing Life into Economics,* Polity Press, Cambridge, 1993; Paul Ormerod, *The Death of Economics,* Faber & Faber, Boston, 1994.

[51] Mae-Wan Ho, 'Are Economic Systems Like Organisms?', Institute of Science in Society, 1996. <http://www.i-sis.org.uk/index.php>
[52] Ho, 'Are Economic Systems Like Organisms?', 1996.
[53] Guiliano Pancaldi, 'The Technology of Nature: Marx's Thoughts on Darwin', in *The Natural and the Social Sciences: Some Critical and Historical Perspectives*, (ed) I. Bernard Cohen, Kluwer Academic, Dordrecht, 1994, pp. 257-73.
[54] Karl Marx and Friedrich Engels, *Werke*, Dietz, Berlin, vol. 31, 1957-1968, p. 404.
[55] Rabinbach, *The Human Motor*, p. 72
[56] Cited in Robert E. Ricklefs, *The Economy of Nature: A Textbook in Basic Ecology*, W.W Freeman and Company, New York, 1997, p. 1.
[57] Sharon Kingsland, *The Evolution of American Ecology, 1890 – 2000*, University of Chicago Press, Chicago, 2005.
[58] Although the economics of the Austrian school were certainly in keeping with marginal utility theory, Menger explicitly rejected positivist scientism. He objected to the mathematical identification of price movements with the objective phenomena studied by physicists, seeing 'utility' as the result of subjective and psychological processes. Mirowski argues that to the extent that the neoclassical approach relies on the metaphor utility=energy, the Austrian school cannot be identified as part of the neoclassical project, although conventional historians generally include them within it. Mirowski, *Against Mechanism*, p. 84.
[59] Dorothy Ross, *The Origins of American Social Science*, Cambridge University Press, Cambridge, 1991, p.i.
[60] Joel Cohen, 'Mathematics as Metaphor: a Book Review of "Dynamical System Theory in Biology" by R. Rosen', *Science*, vol. 172, 1971, pp. 674-5.
[61] Kingsland, *The Evolution of American Ecology*, p. 6.
[62] George Perkins Marsh, *Man and Nature: The Earth as Modified by Human Action*, (ed.) David Lowenthal, Harvard University Press, Cambridge MA, 1965.
[63] Marsh, *Man and Nature*, p. 42.
[64] Kingsland, *The Evolution of American Ecology*, p. 8.
[65] Kingsland, *The Evolution of American Ecology*, p. 7.
[66] Alan Bullock and Stephen Trombley (eds.), *The Fontana Dictionary of Modern Thought*, HarperCollins, London, 2000, p. 615.
[67] Worster, *Nature's Economy*, p. 380.
[68] Gregory Bateson, *Steps to an Ecology of Mind*, Ballantine, New York, 1972.
[69] Egerton, 'Changing Concepts of the Balance of Nature', p. 343.
[70] Kim Cuddington, 'The "Balance of Nature" Metaphor and Equilibrium in Population Ecology', *Biology and Philosophy*, vol. 16, no. 4, Sep 2001, pp. 463 – 479.
[71] Mohan Wali, 'Ecology Today: Beyond the Bounds of Science', *Nature and Resources*, vol. 35, no. 2, April-June 1999, p.41.
[72] Wali, 'Ecology Today', p.41.
[73] Josius Braun-Blanquet, *Plant Sociology*, trans. G. Fuller and H. Conrad, McGraw Hill, New York, 1928; Charles Elton, *Animal Ecology*, MacMilan, New York, 1927. Cited in Wali, 'Ecology Today', p. 41.
[74] Wali, 'Ecology Today', p. 41.
[75] Kingsland, *The Evolution of American Ecology*, p. 144.
[76] Frederic Clements, *Plant Succession: An Analysis of the Development of Vegetation*, Carnegie Institute, Washington, 1916, pp. 124-5.
[77] Wali, 'Ecology Today', p.41.
[78] Clive Ponting, *A Green History of the World*, Penguin, London, 1991, p. 260.
[79] Ponting, *A Green History of the World*, p. 260-261.
[80] Kingsland, *The Evolution of American Ecology*, p. 151.
[81] Kingsland, *The Evolution of American Ecology*, p. 150.
[82] Peter Bowler, *Norton History of the Environmental Sciences*, W.W. Norton, 1993, pp. 520-521.
[83] Frederic Clements, 'Experimental Ecology in the Public Service,' *Ecology*, vol. 16, 1935, p. 345.
[84] Kingsland, *The Evolution of American Ecology*, p. 151.
[85] Alice Ingerson, 'A Critical Users' Guide to "Ecosystem" and Related Concepts in Ecology', Institute for Cultural Landscape Studies, Arnold Arboretum, Harvard University, 2002.
[86] Bowler, *Norton History of the Environmental Sciences*, W.W. Norton, pp. 520-521.
[87] Brian Mittman, 'Theoretical and Methodological Issues in the Study of Organizational Demography', *Research in the Sociology of Organizations*, 1992, p. 152.
[88] Worster, *Nature's Economy*, p.232.

[89] Luc Ferry, *The New Ecological Order*, trans. C. Volk, University of Chicago Press, Chicago, 1992.
[90] Kingsland, *Evolution of American Ecology*, p. 201.
[91] The phrase is borrowed from Michael Whites study of the role of 'energy' in W.S Jevons attempts to develop an exact science of economics, entitled 'In the Lobby of the Energy Hotel: Jevon's Formulation of the Postclassical "Economic Problem"', *History of Political Economy*. vol. 36, no. 2, 2004, p. 241.
[92] According to Allee et. al., "[...] the community maintains a certain balance, establishes a biotic order, and has a certain unity paralleling the dynamic equilibrium and organisation of other living systems. Natural selection operates upon the whole interspecies system, resulting in a slow evolution of adaptive integration and balance. Division of labour, integration, and homeostasis characterise the organism and supra-organismic intra-species population. The inter-species system has also evolved these characteristics of the organism and may this be called an ecological supraorganism." W. Allee, A. Emerson, O. Park, T. Park and K. Schmidt, *Principles of Animal Ecology*, W. B. Saunders, Philadelphia, 1949, p. 728.
[93] A botanist, veteran of the Boer War and a keen participant in the forums of the League of Nations, Smuts was a South African statesman whose ecological views and philosophical holism, contributed to the 'natural' justification of the separation and confinement of various native South African societies to 'Bantustans', to 'homelands ' where in a process of 'separate but equal development' African cultures could evolve in accordance with their environment at their own slow pace, 'protected' by racist legal geographies from the modernity they were not ready for in evolutionary terms. The anti-apartheid communist Edward Roux was also an ecologist who argued against the scientific value of the racial hierarchies of holist evolutionary ecology. Because of his activism, his employment in research positions was allowed by the State on the rounds that he refrain from politics. However, even Roux's works on grassland ecology that were submitted for approval as 'purely scientific' to the censor were treated with great suspicion, as the legitimacy of the South African racial order was dependent on the official holist view of the natural order. Peder Anker, 'The Politics of Ecology in South Africa on the Radical Left', *Journal of the History of Biology*, vol. 37, 2004, pp.303-331.
[94] Arthur Tansley, 'The Use and Abuse of Vegetational Concepts and Terms', *Ecology*, vol. 16, 1935, p.285 – 307.
[95] Tansley, 'The Use and Abuse of Vegetational Concepts and Terms', p. 299.
[96] Philip Mirowski, 'Ecology in the Mirror of Economics', editorial posting, *History of Economics Society*, posted 6 October 1996. <http://www.eh.net/lists/archives/hes/oct-1996/0042.php>
[97] It is important to note that Tansley worked within a British tradition of ecological science in the service of civil administration, a milieu which had these problems in mind from the outset. 'Carrying capacity' a key term in the 1970s terminology of population crisis and 'overshoot', ties population numbers to the maximum 'yield' of their supporting ecosystems, was developed for the purposes of colonial political economy, and was originally a methodology to determine what part of peasant agricultural production was 'surplus' to the survival needs of its producers, in order to determine the maximum level of taxation that could be sustained without engendering rebellions or depopulation in given territories. See John McKenzie, 'Empire and the Ecological Apocalypse: The Historiography of the Imperial Environment' in *Ecology and Empire: Environmental History of Settler Societies*, (ed.) Tom Robin, Keele University Press, Edinburgh, 1997.
[98] Kingsland, *The Evolution of American Ecology*, pp. 178-9.
[99] Ernst Haeckel, *Die Welträtsel*, Stuttgart, 1899, p. 87. Translation from Rabinbach, p. 24.
[100] Rabinbach, *The Human Motor*, p. 56.
[101] Ingerson, 'A Critical Users' Guide to "Ecosystem" and Related Concepts in Ecology', p.11.
[102] Ingerson, 'A Critical Users' Guide to "Ecosystem" and Related Concepts in Ecology', p.11.
[103] Nicholas Georgescu-Roegen, 'The Steady State and Ecological Salvation: a Thermodynamic Analysis', *Bioscience*, vol. 27, no. 4, 1977, p. 268.
[104] Tim Jackson, 'Sustainability and the "Struggle for Existence": the Critical Role of Metaphor in Society's Metabolism', paper presented at the conference *Nature, Society, History,* Vienna, Austria, 30 Sept to 2 Oct 1999, p.1.
[105] Ludwig Boltzmann, 'The Second Law of Thermodynamics', in *Theoretical Physics and Philosophical Problems,* (ed.) B. McGuiness, Reidel, Dordrecht, [1886] 1974, p. 19.
[106] Bertrand Russell, *Why I Am Not a Christian and Other Essays on Religion and Related Subjects*, Simon and Schuster, New York, 1957, p 106.
[107] Brooks Adams, 'The New Industrial Revolution', *Atlantic* Monthly, vol. 87, 1901, p. 165.
[108] Ernst Schrödinger, *What is Life?*, Cambridge University Press, Cambridge, Mass., [1944] 1967.
[109] Schrödinger, *What is Life?*, p. 79..
[110] Alfred Lotka, 'An Objective Standard of Value Derived from the Principle of Evolution', *Journal of the Washington Academy of Science*, vol. 4, 1914, pp. 409 – 18.

[111] Sharon Kingsland, 'Economics and Evolution: Alfred Lotka's Economy of Nature' in *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* (ed.) Philip Mirowski, Cambridge University Press, New York, 1994.
[112] Anson Rabinbach, *The Human Motor: Energy Fatigue and the Origins of Modernity*, University of California Press, Berkley, 1992, p. 182.
[113] Kingsland, 'Economics and Evolution', p. 158.
[114] Cited in Jackson, 'Sustainability and the "Struggle for Existence"', p. 6.
[115] Cited in Jackson, 'Sustainability and the "Struggle for Existence"', p. 6.
[116] Jackson, 'Sustainability and the "Struggle for Existence"', p. 6.
[117] Kingsland, 'Economics and Evolution', p. 239.
[118] Kingsland, 'Economics and Evolution', p. 240.
[119] Alfred Lotka, *Elements of Mathematical Biology*, Dover, New York, 1956, p. 428. Originally published as *Elements of Physical Biology*, 1925.
[120] Howard Scott, *Science versus Chaos!*, Technocracy, New York, 1933.
[121] Scott, *Science versus Chaos!*, 1933.
[122] Peter Taylor, 'Technocratic Optimism: H.T. Odum and the Partial Transformation of Ecological Metaphor after World War II', *Journal of the History of Biology,* vol. 21, no. 2, 1988, pp. 213.
[123] E.J. Mishan, *The Costs of Economic Growth*, Staples Press, London, 1967.
[124] Frederick Clements and Victor Stafford, *Bio-Ecology,* John Wiley and Sons, New York, 1939.
[125] G. E. Hutchinson, 'Review: Bio-Ecology,' *Ecology*, vol. 21, 1940, pp. 267-268.
[126] Raymond Lindeman, 'The Trophic-Dynamic Aspect of Ecology', *Ecology*, vol. 23, no. 4, 1942, pp. 399–417.
[127] Cited in Taylor, 'Technocratic Optimism: H.T. Odum and the Partial Transformation of Ecological Metaphor after World War II', p. 238.
[128] Cited in Worster, *Nature's Economy*, p. 306.
[129] Worster, *Nature's Economy,* p. 306-311.
[130] Here again we see the use of a fertile metaphor in opening up new avenues of scientific inquiry. This question of metabolism more recent emergence of such necessary disciplines as ecological economics and industrial ecology, which emphasize a substantive analysis of the economy in terms of real material flows.
[131] Worster, *Nature's Economy*, p. 292.
[132] To be fair, this history was largely forgotten until Georgescu Roegen's (1971) *The Entropy Law and the Economic Process* and was not to be critically investigated in full until Mirowski's (1989) *More Heat than Light: Economics as Social Physics.* While Georgescu Roegens concerns where substantive, as he sought to point out the physical and ecological impossibility of perpetual growth, Mirowski's works have been generally theoretical. This thesis is intended as an attempt to place these perspectives side by side and suggest a research agenda for historians interested in how economics has maintained and increased its intellectual hegemony in the face of deepening ecological crisis, maintaining its core abstractions about a stable machinic nature called the market while everywhere 'nature' is rendered unstable by the very operations of real machines and real markets.
[133] Robert E. Ricklefs, *The Economy of Nature: A Textbook in Basic Ecology,* W.W Freeman and Company, New York, 1997, p. 1.
[134] Lotka, *Elements of Physcial Biology,* 1922.
[135] Jeremy Rifkin, *The Biotech Century*, Tarcher/Putnam, New York, 1998, p. 197.
[136] Wiener, Norbert. *Cybernetics: or Control and Communication in the Animal and the Machine,* Cambridge, MIT Press, 1948.
[137] Manfred Clynes and Nathan Kline first used the term 'cyborg' to refer to the integration of organisms within mechanical systems, in 1960 in a journal called *Astronautics.* It was coined to describe to a US Air Force conference the possibilities of experimental augmentation of laboratory animals that might allow them to engage in feedback stabilisation and control of their metabolic environment, according to Chris Gray, *The Cyborg Handbook* Routledge, New York, 1995, pp. 29, 47.
[138] Ulrich Beck, *The Risk Society: Towards a New Modernity*, trans. Mark Ritter, SAGE, London, 1992.
[139] G. E Hutchinson, 'Circular Causal Systems in Ecology,' *Annual of the New York Academy of Sciences*, vol. 50, 1948, pp. 221-246.
[140] Karl Popper, *The Poverty of Historicism*, Routledge, New York, [1957] 2002.
[141] There were ten Macy conferences. The transactions of the sixth through tenth conferences were published in a series titled, *Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems*, (ed.) Heinz von Foerster, Josiah Macy, Jr. Foundation, 1954.

[142] Katherine Hayles, *How We Became Posthuman: Virtual Bodies In Cybernetics, Literature, And Informatics*, University of Chicago Press, Chicago 1999; Philip Mirowski, *Machine Dreams : Economics Becomes a Cyborg Science*, Cambridge University Press, Cambridge 2002
[143] Lawrence Frank, 'Foreword', *Annual of the New York Academy of Sciences*, vol. 50, 1948, pp. 192-5.
[144] Gregory Bateson, 'Physical Thinking and Social Problems', *Science*, vol. 103, 1946, p. 717.
[145] G. Hutchinson, 'Social Theory and Social Engineering', *Science*, vol. 104, 1946, p. 167
[146] Taylor, 'Technocratic Optimism: H.T. Odum and the Partial Transformation of Ecological Metaphor after World War II', p. 221.
[147] Warren McCulloch, 'A Recapitulation of Theory with a Forecast of Several Extensions', *Annual of the New York Academy of Science*, vol. 50, 1948, p. 264.
[148] Taylor, 'Technocratic Optimism: H.T. Odum and the Partial Transformation of Ecological Metaphor after World War II', p. 238.
[149] Bill Bryant, 'Nature and Culture in the Age of Cybernetic Systems', paper delivered to the American Studies Association Annual Conference, Detroit Michigan, October 12-15, 2000, p. 1. Available: <http://epsilon3.georgetown.edu/~coventrm/asa2000/panel3/bryant.html>
[150] Bryant, 'Nature and Culture in the Age of Cybernetic Systems', 2000, p 2.
[151] Sharon Kingsland, *Evolution of American Ecology*, Chap. 7.
[152] Wiener, *Cybernetics*, 1948.
[153] Arthuro Rosenblueth, Norbert Wiener, and Julian Bigelow, 'Behaviour, Purpose and Teleology', *Philosophy of Science*, vol. 10, 1943.
[154] Bryant, 'Nature and Culture in the Age of Cybernetic Systems', p. 2.
[155] See Philip Mirowski, 'Some Cyborg Genealogies, or How the Demon Got its Bots', Chapter 2, *Machine Dreams*, Cambridge University Press, 2002, pp. 26-93.
[156] Daniel Bell, *The Coming of Post-Industrial Society: a Venture in Social Forecasting,* Basic Books, New York. [1973] 1976, p. 404.
[157] Bell, *The Coming of Post-Industrial Society,* p. 464.
[158] Bell, *The Coming of Post-Industrial Society,* p. 464.
[159] John Stewart, 'The Development of Social Physics', *American Journal of Physics*, vol. 18, no. 5, May 1950, pp. 239-53.
[160] To repeat a phrase of Miroswski's, *Machine Dreams*, p. 56.
[161] Norbert Wiener, 'A Scientist Rebels', letter to Mr. George Forsythe, reprinted in *Science Technology, and Human Values*, vol. 8, no. 3, 1983, pp. 36-38.
[162] Donald MacKenzie, *Knowing Machines: Essays on Technical Change*, MIT Press, Cambridge MA and London, 1996, p.112.
[163] MacKenzie, *Knowing Machines*, p. 113.
[164] John von Neumann and Oskar Morgenstern, *Theory of Games and Economic Behaviour,* Princeton University Press, 1944.
[165] Nancy Stern, *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers,* Digital Press, 1981, pp62-63. Cited in MacKenzie, *Knowing Machines*, p. 112.
[166] Phillip Mirowski, *Machine Dreams: How Economics Became a Cyborg Science*, Cambridge University Press, Cambridge, 2002.
[167] Mirowski, *Machine Dreams*, p. 158.
[168] Mirowski, *Machine Dreams*, p. 313.
[169] Mirowski, *Machine Dreams*, p. 157.
[170] Sue Ravenscroft and Paul Williams, 'Making Imaginary Worlds Real: The Case of SFAS 123R', February 2007, p. 19. <www.ivey.uwo.ca/Research/IRS_Papers/Williams.pdf.>
[171] Alfred Wohlstetter 'Maintaining The Delicate Balance of Terror', *Foreign Affairs*, April 1959.
[172] Peter Goodchild, *Edward Teller: the Real Dr. Strangelove*, Harvard University Press, 2005.
[173] David Nye, *American Technological Sublime*, MIT Press, Cambridge Mass., 1994, pp. 234-236.
[174] Vitaly Adushkin and William Reith, 'The Containment of Soviet Underground Nuclear Explosions', *US Geological survey, Open File Report,* 2001.
[175] Cited in Simon Shackley, 'Trust in Models? The Mediating and Transformative Role of Computer Models in Environmental Discourse', in Michael Redclift and Brian Woodgate (eds.) *The International Handbook of Environmental Sociology*, Cheltenham UK, Edward Elgar, 1997.
[176] James Gleick, *Chaos*, Abacus, London, 1987, p.18.
[177] Nye, *American Technological Sublime*, p. 235.

[178] Wallace Arthur, *The Green Machine: Ecology and the Balance of Nature*, Basil Blackwell, Oxford, 1990, p. 225.
[179] Howard T. Odum, 'Radiation Ecology', Chapter 17 in *Fundamentals of Ecology*, (ed.) Eugene Odum, W.B. Saunders, Philadelphia, 1971, pp. 451-467.
[180] Keller, 'Talking about the Weather', p. 3.
[181] John Lewis Gaddis, *The Cold War*, Allen Lane, London, 2005.
[182] Gordon Edwards, 'A Metaphorical Framework: the Ecosystem versus The Machine', Part One of the *CCNR Final Submission to the Ontario Royal Commission on Electric Power Planning*, June 1978.
[183] Kingsland, *Evolution of American Ecology*, p. 195.
[184] Kingsland, *Evolution of American Ecology*, p. 189.
[185] Kingsland, *Evolution of American Ecology*, p. 192.
[186] Odum, *Environment, Power and Society*, p. 294-295.
[187] Howard Neufeld, 'The History of the Ecosystem Concept: Part 3, Post WW-II Ecology', 2001.
<http://www.appstate.edu/~neufeldhs/Ecosystems/OriginsPart3.htm>
[188] Howard T. Odum, 'The Attitude Revolution' in *The Crisis of Survival*, (eds. E. P. Odum et.al) Scott, Foreman and Company, Glenview, Illinois, 1970, p. 13.
[189] Howard. T. Odum, 'Energy, Ecology, & Economics', *Mother Earth News*, no. 27, 1974.
<http://www.mnforsustain.org/energy_ecology_economics_odum_ht_1973.htm>
[190] Odum, *Environment, Power and Society*, p. 54.
[191] Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 196.
[192] Wikipedia contributors, 'Emergy', *Wikipedia, The Free Encyclopedia*, 2007.
<http://en.wikipedia.org/w/index.php?title=Emergy&oldid=142230285>
[193] Taylor, 'Technocratic Optimism: H.T. Odum and the Partial Transformation of Ecological Metaphor after World War II', p. 213-244.
[194] Odum, *Environment, Power and Society*, p. 209.
[195] Odum, *Environment, Power and Society*, p. 209.
[196] Odum, *Environment, Power and Society*, p. 203.
[197] Hornborg, *Power of the Machine*, Chap. 3.
[198] Hornborg, *Power of the Machine*, p. 63.
[199] H. T. Odum, *Fundamentals of Ecology*, (ed.) Eugene P. Odum, Saunders, Philadelphia, 1971, p. 405.
[200] Odum, *Environment, Power and Society*, p. 259.
[201] Odum, *Environment, Power and Society*, p. 244.
[202] John Gowdy and Susan Messner, 'The Evolution of Geogescu-Roegen's Bioeconomics', *Review of Social Economy*, vol. 56, no. 2, 1998, p. 152.
[203] Inge Ropke, 'The Early Modern History of Ecological Economics', *Ecological Economics*, no. 50, 2004, p. 293-314.
[204] Chunglin Kwa, 'Modelling Technologies of Control', *Science as Culture*, vol. 4, no. 3, 1993, p. 364.
[205] Taylor, 'Ecological Metaphor after World War II', p. 244.
[206] B.A. Manssen and J.M McGlade, 'Ecology, Thermodynamics and H.T. Odum's Conjectures', *Oecologia*, vol. 93, no. 4, 1993, pp. 582-596.
[207] Taylor, 'Ecological Metaphor after World War II', p. 246.
[208] Gowdy and Messner, The Evolution of Geogescu-Roegen's Bioeconomics', p.138.
[209] Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 335.
[210] Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 282.
[211] Georgescu-Roegen, *The Entropy Law and the Economic Process*, p. 282.
[212] Michael Begon, John Harper and Colin Townsend, *Ecology: Individuals, Populations and Communities*, Blackwell Science, Cambridge, MA, 1995, p. 648.
[213] Begon, Harper and Townend, *Ecology*, p. 648
[214] Cited in William Callebaut, (ed) *Taking the Naturalistic Turn*, University of Chicago Press, Chicago, 1993, pp. 262-3
[215] John Tschirhart, 'Ecological Transfers in Non-Human Communities Parallel Economic Markets in a General Equilibrium Model', *Journal of Bioeconomics*, vol. 5, 2003, pp. 193 - 214.
[216] Arjo Klamer & Thomas Leonard, 'So, What's an Economic Metaphor?' in *Markets Read in Tooth and Claw: Natural Images in Economic Thought;* (ed.) Philip Mirowski, Cambridge University Press, Cambridge and New York, 1994, p. 39.

**Conclusion: the New Economy, the New Ecology and the New Biophysics.**

*Disintegration characterizes this time, and thus uncertainty: nothing stands firmly on its feet or on a hard faith in itself. One lives for tomorrow for the day after tomorrow is dubious. Everything on our way is slippery and dangerous, and the ice that still supports us has become thin. All of us feel the warm, uncanny breath of the thawing wind: where we still walk, soon no one will be able to walk.*

-Friedreich Nietzsche[1]

*The way to achieve harmony with Nature is first to break free of old metaphors and embrace new ones so that we can lift the veils that prevent us from accepting what we observe.*

- Daniel Botkin[2]

In these concluding pages we will consider and reflect upon the implications this history of the twin sciences. In attempting to draw some tentative conclusions, I will also attempt to show how the themes of the thesis (the interactions between Nature and Society as mediated by the Natural and the Social Sciences, the dialectical reciprocity between transcendent millennialism and reductionist social physics in the ideological history of modernity) and the analytical method employed in it (which has drawn on the anthropology of classificatory schemes, the analysis of metaphor, and the history and sociology of science) can be extended profitably into the analysis of more recent events, debates and configurations.

I have argued that the history of Western historical consciousness shows that the synchronous rise of the modern state, the opening of the New World as a resource frontier, and the scientific revolution associated with Galileo and Newton eventually coalesced in a secular ideology of progress. The ideology of Progress was not, however, a clean break from the past and carried over a similar sense of expectation in the realisation of the millennium 'here on Earth'. The diminution of God as an uncomplicated invariance principle, however, led to the Enlightenment search for eternal 'laws of nature' that would provide certainty, and 'laws of history' that would allow prediction, control and improvement of social 'forces'. The history of the construction of 'the economy' as the scientific object of a science of society as viewed by the national state, reveals a history of metaphors drawn directly or indirectly from machines. This begins with the foundational texts of modern science, which conceives of the task of physics as the elucidation of Nature's hidden mechanisms. As progress was aligned with the improvement of science, and as the improvement of science was linked to the improvement of machines, the machine took on a dual role in Western culture: it was both the physical proof of the eternal laws revealed by science; and it was a totem of the industrial sublime, the promissory symbol of the realisation of the secular millennium.

With the coal and steam-driven expansion of the empire of the machine in the 19th century, the ideas of automatic 'balance' and self-regulating 'equilibrium', inherent in the theological notion *oeconomia*, took hold in political economy. This occurred first in the association of a liberal market society by analogy with the Watt steam-governor, a homeostat that incorporated 'self regulation' into popular notions of 'equilibrium'. This metaphor was then extended and abstracted in the neoclassical synthesis. The conservation principles derived from the study of engines at the basis of the new unification of science around the concept of *Arbeitskraft,* revealed 'labour power' (later 'energy') as the ur-stuff of the cosmos; appropriated as 'utility', 'proto-energy' was found to be a quantitative constant underlying the kaleidoscopic diversity of production and exchange as revealed in prices. We have already discussed at length the serious consequences of the utopianism of Helmholtzian energetics that remains embedded in the neoclassical ontology of nature. 'The economy' is portrayed as a body in motion that continually returns to equilibrium, qualitatively unchanged by its motion, like a marble coming to rest at the bottom of a bowl. Hopefully, it is not necessary to restate that this idea is thoroughly incompatible with the phenomena of 'growth'.

The industrial machine as a mother-lode of metaphor for social relations remains incompletely realised. Notably, both the metaphor of 'self-regulation' and 'perpetual circulation of utility' disguised the fact that the thermodynamic engine is a 'dissipative structure', dependant on the continuous degradation of a flow of exergy to maintain its motion and form. Had the 2nd law not been selectively excluded from the machine metaphor, the implications would have been starkly different: the 'self-regulating' market would have to be seen as a 'mechanism' that only 'worked' by continuously and inefficiently degrading fresh natural resources into unusable form. As thermodynamic engines are dependant upon differential thermal and pressure gradients to open energy conversion pathways with which to 'do work', incorporating this aspect of the metaphor might also have implied that capitalism of necessity requires the continuous reproduction of classes of humans of *different value* in order to 'do the work' of creating surplus value. Clearly, these consequences of the 2nd law go against the transcendent vision of liberal social physics in presenting commodity exchange as a purely circular flow, machines as 'productive', and the maximisation of 'production' through deregulated markets as the route by which all the atoms/people will arrive at a democratic plateau of universal mass consumption. Such a view would interpret globalisation not as a 'rising tide that will lift all boats', but as predicated upon steepening and exploiting the 'value gradients' between the price differentials of workers in the 'first' and 'third worlds', in order to accelerate the flow of negentropy from peripheries to the 'dissipative structures' of post-industrial consumer societies. Finally, in exposing the machine as a process of flows rather than a thing-in-itself, the incorporation of the second law into the image of Society as an 'economic machine' might have prevented 'the economy' from being reified as a bounded, discrete, universal and arithmetical structure of social life, but exposed it as existing in a diffuse 'dialectical penumbra' (to use a favourite term of Georgescu-Roegen's); a continuum of overlapping concepts and categories from psychology, biology, sociology, law; most of which are qualitative (e.g. 'justice', 'evolution' or 'the enjoyment of life') and incapable of ever being converted into a mathematical formalism. Despite the value of functionalist accounts of natural and social systems in eliminating the more obvious mystical projections, functionalism has no ethical content, it cannot on its own tells us as social beings what to do.

The incomplete history of ecology I have attempted here has presented it not in its aspect as an independent science of the interactions of non-human life forms, pursued for the sake of knowledge alone, but has rather portrayed it (perhaps unfairly) as a kind of junior sister science of economics that arose on the peripheries of rapidly expanding industrial societies. As the story of Clements suggests, the consolidation of ecology as a science was motivated by attempts to reconstruct the primordial 'balance of nature' of the prairies from what remained, long after the resource frontier and its wave of violent transformation had passed over. After the twin catastrophes of Wall Street and the Dustbowl, ecology was put forward as tool with which to build a stable, agrarian national community in relative synchrony with the native 'climax community', and to avoid the destructive chaos of speculative laissez-faire individualism. This example suggests that one (thoroughly functionalist) way to describe the relation of the two economies of nature is to see economics as the applied science of maximising industrial throughput in the centre of the human economy, and ecology as the applied science of minimising long term damage to 'the environment' on the outer boundary of Society, developed only after industrialism was running out of easily accessible 'pristine' ecosystems to colonise. The emergence of ecology coincides with the closure of the long frontier.

That economics is related to ecology is of course not a new idea. In a 1933 book called *The Science of Life*, H.G. Wells and Julian Huxley defined ecology as "biological economics, or the extension of economics to the whole of life."[3] This in itself is unremarkable: scientific progress is often aided by interdisciplinary work and the exfoliation of a fertile metaphor, and the various branches of human knowledge rarely have water-tight boundaries. Indeed, the initial methodological problem posed in the Introduction was to explain why, given their closely parallel histories of theory selection and intermittent moments of symbiosis, do ecology and economics have such incommensurable views of the next few decades of 'universal history'? On one side, we have ecologists trying vainly to do something about the earth's sixth mass extinction crisis and the unravelling of ocean, forest and soil ecosystems globally, and on the other we have economists proposing more growth as the source of the technological innovation needed to finally achieve 'sustainable growth'.

Given that the questions should concern us in assessing the relationship of the twin sciences: to what extent has ecology been influenced by the seemingly anti-ecological tenets of neoclassical economics? And secondly, why has the traffic been generally one-way? If ecology is by definition a form of 'bioeconomics', why has economics been so resistant to feedback from ecology? '

In response to the first question, there exists an entire literature in ecology dating from neoclassical revolution of the 1970s, which we have not had the time or space to explore, that extensively borrowed concepts from behavioural microeconomics, the theory of the firm, consumer theory and so on.[4] This notably produced a whole line in 'optimal foraging theory' based on rational maximisation, equilibrium and fixed preferences, which in a classic piece of economics imperialism, was subsequently re-exported back across the Nature/Society boundary into functionalist anthropology and visited upon unsuspecting hunter-gatherers from Amazonia to Alaska, whose 'natural' economic behaviour in turn confirmed the 'rationality' of the modern bargain hunter. While we have examined the more recent efforts of Tschirhart, in order to savour the paradoxes of Walrasian ecology, what has rather captured our attention is the construction of ecology as a (substantive) biophysics, which to some limited extent mirrored the earlier construction of economics as a (subjective) social physics. As we have seen, the closest evolutionary ancestor between the two 'economies of nature' was Lotka, who in developing a mathematical theory of predator/prey oscillations and an energetic theory of evolution, got his inspiration from Spencer's 'social organism', Jevon's 'objective' mechanics of price determination, and Solvay's social energetics. While Lotka himself saw industrialisation as the millennial realisation of the 'Great World Purpose', his introduction into ecology of Boltzmanns' thermodynamics, his treatment of the biosphere as the 'Great World Engine', ultimately yielded the radical critiques of industrial growth ideology we have encountered in H.T. Odum's systems ecology and Georgescu-Roegen' s bioeconomics.

There are many possible answers to the second question. The most simple and likely is that ecology remains a subversive science: it continues to challenge the gods of growth and the market, and threatens to undermine the status quo. After all, it is those in power who get to impose their metaphors on public discourse, and it is the powerful consumers of the globes resources in the postindustrial cores of the world economy who stand to benefit most from the continuation of business as usual. On the level of philosophy, the most satisfying answer comes from our discussion of what I have termed the 'ontological collision' that occurred when Odum and Georgescu-Roegen, in turning Lotka's attempt to analyse the 'evolution of the world system as a whole' into substantive accounts of the thermodynamic relation between technomass and the biosphere, exposed the vacuity of the original physics metaphor. (Of course for Odum, this was not consciously elaborated, he merely brushed aside economics and proceeded to construct his own equally abstruse energy theory of value.) Alfred Marshall's prediction that economics would become less mechanical and more biological as it 'matured' seems to have been blocked by the fact that any explicit and systematic attempt to follow through on the 'growth' metaphor and analyse the 'industrial super-organism' would invite measurement of the 'economy' as a 'metabolic' system of trans-boundary material flows, which would make it much harder to balance the books in a way that appeared just, and would throw the consensus on the Millennium of permanent growth into crisis. It would make it much harder to downplay ecological degradation. Nevertheless it seems to me that the continuing resistance of economics to ecology is perhaps the most serious question of our time. We shall now further this issue, and attempt to bring the thesis into the present by briefly commenting on some more recent developments in this relationship.

This thesis has argued that the contradictory metaphorical matrix surrounding the terms 'growth' and 'equilibrium' is crucial to understanding the incommensurability between ecology and economics (as evidenced by their contradictory assessments of the 'state of the world') precisely because the provenance of those terms betrays a covert history of conceptual borrowing. I have also argued that what mediates the exchange, projection and counter –projection of images between Nature and Society has, on average, tended to be a machine metaphor. Despite their patent artificiality, machines tend to be regarded by Westerners somewhat mysteriously as external to social relations, and thus capable of 'speaking' with the unmediated voice of Nature. With these postulates in mind, we now present a brief update of the Economy of Nature as it appears this side the new millennium.

In assessing the intervening years between the early 1970s and our own time, it is overwhelmingly clear that the discourse and 'nature' of environmental crisis has changed considerably, and the terms of cultural and political engagement between ecology and economics have been substantially altered. In 1971 environmentalism was seen unequivocally as a political threat to capitalist industry and the 'free enterprise system': a threat that in no small part sparked the neoliberal revolution by mobilising business into effective anti-regulation lobbies, funding anti-environmentalist think tanks, taking the battle for intellectual respectability into the halls of academia, and aiding the meteoric rise of neoclassical economics to institutional hegemony. By contrast, Northern corporations now almost universally have internal processes of environmental risk management and advertise their green credentials at every opportunity.[5] Where once a small group of prophetic citizen scientists and bearded millenarians hastened to warn the complacent majority that it was possible for the ecosystems comprising the biosphere to be systematically unravelled to the point of collapse in the future, the sense that the earth is increasingly 'out of balance' is a feature of the world now communicated daily in every newspaper; some of us feel it in our very bones.

While the sudden and sharp apocalyptic encounter with population limits falsely prophesied by ecologists such as Paul Erlich or the imminent exhaustion of minerals too readily attributed to the Club of Rome have not materialised, these versions of crisis, based in simple linear extrapolations, seem quaint and naive in the face of the hyperabundant forms of ecological and structural eco-social crises that feature in contemporary crisis discourse. The broaching of 'limits' is not, as the metaphor suggests, experienced as an abrupt 'end', like driving into a wall or off a cliff. Rather, as Frederick Buell has argued, we are all now habituated to our claustrophobic immersion in a slow motion crisis, one that does not appear as "an event breaking into history" at the End of the World, with all the implications of sudden finality, extermination, and rapture, but is lived through daily on the edge of our awareness as a continuous and psychologically numbing experience of stressed and deteriorating environments, increasing exhaustion of natural abundance, sharpening social conflict over resource security and the distribution of risks, and the foreclosure of options for future generations to escape from or avoid the damage left to them by previous ones.[6] While we do not have the space to even begin to outline in detail the multiple dimensions of contemporary crisis discourse, an initial list compiled by Buell might indicate the proliferation and intensification of current ecological concerns, with new risks piling up on the older hazards:

> "At the very least [such a list must] include an energy (and also other resources) crisis; a multifactoral waste crisis; an open space crisis; a wetlands crisis; a forest crisis; a soils crisis; an ocean crisis; a freshwater crisis; a biodiversity crisis; an acid rain crisis; an ozone hole crisis; a global warming crisis; an environmental toxification crisis; a global disease crisis; a population crisis; a growth or development crisis. Many of these crises are themselves plural. Problems with wastes for example, include garbage, sewage and toxic waste – and the latter of these problems breaks further down into wastes from agricultural chemicals and fertilisers, industrial chemicals, and nuclear energy and weapons, items often treated as separate crises [...] Forest loss, like other major ecological changes, sets off a cascade of other problems – it involves economic and social disruption, it sacrifices a carbon sink, it entails the loss of numerous species of plants and animals, it alters the hydrologic cycle, it plunges local

> populations into misery and it degrades life for global populations. If these crises seem unmappably plentiful, this abundance becomes greater when one considers that each area has accumulated is own collection of activists, experts, science, regulatory law, regulatory structures, interests and patterns of controversy; the intellectual and social variety surrounding each crisis further blurs the clear eyes that would grasp the whole."[7]

The systematic theorisations of the relationship of the industrial economy to the biosphere that we concluded the previous chapter with, those of Georgescu-Roegen and H.T. Odum, were written at a time when the idea that humans could affect the earth as a whole was still entirely novel and regarded as preposterous by many thinkers. They were also written at a time when the intense politicisation and counter-politicisation of environmental science was only beginning. What seemed obvious and central to both these men, and to many other early analysts, were the grave errors of standard economic theory in its modelling of 'growth' and 'equilibrium', scientific failures so grievous as to render the entire edifice of neoclassical economics untenable and its continued application to the maximisation of industrial expansion be the something akin to quasi-scientific superstition. A basic working knowledge of the laws of thermodynamics plainly showed that the machine dream of infinite growth was predicated upon thermodynamic disequilibrium on a planetary scale, and to try and to defer waking up from this dream was to invite depletion and destruction. For Odum, who moved from analysis to a normative and prescriptive cyborg vision, the solution was clear. Like many 1970s environmentalists, he advocated a controlled transition from free-wheeling petroleum-based economic growth to an intensely managed state of ecological equilibrium, where energy replaced money as the universal standard of value. Future development (not growth) would be derived from the life sciences, and Odum saw existing biodiversity as an "immense bin of parts for the ecological engineer."[8] Georgescu-Roegen, for his part, offered no positive program, nor did he see that biotechnology offered any escape from the thermodynamic limits to perpetual growth. He thought that the development of solar technology would be the best hope of modern society to slow the maximisation of entropy. He expressed little confidence in the possibility of an ill-defined 'steady state' as the path to 'ecological salvation', suggesting only that the optimal human population would be that which could be supported solely by organic agriculture, and insisting that "any piece of armament or a two-garage car means less food for the hungry of today and fewer plowshares for some future (however distant) generation of humans like our selves."[9] Noting the euphoria surrounding recent developments in the manipulation of molecular DNA, he appended a sharp critique of "eugenic engineering" and the heralds of the "genetical millennium" to his definitive statement on economics.[10]

As independent founders of ecological economics, they both offered glimmers of hope in a shift away from 'Newtonian' economics to one grounded in the evolutionary perspective of biophysics.

In what follows we will consider how the contradiction between 'equilibrium' and 'growth' revealed by the biophysical perspective was robbed of its self-evident character. Even as the anti-environmentalist denial of limits became more strident as the new right gathered strength in the wake of the 1970s crisis of Fordism, neoliberal theorists of the 'postindustrial' transformation of capitalism increasingly incorporated select elements of ecological discourse, and as we approach the present, begin to hold out the promise of a new bioeconomy to come – although one starkly different from that envisaged in the 1970s, as it is committed entirely to deregulated markets, celebrates disequilibrium, and remains fiercely opposed to any notion of limits. Seen in this light, the 1971 works of Odum and Georgescu-Roegen represent the swansong of a society self-conceived as industrial, and its corollary, an industrial conception of nature and society that was becoming outdated in the new era characterised by the rapid evolution of information technology, the denationalisation and deregulation of networked finance markets, and the momentous developments in the life sciences that also can be traced to this time.

In the 1970s, the sudden political success of environmentalism, the rapid emergence of an environmental state apparatus under the inaugural pen of Richard Nixon, and the general sense of crisis in the United States led some declare that the age of ecological limits was at hand. After the wide attention given to the Club of Rome report, President Carter called for more study into resource and pollution futures and the *Global 2000 Report*, published in 1980, further elaborated the pessimistic futurology of 'limits to growth.' Upon election his election in 1980, one of Reagan's first acts was to commission a refutation of this report entitled *The Resourceful Earth: the Global 2000 Report Revised* from two right-wing futurologists: Herman Kahn and Julian Simon. The Reagan Revolution was in many ways a nationalistic revival of industrial optimism, and accompanying it were the neoclassical prescriptions of privatisation, deregulation and the small state. In Reagan's second inaugural address, he outlined the neoliberal vision in a way that married American exceptionalism to a Disneyesque anti-environmentalism:

> "....our new beginning is a continuation of that beginning created two centuries ago when, for the first time in history, government, the people said, was not our master, it is our servant; its only power that which we the people allow it to have. That system has never failed us, but, for a time, we failed the system. We asked things of government that government was not equipped to give. We allowed taxes and inflation to rob us of our earnings and savings and watched the great industrial machine that had made us the most productive people on Earth

> slow down and the number of unemployed increase...We believed then and now there are no limits to growth and human progress when men and women are free to follow their dreams."[11]

Reagan's policy of monetary stabilisation, welfare cutbacks, regressive tax cuts, and the rolling back of environmental law did little to halt the de-industrialisation of the US and the expansion of the 'rust belt'. His appointment of James Watt as Minister of the Interior, the first institutional appointment of a bellicose anti-environmentalist, signified the rise of an organised and well-funded counter-environmentalist movement on the right of US politics. A conservative Christian who saw conservation as invalidated by the imminent return of Christ, he once speculated after a meeting with the moderate National Wildlife Foundation whether "the real nature of the extreme environmentalists" was "to weaken America." [12] His vision of the US by the year 2000 was that *all* of the then existing 80 million acres of roadless federal lands classified as 'wilderness' would be leased for grazing, mining, timber extraction and oil production.[13] Indeed it is arguably a common opposition to environmental politics and modern biological science that holds together the other wise morally inexplicable contemporary neo-conservative alliance of Protestant fundamentalism (with its creationist ontology and end-times eschatology) to laissez-faire economic liberalism (with its Helmholtzian utopianism and productivist view of economic growth). While this thesis has suggested certain similarities between Christian theology and orthodox economic science, the full explication of these urgent contemporary political configurations must be a subject for another day.

With the upturn of the 'new economy' in the mid-1990s, the euphoria surrounding the information technology revolution and the long speculative boom of the NASDAQ, many commentators in US business publications and popular media began to transform the 1970s postindustrial thesis into the millennial realisation of prophecy. It seemed that Alvin Toffler was right all along: 'Second Wave' machine civilisation was on the way out, and a higher order 'Third Wave' of technological civilisation was emerging from the social fluctuations, instability, and turbulence that accompanied its demise. Perhaps mirroring the massive financialisation of the economy and the dwarfing of the value of the trade goods and services by the rise of derivative markets, the central product of the 'new economy' was increasingly claimed to be a disembodied 'information' or 'knowledge'. With the advent of 24-hour online share trading, brand management, out-sourcing, down-sizing and e-commerce, the deindustrialisation of the 'rust belt', a source of national shame in the Reagan era recessions, was transformed into a postindustrial vision of a prosperous global future in which American ingenuity would lead the way.[14]

Globalisation, previously a source of anxiety, became uncritically popularised into the American mainstream with President Bill Clinton, who fashioned an optimistic post-Cold War celebration of a new global future for humanity. Clinton celebrated the arrival of the third millennium with a vision of a common future of peace and harmony,

> "[...] a future rooted in the forces of freedom and enterprise and globalisation and science and technology that have powered so much of this century [...] the forces of science, technology and globalisation have shattered the boundaries of possibility".[15]

Clinton's comments reflected the enthusiasm of corporate discourses of globalisation, which in the late 1990's took on a millennial fantasy of a new epoch freed from the limitations of the past.[16] History had ended and taken ideology with it, socialism was dead. What was notable about the technophile celebration of globalisation was its complete divorce from the discourse of global environmental crisis.[17] This can be attributed to a particularly mystical idealism that accompanied the rise of the NASDAQ. We have already explained how the neoclassical economy of nature denies natural resources any necessary role in the production of value, attributing growth solely to capital, machinery and labour. In the age of information, however, not even machines or workers were needed for the *ex nihilo* creation of wealth: as Charles Leadbetter, a policy stylist for Tony Blair's New Labour argued, we were now 'living on thin air':

> "In old capitalism, the critical assets were raw materials, land, labour and machinery. In the new capitalism, the raw materials are know-how, creativity, ingenuity and imagination... As a result, the opportunities for growth are boundless."[18]

Like unions, taxes, regulations, social insurance and territorial nation-states, environmentalism was clearly an artefact of dreary 'old economy' thinking. The Cato Institute economist Julian Simon, was fond of quoting the physicist Frank Tipler to this effect:

> "[..] the ultimate constraint is not energy but information. Because we can increase the stock of information without limit, there is no need to consider our existence finite."[19]

In such discourses, the key shift from the 'old' to the 'new' economy implied a disconnection from the embeddedness and embodiment of economic growth in the vast quantity of material flows required to support the intensification of Northern consumption. In reality, the 'industrial' sector of modern economies did not of course become 'weightless', 'frictionless' or dematerialise. While industrial labour, pollution and material intensive commodity production were increasingly outsourced, the consumption of industrial commodities did not cease but continued to expand in the postindustrial cores of the world economy. The 'e-conomy' was merely built into the pre-existing industrial economy. The Internet created a substantial demand for energy to power not only the humble desktop PC, but also the warehouses full of servers, routers, processors and air-conditioners. There is genuine debate over whether the new digital infrastructure led to efficiency gains in other sectors, but it seems little credence can be given to claims that the total energy requirement of the 'advanced' countries has done anything but continue to increase through the e-revolution.

Given the common repetition of the doctrine of dematerialisation it is worth noting that 'information' can be technically described as 'negentropy', that is, highly ordered matter/energy manifest as morphological form that is highly 'improbable' according to a statistical interpretation of the second law. The concentration of 'negentropy', or non-randomness, is matched by the export of a greater amount of entropy to the environment. For example, the industrial ecologists Williams, Ayres and Heller have shown that the production of a single 32 MB DRAM chip, weighing only 2 grams, consumes 1600 grams of fuel, 700 grams of gases (mostly nitrogen), several hundred different chemical inputs totalling 72 grams, and 32 litres of water.[20] With the exception of water, all of these inputs have already gone undergone substantial processing and transport. The silicon required for chips is of such high purity that it requires 160 times more energy to refine than ordinary silicon. "Due to its extremely low entropy, [...] the materials intensity of a microchip is orders of magnitudes higher than traditional goods."[21] Most of the environmental risks associated with information technology are borne by East Asia, where computers are assembled, and once superseded, where they are shipped back to as toxic waste too expensive to store or recycle in the 'postindustrial' cores.[22]

To summarise, in announcing an epochal shift into 'Third Wave' information society, the cyborg economists endowed millennial capitalism with the capacity to continue its infinite expansion in the midst of ecological crisis by associating growth with the 'frictionless' replication of 'information'. Given our interest in the intersection of millennialism and social physics, it might be worth noting that Frank Tipler, the physicist of infinite dematerialisation cited by Julian Simon, sees information technology as the beginning of the end of human embodiment. Artificial intelligence software, he predicts, and the uploading of human minds into machines, will spark an autonomisation of consciousness from flawed biological 'meat machines'. Human immortality *in silico* is the first step on an evolutionary path toward super intelligent post-biological beings whose destiny is to awaken the universe, networking every bit of matter/energy into a single computational mesh. In making this claim Tipler is sure of his foundations:

> "I shall make no appeal, anywhere to revelation. I shall appeal to the solid results of modern physical science..."[23]

Nevertheless his quantum information eschatology takes a form that the reader might be familiar with, as his ambition is to devise:

> "[...] a testable physical theory for an omnipresent, omniscient, omnipotent God who will one day in the far future resurrect every single one of us to live forever in an abode which is in all essentials the Judeo-Christian heaven."[24]

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Given our exploration of the DMDM thesis thus far, it should come as no surprise that accompanying the celebration of chaos and disequilibrium, the enthusiasm for informatic dematerialisation and 'new paradigm' thinking in the exuberant cultures of the 'new economy', was the emergence of a 'new ecology'. The 'new ecology', primarily associated with Daniel Botkin, defined its newness in terms of a conscious repudiation of the balance-of-nature tradition of the 'old ecology'.[25] The new ecology rejected the successional climax, the holism of the systems approach, gradualist accounts of evolution, even the 'punctuated equilibrium' theory of Eldridge and Gould[26] and saw natural landscapes as chaotic and stochastic expressions of indeterministic and continuous change. As Christensen put it in 1996:

> "We tend to think of the 'natural world' [...] as existing in some sort of long-term stasis. We assume that, when not upset by human impacts, [nature] will return to some predetermined 'stable state,' much as a pendulum returns to its nadir position. During half of this century the notion of ecosystem succession to a stable 'climax community' was one of the unifying principles of ecology. [...] But we now know that ecosystem change is inevitable. Ecologists now view landscapes as complex mosaics, patches undergoing continuous change."[27]

Botkin's rejection of 'mechanism' and any notion of global stability in ecosystems, led to a critique of conservation biology and preservationist environmentalism, and the entire edifice of environmental law, which he saw as built on the incorrect 'balance of nature' tradition. But what was perhaps most striking here was the conclusion that because nature was decidedly *not* a machine, we were obliged to convert it into one. 'Lifting the veils' (the literal meaning of the Greek *apokalupsis*) of our old obscuring machine metaphors led Botkin not to a vision of the catastrophic end of nature, but to a vision of the coming postindustrial millennium, where the age of Nature as something with its own *Dasein*, independent of and external to the human economy, was finally at an end:

> "We have the power to mold nature into what we want it to be. [..] Nature in the twenty-first century will be a nature that we make. [..] We do not take an engineering approach to nature, we do not borrow the cleverness and the skills of the engineer, which is what we must do...we need to instrument the cockpit of the biosphere."[28]

Whereas old ecologists like H.T. Odum argued that the economy must be re-engineered to fit harmoniously within the biosphere, Botkin here proposes precisely the opposite, to re-engineer the biosphere in such a way as to force it to accommodate to the permanent expansion and technological development of the modern economy. While we won't discuss what the 'old' ecologists may have thought about such matters, the 'new ecology' was selectively woven tightly into the web of metaphors feeding the 'new economy' discourse, and the vast corpus of 'new paradigm' business management literature. The new economists were fond of quoting Frederick von Hayek, who had long sought to reconceive of economic processes within the idiom of Darwinian theory. Long before the complexity sciences had provided a rigorous account of spontaneous self-organisation in organisms and ecosystems, Hayek had theorised markets as a form of 'spontaneous order'. It is theoretically unclear from his work, however, whether 'the market' is an *object of evolution*, the final result of a long group selection process whereby other social institutions have been out-competed to the point of extinction, or more grandly, the *context of evolution* within which the selection of all orders takes place.[29] Free-market environmentalists nevertheless saw the purification of the true, unhampered nature of the market as necessary to their project. According to John Baden of the Foundation of Research on Economics and the Environment (FREE), Hayek had demonstrated that "central planning" – here conflated with environmental law – "always fails" because "the information needed to create wealth is widely scattered" and central planners can only ever attain a fraction of the knowledge required to "serve people's economic desires and foster innovation."[30] Dissolving any distinction between Nature and Society, he argued that:

> "[...] economies are like ecosystems. They are interdependent, complex and must constantly adjust. When we read this article, [Hayek's 'The Use of Knowledge in Society, *American Economic Review* 1945] we understand why there are such conflicts between bureaucracies, which drive toward uniformity, and ecosystems,

where knowledge of local conditions is critically important. Economies, like ecosystems, cannot be designed. No one can run them. Both evolve and prosper to the extent they remain in sync with the laws of nature." [31]

The laws of nature are the laws of supply and demand, nature herself supports laissez faire. As the selective appropriation of the new ecology led to calls for the winding back of 'command and control' environmental law and the subordination of land management to private property and the free market, it also led to calls for further deregulation of the economy, and celebrated the precariousness of business and employment driven by financial speculation, short term contracts and exposure to global competition. As the popular writer Kelvin Kelly wrote:

"In the industrial perspective, the economy was a machine that was to be tweaked to optimal efficiency, and, once finely tuned, maintained in productive harmony. Companies or industries especially productive of jobs or goods had to be protected and cherished at all costs, as if these firms were rare watches in a glass case. .... As networks have permeated our world, the economy has come to resemble an ecology of organisms, interlinked and coevolving, constantly in flux, deeply tangled, *ever expanding* at its edges. As we know from recent ecological studies, *no balance exists in nature*; rather, as evolution proceeds, there is perpetual disruption as new species displace old, as natural biomes shift in their makeup, and as organisms and environments transform each other. So it is with the network perspective: companies come and go quickly, careers are patchworks of vocations, industries are indefinite groupings of fluctuating firms." [my italics][32]

With a new spin on an old theme, the popular mobilisation of the new ecology led to the neo-Darwinian justification of laissez-faire, entrepreneurial neoliberal economics, and the idea that nature itself is constructed upon similar principles of catastrophic emergence. The ideological uses of a new ecology which asserts radical instability and change as inevitable were manifold, both in the naturalisation of the deregulated venture capital frenzy of the 'new economy' and in the neutralisation of accounts of environmental crisis as a standpoint from which to build a structural critique of industrial capitalism.

The great and monstrous irony of the <economy is an ecosystem> metaphor was that its strident opposition to democratic regulatory institutions further undermined actually existing ecosystems. Calls for nature conservation, endangered species protection, family planning, precaution in biotechnology development, mandated emissions standards, carbon taxes, subsidies for photovoltaic technology development, quotas on fisheries, Tobin taxes, the labelling of genetically modified food or any other policy designed to maintain the integrity of the biosphere and limit the destabilization of the 'balance of nature', could be tarred as an unnatural intervention in the miraculous powers of 'the market' to bring 'order out of chaos', to spontaneously bring forth a dematerialised, ecologically modern clean green natural capitalism in the nick of time. Whatever actual scientists may have thought about the appropriation of their science by neoliberal economics, in rejecting the notion of 'ecological equilibrium', the new ecology was easily bent into providing support not only for the deregulation and privatisation of the atmospheric, terrestrial, oceanic and biogenetic commons, but also into upholding the millennial doctrine of infinite economic growth.

With the popularisation of the of the 'chaos theory' of the Sante Fe Institute,[33] the autopoetic systems theory of Humberto Maturana and Francisco Varela [34], and the far-from-equilibrium dynamical systems theory of Ilya Prigogine [35], a new philosophy of nature emerged that emphasized the irreducible non-linearity and far-from-equilibrium dynamics of living systems. Reductionist, mechanistic accounts of the 'laws of nature' deterministic first-order cybernetic models derived from industrial machines were challenged by biological models that emphasise the active role of organisms as subjective, autonomous agents, the fuzziness of the boundaries between natural objects, and thus the fundamental complexity, indeterminacy and openness of living systems. Complexity science emphasises the processual nature of change, disavowing equilibrium models for a focus on self-organisation and the emergent properties of living systems. Evolution was seen to be most potentially creative while 'on the edge of chaos', leaping phoenix-like through catastrophic destruction to generate wholly new worlds.

The most important figure of this 'new paradigm' was Ilya Prigogine, whose work in biochemistry and non-equilibrium thermodynamics has revolutionised the age old debate about the apparently contradictory relation between the entropy law and the evolutionary increase of biological complexity over time. To cut a long story short, where once the ontogenetic and phylogenetic evolution of organisms and ecosystems was seen as a standing refutation of the entropy law – which posited a universal drift from order to chaos – the work of Prigogine and his various colleagues have argued that the disorder associated with far-from-equilibrium states tends to bring about order through spontaneous reorganisation in the midst of crisis.[36] 'Dissipative structures', which can be living creatures or non-living phenomena such as tornadoes, store 'information' in the form of internal structuration in a state far-from-equilibrium and export disorganisation or entropy to their immediate environment.[37] Dissipative structures pass through successive thresholds of disequilibrium, at some point they are compelled to bifurcate along one of multiple organisational pathways, none of which are predictable from initial conditions. Given a sufficiently large number of iterations, the chaotic production of disorder associated with the entropy law is leads to the emergence of spontaneous and novel forms of order, and is thus the fundamental driver of complexity:

> "At all levels, be it the level of macrophysics, the level of fluctuations, or the microscopic level, nonequilibrium is the source of order. Nonequilibrium brings 'order out of chaos'"[38]

The new non-mechanistic theories of living systems have provided valuable new insight within their domains, reconciling contemporary physics to biology and dealing a body blow to *ceteris paribus.* They shifted the focus from the isolated objects of reductionism to stress interconnection, subjectivity and process. For these very reasons, the early 1990s popularisation of chaos theory, complexity science and non-linear thermodynamics was initially welcomed by environmentalists, who saw in these theories an affirmation of the sensitivity of the earths biogeochemical 'balances' and of complex ecological communities to apparently minor disturbances, a vindication of the profound unpredictability of novel chemicals and engineered organisms beyond the laboratory, and an argument against the machine dreams of industrial growth ideology.

In what appeared a promising development, the new biophysics led to an internal challenge to the neoclassical orthodoxy in the form of the 'evolutionary economics' of the Sante Fe institute. This new genre of economics rejected the Newtonian paradigm and the equilibrium social physics of the orthodoxy as the *ne plus ultra* of economic explanation and outsourced its metaphorical supply chain to the new biological sciences and non-linear thermodynamics. This attention to biology and thermodynamics could have led to economics actually taking seriously the deepening of ecological crisis and the attendant risks of exponential economic growth as Georgescu-Roegen and Odum, the inventors of the biophysical approach might have hoped. Rather it was turned into further appropriations of natural metaphors to analyse price movements toward 'strange attractors' on the capital markets, obscuring both the physical and biological context of the 'real' economy.

As the popularisation of the new biophysics matured within the neoliberal euphoria for the autopoetic, emergent phenomena of the information revolution and global deregulation, the effect was to obscure ecological crisis and the shifting of risks onto poor communities and to further marginalise calls for meaningful environmental reform. Prigogine himself seems to tacitly endorse the neoliberal interpretation of his biophysics. His seminal work *Order out of Chaos,* co-authored with Isabelle Stengers, was prefaced with an essay by the right-libertarian futurist Alvin Toffler, who announced a civilisational 'paradigm shift' from a Newtonian to a Prigoginian world view in line with his theory of radical postindustrialisation.[39]

In its appropriation of nature to justify the deregulation of social controls on corporate activity, the economic interpreters of the 'new ecology', complexity theory, and chaos theory provided a scientific, theoretical glamour to a culture of environmental disregard dwelling within even greater potential risks than before.[40] Capitalism was re-fitted onto a post-equilibrium ecosystem metaphor stressing continuous, growth, change, death, evolution, survival of the fittest, complexity, and non-linear relationships: naturalising capitalism and at the same time normalising ecological crisis. But of course the metaphysical celebration of non-linear economic complexity obscures the simple linearity of the physical logic of depletion. Prigoginian leaps into higher states of organisation may well deliver miraculous new technologies that are for now unimaginable, just as the rapid construction of the Internet was unpredictable. However, what was not often considered is that the leap into new states of organisation and higher complexity is predicated on the continuous degradation of high quality energy through the system, and at the moment that means fossil or nuclear fuel dependence. As Hornborg has argued, industrial civilisation is a 'dissipative structure', precisely because the innovation, organisation, maintenance and expansion of core infrastructure is a consequence of the continual 'dissipation' of flows of imported natural capital, and the export of 'disorganisation', waste of its underdeveloped peripheries, a situation of unequal global exchange facilitated by financial imperialism.[41] Chaotic and unpredictable fluctuations leading to rapid major phase transitions, on this view, might easily produce a *Limits to Growth* style meltdown or realise the worst carbon-induced nightmares of climatologists.

While this discursive revolution of 'non-linear systems' has done little to halt the linear logic of depletion and extinction in the Amazon basin, among ocean fisheries, and in the worlds' oil fields, it has, as Melinda Cooper demonstrates, lent increasing importance to the rise of the 'bioeconomy' of the commercial life sciences since the development of recombinant DNA technology (gene-splicing) in 1973.[42] A profoundly important 'bifurcation point' in this history is the awarding of a US patent – in 1971 of course – to Ananda Mohan Chakravarty and his employer, General Electric. Chakravarty had, in his own words, 'merely shuffled the genes' of the pseudomonas bacterium, but the Court found that he had 'invented' a new species and thus awarded intellectual property rights to this microbe, its offspring and all life-forms modified according to the process. This set a precedent for the patenting of life and life-forms, including seeds, plants, mice, sheep, cows and even parts of human beings.[43] Although this patent was itself never used, it was of crucial significance that the burgeoning privatisation and industrialisation of life made possible by this decision, began with a micro-organism that had been designed to eat, transform, and help neutralise sea-borne oil spills. In other words, the commercial revolution in biotechnology is itself the accidental result of the emergence of ecological crisis in the 1970s. In more recent years, biotech start-ups have promised us that trees will be genetically engineered to grow faster, in order to absorb more carbon dioxide.[44] Nature, it seems, must be accelerated: she can no longer afford her ante-diluvian cycles of regeneration to be slower than the circuits of production.

But as Cooper suggests, it is the US Energy Policy Act of 2005 – which explicitly calls for a new 'bioeconomy' – that brings us full circle back to the debate between the futurists of the 1970s and the Club of Rome. The Act is not a road to Damascus conversion on the part of Bush, it is not a response to ethical or ecological concerns about climate change. It is rather the deathbed conversion of an anti-environmentalist 'old economy' administration very close to Big Oil, an industry faced with reports of declining oil discovery and analyses that it may already have passed its peak level of output. Faced with the rising costs of enacting the Carter Doctrine in the Middle East, the Act calls for the promotion of R&D into the domestic biofuels industry in the United States, a speculative investment seen as a reward for the corn-growing Republican states, but also the private biotechnology sector, already awash in federal support from the military. As she further notes, the Act does little to reduce energy demand or carbon emissions, and while rewarding supporters in the nuclear, ethanol and corn farming sector, the Act eliminates federal support for geothermal, solar and hydropower research.[45] Infinite growth is maintained even within the crisis of limits by the speculative engineering of life.

Needless to say, this is not the bioeconomy foretold by the likes of Odum and Georgescu-Roegen. Against Odum's hopes, the import of ecological terms into economic discourse yielded not an 'attitude revolution' regarding the ethical and survivalist need to establish a 'steady state' economy in 'ecological equilibrium' but rather established the naturalness of corporate-led economic growth. The biophysical critique of economic mechanism undertaken by Georgescu-Roegen remains cogent, and yet the post-equilibrium paradigm of Prigoginian biophysics led not to a re-appraisal of industrial growth, but to the hyping of a speculative postindustrial and 'genetical millennium' to come, one that will supposedly emerge spontaneously from the maximisation of chaos associated with increasing throughput of energy. Huxley's definition of ecology as 'the extension of economics to all of life' is gains new cogency when we consider the elaborate new forms of bioinformatic property rights awarded by the US Patent Office: intellectual 'capital' enclosed in living flesh, regenerating the future growth of the economy through the extension of capitalist social relations to the universal solvent and *potentia* of recombinant deoxyribonucleic acid.

Perhaps the final words should go to the historian of liberal economics, insurance and risk, Francois Ewald. Ewald argues for the impossibility of quantifying ecological risk, both at the level of micro-exposures to 'ordinary' ambient pollution and at the level of catastrophic macro-hazards such as Chernobyl. Because of the impossibility of rendering different risks commensurable within the quantitative actuarial calculus of insurance pricing, ecological risk is by definition uninsurable. The broader implication for the incommensurability of the twin economies of nature, he concludes, is that:

> "With ecological risk, nature becomes social through and through; the problematic of nature is overtaken by radical artifice. The ineluctable conclusion of the logic of balance: everything becomes political down to what seems most natural in nature. .... Nature is perhaps the last and most massive form of an artifice dedicated to hiding the fact that the order in which we are condemned to live is an order of pure politics, an order of pure decision that can nourish itself only on its own values, and cannot rely on an objectivity that supposedly transcends it." [46]

While the patient reader may well expect such a relativistic conclusion to an explication of the Durkheim-Mauss-Douglas-Mirowski thesis, it seems to me that the while economics has always been the loudest and most overbearing sibling of the twin economies of nature, it remains the case that human economies, with their incredible novelty in the history of the biosphere, remain objectively embedded within ecosystems, even if they are rapidly being disassembled. The prospect of a fully engineered biosphere is certainly objectionable on aesthetic grounds: given the current ecological/economic condition of the majority of the human population, the postindustrial millennium of universal mass consumption *and* ecological modernisation seems wholly unrealisable at the current state of science and technology. If this is so, then perhaps our most pressing task is to reverse the disciplinary ranking of the two sciences. If the economy is a subset of the ecosystem, it would follow that economics should rightly be a subset of ecology. Rather than ecology being a subordinate 'bioeconomics' as Worster complained 30 years ago, perhaps it is time that economics was reconfigured as 'socio-ecology', or better still, as 'human ecology'?

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While the historical method employed here could yield any number of further investigations on the metaphorical, philosophical and political dimensions on the topic, and continue reaping the ironic fruits of physics envy until the end of the world, it is perhaps time to bring the present study down to earth with a simple common-sense conclusion, as provisional as it may be. The first might be that universal history really is, as Borges suggests, the intonation given to a handful of metaphors. The terms of engagement between Nature and Society are continually renegotiated as modernity produces new Millenniums with which to counter new Apocalypses.

Despite the efforts of ecological reductionists like Odum and economics imperialists like Tschirhart, the most obvious of the many barriers to the unification of the sciences is the patent fact that *the 'price system' has no clear and direct physical or biological analogue*. This means that the entire of lexicon of economising - efficiency, production, work, growth, consumption, division of labour, power, waste, exchange and value - is similarly irredeemably anthropomorphic and confounded by an overeager identification of culturally, socially and politically constructed values with natural facts. Similarly the 'power' of wealthy societies to strip the landscapes of peripheries of their resources, to harness their populations cheap labour in converting the landscape to soybean plantations to be exported to feedlot cattle yards, and simultaneously to increase the complexity and scale of industrial infrastructure, while indeed only possible due to the vast quantities of exergy consumed by industrial technomass, is not reducible to exertions of Newtonian force upon resistant surfaces. Power is a social and political relationship between actors and a discursive field, and the power of the machine, or the power of money is no exception to this. While there are elective affinities between them, energy and money are not equivalent currencies, organisms are not machines, and ecosystems are not the same as economies.

A more important policy conclusion would be that 'markets', no matter how natural we try to make them by appealing to statistical mechanics, or natural selection, or cellular automata, or Stuart Kauffman, are not going to deliver 'sustainability' on their own. Difficult political decisions, legal apparatuses, treaty negotiations and value judgements and moral communities must be crafted. Similarly, economic 'growth' is a highly misleading metaphor, growth is not 'good for the environment', no matter how 'natural' or 'virtual' our cultures machine fetishism makes growth appear. Growth and equilibrium are, metaphorically speaking, very full houses. Growth can mean ontogeny, phylogeny, the life cycle, Progress, accumulation, compound interest, development, evolution, expansion, maximisation, industrial production, and biological reproduction. 'Equilibrium' is also term rich with a portmanteau of combinations of cultural baggage and scientific expressions – fairness, balance, stability, regularity, stasis, homeostasis, heat death, efficiency, natural law, equivalence, timelessness, energy conservation. In short, the very terms used to negotiate between Nature and Society, between ecology and economics, between life and non-life, between energy and money, between living systems and social systems, are so loaded with the faded coinage of contradictory metaphors and usages that they can be bent into almost any articulation of the economy of nature by those with the power, money or sheer energy to impose their favourite metaphor upon the public domain. Metaphors do not, however, go all the way down.

This is not to say that science is 'just a story', but for any knowledge to be meaningful and to do good, it needs to be in one, whether a moral parable or a grand myth of universal scope. Perhaps the least contradictory relation that we have dealt with is the incommensurability of the finite and the infinite. Time and space may well extend in every direction, but most of it is not life on earth, where we have our home, life under law, and share what we know of the living.

Oikos,
Nomos,
Logos.

Marrickville, July 2007.

## Endnotes

[1] Friedrich Nietzsche, *The Will to Power*, (eds.) Walter Kaufmann, and R. J. Hollingdale, New York, 1967, pp. 48, 134.
[2] Daniel Botkin, *Discordant Harmonies: a New Ecology for the Twentieth Century*, Oxford University Press, New York, 1990, p.189
[3] Cited in David Rapport and James Turner, 'Economic Models in Ecology', *Science*, vol. 195, January 1977, p. 367.
[4] A slew of papers in this genre are discussed in Rapport and Turner, 'Economic Models in Ecology', p. 367- 373.
[5] Andrew Hoffman, *From Heresy to Dogma: an Institutional History of Corporate Environmentalism*, New Lexington Press, San Francisco, 1997.
[6] Frederick Buell, *From Apocalypse to Way of Life: Environmental Crisis in the American Century*, Routledge, New York, 2003, p. 78.
[7] Buell, *From Apocalypse to Way of Life*, p. 74, 79.
[8] H. T. Odum, *Environment, Power and Society*, Wiley Interscience Sydney, 1971, p. 259.
[9] Nicholas Georgescu-Roegen, 'The Steady State and Ecological Salvation: a Thermodynamic Analysis', *Bioscience*, vol. 27, no. 4, 1977, p. 277.
[10] Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process*, Harvard University Press, 1971, p. 428.
[11] President Ronald Reagan, *Second Inaugural Address to the Nation* (delivered January 21, 1985) Text available at <http://www.reaganfoundation.org/reagan/speeches/second.asp>
[12] Cited in Buell, *From Apocalypse to Way of Life*, p. 19.
[13] Anon, 'The Legacy of James Watt', *Time*, October 24, 1983. <http://www.time.com/time/magazine/article/0,9171,926267,00.html>
[14] Thomas Frank, *One Market Under God: Extreme Capitalism, Market Populism, and the End of Economic Democracy*, Vintage,
[15] Bill Clinton, "Remarks by the President and the First Lady at "Millennium around the World" event, Ronald Reagan International Trade Center, Washington DC. Cited in Gearoid O Tuaththail (2000) *Geopolitics @ Millennium: Paranoid Fantasies and Technological Fundamentalism Amidst the Contradictions of Contemporary Modernity*. <http://www.majbill.vt.edu/geog/faculty/toal/publish.html>
[16] Fernando Coronil 'Towards a Critique of Globocentrism: Speculations on Capitalism's New Nature', *Public Culture,* vol 12, no. 2, 2000, pp. 351-374
[17] Frederick Buell 'Globalization without Environmental Crisis: The Divorce of Two Discourses in US Culture', *symploke* vol 9, no. 1-2, 2001, p 47.
[18] Charles Leadbeater, *Living on Thin Air: the New Economy*, London, Penguin, 2000, p. 1.
[19] Cited in Buell, *Apocalypse to Way of Life*, p. 220.
[20] Eric Williams, Robert Ayres and Miriam Heller, 'The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices', *Environmental Science and Technology,* vol. 36, pp. 5504-5510.
[21] Williams, Ayres and Heller, 'The 1.7 Kilogram Microchip', p. 5504.
[22] Alastair Iles, 'Mapping Environmental Justice in Technology Flows: Computer Waste Impacts in Asia', *Global Environmental Politics,* vol. 4 no. 4, 2004, pp. 74- 104.
[23] Says Tipler: "If life evolves in all the many universes in a quantum cosmology, and if life continues to exist in all these universes, then all of these universes, which includes *all* possible histories among them, will approach the Omega Point. At the instant that the Omega Point is reached, life will have gained control of all matter and forces not only in a single universe, but in all universes whose existence is logically possible; life will have spread into all spatial regions in all universes which could logically exist and will have stored an infinite amount of information, including all bits of information which it is logically possible to know." Cited in Damien Broderick, *The Spike: Accelerating into the Unimaginable Future,* Reed Books, Melbourne, 1997, pp. 227- 229.
[24]Broderick, *The Spike* pp. 227- 229
[25] Daniel Botkin, *Discordant Harmonies: A New Ecology for the Twenty-First Century,* 1990; Stewart Pickett et al., 'The New Paradigm in Ecology,' in *Conservation Biology: the Theory and Practice of Nature Conservation, Preservation and Management,* eds. Peggy Fiedler and Subdoh Jain, 1992.
[26] Niles Eldredge and Steven J. Gould, 'Punctuated Equilibria: an Alternative to Phyletic Gradualism' in *Models in Palaeobiology,* (ed.) T. Schopf, Freeman Cooper, 1972, pp. 82-115.
[27] Norman Christensen, 'Science and the Sustainable Use of Land', in *Land Use in America,* (eds.) H. Diamond and P. Noonan, Lincoln Institute of Land Policy, Cambridge MA, 1996.

[28] Botkin, *Discordant Harmonies*, pp.16, 32.
[29] Geoffrey M. Hodgson, 'Hayek, Evolution and Spontaneous Order', in Philip Mirowski (Ed.) *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* Cambridge University Press, Cambridge and New York, 1994, p. 430.
[30] John A. Baden 'Understanding the Failings of the Socialist Economic Model', *Seattle Times,* 5th October, 1995. <www.free-eco.org/>
[31] Baden, 'Understanding the Failings of the Socialist Economic Model', 1995.
[32] Kevin Kelly, *New Rules for the New Economy: 10 Radical Strategies for a Connected World,* Viking, New York, 1998, Chapter 8. <http://www.kk.org/newrules/newrules-8.html>
[33] See Fritjof Capra, The *Web of Life: A New Scientific Understanding of Living Systems,* Doubleday, New York, 1996; and Stuart Kauffman, *Investigations,* Oxford University Press, New York, 2000.
[34] Humberto Maturana and Francisco Varela, *Autopoiesis and Cognition: The Realization of the Living,* Reidel Publishing Company, Dordrecht, Holland, 1980.
[35] See Ilya Prigogine and Isabelle Stengers, Order *out of Chaos: Man's New Dialogue with Nature,* Heinemann, London 1984; Ilya Prigogine, *The End of Certainty: Time, Chaos, and the New Laws of Nature,* Free Press, New York, 1997.
[36] Shelton A. Gunaratne 'Thank You Newton, Welcome Prigogine; Unthinking Old Paradigms and Embracing New Directions', *Communications,* vol. 26, 2003, p. 436.
[37] Gunaratne, 'Thank You Newton, Welcome Prigogine', p. 443.
[38] Prigogine and Stengers, Order *out of Chaos*, p. 287.
[39] Ilya Prigogine and Isabelle Stengers, Order *out of Chaos: Man's New Dialogue with Nature,* Heinemann, London, 1984.
[40] Buell, *Apocalypse to Way of Life*, p. 224.
[41] Alf Hornborg, *The Power of the Machine: Global Inequalities of Economy, Technology and Environment,* Altamira Press, CA, 2001.
[42] Melinda Cooper, 'Life, Autopoesis, Debt: Inventing the Bioeconomy', *Distinktion*, no. 14, 2007, 25-43.
[43] The Hindu, 'Engineering Life', Wednesday, 4 December, 2002.
[44] For a glimpse into the bio-industrialisation of forestry, see: 'Supertrees: ForBio of Australia is engineering better trees. The potential gain is enormous,' *Forbes.com,* August 10, 1998. <http://www.forbes.com/global/1998/0810/0109052a.html>; Rachel Asante Owusu, 'GM Technology in the Forest Sector', World Wildlife Fund Briefing Paper 19, November 1999. <www.wwf-uk.org>
[45] Cooper, 'Life, Autopoesis, Debt', p. 38-39.
[4646] Francois Ewald, 'Two Infinities of Risk' in *The Politics of Everyday Fear*, (ed.) Brian Massumi, University of Minnesota, Minneapolis, 1993, pp. 221-228.

## Bibliography


Adam, Barbara. *Timescapes of Modernity: the Environment and Invisible Hazards,* Routledge, London, 1998.

Adams, Brooks. 'The New Industrial Revolution', *Atlantic Monthly*, vol. 87, 1901.

Adams, Henry. *The Education of Henry Adams: An Autobiography*, Boston and New York, 1918.

Adas, Michael. *Machines as the Measure of Men: Science, Technology, and Ideologies of Western Dominance*, Cornell University Press, 1989.

Adushkin, Vitaly and William Reith, 'The Containment of Soviet Underground Nuclear Explosions', *US Geological Survey, Open File Report,* 2001.

Allee, W., A. Emerson, O. Park, T. Park and K. Schmidt, *Principles of Animal Ecology*, W. B. Saunders, Philadelphia, 1949.

Allen, T., A. Zellmer and C. Wuennenberg, 'The Loss of Narrative' in *Ecological Paradigms Lost: Routes of Theory Change,* (eds.) Kim Cuddington and Beatrix Beisner, Elsevier, Amsterdam, 2006.

Akiyoshi, Arakawa. 'Economics as Social Physics (Part II) The Natural Law Tradition', 2003. <www.jef.or.jp/en/jto/200005_012.html>

Anker, Peder. 'The Politics of Ecology in South Africa on the Radical Left', *Journal of the History of Biology*, vol. 37, 2004, pp. 303-331.

Anon, 'Those Neo-Nazi Greens Should Be Taken Out the Back and Shot', 2003. <http://www.ironyparty.org/ipa02nov03.htm>

Anon, 'The Legacy of James Watt', *Time*, October 24, 1983. <http://www.time.com/time/magazine/article/0,9171,926267,00.html>

Anon, 'Science and Technology: The Litany and the Heretic; "The Skeptical Environmentalist"', *The Economist,* vol. 362, no. 8258, 2 February 2002, p. 83.

Arrow, Kenneth. 'General Equilibrium', *Collected Papers*, vol. 2, Blackwell, Oxford, 1983.

Arthur, Wallace. *The Green Machine: Ecology and the Balance of Nature,* Basil Blackwell, Oxford, 1990.

Ayres, Robert. *Information, Entropy and Progress: A New Evolutionary Paradigm,* American Institute of Physics, Woodbury NY, 1994.

Ayres, Robert. 'Two Paradigms of Production and Growth', Occasional Paper, Centre for the Management of Environmental Resources, INSEAD, 2002.

Ayres, Robert. *The Turning Point: The End of the Growth Paradigm,* Earthscan, London, 1999.

Baden, John. 'Understanding the Failings of the Socialist Economic Model', *Seattle Times,* 5th October 1995. <www.free-eco.org/>

Banerjee, Abhijit. 'Inside the Machine: Towards a New Development Economics', *Boston Review*, vol. 32, no. 2, 2007, pp. 12-18.

Bambach, Richard. 'Ecology as an Economy', [review of *Nature: an Economic History* by G. J Vermeij, 2004], *American Scientist,* vol. 93, no. 2, 2005.

Baker, Keith. *Condorcet: from Natural Philosophy to Social Mathematics*, University of Chicago Press, Chicago, 1975.

Barnett, Harold and Chandler Morse, *Scarcity and Growth,* John Hopkins Press, Baltimore, 1963.

Bateson, Gregory. *Steps to an Ecology of Mind,* Ballantine, New York, 1972.

Bateson, Gregory. 'Physical Thinking and Social Problems', *Science*, vol. 103, 1946, p. 717.

Bauman, Zygmunt. *Intimations of Postmodernity*, Routledge, London, 1992.

Beck, Ulrich. *Ecological Politics in the Age of Risk,* trans. Amos Wiesz, Polity Press, Cambridge, MA, 1995.

Beck, Ulrich. *The Risk Society: Towards a New Modernity*, trans. Mark Ritter, SAGE, London, 1992.

Beder, Sharon. *Global Spin: the Corporate Assault on Environmentalism,* Scribe Publications, Melbourne, 1997.

Begon, Michael, John Harper and Colin Townsend, *Ecology: Individuals, Populations and Communities,* Blackwell Science, Cambridge, MA, 1995.

Bell, Daniel., Anthony Wiener and Herman Kahn, *The Year 2000,* Macmilan, London, 1967.

Bell, Daniel. *The Coming of Post-Industrial Society: a Venture in Social Forecasting,* Basic Books, New York. [1973] 1976.

Bernstein, Steven. *The Compromise of Liberal Environmentalism,* Columbia University Press, New York, 2001.

Bigelow, Gordon. 'Let There Be Markets', *Harper's Magazine*, vol. 310, May 2005.

Blaug, Mark. *The Methodology of Economics,* Cambridge University Press, Cambridge UK, 1980.

Blumenberg, Hans. *The Legitimacy of the Modern Age,* Cambridge, MIT Press, 1983.

Bohm-Bawerk, Eugen. *Capital and Interest,* Libertarian Press, South Holland, vol. 2, book 3, 1959, pp. 143-145.

Boltzmann, Ludwig. 'The Second Law of Thermodynamics', in *Theoretical Physics and Philosophical Problems,* (ed. B. McGuiness), Reidel, Dordrecht, [1886] 1974.

Borges, Jorge Louis. 'The Fearful Sphere of Pascal', in *Labyrinths: Selected Stories and Other Writings*, (ed. J.W Donald), 1962.

Botkin, Daniel. *Discordant Harmonies: a New Ecology for the Twentieth Century*, Oxford University Press, New York, 1990.

Bourdieu, Pierre. 'The Essence of Neoliberalism', *Le Monde Diplomatique,* trans: Jeremy Shapiro, December 1998.

Bowler, Peter. *Norton History of the Environmental Sciences*, W.W. Norton, 1993.

Boyd, Richard. 'Metaphor and Theory Change: What is Metaphor For?' in *Metaphor and Thought*, (ed.) Andrew Ortony, Cambridge University Press, Cambridge, 1993.

Boylan, Thomas A. & Paschal F. O' Gorman, 'The Duhem-Quine Thesis in Economics: A Reinterpretation', *Paideia,* 1998. <http://www.bu.edu/wcp/Papers/Econ/EconDvor.htm>

Bozeman, John. 'Technological Millenarianism in the United States' in *Millennium, Messiahs and Mayhem: Contemporary Apocalyptic Movements,* (eds.) T. Robbins and S. Palmer, Routledge, New York and London, 1997, pp. 139-158.

Bradley, Robert. 'The Increasing Sustainability of Conventional Energy', *Cato Institute,* Policy Analysis No. 341, 22 April 1999. <www.cato.org/pubs/pas/pa-341es.html>

Broderick, Damien. *The Spike: Accelerating into the Unimaginable Future,* Reed Books, Melbourne, 1997.

Braun-Blanquet, Josius. *Plant Sociology,* trans. G. Fuller and H. Conrad, McGraw Hill, New York, 1928.

Browne, Janet. *Charles Darwin: Voyaging,* Random House, London, 1995.

Bruckner, John. *A Philosophical Survey of the Animal Creation,* London, 1768.

Bryant, Bill. 'Nature and Culture in the Age of Cybernetic Systems', paper delivered to the American Studies Association Annual Conference, Detroit Michigan, October 12-15, 2000. <http://epsilon3.georgetown.edu/~coventrm/asa2000/panel3/bryant.html>

Buck-Morss, Susan 'Envisioning Capital: Political Economy on Display' in *Visual Display: Culture Beyond Appearances,* (eds.) Lynne Cooke and Peter Wollen, Bay Press, Seattle, 1995.

Buell, Frederick. 'Globalization without Environmental Crisis: The Divorce of Two Discourses in US Culture', *symploke,* vol 9, no. 1-2, 2001, p. 47.

Buell, Frederick. *From Apocalypse to Way of Life: Environmental Crisis in the American Century,* Routledge, New York, 2003.

Bull, Malcolm. 'On Making Ends Meet' in *Apocalypse Theory and the Ends of the World,* (ed.) Malcolm Bull, Blackwell Publishers, UK, 1995.

Bull, Malcolm. *Seeing things Hidden: Apocalypse, Vision and Totality,* Verso, London, 1999.

Bullock, Alan and Stephen Trombley (eds.), *The Fontana Dictionary of Modern Thought,* HarperCollins, London, 2000.

Bunker, Stephen and Paul Ciccantell, *Globalization and the Race for Resources,* John Hopkins University Press, Baltimore, 2005.

Bush, President George W.. Speech of 7 December 2001. <www.whitehouse.gov/news/releases/2001/21/20011207.html>

Buzo, Alex. *Meet the New Class,* Angus and Robertson, Sydney, 1981.

Callebaut, William. (ed) *Taking the Naturalistic Turn,* University of Chicago Press, Chicago, 1993.

Capra, Fritjof. The *Web of Life: A New Scientific Understanding of Living Systems,* Doubleday, New York, 1996.

Calvert, J.B. 'Machines', 2007. <http://www.du.edu/~jcalvert/tech/machines/machines.htm>

Carson, Rachel *The Silent Spring,* Hamilton, London, 1963.

Cartwright, Nancy. 'Ceteris Paribus Laws and Socio-Economic Machines', *The Monist*, vol. 78, 1995, pp. 276-94.

Cavanaugh, William T. 'A Fire Strong Enough to Consume the House: the Wars of Religion and the Rise of the State', *Modern Theology*, vol. 11, no. 4, 1995.

Christensen, Norman. 'Science and the Sustainable Use of Land', in *Land Use in America,* (eds.) H. Diamond and P. Noonan, Lincoln Institute of Land Policy, Cambridge MA, 1996, pp. 273 – 293.

Cirillo, Renato. 'The 'Socialism' of Léon Walras and His Economic Thinking', *American Journal of Economics and Sociology,* vol. 39, no. 3, 1980, pp. 295-303.

Clements, Frederic. 'Experimental Ecology in the Public Service,' *Ecology,* vol. 16, 1935, p. 345.

Clements, Frederic. *Plant Succession: An Analysis of the Development of Vegetation*, Carnegie Institute, Washington, 1916.

Clements, Frederick and Victor Stafford, *Bio-Ecology,* John Wiley and Sons, New York, 1939.

Cobden, Richard. 'Free Trade with All Nations', speech given at Manchester, England on the 15 January 1846. <http://www.cooperativeindividualism.org/cobdenonfreetrade.html>

Cohen, Bernard. 'Newton and the Social Sciences, with Special Reference to Economics, or, the Case of the Missing Paradigm' in *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* (ed.) Philip Mirowski, Cambridge University Press, Cambridge and New York, 1994.

Cohen, Bernard. (ed.) *The Natural Sciences and the Social Sciences,* Kluwer Academic, Dordrecht, Netherlands, 1994.

Cohen, Joel. 'Mathematics as Metaphor: a Book Review of "Dynamical System Theory in Biology" by R. Rosen', *Science,* vol. 172, 1971, pp. 674-5.

Cohn, Norman. *The Pursuit of the Millennium*, Secker & Warburg, London, 1957.

Cooper, Melinda. 'Life, Autopoesis, Debt: Inventing the Bioeconomy', *Distinktion*, no. 14, 2007.

Cooper, Melinda. 'On The Brink: From Mutual Deterrence To Uncontrollable War', *Contretemps: An Online Journal of Philosophy*, vol. 4, 2004. < http://www.usyd.edu.au/contretemps/4september2004/Cooper.pdf>

Coronil, Fernando. 'Towards a Critique of Globocentrism: Speculations on Capitalism's New Nature', *Public Culture,* vol. 12, no. 2, 2000, pp. 351-374

Coser, Larry. *Masters of Sociological Thought: Ideas in Social and Historical Context*, Harcourt Brace, New York, 1977.

Cox, Brad. 'Bioeconomics: Economics as Ecosystem, not Machine', 2004. <http://www.virtualschool.edu/mon/Bionomics/>

Craige, Betty Jean. *Eugene Odum: Ecosystem Ecologist & Environmentalist*, University of Georgia Press, 2002.

Cuddington, Kim 'The "Balance of Nature" Metaphor and Equilibrium in Population Ecology', *Biology and Philosophy*, vol. 16, no. 4, Sep 2001, pp. 463 – 479.

Cuyahoga River Online Exhibition, 'Fires on the Cuyahoga River', Cleveland Press Collection, Cleveland State University Library, 1999. <http://web.ulib.csuohio.edu/SpecColl/croe/accfire.html>

Daly, Herman. (ed.) *Valuing the Earth,* Ethics, MIT Press, 1993.

Daly, Herman. *Beyond Growth: The Economics of Sustainable Development,* Beacon Press, Boston, 1996.

Daly, Herman. *Ecological Economics and the Ecology of Economics: Essays in Criticism*, Edward Elgar, Cheltenham UK, 1999.

Davis, Erik. *Techgnosis: Myth, Magic, Mysticism in the Age of Information*, New York, Harmony Books, 1998.

Davis, Mike. *Late Victorian Holocausts: El Nino Famines and the Making of the Third World,* Verso, London, New York, 2001.

Deleuze, Gilles. & Felix Guattari, *1000 Plateaus: Capitalism and Schizophrenia,* trans. Brian Massumi, Athlone Press, London, 1996.

Desmond, Jerry. *Desmond's Concise History of Ireland*, 1998, <http://members.tripod.com/~JerryDesmond/index-2.html>

Dillon, John. 'Will US Debt Lead to a Financial Crisis?' Kairos Policy Briefing Paper No. 2, February 2006.

Dixon, Robert. 'The Origin of the Term "Dismal Science" to Describe Economics', Working Paper 1999/715, Department of Economics, University of Melbourne, 1999. <www.economics.unimelb.edu.au/research/workingpapers/wp97_99/715.pdf>

Dolman, Anthony. *Resources, Regimes and World Order*, Pergamon Press, New York, 1981.

Douglas, Mary. *Leviticus as Literature,* Oxford University Press, Oxford, New York, 1999.

Douglas, Mary. *Natural Symbols*, Penguin, London, 1973.

Douglas, Mary. *Purity and Danger: an Analysis of Concepts of Pollution and Taboo,* Routledge, New York, [1970] 2002.

Doyle, Richard. *On Beyond Living: Rhetorical Transformations of the Life Sciences*, Stanford University Press, Stanford, 1997.

Durkheim, Emile and Marcel Mauss, *Primitive Classification*, trans. Rodney Needham, University of Chicago Press, Chicago, 1963.

Durkheim, Emile. *The Elementary Forms of Religious Life*, trans. Carol Cosman, Oxford World Classics, London, 2001.

Eco, U., Gould, S.J, Carriere, J-C and Delumeau, J-C , *Conversations About the End of Time,* Penguin, London, 1999.

Eddington, Sir Arthur Stanley. *The Nature of the Physical World*, Cambridge University Press, Cambridge, 1928.

Editor. 'Science under attack by the Bush Administration', *Nature,* vol. 439, no. 7079, February 2006, p. 891.

Editor. 'Let them eat pollution', *The Economist,* February 8, 1992.

Edwards, Gordon 'A Metaphorical Framework: the Ecosystem versus The Machine', Part One of the *CCNR Final Submission to the Ontario Royal Commission on Electric Power Planning*, June 1978.

Egerton, Frank. 'Changing Concepts of the Balance of Nature,' *Quarterly Review of Biology*, vol. 48, June 1973, pp. 323-350.

Eldredge, Niles and Steven J. Gould, 'Punctuated Equilibria: an Alternative to Phyletic Gradualism' in *Models in Palaeobiology*, (ed.) T.M. Schopf, Freeman Cooper, 1972, pp. 82-115.

Elton, Charles. *Animal Ecology*, MacMilan, New York, 1927.

European Commission, 'European Commission 2001 White Paper on Strategy for a Future Chemicals Policy', COM (2001) 88, Brussels, 2001.

Ewald, Francois. 'Two Infinities of Risk' in *The Politics of Everyday Fear*, (ed.) Brian Massumi, University of Minnesota, Mineapolis, 1993.

Ferro, Marc. *Colonization: a Global History*, Routledge, London, 1997.

Ferry Luc, *The New Ecological Order,* trans. Volk, C., University of Chicago Press, Chicago, 1992.

Fieser, James and Bradley Dowden, 'Laws of Nature', *Internet Encyclopedia of Philosophy*, 2007. <http://www.iep.utm.edu/l/lawofnat.htm>

Fine, Ben. 'Economics Imperialism and Intellectual Progress', *History of Economics Review*, vol. 32, 2000, pp. 10-35.

Fischer-Kowalski, Marina and Walter Hüttler, 'Society's Metabolism: Review of the Intellectual History of Materials Flow Analysis Part II: 1970 - 1998', *Journal of Industrial Ecology*, no. 30, 1998, pp. 107-136.

Flannery, Tim. *The Future Eaters: An Ecological History of the Australasian Lands and People*, Martin Secker & Warburg Limited, 1996.

Frank, Thomas. *One Market Under God: Extreme Capitalism, Market Populism, and the End of Economic Democracy*, Vintage, New York, 2002.

Fonseca, Gonçalo, 'Neoclassical Optimal Growth: Golden Rules and the Ramsey Exercise,' *The History of Economic Thought Website.* <http://cepa.newschool.edu/het/essays/growth/optimal.htm>

Forbes.com, 'Supertrees: ForBio of Australia is engineering better trees. The potential gain is enormous,'. August 10, 1998. <http://www.forbes.com/global/1998/0810/0109052a.html>

Foucault, Michel. *Society Must Be Defended: Lectures at the Collége de France, 1975-76,* trans. David Macey, Allen Lane, London, 2003.

Foucault, Michel. *The Order of Things: An Archaeology of the Human Sciences,* Pantheon, London, 1970.

Frank, Lawrence. 'Foreword', *Annual of the New York Academy of Sciences*, vol. 50, 1948.

Friedman, Milton. *Essays in Positive Economics,* University of Chicago Press, Chicago, 1953.

Friedman, Milton. 'The Social Responsibility of Business is to Increase Profits', *New York Times Magazine*, 13 September 1970, pp. 32-33.

Fukuyama, Francis. *The End of History and the Last Man,* Avon Books, New York, 1992.

Fuller, Stephen. 'Science Studies Through the Looking Glass: an Intellectual Itinerary' in *Beyond the Science Wars: the Missing Discourse about Science and Society*, (ed.) U. Segerstråle, State University of New York Press Albany, 2000.

Gaddis, John Lewis. *The Cold War*, Allen Lane, London, 2005.

Galbraith, John K. Interview with Kirsten Garrett, on 'Background Briefing', Australian Broadcasting Corporation (ABC) radio, Sydney, 15 Jan 2006. < http://www.abc.net.au/rn/ta lks/bbing/stories/s1539282.htm>

Gentner, D. and M. Jeziorski, 'The Shift from Metaphor to Analogy in Western Science' in *Metaphor and Thought*, (ed.) A. Ortony, Cambridge University Press, Cambridge, 1993, pp. 447- 80.

George, Susan. 'A Short History of Neoliberalism', paper presented at the *Conference on Economic Sovereignty in a Globalising World*, Bangkok, March 24-26, 1999.

Georgescu-Roegen, Nicholas. *The Entropy Law and the Economic Process*, Harvard University Press, 1971.

Georgescu-Roegen, Nicholas. 'The Entropy Law and the Economic Problem', in *Valuing the Earth: Economics, Ecology, Ethics*, (eds.) Herman E. Daly and Kenneth Townsend, MIT Press, 1993.

Georgescu-Roegen, Nicholas. 'The Steady State and Ecological Salvation: a Thermodynamic Analysis', *Bioscience*, vol. 27, no. 4, 1977, p. 268.

Glansdorff, Paul and Ilya Prigogine, *Thermodynamic Theory of Structure, Stability, and Fluctuations*, Wiley-Interscience, New York, 1971.

Gleick, James. *Chaos*, Abacus, London, 1987.

Glikson, Andrew. 'Climate of Denial: Climate Change Skepticism and the Price of the Earth', 2005. <http://www.mapw.org.au/>

Goodchild, Peter. *Edward Teller: the Real Dr. Strangelove*, Harvard University Press, 2005.

Gooding, E.S. *Economics and the Environment*, Prentice Hall, 1999.

Gossens, Hermann. *The Laws of Human Relation and the Rules of Human Action Derived Therefrom*, trans. Rudolph Blitz, Cambridge, Massachusetts, 1983.

Gould, Stephen Jay. 'Time Scales and the Year 2000', in *Conversations About the End of Time*, Penguin, 1999.

Gowdy, John and Susan Messner, 'The Evolution of Geogescu-Roegen's Bioeconomics', *Review of Social Economy*, vol. 56, no. 2, 1998, p. 152.

Grattan-Guiness, Ivor. 'Work for the Workers', *Annals of Science*, vol. 41, 1984, pp. 1- 33.

Gray, Chris. *The Cyborg Handbook*, Routledge, New York, 1995.

Greenspan, Alan. 'Globalization', speech to the Council on Foreign Relations, New York, 10 March 2005. <http://www.federalreserve.gov/BOARDDOCS/Speeches/2005/20050310/default.htm>

Gross, Paul and Norman Levitt, *Higher Superstition: The Academic Left And Its Quarrels With Science*, John Hopkins University Press, Baltimore, 1998.

Gudeman, Stephen. *Economics as Culture: Metaphors and Models of Livelihood*, Routledge, London, 1986.

Gunaratne, Shelton. 'Thank You Newton, Welcome Prigogine; Unthinking Old Paradigms and Embracing New Directions', *Communications*, vol. 26, 2003, p. 436-444.

Haeckel, Ernst. *Die Welträtsel*, Stuttgart, 1899.

Haken, Hermann., Anders Karlqvist and Uno Svedin (eds), *The Machine as Metaphor and Tool*, Springer Verlag, Berlin, 1993.

Hamilton, Clive. *Growth Fetish*, Allen and Unwin, Sydney, 2003.

Hardin, Garret. 'Perpetual Growth: the Next Dragon Facing Biology Teachers', address to the National Association of Biology Teachers, Houston, Texas, November 1990.

Hardin, Garrett. *The Ostrich Factor: Our Population Myopia*, Oxford University Press, New York, 1999.

Hayek, Freidrich. *The Fatal Conceit: The Errors of Socialism*, ed. W. W. Bartley III, Routledge, 1988.

Hayles, Katherine. *How We Became Posthuman: Virtual Bodies In Cybernetics, Literature, And Informatics*, University of Chicago Press, Chicago 1999.

Hegel, Georg Wilhelm Friedrich. *Lectures on the Philosophy of World History*, ed. Duncan Forbes, trans. Hugh Barr, Cambridge University Press, 1980.

Heidegger, Martin. 'The Age of the World Picture' in *The Question Concerning Technology*, New York, 1977.

Helmholtz, Hermann von. 'On the Law of the Conservation of Force', 1863. <http://www.fordham.edu/halsall/mod/1862helmholtz-conservation.html>

Hesse, Mary. 'The Explanatory Function of Metaphor', in *Logic, Methodology, and Philosophy of Science,* ed. Yehuda Bar-Hillel, Elsevier, Amsterdam, 1972.

Hesse, Mary. 'Quine and a new Empiricism', in *Knowledge and Necessity*, ed. G.N.A. Vesey, Royal Institute of Philosophy Lectures, Macmillan, London, 1970, vol. 3, p. 195.

Hesse, Mary. *Science and the Human Imagination*, Philosophical Library, New York, 1955.

Hill, Michael Ortiz. 'Mine Eyes Have Seen the Glory: Bush's Armageddon Revisited', *CounterPunch*, 4 January 2003. <http://www.counterpunch.org/hill01042003.html>

Ho, Mae-Wan. 'Are Economic Systems Like Organisms?', Institute of Science in Society, 1996. <http://www.isis.org.uk/index.php>

Hodgson, Geoffrey. *Economics and Evolution: Bringing Life into Economics*, Polity Press, Cambridge, 1993.

Hodgson, Geoffrey. 'Hayek, Evolution and Spontaneous Order', in *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* (ed.) Philip Mirowski, Cambridge University Press, Cambridge and New York, 1994.

Hoffman, Andrew. *From Heresy to Dogma: an Institutional History of Corporate Environmentalism*, New Lexington Press, San Francisco, 1997.

Hornborg, Alf. *The Power of the Machine: Global Inequalities of Economy, Technology and Environment,* Altamira Press, CA, 2001.

Howard, Prime Minister John. 'Archbishop Sir James Duhig Memorial Lecture', given at St Leo's College Brisbane, 5 September 2002. <http://www.pm.gov.au/news/speeches/2002/speech1826.htm>

Hubbert, M. King. 'Nuclear Energy and Fossil Fuels', paper presented before the Spring Meeting of the Southern District, American Petroleum Institute, Plaza Hotel, San Antonio, Texas, March 7-9, 1956.

Hudson, Michael. *Super Imperialism: the Origins and Fundamentals of U.S. World Dominance,* Pluto, London, [1972] 2003.

Hutchinson, Evelyn. 'Social Theory and Social Engineering', *Science*, vol. 104, 1946, p. 167.

Hutchinson, Evelyn. 'Circular Causal Systems in Ecology,' *Annual of the New York Academy of Sciences*, vol. 50, 1948, pp. 221-246.

Hutchinson, Evelyn. 'Review: Bio-Ecology,' *Ecology*, vol. 21, 1940, pp. 267-268.

Iles, Alastair. 'Mapping Environmental Justice in Technology Flows: Computer Waste Impacts in Asia', *Global Environmental Politics,* vol. 4 no. 4, 2004, pp. 74- 104.

Ingerson, Alice. 'A Critical Users' Guide to "Ecosystem" and Related Concepts in Ecology', Institute for Cultural Landscape Studies, Arnold Arboretum, Harvard University, 2002.

Ingrao, Bruna and Giorgio Israel, *The Invisible Hand: Economic Equilibrium in the History of Science,* trans. Ian Mcgilvray, M.I.T. Press, Cambridge , Massachusetts, 1990.

Intergovernmental Panel on Climate Change, 'Third Assessment Report: Climate Change Report 2001', 2001. <http://www.ipcc.ch/pub/online.htm>

Jackson, Tim. 'Sustainability and the "Struggle for Existence": the Critical Role of Metaphor in Society's Metabolism', paper presented at the conference *Nature, Society, History,* Vienna, Austria, Sept 30 to Oct 2 1999.

James, Lawrence. *Raj: The Making and Unmaking of British India,* Little, Brown and Co., London, 1998.

Jayasuriya, Kanishka. 'Globalisation, Sovereignty, and the Rule of Law: from Political to Economic Constitutionalism', *Constellations,* vol. 8, no. 4, 2001, pp. 442-460.

Jevons, William Stanley. *The Principles of Economics: A Fragment of a Treatise on the Industrial Mechanism of Society and Other Papers,* (ed. Henry Higgs), London, MacMillan, [1871], 1969.

Jevons, William Stanley. *Pure Logic and Other Minor Works*, Macmillan, London, 1890.

Jevons, William Stanley. *Theory of Political Economy*, London, MacMillan, 1871.

Jones, Evan. 'Obituary: J.K. Galbraith', *Journal of Australian Political Economy,* vol. 57, no. 12, 2007.

Joyce, James. *Ulysses,* Penguin Books, London, 1992 [1922].

Kagel, John et. al, *Economic Choice Theory: an Experimental Analysis of Animal Behaviour,* Cambridge University Press, 1995.

Kant, Immanuel "On History" (1784). Translated by Lewis White Beck and published in excerpt under the title 'Idea for a Universal History from a Cosmopolitan Point of View', Bobbs-Merrill Co., 1963.

Kauffman, Stuart. *Investigations,* Oxford University Press, New York, 2000.

Keller, Carol. 'Talking about the Weather: the Greening of Eschatology' in *Ecofeminism and the Sacred*, (ed.) Carol Adams, Continuum, New York, 1993.

Keller, Evelyn Fox. *Refiguring Life: Metaphors of Twentieth-Century Biology*, Columbia University Press, New York, 1995.

Kelly, Kevin. *New Rules for the New Economy: 10 Radical Strategies for a Connected World*, Viking, New York, 1998, Chapter 8. <http://www.kk.org/newrules/newrules-8.html>

Kingsland, Sharon. *Modelling Nature: Episodes in the History of Population Ecology*, University of Chicago Press, Chicago, 1985.

Kingsland, Sharon. 'Economics and Evolution: Alfred Lotka's Economy of Nature' in *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* (ed.) Philip Mirowski, Cambridge University Press, New York, 1994.

Kingsland, Sharon. 'The Evolution of American Ecology: 1890-2000', John Hopkins University Press, Baltimore, 2005.

Kingston, Margot. 'Nazi Greens an Enemy of Democracy, Government Decrees', *Sydney Morning Herald,* 29 October 2003.

Klamer, Arjo and Thomas Leonard, 'So What's an Economic Metaphor?' in *Natural Images in Economic Thought: Markets Read in Tooth and Claw* (ed. P. Mirowski), Cambridge University Press, Cambridge and New York, 1994.

Klein, Naomi. 'Baghdad Year Zero: Pillaging Iraq in Pursuit of a Neo-con Utopia', *Harper's Magazine,* September 2004. <http://www.nologo.org/>

Koselleck, Reinhardt. *Futures Past: on the Semantics of Historical Time,* trans. Keith Tribe, MIT Press, Cambridge Ma, 1985.

Kosolopav, V. *Mankind and the Year 2000*, Progress Publishers, Moscow, 1976.

Kuhn, Thomas. *The Structure of Scientific Revolutions,* University of Chicago Press, Chicago and London, 1963.

Kumar, Krishan. *Prophecy and Progress: The Sociology of Industrial and Post-Industrial Society,* Penguin, Hammondsworth UK, 1978.

Kwa, Chunglin. 'Modelling Technologies of Control', *Science as Culture,* vol. 4, no. 3, 1993, p. 364.

Lakoff, George and Mark Johnson, *Metaphors We Live By*, University of Chicago Press, Chicago, 1987.

Landes, Richard. 'Lest the Millennium Should Be Fulfilled: Apocalyptic Expectations and the Pattern of Western Chronography, 100 – 800', in *The Use and Abuse of Eschatology in the Middle Ages,* eds. W. Verbeke, D. Verhelst, and A. Welkenheysen, Leuven, Leuven University Press, 1988.

Landsfeld, Stephen. 'GDP: One of the Great Inventions of the 20th Century', *January 2000 Survey of Current Business*, U.S. Bureau of Economic Analysis, 2000.

Leadbeater, Charles. *Living on Thin Air: the New Economy*, London, Penguin, 2000.

Lecuyer, Bernard-Pierre. 'Probabilistic Thinking', in *The Natural Sciences and the Social Sciences: Some Critical and Historical Perspectives,* ed. I. B. Cohen, Kluwer Academic, Dordrecht, 1994.

Lienhard. John. 'Engines of Our Ingenuity: No. 69, Steam Engines in England', 1997. <www.uh.edu/engines/epi69.htm>

Lilley, Stephen. *Men, Machines and History: The Story of Tools and Machines in Relation to Social Progress,* Lewis and Wishart, London, 1965.

Lindeman, Raymond. 'The Trophic-Dynamic Aspect of Ecology', *Ecology*, vol. 23, no. 4, 1942, pp. 399–417.

Lomborg, Bjørn. *The Skeptical Environmentalist: Measuring the Real State of the World*, Cambridge University Press, Cambridge UK, 2001.

Lotka, Alfred. 'An Objective Standard of Value Derived from the Principle of Evolution', *Journal of the Washington Academy of Science*, vol. 4, 1914, pp. 409 – 18.

Lotka, Alfred. *Elements of Mathematical Biology*, Dover, New York, [Originally published as *Elements of Physical Biology*, 1925] 1956.

Lowith, Karl. *From Hegel to Nietszche,* trans. David E. Green, Doubleday, New York, 1967.

Lowith, Karl. *Meaning in History*, trans. James Sibree, University of Chicago Press, Chicago, 1949.

Luce, Henry. 'The American Century', reprinted in *The Ambiguous Legacy*, ed. M. J. Hogan, Cambridge University Press, Cambridge, UK, 1999.

MacKenzie, Donald. *Knowing Machines: Essays on Technical Change*, MIT Press, Cambridge MA and London, 1996, p.112.

Malthus, Thomas Robert. *An Essay on the Principle of Population,* ed. Anthony Flew, Hammondsworth, Penguin, 1970.

Manssen B.A. and J.M McGlade, 'Ecology, Thermodynamics and H.T. Odum's Conjectures', *Oecologia,* vol. 93, no. 4, 1993, pp. 582-596.

Maturana, Humberto and Francisco Varela, *Autopoiesis and Cognition: The Realization of the Living,* Reidel Publishing Company, Dordrecht, Holland, 1980.

Margulis, Lynn & Dorion Sagan, *Microcosmos: Four Billion Years of Microbial Evolution,* University of California Press, Berkeley and Los Angeles, 1997.

Marsh, George Perkins. *Man and Nature: The Earth as Modified by Human Action,* ed. David Lowenthal, Harvard University Press, Cambridge MA, 1965.

Marshall, Alfred. *Principles of Economics*, Macmillan for the Royal Economic Society, London, 1961.

Marx, Karl and Friedrich Engels, *Werke,* Dietz, Berlin, vol. 31, 1968.

Marx, Karl and Freidrich Engels, *Collected Works: Karl Marx: Capital, Vol. II,* International Publishers, 1996.

Marx, Karl. 'Notes on Machines', *Economy and Society*, vol. 1, no. 3, [1908] 1973, p. 244- 254.

Marx, Karl. 'Value, Price and Profit', Speech by Marx to the First International Working Men's Association, June 1865. <http://www.marxists.org/archive/marx/works/1865/value-price-profit/>

Marx, Karl. *Grundrisse,* Harmondsworth, Penguin, 1993.

Mayr, Otto. *Authority, Liberty and Automatic Machinery in Early Modern Europe,* John Hopkins University Press, Baltimore, 1986.

Mayumi, Kozo. *Origins of Ecological Economics: the Bioeconomics of Georgescu-Roegen*, Routledge, London, 2001.

McClare, C. W. F. 'Chemical machines, Maxwell's demon and living organisms', *Journal of Theoretical Biology*. vol. 30, 1971, pp. 1-34.

McCloskey, Donald. 'The Rhetoric of Economics,' *Journal of Economic Literature*, vol. 31, June 1983, p. 434-61.

McCulloch, Warren. 'A Recapitulation of Theory with a Forecast of Several Extensions', *Annual of the New York Academy of Science*, vol. 50, 1948, p. 264.

McKenzie, John. 'Empire and the Ecological Apocalypse: The Historiography of the Imperial Environment' in *Ecology and Empire: Environmental History of Settler Societies*, (ed.) Robin, Keele University Press, Edinburgh, 1997.

McKibben, Bill. *The End of Nature,* Viking, London, 1990.

Meadows, Donnella. et al. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind,* Pan, London, 1972.

Merriam-Webster Online Dictionary, 'Definition of Dialectic', 2007. <http://www.mw.com/dictionary/dialectic>

Meyerson, Emile. *Identity and Reality,* trans. Kate Loewenberg, Routledge, [1908] 2002.

Midgely, Mary. *Science as Salvation: a Modern Myth,* Routledge, London, 2002.

Mirowski, Philip. 'Macroeconomic Instability and the 'Natural' Economic Process in Early Neoclassical Economics', *Journal of Economic History*, vol. 44, no. 2, 1987, pp. 345-354.

Mirowski, Philip. *Against Mechanism, Protecting Economics from Science,* Rowman and Littlefield, Totowa, New Jersey, 1988

Mirowski, Philip. *More Heat than Light: Economics as Social Physics: Physics as Nature's Economics*, Cambridge University Press, Cambridge, 1989.

Mirowski, Philip. 'The Realms of the Natural', in *Natural Images in Economic Thought: Markets Read in Tooth and Claw,* (ed.) Philip Mirowski, Cambridge University Press, New York, 1994.

Mirowski, Philip. 'Ecology in the Mirror of Economics', editorial posting, *History of Economics Society,* 6 October 1996. <http://www.eh.net/lists/archives/hes/oct-1996/0042.php>

Mirowski, Philip. *Machine Dreams: How Economics Became a Cyborg Science,* Cambridge University Press, Cambridge, 2002.

Mitropoulous, Angela and Brett Neilson, *Academia Inc. and the Culture War,* unpublished article, University of Western Sydney, 2005.

Mittman, Brian. 'Theoretical and Methodological Issues in the Study of Organizational Demography', *Research in the Sociology of Organizations*, 1992, p. 152.

Modhrizinska, Y. and C. Stephanyan, *The Future of Society*, Progress Publishers, Moscow, 1973.

Monbiot, George. *The Age of Consent,* Flamingo, London, 2004.

Morrow, R. A. *Critical Theory and Methodology*, Thousand Oaks, New Delhi, 1994.

Mumford, Lewis. *The Myth of the Machine: Technics and Human Development*, Harcourt Brace, and World, Michigan, 1967.

Nash, David S. 'The Failed and Postponed Millennium: Secular Millennialism Since the Enlightenment' *Journal of Religious History*, vol. 24, No. 1, February 2000.

Neufeld, Howard. 'The History of the Ecosystem Concept: Part 3, Post WW-II Ecology', 2001. <http://www.appstate.edu/~neufeldhs/Ecosystems/OriginsPart3.htm>

Niele, Frank. *Energy: Engine of Evolution*, Shell Global Solutions, Elsevier, Amsterdam, 2005.

Nietszche, Friedreich. 'The Gay Science', in *Nietzsche: Selected Writings*, (ed) Stephen Metcalfe, Shristi, New Delhi, 1995.

Nietzsche, Friedreich. *Twilight of the Idols,* trans. Duncan Large, Oxford University Press, Oxford, vol. I, [1888] 1998.

Nietzsche, Friedreich. *Philosophy and Truth: Selections from Nietzsche's Notebooks of the Early* 1870s, ed. Daniel Brezeale, Humanities Press, New Jersey, 1979.

Nietzsche, Friedreich. *The Will to Power*, (eds.) Walter Kaufmann, and R. J. Hollingdale, New York, 1967.

Noble, David. *The Religion of Technology: the Divinity of Man and the Spirit of Invention,* Alfred A. Knopf, New York, 1997.

Norris, Christopher. 'Versions of Apocalypse: Kant, Derrida, Foucault' in *Apocalypse Theory and the Ends of the World*, (ed. Malcolm Bull) Blackwell, Oxford, 1995.

Nuri, Vladimir. 'Fractional Reserve Banking as Economic Parasitism: A Scientific, Mathematical, and Historical Exposé, Critique and Manifesto', 2001. < http://ideas.repec.org/p/wpa/wuwpma/0203005.html>

Nye, David. *American Technological Sublime*, MIT Press, Massuchusetts, 1994.

Odum, Eugene P. *Fundamentals of Ecology,* W.B. Saunders, Philadelphia, 1971.

Odum, Howard T. 'Energy, Ecology, & Economics', *Mother Earth News*, no. 27, 1974. <http://www.mnforsustain.org/energy_ecology_economics_odum_ht_1973.htm>

Odum, Howard T. *Environment, Power and Society*, Wiley Interscience, New York and Sydney, 1971.

Odum, Howard T. 'Radiation Ecology', Chapter 17 in *Fundamentals of Ecology,* (ed.) Eugene P. Odum, W.B. Saunders, Philadelphia, 1971.

Odum, Howard T. 'The Attitude Revolution' in *The Crisis of Survival*, eds. E. P. Odum et al., Scott, Foreman and Company, Glenview, Illinois, 1970.

Odum, Howard. T. 'Energy, Ecology, & Economics', *Mother Earth News*, no. 27, 1974. <http://www.mnforsustain.org/energy_ecology_economics_odum_ht_1973.htm>

Ormerod, Paul. *The Death of Economics,* Faber & Faber, Boston, 1994.

O Tuaththail, Gearoid. 'Geopolitics @ Millenium: Paranoid Fantasies and Technological Fundamentalism Amidst the Contradictions of Contemporary Modernity', 2001. <http://www.majbill.vt.edu/geog/faculty/toal/publish.html>

Owusu, Rachel Asante. 'GM Technology in the Forest Sector', World Wildlife Fund Briefing Paper 19, November 1999. <www.wwf-uk.org>

Pancaldi, Guiliano 'The Technology of Nature: Marx's Thoughts on Darwin', in *The Natural and the Social Sciences: Some Critical and Historical Perspectives*, (ed) I. Bernard Cohen, Kluwer Academic, Dordrecht, 1994.

Pepper, Stephen. *World Hypotheses*, University of Berkeley Press, California, 1942.

Pickett, Stewart. 'The New Paradigm in Ecology,' in *Conservation Biology: the Theory and Practice of Nature Conservation, Preservation and Management,* (eds.) Peggy Fiedler and Subdoh Jain, Mong Press, Baltimore, 1992.

Ponting, Clive. *A Green History of the World,* Penguin, London, 1991.

Popper, Karl. *The Poverty of Historicism*, Routledge, London, [1957] 2002.

Popper, Karl. *The Open Universe: An Argument for Indeterminism,* Routledge, 1992.

Powell, Lewis F. 'Attack on American Free Enterprise System. Memorandum to Eugene B. Sydnor, August 23, 1971', *Media Transparency.* <www. mediatransparency.org/stor.php?storyID=22>

Prigogine, Ilya and Isabelle Stengers, *Order out of Chaos: Man's New Dialogue with Nature,* Heinemann, London, 1984.

Prigogine, Ilya. 'The Chaotic Universe', panel discussion transcribed in *Art Meets Science and Spirituality in a Changing Economy,* ed. Louwrien Wijers, Academy Editions, London, 1996.

Prigogine, Ilya., Gregoire Nicolas and A. Bablyoantz, 'Thermodynamics of Evolution', *Physics Today*, vol 23, no. 11/12, November/December 1972, pp. 22-28 (Nov.) and 38-44 (Dec.).

Prigogine, Ilya. *The End of Certainty: Time, Chaos, and the New Laws of Nature,* Free Press, New York, 1997.

Proctor, J. D. 'Environmental and Ecological Concepts of Nature', in *International Encyclopedia of the Social and Behavioural Sciences,* Elsevier Science, 2001, p. 10399.

Pyne, Stephen J. *Burning Bush: A Fire History of Australia*, Henry Holt, New York, 1991.

Rabinbach, Anson. *The Human Motor: Energy, Fatigue and the Origins of Modernity,* University of California Press, Berkeley, 1992.

Rabinow, Paul. *Anthropos Today: Reflections on Modern Equipment*, Princeton, N.J. Princeton University Press, 2003.

Raitt, Suzanne. 'Psychic Waste: Freud, Fechner and the Principle of Constancy' in Gay Hawkins and Stephen Muecke (eds), *Culture and Waste: The Creation and Destruction of Value,* Roman and Littlefield, Lanham MA, 2003.

Rapport, David and James Turner, 'Economic Models in Ecology', *Science*, vol. 195, January 1977, p. 367-373.

Ravenscroft, Sue and Paul Williams, 'Making Imaginary Worlds Real: The Case of SFAS 123R', February 2007. <www.ivey.uwo.ca/Research/IRS_Papers/Williams.pdf.>

Reagan, President Ronald. *Second Inaugural Address to the Nation* (delivered January 21, 1985). <http://www.reaganfoundation.org/reagan/speeches/second.asp>

Redclift, Michael and Brian Woodgate (eds.) *The International Handbook of Environmental Sociology*, Cheltenham UK, Edward Elgar, 1997.

Reuleaux, Franz. *The Constructor: a Handbook of Machine Design,* Philadelphia, 1894.

Ricklefs, Robert E. *The Economy of Nature: A Textbook in Basic Ecology,* W.W Freeman and Company, New York, 1997.

Rifkin, Jeremy. *The Biotech Century,* Tarcher/Putnam, New York, 1998.

Robbins, Lionel. *An Essay On the Nature and Significance of Economic Science*, New York University Press, New York, 1932.

Ropke, Inge. 'The Early Modern History of Ecological Economics', *Ecological Economics*, vol. 50, 2004, p. 293-314.

Rosenblueth, Arturo., Norbert Wiener, and Julian Bigelow, 'Behaviour, Purpose and Teleology', *Philosophy of Science*, vol. 10, 1943.

Ross, Dorothy. *The Origins of American Social Science*, Cambridge University Press, Melbourne, 1991.

Rostow, Walt. *The Stages of Economic Growth: a non-Communist Manifesto,* Cambridge University Press, Cambridge, 1961.

Rothschild, Michael. *Bionomics: Economy As Ecosystem,* Henry Holt & Company, 1995.

Rowlands, Peter. 'What if? 1684, the Difficult One', *New Scientist*, 20 August 2005, p. 37.

Ruggie, John. 'International Regimes, Transactions and Change: Embedded Liberalism in the Postwar Economic Order', *International Organization*, vol. 36, no. 2, 1982.

Russell, Bertrand. *Why I Am Not a Christian and Other Essays on Religion and Related Subjects*, Simon and Schuster, New York, 1957.

Russet, Cynthia. *The Concept of Equilibrium in American Social Thought,* Yale University Press, New Haven and London, 1966.

Schabas, Margaret. 'From Political Economy to Market Mechanics: The Jevonian Moment in the History of Economics', *Boston Studies in the Philosophy of Science*, vol. 150, 1994, p. 235.

Schabas, Margaret. 'The Greyhound and the Mastiff', *Natural Images in Economic Thought,* ed. P. Mirowski, Cambridge University Press, New York.

Schama, Simon. *Landscape and Memory,* Fontana Press, London, 1995, p.10.

Schrödinger Ernst. *What is Life?*, Cambridge University Press, Cambridge, Massachussetts [1944] 1967.

Schumacher, Eric. *Small is Beautiful,* Abacus, London, 1973.

Scott, Howard. *Science versus Chaos!*, Technocracy, New York, 1933.

Seligman, Ben. *Main Currents in Modern Economics*, Free Press, Glencoe, 1962.

Shackley, Simon. 'Trust in Models? The Mediating and Transformative Role of Computer Models in Environmental Discourse', in *The International Handbook of Environmental Sociology,* (eds.) Michael Redclift and Brian Woodgate, Cheltenham UK, Edward Elgar, 1997.

Shiva, Vandana. 'How Free is Free India?', *Resurgence*, June 1997. <www.resurgence.org/resurgence/articles/shiva_jun97.htm>

Sieferle, R.F. *The Subterranean Forest: Energy Systems and the Industrial Revolution,* White Horse Press, [1982] 2000.

Sills, David. 'Natural Law' in *International Encyclopaedia of the Social Sciences*, Macmillan Company, New York, 1968.

Simon, Julian. 'The State of Humanity: Steadily Improving', Cato Policy Report 17 (5), Cato Institute, Washington, D.C., 1995, p. 14.

Smith, Adam. *The Theory of Moral Sentiments*, (eds.) D. D. Raphael and A. L. Macfie, Indianapolis, Liberty Fund, 1976.

Soddy, Frederick. *Cartesian Economics,* Hendersons, London, 1922.

Soddy, Frederick. *Science and* Life, Dutton, New York, 1920.

Sollner, Fritz. 'A Re-examination of the Role of Thermodynamics for Environmental Economics', *Ecological Economics,* vol. 22, 1997, pp. 175-201.

Soros, George. *The Crisis of Global Capitalism: Open Society Endangered,* Little, Brown and Company, London, 1998.

SourceWatch, entry on 'Hudson Institute', 2007. <http://www.sourcewatch.org/index.php?title=Hudson_Institute>

Stern, Nancy. *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers,* Digital Press, Bedford MA, 1981.

Stern, Nicholas. 'Stern Review on the Economics of Climate Change', HM Treasury, 2006. <.http://www.hmtreasury.gov.uk/media/8A8/C1/Summary_of_Conclusions.pdf>

Stewart, Jean and Jonathan Kemp (eds.), 'Conversation between D'Alembert and Diderot' in *Diderot: Interpreter of Nature*, International Publishers, 1943. <http://www.marxists.org/reference/archive/diderot/1769/conversation.htm>

Stewart, John. 'The Development of Social Physics', *American Journal of Physics*, vol. 18, no. 5, May 1950, pp. 239-53.

Stoler, Ann Laura. *Race and the Education of Desire: Foucault's History of Sexuality and the Colonial Order of Things*, Duke University Press, Amherst, 1995.

Summers, Lawrence. Interview with editor John Heilemann, *Wired*, July 1997.

Suzuki, David and Anne McConnell, *The Sacred Balance: Rediscovering our Place in Nature,* Greystone Books, Seattle, 1999.

Swift, Adam. *Mapping Posthuman Discourse and the Evolution of Living Informatics,* Doctoral Thesis, Queensland University of Technology, 2006.

Szerszynski, Bronislaw. 'On Knowing What To Do: Environmentalism and the Modern Problematic,' in *Risk, Environment and Modernity: Towards a New Ecology*, (eds.) Scott Lash, Bronislaw Szerszynski, and Brian Wynne, Sage/TCS, London, 1996.

Tansley, Arthur. 'The Use and Abuse of Vegetational Concepts and Terms', *Ecology*, vol. 16, 1935, p. 285 - 307.

Taylor, Owen and Ben Kiernan, 'Bombs Over Cambodia: New Light on US Air War', *Third World Traveller*, May 12, 2007. <http://www.thirdworldtraveler.com/SouthEast_Asia/US_Bombing_Cambodia.html>

Taylor, Peter. 'Technocratic Optimism: H.T. Odum and the Partial Transformation of Ecological Metaphor after World War II', *Journal of the History of Biology*, vol. 21, no. 2, 1988, p. 211-246.

The Hindu, 'Engineering Life', Wednesday, 4 December, 2002.

Thoreau Institute, 'FAQS on Free Market Environmentalism', 2006. <http://www.ti.org/faqs.html>

Toffler, Alvin. *Future Shock*, Random House, New York, 1970.

Toffler, Alvin. *The Third Wave*, Bantam Books, New York, 1981.

Treanor, Paul. 'Neoliberalism: Origins, Theory, Definition' 2006. <http://web.inter.nl.net/users/Paul.Treanor/neoliberalism.html>

Trenchard, John. *An Argument Shewing That A Standing Army Is Inconsistent With A Free Government* [1697], cited by David Wootton, 'Liberty, Metaphor, and Mechanism: Checks and Balances and the Origins of Modern Constitutionalism', 2003. <www.constitution.org/lg/check_bal.doc>

Tschirhart, John. 'Ecological Transfers in Non-Human Communities Parallel Economic Markets in a General Equilibrium Model', *Journal of Bioeconomics*, vol. 5, 2003, pp. 193 - 214.

US Bureau of Economic Analysis, 'GDP: One of the Great Inventions of the 20th Century', *Survey of Current Business*, January 2000. <http://bea.gov/bea/aw/0100od/maintext.htm>

Van Krieken, Richard. *Sociology: Themes and Perspectives*, Pearson, Sydney, 2000, p.81.

Vermeij, Geerat. *Nature: an Economic History*, Princeton University Press, Princeton and Oxford, 2004.

Vernadsky, Vladimir. *The Biosphere*, trans. David Langmuir, Copernicus, New York, 1998.

Vitousek, P., P. Ehrlich, A. Ehrlich, and P. Matson, 'Human Appropriation of the Products of Photosynthesis', *Bioscience*, vol. 36, no. 6, 1986, pp. 368 - 373.

von Foerster, Heinz. (ed.) *Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems*, Josiah Macy, Jr. Foundation, New York, 1952.

von Mises, Ludwig. *Human Action*, trans. Bettina Greaves, Foundation for Economic Education, Irvington AL, [1940] 1996. <http://www.mises.org/humanaction.asp>

von Neumann, John and Oskar Morgenstern, *Theory of Games and Economic Behaviour*, Princeton University Press, 1944.

Wacjman, Judy. *TechnoFeminism*, Polity, Cambridge, 2004.

Wackernagel, M.L, Onisto, L., Callejas Linares, A., Lopes, I.S., Falfan, J., Mendez Garcia, A.I. and Suarez Guerrero, M.G *Ecological Footprints of Nations,* Centre for Sustainability Studies, Universidad Anahuac de Xalpa, Mexico City, 1997.

Wali, Mohan. 'Ecology Today: Beyond the Bounds of Science', *Nature and Resources*, vol. 35, no. 2, April-June 1999, p.41.

Walras, Leon. 'Economique et Mechanique'', *Metroeconomica,* vol. 12, no. 1, [1908] 1960, pp. 3-11.

Walras, Leon. *Pure Economics: or the Theory of Social Wealth*, Routledge, 2003.

Waltz, Kenneth. *Theory of International Politics,* Addison-Wesley, Reading, Massachusetts, 1979.

Weber, Eugen. *Apocalypses: Prophecies, Cults and Millennial Beliefs through the Ages*, Pimlico, London, 1999.

Weingart, Peter and Sabine Massen, 'The Order of Meaning: The Career of Chaos as a Metaphor', *Configurations,* vol. 5, no. 3, 1997, pp. 463-520.

White, Hayden. *Metahistory: the Historical Imagination in Nineteenth Century Europe*, John Hopkins University Press, Baltimore, 1973.

White, Michael. 'In the Lobby of the Energy Hotel: Jevon's Formulation of the Postclassical "Economic Problem"', *History of Political Economy,* vol. 36, no. 2, 2004.

Whitehead, Alfred North. *Science and the Modern World: Lowell Lectures*, New American Library, [1925] 1956.

Wiener, Jonathon. 'Beyond the Balance of Nature', *Duke Environmental Law and Policy Forum*, vol. 7, no 1, 1996.

Wiener, Norbert. 'A Scientist Rebels', letter to Mr. George Forsythe, reprinted in *Science Technology, and Human Values*, vol. 8, no. 3, 1983, pp. 36-38.

Wiener, Norbert. *Cybernetics: or Control and Communication in the Animal and the Machine,* Cambridge, MIT Press, 1948.

Wikipedia contributors, 'Commensurability (philosophy of science)', *Wikipedia, The Free Encyclopedia,* 2007. <http://en.wikipedia.org/wiki/Incommensurable>

Wikipedia contributors, 'Measures of national income and output', *Wikipedia, The Free Encyclopedia*, 2007. < <http://en.wikipedia.org/wiki/GNP>

Wikipedia contributors, 'Emergy', *Wikipedia, The Free Encyclopedia*, 2007. <http://en.wikipedia.org/w/index.php?title=Emergy&oldid=142230285>

Williams, Eric., Robert Ayres and Miriam Heller, 'The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices', *Environmental Science and Technology,* vol. 36, pp. 5504-5510.

Wilson, Mark. Photograph of Krupps coal trencher, 'World's Largest Digger: Digs, Potentially Destroys World', 18 November 2006. <http://gizmodo.com/gadgets/krupps/worlds-largest-digger-digs-potentially-destroys-world-215801.php>

Williams, Raymond. 'Ideas of Nature' in *Problems in Materialism and Culture,* (ed.) Raymond Williams, Verso Press, London, 1989.

Wilson, Edward O. *Consilience: the Unity of Knowledge*, Vintage, Cleveland, 1999.

Wilson, Woodrow. *Constitutional Government in the United States,* Columbia University Press, 1908.

Wohlstetter, Alfred. 'Maintaining The Delicate Balance of Terror', *Foreign Affairs*, April 1959.

Wootton, David. 'Liberty, Metaphor, and Mechanism: "Checks and balances" and the Origins of Modern Constitutionalism,' 2003. <http://www.constitution.org/lg/check_bal.htm>

World Bank, *Responsible Growth for the New Millennium: Integrating Society, Ecology, and the Economy,* World Bank Publications, 2004.

Worster, Donald. *Nature's Economy: the Roots of Ecology,* Cambridge University Press, New York, 1977.

Worster, Donald. *The Wealth of Nature: Environmental History and the Ecological Imagination*, Oxford University Press, New York, 1993.