The Service Science of Climate Change Policy Analysis: applying the Spatial Climate Economic Policy Tool for Regional Equilibria

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The use of Computable General Equilibrium modelling in evidence-based policy requires an advanced policy making frame of reference, advanced understanding of neoclassical economics and advanced operations research capabilities. This paper examines developments in neoclassical economic models for the analysis of strategy and policy. Regions and industries have the ever-present challenge of building a future where production is competitive and employment is durable. In this context, the inhibitor effects of potential climate constraints on regional industries and bilateral trade is currently a topic of major concern to polity. Threats often bring opportunities and these are sometimes major disruptions to traditional industry structure. Therefore of equal interest to some policy makers are the strategic opportunities that a window of superior domestic productivity and resource expansiveness may bring to nations seeking a transformative boost in export performance. The Spatial Climate Economic Policy Tool for Regional Equilibria (Sceptre) is an intertemporal, multiregional general equilibrium model for investigating regional and industry strategies in the presence of global policies such as carbon emission constraints. In its simplest mode, Sceptre translates global climate policies to regional and commodity effects. This is achieved by bringing together traditional markets for commodities with new markets in carbon commodities. These new markets are emission permits trading and a technology function for carbon abatement and amelioration. A general equilibrium is settled by optimising a social welfare function, in the mode of a Negishi format, within a nonlinear economic-climate feedback loop. Both the technology function for carbon abatement and amelioration and the economic-climate feedback loop have precedent in William Nordhaus' DICE model. The social welfare function comprises regional economic expansion factors, which are developed in a multiregional context using a data envelopment or benchmarking technique successfully applied by Thjis ten Raa to single period national and bilateral models. In a novel intertemporal innovation, Sceptre draws together disciplines of economics and finance by substituting resource constraints with Dupont sales to asset ratios in order to dynamically link and mediate the stocks and flows of each commodity. This avoids the issue in Ramsey models that investment is merely an uncontrolled residual of production and consumption, and the issue in the Leontief B-matrix approach that final industry assets are cannibalised. Regionally aggregated Make and Use matrices drawn from GTAP's Social Accounting Matrices are used in the underling economic model as regional-commodity production function tableaux. Outputs for policy

consideration include global geophysical climate effects, regional and industry activity levels, bilateral trade flows, potential resource expansiveness, investment, labour and regional and industry rates of transition from carbon trading to carbon amelioration and abatement.

1. Introduction

1.1 The Policy Context

This paper outlines the development and use of the Spatial Climate Economic Policy Tool for Regional Equilibria (Sceptre), which is a Computable General Equilibrium (CGE) modelling platform. New Service Science principles for management and public policy are defined. Sceptre's evolution through these Service Science principles is discussed and the use of the tool is demonstrated in translating global policy constraints to regional industry effects, testing national and global policies for feasibility and developing sensitivity analysis for risk appreciation. Sceptre's data visualisation and graphical communication of the results of policy research are illustrated. It is also explained how Sceptre may be used by government, industry and firms to reengineer robustly different policy and strategy scenarios for resource expansive production.

1.2 Service Sciences

Research in Computable General Equilibrium deals with the price and quantity of commodities. Services ranging from electricity production to consulting and cleaning are modelled as commodities. The new discipline of Service Sciences takes this concept one step further, regarding commodities and services in an economy as indistinguishable and defining all commerce to be the exchange of services (Vargo & Lusch 2004; Spohrer et al. 2007).

This approach derives from the “father of Service Sciences” Frederick Bastiat (1848) who maintained “The great economic law is this: Services are exchanged for services .... It is trivial, very commonplace; it is, nonetheless, the beginning, the middle, and the end of economic science .... Once this axiom is clearly understood, what becomes of such subtle distinctions as use-value, and exchange-value, material products and immaterial products, productive classes and unproductive classes? Manufacturers, lawyers, doctors, civil servants, bankers, merchants, sailors, soldiers, artists, workers, all of use, such as we are, except for the exploiters, render services. Now since these reciprocal services alone are commensurate with one another, it is in them alone that value resides, and not the gratuitous raw materials and in the gratuitous natural resources that they put to work”

A unique aspect in the exchange of services is that value is only created by the two parties when they meet and the customised service is moulded to the customer's requirements and delivered. Services therefore require a close social interaction between seller and buyer. This close social interaction requires basic trust. When firms engage in collaborative business, the firms require the same levels of trust and defined methodologies for achieving alliances and transparency.

This profound insight leads to a new way of viewing economic activity, called Service Science, which is a leadership discipline with a particular focus on strategies to integrate core competences and external resources. It is the practical extension of game theory into trust strategies for maximising outcomes such as business efficiency, economic welfare and social trust and happiness. Although Service Sciences is a new discipline, two limbs have become apparent (Nettleton 2010a). The first relates to strategies for complex organisations and the second to public policies for countries, regions, trade blocs and the globe.

1.2.1 Service Sciences as game theory thrust strategies

In 1838, Antoine Augustin Cournot's “Researches into the Mathematical Principles of the Theory of Wealth” (Cournot 1838) provided the first formal proposition of game theory. Very early in his career John von Neumann became intrigued by the subject and embarked on the study of games (Von Neumann 1928). Together with his colleague Oskar Morgenstern, von Neumann vigorously expanded the topic throughout the Cold War period (von Neumann & Morgenstern 1953). His ideas were also progressed Merrill Flood & Melvin Dresher at RAND in 1950 (Dresher 1981).

Game theory now provides a basis for understanding ultimatums in economic and political relationships, in which both cooperative trust strategies and betrayal strategies are possible. It is a combination of neoclassical economics, fierce competition and survival of the fastest and fittest. Such assumptions occur in many real circumstances as diverse as nuclear deterrence, the Tour de France bicycle race, cigarette advertising and project management.

Albert Tucker (1980) introduced the idea of prison sentence pay-offs, which led to the elementary two person game becoming the ubiquitous “Prisoner's Dilemma”. Nobel Laureate John Nash (1950) showed that an equilibrium solution exists, which may not be a Pareto Optimum, where all players have perfect information and no player can gain by changing their strategy. For example, the dominant strategy for the two player game is for each player to not trust the other and therefore betray the other. Of course, the Pareto Optimum solution would be where each player is better off by trusting the other and therefore not betraying.

Nobel Laureate Robert Aumann extended the Prisoner's Dilemma to a repeating game called the “Iterated Prisoner's Dilemma,” which is also known as the Peace-War Game. In doing so, Aumann showed that a cooperative outcome could be sustained (Aumann & Shapley 1974)

Robert Axelrod (1984) investigated Aumann's theory in a world-wide competition for computer simulated Iterated Prisoner's Dilemma strategies. He found that if the game has a defined end then the best strategy is to cheat all the time. The logic behind this strategy is that if the best choice on the last or penultimate iteration is to cheat, then the best alternative on the second last iteration is also to cheat, which agrees with von Neumann's analysis.

However, the outcome is different if the game continues with no foreseeable end such that there is no last iteration. In this case the best strategy was a simple tit-for-tat rule submitted by Anatol Rapoport (Rapoport & Chammah 1965). The rule is to trust other players unless they cheat, in which case the next iteration is retaliation followed by forgiveness and a return to the trust rule. Furthermore, it was found that the more that people play the Iterated

Prisoner's Dilemma, the more they recognise that trust strategies maximise everyone's welfare.

Earlier in this paper it was noted that trust strategies form the core of strategic studies in Service Sciences. In terms of the Prisoner's Dilemma, it is the confidence developed by the players in the implicit underlying trust fabric of society and in the rule of law that allows them to enjoy the rivers of gold that flow from Pareto Optima rather than succumb in ignorance and distrust to the dominant strategy of betrayal. Although the extension of this principle into business would seem to be trival, it has taken a long while for the development of complex organisational strategies for resource integration through voluntary interdependence.

Management strategies for complex organisations

This leads to the first limb of Service Sciences, which is collaborative business models and, in particular, leadership strategies for significantly virtualised resource integrating businesses. Such businesses focus on their one or two core competences and outsource all other activities to business partners through service level agreements, which in effect are alliance contracts.

Modern Service Sciences as a formal discipline is the child of the Information Technology. However, IT mainly saw it as a computer service architecture philosophy for plug and play business process providers and 360-degree data availability in organisations. While every businesses benefits from IT enabling technologies, the scope of Service Sciences is significantly more general. It refers to transformative management and business strategies in all functions of the organisation, not just IT. The adjective “transformative” is important because productivity improvement in services is hard to achieve without the key element of changing the way the business is configured to remove dependencies and increase agility. While incremental productivity improvements have been the norm in manufacturing, improvement in service productivity is significantly more challenging. In treating manufacturing and services as indistinguishable, Service Sciences seeks productivity improvement in each through major paradigm change.

The main limb of Service Sciences is therefore concerned with complex organisational strategies to maximise profit by changing the paradigm by which business is done through a set of Service Science trust strategies. This is primarily achieved through business strategies that maximally virtualise organisations so they act as resource integrators, firmly capitalising on their core competence and outsourcing all other processes to business partners. Outsourcing non-core activities and acting as a resource integrator around a firm's own core competence amasses the best of all Ricardian trade advantages to the performance of the firm. Of course, care needs to be taken not to hollow-out the core competences and management of the firm.

The outsourcing of business activities extends right down to near-core critical activities, provided that the outsourcing of these activities can be confidently premised on trust. These trust agreements are documented in service level agreements (SLAs). The best operate as alliance contacts where the costs and benefits of successful joint strategies are shared and legal action over operational issues is mostly barred. Success becomes a function of management's due diligence in modelling business processes, understanding dynamic performance through simulation, and making pragmatic win-win decisions when processes are placed under additional stress due to factors such as business growth, changes in the objectives of each party with the effluxion of time and unexpected events.

Public policies to maximise citizens' welfare

The second limb of Service Sciences is public policy, with two branches. The first branch of Service Sciences in public policy is concerned with maximising citizen welfare. Indeed, the level of trust in a community is intimately related to the level of happiness, which is in turn a major component of community welfare.

There has also been significant interest in the reason why some societies like Switzerland, Iceland and India are happier than Great Britain and America, and very unhappy societies like Moldova. Eric Weiner (2008, pp. 234-6 & 405) found that the deeper the trust ethos in society and sanctions that promote trust, the greater the symbiosis and happiness that people report: “Trust - or to be more precise, a lack of trust - is why Moldova is such an unhappy land .... Moldovians don't trust the products they buy at the supermarket .... they don't trust their neighbours .... they don't even trust their family members. ... For years, political scientists assumed that people living under democracies were happier than those living under any other form of government ... but the collapse of the Soviet Union changed all that. Most (although certainly not all) of these newly independent nations emerged as quasi-democracies. Yet happiness levels did not rise. In some countries they declined, and today the former Soviet republics are, overall, the least happiest places on the planet .... It is not that democracy makes people happy but rather that happy people are much more likely to establish a democracy .... The institutions are less important than the culture. And what are the cultural ingredients necessary for democracy to take root? Trust and tolerance. Not only trust of those inside your group - family, for instance - but external trust. Trust of strangers. Trust of your opponents, your enemies, even. That way you feel you can gamble on other people.”

Nowadays the rule of law is a key element underpinning Western citizens' trust that they are at liberty to enjoy commerce and their private lives without fear and allowing prosperity to grow through commodity and capital markets.

In Britain, the rule of law only evolved from about the tenth century as royal officials increasingly intervened in crime situations to prevent debilitating blood-feuds. Even today the rule of law is not to be taken for granted at an international level. This highlights the second branch of Service Sciences in public policy, which is trust strategies to share the global commons through symbiosis and international resource constraints.

Public policies for international symbiosis and sharing of common resources

This is the second branch of the Service Sciences public policy limb, which encompasses trust strategies to share the global commons through symbiosis and international resource constraints. For example, a treaty to limit greenhouse gas pollution. It is this branch of the Service Sciences public policy limb that the model presented in this paper, called by the acronym Sceptre, is designed to address. It may be used to address international resource constraint policies through the optimisation of Computable General Equilibrium (CGE) economic models, comprising globalised networked production infrastructure, commodity markets and trade.

General equilibrium

Sceptre solves a general equilibrium problem of the von Neumann-type, specifically in the Negishi welfare-optimising format. A combination of general equilibrium, optimisation and game theory trust strategies is embodied in the policy tool.

Von Neumann (1938; Champernowne 1945) sought to resolve the mathematical impasse regarding the five equations derived by Marie-Esprit-Léon Walras (1877) for the simultaneous equilibrium and clearing of all market partial equilibriums in an economy. Unfortunately von Neumann was unable to do so, even though he had become tantalisingly close to doing so in earlier minimax investigations (Von Neumann 1928).

Like Walras, von Neumann had not progressed from the assumption that intrinsic optimisation, through divine, mysterious or other means, proceeded from general equilibrium and the purpose of common good was not required for a society. A commonweal was expected to emerge as an automatic consequence of maximising utility and became clear when the simultaneous equations of a general equilibrium model were solved using algebra.

Divine and Mysterious Optimisation

The concept of divine or mysterious optimisation may be traced back to Aristotle's virtues although we hardly need go back further than Gottfried Leibniz's Theodicy in which he reasoned through what we now call continental rationalism that the world we have is the best of all possible worlds because God would not have settled for less. Leibniz (1710, para. 168) noted that “my fundamental assumption [is] that God has chosen the best of all possible worlds.”

The current order of society and hierarchy of man were therefore optimised by God. The situation of wealth and poverty was the natural order of things and an optimum situation. Furthermore, the problem of evil in the world that concerned so many people was redundant because good and evil were obviously both necessary components of this optimum: “So also on consideration of the metaphysical good and evil which is in all substances, whether endowed with or devoid of intelligence, and which taken in such scope would include physical good and moral good, one must say that the universe, such as it actually is, must be the best of all systems” (Leibniz 1710, para.263).

Indeed, those who were in a position to proceed with a mix of both good and evil could do so with moral impunity. This argument was attractive to many in the Enlightenment. In The Fable of the Bees, Private Vices, Public Virtues (1723), Bernard Mandeville marvelled that private vices, which are publicly deplored, such as greed, vanity and ambition could indeed lead to the public virtue of prosperity.

Leibniz' morally corrosive reasoning was not disputed until Voltaire satirised him as the tragically deluded Dr Pangloss in Candide (1759). However, shortly afterwards, Adam

Smith's The Wealth of Nations (1776, Book IV) again argued for the public virtue of individuals seeking their own profit through diverse approaches. He recognised a mysterious although not necessarily divine optimisation in open markets leads to an automatic optimum for society: “Every individual necessarily labours to render the annual revenue of the society as great as he can. He generally indeed neither intends to promote the public interest, nor knows how much he is promoting it …. He intends only his own gain, and he is in this, as in many other cases, led by an invisible hand to promote as end which was no part of his intention.”

Voltaire's suspicions about the inconsistency of automatic social optimisation did not reach America. Some sixty years after The Wealth of Nations de Tocqueville (1835) observed that Adam Smith's “invisible hand of capitalism” had become the doctrine of Anglo-American commerce and social structure. Furthermore, the great American social experiment in personal liberty and freedom had created a successful, confident and vibrant society. The “hidden hand” had admirably settled markets for raw materials and factors of production such as land, labour, capital and enterprise.

Nowadays, individual liberty still remains largely synonymous with free markets unencumbered by government regulation. Indeed, there is a closure with Leibniz through the conservative political psychological factor of purity-sancity (Haidt & Graham 2007), expressed through religion, where the divine being is credited with granting success to the land of liberty where consumers have the unfettered right to their fill of abundant resources. For example, a recent article about motorcycles that asked the rhetorical question “Is bigger better? Since we're all Americans here, we don't even have to ask that question. Of course it is.” (Palaima et al. 2007) Harrison (2008, pp.151-8) provides an intriguing explanation for this, which is that the modern Western journey is characterised by existential boredom and an aimless, disconsonant path of action and distraction.

Mathematical Optimisation

One can imagine von Neumann's frustration when it fell to Nobel Laureate Paul A Samuelson to demonstrate that von Neumann's problem could be solved using the mathematical optimisation technique of linear programming, which had such an affinity with von Neumann's own minimax research.

Linear programming generates quantity markets for input commodities and prices in the form of marginal utilities. Samuelson showed that an optimal balance of resource allocation occurs through von Neumann's knife-edge specialisation when economies are run to maximise utility: “Thus in this unexpected way, we have found a real normative significance for steady growth - not steady growth in general, but maximal von Neumann growth” (Dorfman et al. 1958, p331). Reflecting on his achievement in refreshing, refining and defending von Neumann's model, Samuelson later quipped that “Neumann's shade owes me a cigar” (Dore et al. 1989, p. 112; Bródy 1974, p. 13).

Von Neumann's knife-edge specialisation is now called the Linear Programming Theorem of Complementary Slackness. It states that a resource constraint can be binding or non-binding. If it is binding then the resource has a marginal productivity and therefore a price. If the constraint is non-binding then the resource remains in abundance and so it has no value.

Von Neumann's knife-edge market assumptions have great importance for national employment in global equilibrium in the presence of free trade. When a country subsidises its exports then unemployment rises elsewhere (Samuelson 1964, p.146). For example, China's subsidising of trade through holding its exchange rate at a low level, is seen as a major reason for entrenched American unemployment (Krugman 2010).

Later in the 1960s, von Neumann also solved his equilibrium model while further developing minimax game theory. In doing so, he pioneered techniques and bold assumptions for which we are indebted. For example, he substituted inequalities for equalities in neoclassical equations and proved the existence of contemporaneous and positive equilibria across all markets.

However, the real power of general equilibrium modelling arrived with Nobel Laureates Kenneth Arrow and Gérard Debreu, and Lionel McKenzie showing that general equilibrium could really exist in an economy (Arrow & Debreu 1954; Debreu 1959).

The social commonweal

As amazing as was his achievement in mathematically generating markets, Samuelson's optimisation had only provided one dimension of the “hand of God”. Still remaining was the second issue of whether markets guarantee a social commonweal. This certainly seemed to be the case in regional areas and even nationally. Resource constraints, such as labour shortages, regularly waxed and waned. Markets appeared to be wonderful means of rationing resources, as long as market rigging and other anti-market behaviour was addressed by the rule of law. When the markets failed to do their job, Keynesian stimulus from government was applied, albeit not without controversy in a nation troubled by any government intervention in the market.

The nature of the problem began to change when resource constraints internationalised in the 1970s, particularly with the 1973 and 1979 oil crises, and as trade liberalised and production shifted from local and multinational plants to take advantage of the best production functions in any country.

The “security” issues of air, food, water, energy and safety have now become vital international resource constraints. This has occurred at a time when the society of nations has yet to establish international rule of law (Kelly 2010). Various superpower geopolitical imperatives and national strategies continue to determine outcomes in their “securities” by a mix of markets and military means. For example, in the 1970s, France ignored an order by the International Court of Justice (IJC), the United Nations main judicial body, to cease atmospheric nuclear tests in the South Pacific Ocean that were depositing radiation on New Zealand and Australia. Anticipating constraints on its unilateralism, America withdrew from the IJC's jurisdiction in 1986. Furthermore, America, Russia, China and India have not yet submitted to jurisdiction of the International Criminal Court, which deals with matters such as genocide, crimes against humanity and war crimes. As such, they are not subject to any international law on these matters.

Security issues about air, food, water, energy and safety usually involve resources that are shared in common, whether it be clean air, ocean fish stocks or safety from nuclear proliferation. In awarding Nobel Laureate Elinor Ostrom the 2009 Prize in Economics, The Royal Swedish Academy of Sciences pointed to the importance of her work in managing commons, which was at the time a highly significant matter for the UNFCCC's upcoming meeting in Copenhagen. The Academy said "Elinor Ostrom has demonstrated how common property can be successfully managed by user associations …. [She] challenged the conventional wisdom that common property is poorly managed and should be either regulated by central authorities or privatized. Based on numerous studies of user-managed fish stocks, pastures, woods, lakes, and groundwater basins, Ostrom concludes that the outcomes are, more often than not, better than predicted by standard theories. She observes that resource users frequently develop sophisticated mechanisms for decision-making and rule enforcement to handle conflicts of interest, and she characterizes the rules that promote successful outcomes" (The Royal Swedish Academy of Sciences 2009).

Ostrom had showed that trust policies to fairly manage various commons could avoid the situation of devastation through over exploitation, which had been identified by Garrett Hardin (1968) as a "Tragedy of the Commons". Ostrom showed this situation of multiple Prisoners Dilemmas could be managed through market mechanisms of private property rights (Elinor Ostrom 1990; Schlager & E. Ostrom 1992; E. Ostrom & Schlager 1996).

As the commons inherent in security issues become subject to increasingly stringent global and national resource limits, regional industries need to quickly adapt to the local effects. Indeed local effects happen extremely quickly given globalised production in a super-free trade environment. Therefore regional industries need to quickly reinvent themselves to adapt to the new circumstances and galvanise to take advantage of new opportunities. While this is occurring, governments need to act with policies that increase the welfare and safety of their citizens while maintaining employment, managing the critical mass of industry and responding to population demographics.

Thus the evolution in global social structure requires general equilibrium responds to the commonweal of the society, involving both the welfare of individuals and detailed spatial regional-industry strategies to weave sustainable strategies that have the best chance of prospering. For example, Australia's Minister for Finance recently called for Australians to reduce the country's enormous reliance on mineral exports by galvanising manufacturing and export service industries as had been achieved in the 1990s with wine, tourism, education and pharmaceuticals (Janda & Hyam 2010). He was echoing concerns about wealth complacency and the productivity-debilitating and manufacturing-alienating effects of what Russian Prime Minister Dmitri Medvedev (2009) had described as "the humiliating dependence on raw materials exports." This is the same phenomena colloquially known as the "Dutch disease" because of The Netherlands' loss of manufacturing and jobs after discovering North Sea oil.

Nettleton (2010c) demonstrates that general equilibrium policy tools have a major place in developing policies and strategies that settle all regions in the world simultaneously. Only in this way can governments and regional industries develop a sensitivity for how ideas may evolve, given that all other societies in the world are concurrently addressing the same issues and seeking the same ends. Indeed the tools of general equilibrium such as market creation through quantity and price optimisation are the tools necessary to develop Ostrom's constraints of the commons and management of these constraints through market mechanisms into Service Science public policy (Nettleton 2010a; 2010b).

2. Intertemporal modelling

2.1 The stocks matrix

The Spatial Climate Economic Policy Tool for Regional Equilibria ("Sceptre") is an intertemporal model that spans more than ten decades. The technique of intertemporal modelling is unique and differs from the usual stocks "B" matrix in important ways. Therefore, the role of the stocks matrix and the equivalent in Sceptre is outlined here.

Karl Marx researched François Quesnay's networked input output problem and the technological conditions of production functions, both of which had largely been overlooked in the classical economics of the time. Marx (1867, Chapter XII) formulated the fundamental concept that production and sales necessarily require both fixed and circulating capital (i.e. capital equipment for production and working capital for inventories, respectively).

Marx referred to the means of production as having "periods of turnover" in which the stock of productive assets is used up. However, Marx' principles of accounting are expressed somewhat circuitously, leaving uncertainty about how the various asset classes relate to the "periods of turnover". Perhaps this arises from the semantics of using the word stock in two different contexts.

The first is "stock of productive assets" as in the total value of a group of assets, or even the physical presence of the group of assets. These assets wear out with production volume or become technologically obsolete over time. The decline in value is represented by a depreciation or amortisation rate. Marx believed that added capital investment equal to depreciation was required to maintain production. In addition, if the level of production increased then proportionately more machinery would be needed, presuming constant returns to scale.

The second context of stock is the inventory component of working capital, being raw materials intermediate assemblies and final goods ready for sale. Inventories do not wear out, except in unusual circumstances, so do not have a depreciation rate. Marx identified that the level of inventories does have a relationship to turnover in that inventories are either in the production process or in a pool that is available to be drawn upon. When the level of throughput increases then proportionately more inventories are needed, again presuming constant returns to scale.

Nobel Laureate Wassily Leontief (1936) pioneered Input-Output analysis. Leontief (1941, p.48; 1953, pp.53-90) and David Hawkins (1948, p.312; Hawkins & Simon 1949, pp.245-8) subsequently developed a dynamic model of the form $(I-A)x^i - B(x^{i+1} - x^i) = f'$ where

x^i is the production in year i, A is the direct requirements coefficient matrix, B as the matrix of stock coefficients and f' is the resource limit. Leontief speculated that this model might not have a solution in the situation where the demand for capital is equal to the positive rate of change of output.

Hawkins (1948, p.313) suggested that the stock coefficients are not independent of the technical coefficients, as assumed by Leontief, but derived from them by multiplication of a Marx-like turnover period. Oskar Lange (1957, pp.323-9; 1960, pp.313-5) developed Hawkins's thoughts further by linking the B matrix stock coefficients with Marx-like turnover periods (Bródy 2004, p.28, note 2). In Lange's formulation, the stock coefficients $B = \{a_{ik} t_{ik}\}$ are defined with respect to the direct requirements coefficients $A = \{a_{ik}\}$.

It may be seen that the terms of each coefficient are related by t_{ik}, which are similar to Marx' turnover periods. For convenience, Marx assumed these turnover periods to be one year. This special case of $t_{ik} = 1$ neatly equates the stock and the flow matrices $B = A$. However, this is merely a curiosity because in reality each t_{ik} significantly varies from the other multipliers. Marx sought to generalise his assumption of one year, engaging the help of Frederick Engels and George Moore. However, this goal was not achieved and led to an apparent contradiction between the first and third volumes of Das Kapital (Bródy 2004, p.53, note 11).

Lange treats the stock matrix as investment coefficients embodying both business growth and current depreciation. This confounds the need to distinguish between asset classes. A better application of the dynamic equation subsequently evolved as $(I-A-D+B)x^i - Bx^{i+1} = f'$, where B is a matrix of expansion capital coefficients and D is a newly added matrix of replacement capital coefficients (Miller & Blair 2009, pp.641-2).

Modern accounting does not have the concept of replacement assets to fill the void created by depreciation. Technological change in modern economies means that assets are rarely replaced like for like. Every investment decision utilises a real option to approach the production opportunity differently.

In recognition that new investment is independent of past investment, the Sceptre model takes a different approach to the Leontief B and D formulation. Investment is maintained and increased through a traditional accounting model framework of stocks and flows. Total asset turnover constraints are introduced to ensure investment remains sufficient for the needs of each economy. This is consistent with financial modelling using the techniques of DuPont analysis to ensure projections are realistic. In finance, the DuPont approach has been used for many years to investigate trends in return on capital.‡1

2.2 Framework accounting stocks and flows model with Sales/Assets constraints

Multiregional commodity accounts can be modelled with the Make V and Use U matrices prepared through standard United Nations' SNA93 national accounting techniques (ten Raa 2005). The productive gross margin is $(U-V^T).s$ where s is the vector of industry activity levels and V^T represents the transpose of V. This productive gross margin is expended on consumption and net exports (or net imports), and invested in industry assets. From these relationships a framework accounting stocks and flows model may be prepared (Nettleton 2010, pp.331-43).

The vector of industry activity levels s is similar to the quantities that von Neumann referred to as the intensities of the productive processes. In 1932, von Neumann wrote “We are interested in those states where the whole economy expands without change of structure, i.e. where the ratios of the intensities $x_1 : \ldots : x_m$ remain unchanged, although $x_{1,} \ldots , x_m$ themselves may change. In such a case they are multiplied by a common factor α per unit of time. This factor is the coefficient of expansion of the whole economy” (Von Neumann 1938, p.3).

Sales/Assets ratios are an important regulator for mediating intertemporal performance. These ratios provide a subtly different way of interpreting the turnover concept that Marx, Hawkins and Lange sought to incorporate directly in their models. Used as constraint resources rather than direct economic model parameters, these Sales/Assets ratios may best be characterised as top-down asset intensity governors of productive intensities. For intertemporal models, these dynamic constraints based on Sales/Assets ratios take the place of von Neumann's static material resource inequalities.

Sales/Assets ratios have the advantage of remaining stable for long periods, so much so that rules of thumb are often used. For example, the Sales/Asset ratio is typically 1 for manufacturers and close to 2 for retailers. However, it might be noted that a manufacturer's Sales/Asset ratio of 1 does not imply that a manufacturer's assets are used-up each year as would be the case for a turnover period. In fact, Sales/Assets ratios are prima facie physical intensities that have little relationship to depreciation.

For the Sceptre model, a Sales/Assets constraint can be readily calculated using the Make matrix as a proxy for Sales. Corresponding Assets are available from an economic database. The equation for each commodity in each country in each period is:

$$V^T \cdot s_t \leq ninvt_{t-1} \cdot \frac{Sales}{Assets}$$

where:
V^T *is the Make matrix*
s_t *is the industry activity matrix*
$ninvt_{t-1}$ *is the net investment at the end of the previous period*

A comparison of Sales/Assets ratios over a period of 7 years may be calculated using GTAP data sets for the base years of 1997 and 2004.‡2 The Sales to Assets ratios for aggregated commodities and regions are shown in Figure 1.

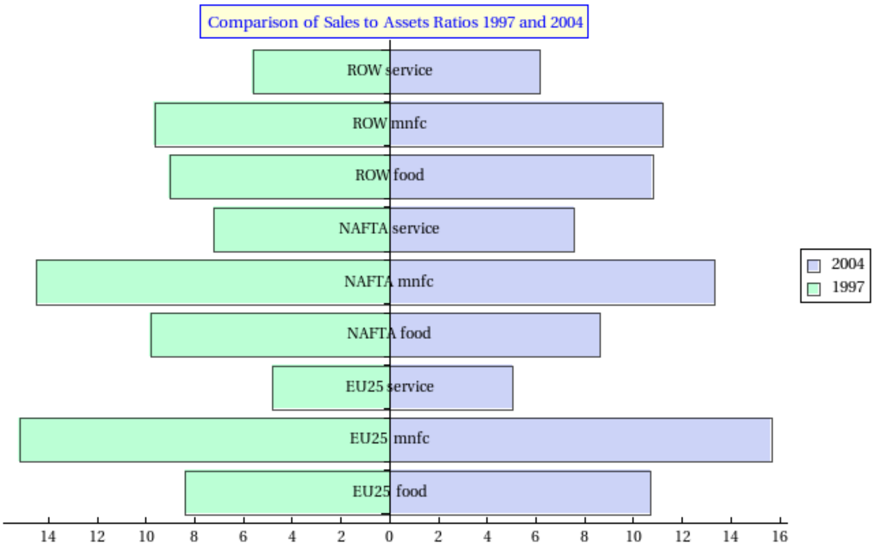

Figure 1: Comparison of Sales to Assets Ratios 1997 (GTAP5) and 2004 (GTAP7) for aggregated commodities (food, manufacturing & services) and regions (NAFTA, EU25 countries and the Rest of the World).

Advantage of using framework accounting model with Sales/Assets constraints

The following analysis demonstrates Sceptre's approach using Sales/Assets constraints is consistent with the Leontief-Hawkins intertemporal equation. However, the Sales/Assets approach has the added advantage that it is consistent with the principle that output in a period is governed only by the closing assets of the previous period.

The Leontief – Hawkins dynamic equation , with B_L *as the Leontief B stocks matrix*

$$(1+A)\ x_t + B_L\ (x_t - x_{t+1}) - Y_t = 0$$

Or , including depreciation (D)

$$(1 + A + B - D)\ x_t - B_L\ x_{t+1} - Y_t = 0$$

And restating the equation as a constraint

$$(1 + A + B - D)\ x_t - B_L\ x_{t+1} - Y_t \geq 0$$

Now casting this equation into its analogous Make and Use format $(\text{with } B = V^T / s2a)$

$$(V^T - U + B - D)\ s_t - B\ s_{t+1} - Y_t \geq 0$$

Since depreciation $D = \delta B$

$$(V^T - U + B - \delta B)\ s_t - B\ s_{t+1} - Y_t \geq 0$$

Upon regrouping terms and shifting the inequality

$$(V^T - U)\ s_t - Y_t \geq B\ [s_{t+1} - (1 - \delta)\ s_t] \quad (1)$$

$$\textit{Now, investment } I_t \textit{ balance is given by}$$
$$I_t = (V^T - U)\, s_t - Y_t$$
$$\textit{so (1) becomes}$$
$$I_t \geq B\,[\,s_{t+1} - (1-\delta)\, s_t\,] \quad (2)$$
$$\textit{Investment } I_t \textit{ can also be defined as a function of net accumulated,}$$
$$\textit{depreciated assets:}$$
$$I_t = a_t - (1-\delta)\, a_{t-1}$$
$$\textit{Therefore, (2) becomes}$$
$$a_t - (1-\delta)\, a_t \geq B\,[\,s_{t+1} - (1-\delta)\, s_t]$$
$$\textit{Upon rearranging, this provides the effective constraint of the}$$
$$\textit{Leontief B intertemporal approach:}$$
$$a_t \geq B\, s_{t+1} + (1-\delta)\,(a_{t-1} - B\, s_t) \quad (3)$$

Inequality (3) is consistent with the DuPont constraints $a_{t-1} \geq B\, s_t$ and by extension with $a_t \geq B\, s_{t+1}$. However, inequality (3) has modified the principle that in a given period sales is only limited by the previous closing assets, which is that $a_t \geq B\, s_{t+1}$ only. Furthermore, inequality (3) does not facilitate a flexible and accurate intertemporal formulation.

2.3 Weaknesses with traditional CGE models

The main weaknesses of using traditional CGE models for climate change analysis is the difficulty in solving comprehensive general equilibrium with spatial disaggregation; the computational complexity in settling intertemporal CGE models, which are already optimisations, within overall climate damage and trade deficit feedback loops; including emissions trading in each country and between countries; applying different abatement regimes in each country, which is perhaps the most important scenario outcome of an economic-climate model; and establishing the redistribution of production between countries after differential carbon pricing and abatement are introduced in each country.

The reason for this is that markets in CGE models are constructed with many equations. This is quite onerous and imbued with many assumptions such as elasticities and marginal productivities. When the number of regions and commodities is expanded, the complexity of the task rapidly expands. The shear scope of addressing this huge set of exogenous variables means that detailed due diligence of assumptions is difficult to complete. This compares to, say, using data such as Input Output data at face value, and creating marketplaces by virtue of the complementary primal and dual formulations present in all optimisations. For example, the Main Theory of Linear Programming simultaneously maximises an output isoquant while minimising resources. At the same time, the resource marginal productivities are established endogenously, instead of exogenously as in traditional CGE models.

Due to the liquidity of production through bilateral trade, government policy makers and private sector industry strategists need models where their own region, country and industry equilibrium is evaluated in a global context. All countries and industries are interested to understand their profile of strengths, weaknesses, opportunities and threats, to appreciate how their endowments compare with those of competitors and trading partners, and to understand intertemporal tradeoffs such as how fast change is required as compared to deferring action. Many strategic choices then have to be made both locally and in response to changes in the relative competitive position of nations. For example, the relocation of distribution warehouses away from areas that may be impacted by climate change.

This highlights the primary limitation in current CGE models, which can't readily provide spatial disaggregation. For example, Australia's CGE models are amongst the most sophisticated in the world. Yet none of the Australian CGE models could easily and directly model the spatial effect of climate change polices in a world setting (Australian Standing Committee on Economics 2008).

A second major issue with existing CGE models is the need to select a production function, such as the Nordhaus DICE Cobb-Douglas function, GTAP's Constant Elasticity function or a Translog function. It is difficult to justify synthetic, econometrically-estimated production functions based on calibration alone. Dale Jorgenson was the first person to use econometrics for estimating American economic parameters, giving rise to the complex task of econometric general equilibrium modelling (Johansen 1978; Hazilla & Kopp 1990).

A third issue with exiting CGE models is that in many intertemporal models using the Ramsay approach, industry investment is merely the excess of production over consumption. Capital accumulation becomes an outcome. This is the reverse of the actual situation where capital investment in industry needs to be maintained and grow with output. To many, the approach of preferring consumption over investment is unremarkable because it seems so much in accord with consumption-led economics, which has been the pervasive Western tenet of political economy. CGE modelling needs a way of inherently controlling investment by industry.

A fourth issue with traditional CGE models is communication. CGE modelling is undertaken in batch processing environments where equations are programmed in specialist modelling languages and presented to industrial optimisation solvers. The results are returned as batch files of text. The lack of a Graphical User Interfaces (GUI) for interactive model development, fast turnaround and visualisation of results is a major disadvantage for research productivity. Even more unsatisfactory is the difficulty in creating rich graphs for presentation to policy makers, which often results in bland tables and minimal graphics. While enhanced graphics can be achieved with supplementary tools, the lack of productivity due to double handling and absence of early visualisation stifles agility and creativity.

2.4 Sceptre model

2.4.1 Sceptre approach

A new regionally disaggregated policy modelling platform is needed for the emerging period of heavily constrained and symbiotic global growth. This tool needs to cope with the plurality of climate-economic policy constraints that multiply the complexity of models. For example, living within current income rather than borrowing to maintain lifestyle, maintaining the purchasing power of the labour force, managing energy requirements and greenhouse gas pollution, while achieving social objectives such as expanding both population and the welfare of the population.

Nettleton (2010a) describes the development of the Sceptre tool, which is designed to address these issues. It uses recent developments in constructing models with multiregional Input-Output productions functions, trade flows and markets that provide smooth substitution across regional industries and between countries. The schema of production functions is extended with commodity markets for emissions permits, and amelioration and abatement markets that respond to geophysical constraints, time and price.

Sceptre utilises ten Raa's Make (V) and Use (U) tables from national accounts instead of the more synthesised Input Output tables or the equivalent Leontief (A) matrix (ten Raa 2005). The V, U and A matrices are related by the equation $U=A.V^T$, where V^T is the transpose of the V matrix. As Gross Domestic Product is V^T-U , many industrial relationships can be conveniently modelled by retaining the U and V format. For example, pollution, emissions trading, abatement and various energy sources can be directly modelled. Creating Leontief's A matrix (and, for this matter, Leontief's B matrix) is useful for many traditional analysis purposes but sacrifices information. In contrast to utilising techniques associated with the Leontief A matrix, ten Raa's $(V^T-U).s$ may be used as a straightforward production function, where s is the activity vector of the commodity production units.

The Use-Make model implies a Leontief production function, which is a constant return to scale formulation and special case of the Constant Elasticity of Substitution model. Applied in a multi-industry model, there is substitution between industries of the factors of production such as materials, labour and capital. The optimisation process dual solution settles the market by balancing marginal productivities and therefore marginal prices for *tétonnement*. This overcomes the usual objection to Leontief production function where there is no substitution of the factors of production within a single industry. Studies comparing data envelopment analysis (DEA) and transcendental production functions (Translog) demonstrate that there is little value in providing a more advanced econometrically synthesised production function. The long use of DEA in government and industry imparts confidence in the use of optimisation-type production functions.

ten Raa's benchmarking optimisation of $(V^T-U).s$ is in itself a highly efficient production function across industry sectors, both for domestic substitution and international substitution through bilateral trade flows. It models the trade-off effects in policy scenarios across regions and industries. This analysis becomes insightful when intertemporal outcomes are also constrained as in climate modelling. However, the Armington assumption underlying all multiregional input output models and CGE models is still applied: that commodities in the same statistical class are substitutes, albeit imperfect substitutes (Armington 1969). It applies to domestic industries as well as the international trade of commodities.

ten Raa's benchmarking approach has the advantage that intertemporal economic models can be readily, directly and transparently solved by fast linear programming (ten Raa 2005; 2008). In contrast to current CGE models, these benchmarking models are holistic, comprehensive and highly flexible for testing new policy formulations and the turnaround is very fast. Interior point nonlinear programming brings these benchmarking models to the next level of sophistication, for example, when nonlinear climate scientific equations are used. While not nearly as fast as linear programming, nonlinear models remain holistic and flexible.

The schematic structure of Sceptre is generally as follows:

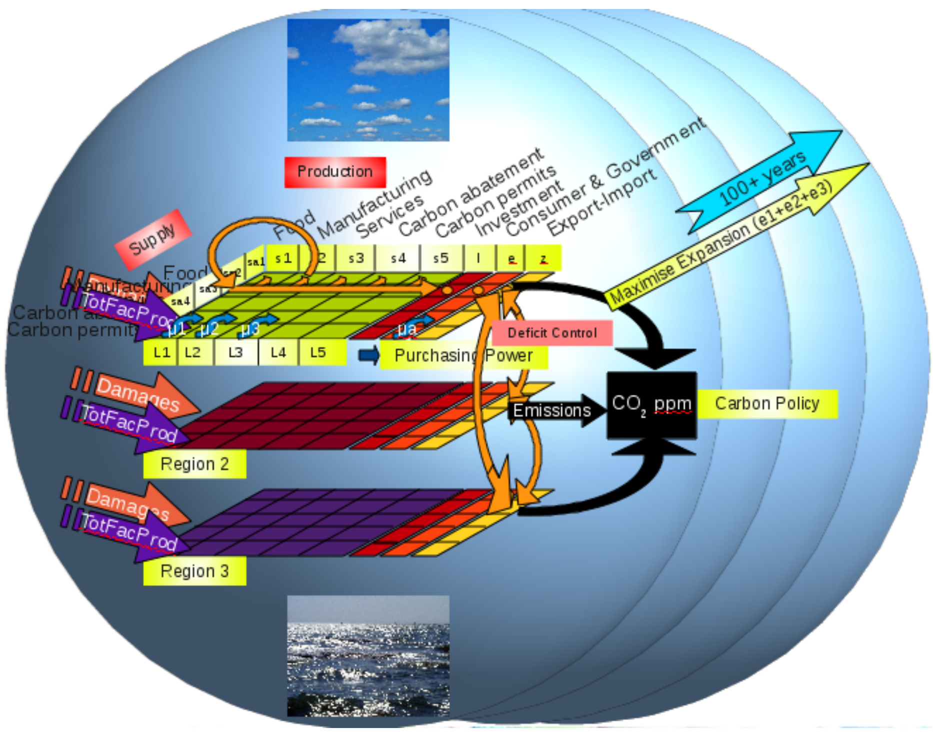

__Fig 1__ Sceptre model schematic diagram

In this schematic diagram, multiple globes represent the intertemporal nature of the model. The geophysical carbon model for the atmosphere and oceans model is adapted from Nordhaus' DICE (2008; 2009). Industrial emissions lead to rises in atmospheric and ocean temperatures and ultimately to an economic damage function. This damage feedback increases the inputs required for production. However, technological change acts in the opposite direction, reducing production inputs through growth in Total Factor Productivity. These effects are used to modify the Use matrix.

Three regions are shown, which are bilaterally interconnected through trade. Trade deficits of each are controlled such that unrealistic global imbalances do not occur.

In each region the economy comprises aggregated food, manufacturing and services sectors together with carbon abatement and permit markets. Small blue arrows represent permit markets evolving to abatement markets as the price of carbon rises. The endogenous rate that each commodity market evolves is indicated as μ_1 to μ_3 .

The regional matrices represent tabular production functions for each commodity with s_1 to s_5 being the activity levels of the respective commodity productions sector. L_1 to L_5 represent labour constraints in each commodity sector.

The utilisation of DuPont sales-to-assets ratios as resource limit inequalities mediates flows by stocks, thereby bringing realism to the performance of the economic model while retaining the elegance of tableau productions functions. DuPont Analysis deconstructs Return on Assets (all assets, including buildings, machinery, inventories and debtors) with equation:

$$Return\,on\,Assets = Profit / Assets = Profit / Sales * Sales / Assets$$

For example, a certain level of assets is needed to support an expected economic output or sales volume. As previously mentioned, this might be twice sales for a manufacturer, while for a retailer it might be equal to sales. Therefore, capital formation in intertemporal models can be satisfied with a constraint on future economic output that limits future flows to the level of opening capital stock multiplied by a Sales/Asset ratio. In the schematic diagram, these sales-to-asset ratios are sa_1 to sa_5 .

The overall use of commodity production comprises Investment, Consumer and Government consumption and Net Exports, together with industrial uses of commodities (represented by the orange arrows). The Purchasing Power links between labour and the Consumer and Government consumption vector indicates the closure of the model for households.

2.4.2 Objective function

The complete mathematical model is shown in the following components of the problem specification. The objective function is the Net Present Value of the sum of regional expansion in consumption per capita.

$$\underset{s,\, z,\, i,\, \gamma,\, inv,\, \mu}{Maximise} \;\; NPV\left(\sum \frac{\gamma}{pop}\right):$$

where NPV is the discounted net present value of the simple sum of regional indexes of consumption per capita, calculated as the index of expansion of consumption in each regional economy (γ)*, compared to the initial period, divided by the index of population growth in each region* (pop)

This objective function differs from the traditional CGE welfare function of the Negishi format, where the consumer welfare function embodies Arrow-Pratt's constant relative risk aversion (CRRA) criterion. This provides a constant elasticity of intertemporal substitution of ε and welfare utility of $u(c)$ as follows:

$$\varepsilon = 1/\alpha$$

$$u(c) = \frac{-c^{1-\alpha}}{(1-\alpha)}$$

where:

ε *is the constant elasticity of intertemporal substitution*

α *is the marginal elasticity of utility*

ρ *is the pure time rate of preference*

u *is welfare utility*

c *is per capita consumption*

Discount rate

While it is possible to implement this utility function as Sceptre's objective function, this has not been done for two reasons. The first is that people in various regions of the world have very different marginal elasticities of utility for their next dollar of consumption.

The second reason concerns the discount rate. Sir Nicholas Stern (2007), Nordhaus (2008, pp.10 & 61; 2009) and The Garnaut Climate Change Review (2008, p28) all use the Ramsey equation to endogenously calculate real discount rate, albeit based on four independent assumptions $\{c, g, \rho, \alpha\}$ with non-diversified cumulative errors. Two assumptions, $\{c, g\}$ vary within and across cases and the other two $\{\rho, \alpha\}$ are not well understood at all. For example, Heal (2005) notes that the utility discount rate reflects ethical judgements and its relationship to the social discount rate requires a wide understanding of political economy issues such as preferences, complementarities and substitutabilities.

Weitzman (2001) notes that this ethical judgement is particularly poignant in the case of the marginal elasticity of future utilities α. He suggests that this assumption cannot be fully validated: “Economic opinion is divided on a number of fundamental aspects, including what is the appropriate value of an uncertain future “marginal product of capital” …. which depends, after all, on the ultimately unpredictable rate of technological progress.”

Occam's Razor, or the law of parsimony in assumptions, suggests *Entia non sunt multiplicanda praeter necessitatem*, which approximately translates to *Entities should not be multiplied more than necessary.*‡3 Since one of the major weaknesses in traditional CGE modelling is the copious number of assumptions, restricting the number of assumptions in the Sceptre model has been one of the guiding principles in its design. In regard to consumption and production functions, this means a simpler explanation is better than a complex one.

As the benchmarking of economic expansion does not require a welfare utility function with constant elasticity of utility, there is no need to be other than parsimonious with this assumption. The rationale for this decision is that a benchmarking model seeks to reorganise the factors of production to expand an economy by more efficiently using all available resources but at the same time keeping the basket of consumed commodities in constant proportions. This contrasts to a welfare model that seeks to maximise aggregate consumption. The difference in these methods is analogous to the complementary techniques of benchmarking using Data Envelopment Analysis (DEA) and, say, using Principal Components with the Translog production function.

In an earlier survey of empirical practice, Weitzman (1998) found that the future real discount rates being used by practitioners had a mode of 2% pa, median of 3% pa and mean of 4% pa. In 2001, Weitzman recommended that economists use a schedule of real discount rates reducing from 4% for 1 to 5 years, 3% for 6 to 25 years, 2% for 26 to 75 years and 1% for 75 to 300 years.

Discounting long term financial returns is relatively uncontroversial amongst equities analysts and project finance credit analysts. These finance sector analysts consider that the perpetuity growth rate of company earnings trends to the historical long term sustainable growth in Gross Domestic Product. Avoiding the recent decade of extraordinary economic stimulus and leverage, the historical median growth rates in Retained Earnings for the S&P was about 4% pa from 1960 to 1995 (Penman 2001, p.188).

A rate of 4% pa is consistent with William Nordhaus' application of the Ramsey discount rate. Furthermore, in response to Weitzman's warning above, it is apparent that Western economies hold a shared and pervasive belief in the virtue of markets and technology. It is regarded as a truism of markets that future problems will elicit entrepreneurial technological innovation to solve those problems. This belief is also expressed as a strong preference for current consumption over future consumption, given that people's future welfare will be higher due to technological progress.

A constant real discount rate of 4% pa is utilised in this research in recognition of Western confidence in economic growth through technological innovation; preference for current consumption over future; a desire for consistency with William Nordhaus' economic-climate model; consistency with other researchers and the financial industry; and a desire to avoid introducing unnecessarily variables.

2.4.3 Constraints

The mathematical calculation of the objective function with its utilitarian assumption is only of limited usefulness in comparing strategies and policies. Of much greater importance is the behaviour of shadow prices, the local and international substitution of labour and commodities and, in the case of climate models, the rate of switching from financial payments for emissions permits to paying for backstop amelioration and abatement technology services to remove emissions. For example, after industry and consumers have reorganised themselves nationally and internationally as much as possible in response to price signals, it is the absolute reduction in emissions that is the important factor in ameliorating climate change.

As a result, most of the interest in benchmarking is in the constraints rather than in the objective function. Unfortunately, constraints are the most computationally expensive area of optimisation models. This is also where the complexity of the economic model shows itself. While the objective function may be relatively simple, each constraint in each time period is an exceedingly long symbolic equation containing the whole of the accumulated model of the economy and the climate change science equations.

It has been noted that benchmarking an intertemporal multiregional input output model to give rise to the commodity and factor markets through the dual formulation takes advantage of the theorem of complementary slackness and the main theory of linear programming. However, this adds a significant layer of complexity. Firstly, consumption demand and labour supply in each country is a function of population growth. Secondly, there is a substitution of labour between industries of a country as well as the mutual substitution of commodity production with other countries, which all use different technologies and have different production functions. Thirdly, investment becomes an endogenous variable. Finally, accumulating climate factors become a major feedback issue.

An additional layer of complexity in the task is including non-linear climate equations. The linear MRIO equations for material balance are relatively simple for a single period model and can be analytically expressed. Models can be solved quickly through Simplex linear programming. However, when nonlinear climate models are included, Simplex is no longer possible and non-linear optimisation techniques such as Interior Point are required.

In Sceptre, a nonlinear constraint schema is constructed by specifying constraints at a high level of abstraction, and then substituting constraint variables with symbolic solutions to the combined multi-regional input output (MRIO) and climate feedback models. This results in the constraints being expressed as efficient equations comprising only the most fundamental input variables to the MRIO model.

Complexity is further increased when the model becomes intertemporal. There is a compounding rolling forward of single period models. Each successive phase of the model comprises all the symbolic equations of the antecedent models. The very large set of extremely long, complicated and highly nonlinear equations in the underlying model requires a computing environment with powerful symbolic and numerical processing.

Notwithstanding the nature of the underlying schema of equations, the key advantage of this approach is that, at the abstract level of description, an intertemporal MRIO climate model has a relatively small number of symbolic inequality and equality constraints. The constraints used in Sceptre are:

Commodity flows balance ,	$(V^T - U)\, s * TFP * dam - \gamma\, y_0 - inv * i - exim * z = 0$	*where* V^T *is the Make matrix*, U *is the Use`matrix*, s *is industry activity*, TFP *is Total Factor Productivity*, dam *is the fractional economic damage feedback multilpier due to global temperature rise*, y_0 *is initial consumption vector*, inv *is investment vector with activity* i *& exim is net exports with activity* z
Sales $(V^T * s)$ *being limited by assets*	$V^T * s \leq s2a \cdot closewdv_{t-1}$	*where* $s2a$ *is sales to asset ratio &* $closewdv_{t-1}$ *is the previous period closing written down value of assets*

Maintenance Consumption per capita	$ypc_{t-1} \leq ypc_t$	*where* ypc_t *is per capita consumption at time t*
Final Period Investment	$inv_{n-1} \leq inv_n$	*where* inv_n *is Investment in the final period*
Closing model for Trade	$Deficit_t \leq Deficit_0$	*where* $Deficit_0$ *is the initial Balance of Payments trade deficit*
Labour Endowment	$\sum L_{sector} * s \leq N$	*a region s aggregate utilisation of labour is constrained by the total labour endowment of the region*
Closing for Households	$\sum L_{sector} * s \geq$ *initial labour employed* $* \gamma$	*aggregate region workforce wages need to increase at the same rate as the consumption vector* (γ)
Industrial Emissions Amelioration & Abatement	*physical emissions* $= s*(1-\mu)*emissions_0$	*where* $emissions_0$ *is the initial level of industrial emissions and* μ *is the engineering control rate of emissions, which incurs a regional backstop technology cost dependent upon both* μ *& time*
Emission Permits Market	*emission permits* $= s*\mu*emissions_0$	*Emissions permits is a commodity required for carbon emitting production*
Economic Damage Function	*dam = nonlinear DICE function of cumulative emissions*	*In the DICE geophysical model, solar radiation absorbed by carbon in the atmosphere heats the atmosphere and ocean reservoirs*
Constraint on Atmospheric Temperature	*temp rise* ≤ 2 *degC (temp rise = nonlinear DICE function of cumulative emissions)*	*Example of consensus international constraint to limit prospective atmospheric temperature rise, economic damages & adverse social impacts*

2.4.4 Data

Nettleton (2010b) describes the advantages of using Global Trade Analysis Project (GTAP) data CGE research, including its availability, consistency, geographic coverage and linkage with World Bank, OECD and IEA data (Purdue University Department of Agricultural Resources 2008; Hertel & Walmsley 2008; Lee 2008; McDonald & Thierfelder 2004).

Mathematica's country databases provide additional high quality data to supplement GTAP (Wolfram Research 2010). Nettleton (2010, pp.639-52) provides detailed procedures for aggregating and mining this data. The following population results have been obtained by aggregating Mathematica Country Databases for the European Union, NAFTA and Rest of World (ROW). Figures 1 and 2 compare these three regions in terms of Gross Domestic Product (GDP) and population. It may be noted that the three aggregated regions have approximately the same share of global GDP.

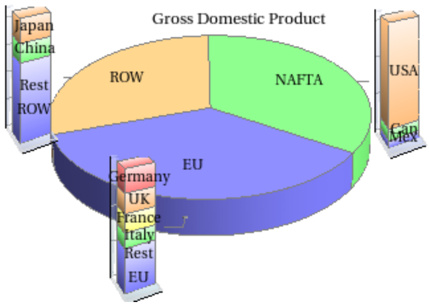

Fig. 2 Regional shares of global GDP

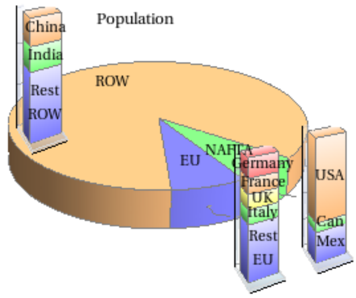

Fig. 3 Regional shares of global Population

3. Results

Sceptre provides the following illustrative results for selected international policies to deal with global warming. Two sets of results are presented. The first demonstrates the range of outputs for a single policy. The second compares selected outputs for a range of policies.

The first policy is that of limiting global temperature rise to 2°C above pre-industrial levels by 2100. This policy goal had previously been accepted by the Major Economies Forum at its July 2009 inaugural meeting in L'Aquila, Italy and is consistent with the IPCC's recommendations to ameliorate global warming. It is policy supported by the vast majority of scientists.

A similar stated policy goal of 2°C at 2050 was agreed by America, China, India, Brazil and South Africa at the Copenhagen 2009 meeting of the United Nations Framework Convention on Climate Change. While retaining the headline of 2°C, the policy brings forward the snapshot to 2050. This significantly weakens the objective because atmospheric temperature would be rising strongly at 2050 even though the temperature rise is significantly less than 2°C at that time. The Potsdam Institute has estimated that the Copenhagen pledges are more consistent with a rise of at least 3°C by 2100 (Rogelj et al. 2010).

3.1 Results for 2°C at 2100 policy

3.1.1 Economic expansion

In 2004, the regions NAFTA (America, Canada and Mexico), the European Union (25 countries) and the Rest of the World (ROW) had Gross Domestic Products as shown in the following table:

Table 1 Gross Domestic Product 2004

Gross Domestic Product 2004 US$ trillion	
EU25	13.3
NAFTA	12.8
ROW	14.8
Total	41.0

[a] Source GTAP 7 aggregations

Figure.4 (below) shows Sceptre's result for the regional expansion of consumption. It may be seen that there is a marked difference between regions. The EU25 has subdued performance. Its economic expansion starts with a 2% increase in the first decade and saturates at about 14%. This compares to a 6.7% increase in exogenous population.

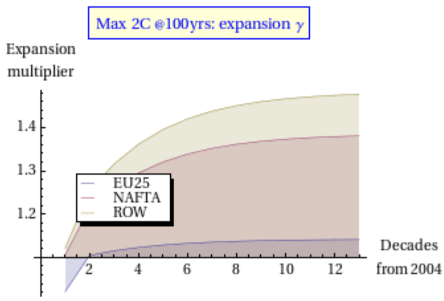

Fig 4 Expansion of Regional Consumption Vector

NAFTA's economic expansion jumps 10% in the first decade and saturates at about a 38% increase. This compares to a 29.1% increase in population. The Rest of the World (ROW) sector expands 12% in the first decade. This saturates toward a 48% expansion, which compares to an increase in population of 38.1%.

These increases suggest a significant increase in output in real terms because the increases are solely due to trade and production efficiency and the growth of labour availability. The average increase in living standard at the end of the projection is the same in each case at about 6.95% in real terms. This reflects the objective function that equally weights per capita increases in welfare in all regions.

3.1.2 Proportion of emissions ameliorated or abated

The control profile is the proportion of emissions actively ameliorated or abated, in comparison to being satisfied by the purchase of emissions permits. It may be noted that after an interregnum of six decades, control requirements rapidly increase in order to achieve the 2°C temperature rise constraint. The illustrations Figures 5, 6 and 7 show the emissions control profile for the production of food, manufactured goods and services respectively. Figure 8 shows the control profile for consumer generated emissions.

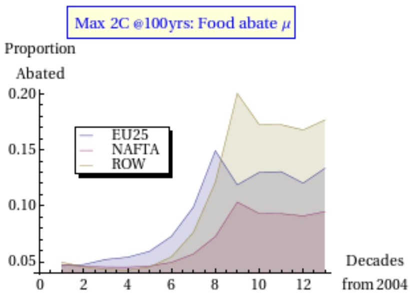

Fig 5 Control Rate in Regional Food Sector

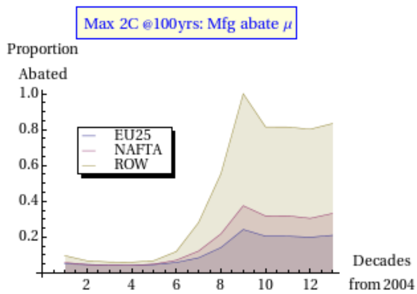

Fig 6 Control Rate in Regional Manufacturing Sector

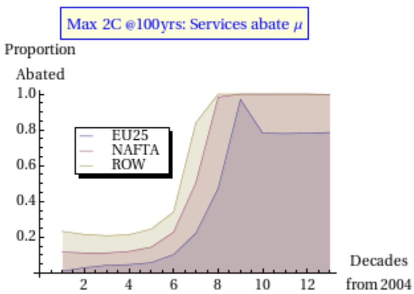

Fig 7 Control Rate in Regional Services Sector

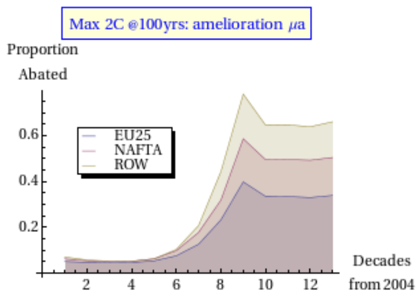

Fig 8 Control Rate in Regional Consumption Sector

The following table summarises the saturation emissions control levels in each country and industry.

Table 2 Saturation emissions control rates

Saturation emission control rates			
Emissions controlled	**EU25**	**NAFTA**	**ROW**
Food	14%	9%	18%
Manufacturing	21%	33%	83%
Services	79%	100%	99%
End Consumption	34%	50%	66%

Source: Sceptre

It may be seen in the above table that the control requirements for food are relatively modest. However, the high figure for ROW manufacturing and end consumption shows how energy and emissions intensive these sectors are across the ROW region. It may be noted that for services production, which includes electricity production, very high or complete control is required in all regions. This demonstrates the crucial importance of controlling emissions from electricity generation.

3.1.3 Price of amelioration and abatement

A paramount issue is the cost and availability of green infrastructure and technology. The Sceptre policy tool may be employed in developing a policy response to the technology factor. Sceptre is able to exemplify the potential cost of amelioration or abatement where the emissions control rate varies across regions and industries. This is shown in the following three illustrations for the policy case of 2°C maximum rise at 100 years.

Figures 9 to 12 below show the average price of amelioration and abatement based on the above control rates.

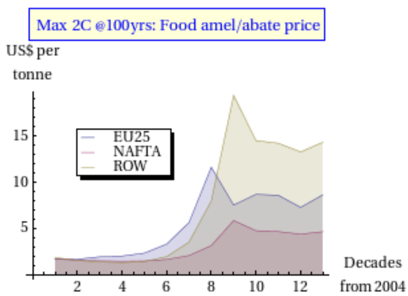

Fig. 9 Price of Emissions Control in Food

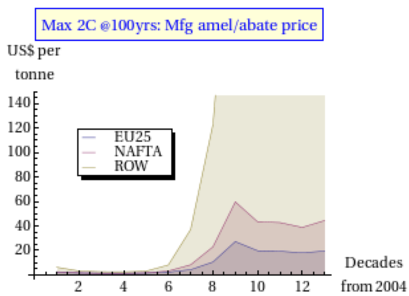

Fig. 10 Price of Emissions Control in Manufacturing

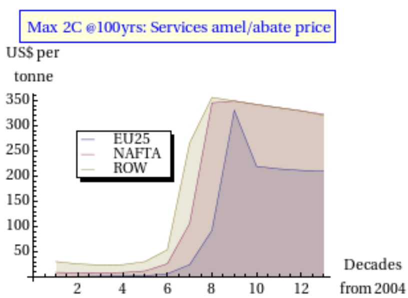

Fig. 11 Price of Emissions Control in Services

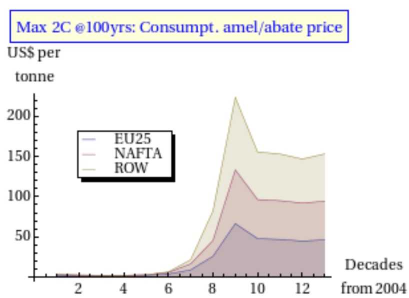

Fig. 12 Price of Emissions Control in Consumption

The saturation prices for each commodity in each region are shown in the following table:

Table 3 Saturation prices for emissions control

Saturation prices for emissions control			
US$ per tonne Carbon	**EU25**	**NAFTA**	**ROW**
Food	9	5	14
Manufacturing	19	44	233
Services	209	322	320
End Consumption	46	94	153

Source: Sceptre

In an international market, emission permits could be expected to trade at the marginal cost of the next unit of amelioration and abatement. In the table above, emission permits would trade at US$322.

While costs of amelioration or abatement are relatively low in the food industry, an exceedingly high cost of adjustment may be seen in ROW manufacturing, comprising mainly developing countries. In the services sector, which includes electricity generation, the amelioration/ abatement cost is high for all countries. This demonstrates that developing countries are very exposed to the cost of green technology and infrastructure. However, under this 2C policy scenario, these high costs do not become an imperative until mid-century.

3.1.4 Industrial emissions

Figure 13 shows land clearing emissions in purple and industrial emissions in blue. Total emissions is the sum of these two components.

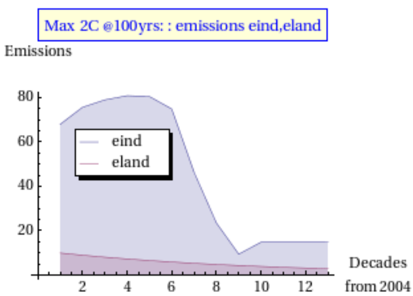

Fig 13 Aggregate Emissions from Industrial Sources
(eind) and Other Emissions (eland)

In order to meet the 2°C temperature rise constraint while maximising welfare, industrial emissions show an increasing profile for 5 decades to a maximum of 80 GtC/decade. This is 8 Gt per annum, which is 38% higher than the 1990 level of 5.81 GtC. After reaching the 80 GtC/decade maximum, emissions must drop by 88% to 9.4 GtC/decade after 9 decades. This level is equivalent to 0.94 GtC per annum, which is an 83% reduction compared to the 1990 level.

This shows that various widely discussed objectives for a 20% or 40% reduction by 2020 (compared to 1990 levels) and 50%, 60% or 80% reduction by 2050 may not be fully consistent with maximising economic welfare but do represent a progressive approach to controlling emissions that mitigates the risk of reducing emissions by 88% in just one decade.

3.1.5 Temperature rise and economic damage function

Figure 14 shows how the 2°C limit on atmospheric temperature rise is approached after 8 decades and then stabilises. There is also a strong, albeit delayed rise in ocean temperature, the effects of which are yet to be understood. Figures 15 and 16 show the associated concentration of carbon and radiative forcing.

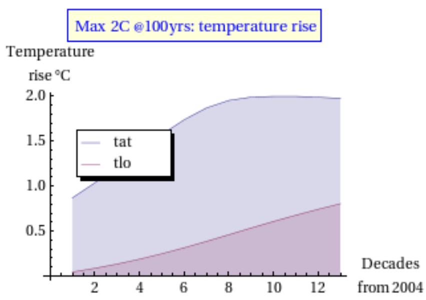

Fig 14 Temperature Rise in Atmosphere (tat) and Lower Oceans (tlo)

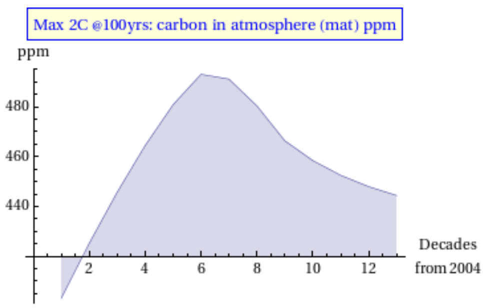

Fig 15 Concentration of Carbon in the Atmosphere

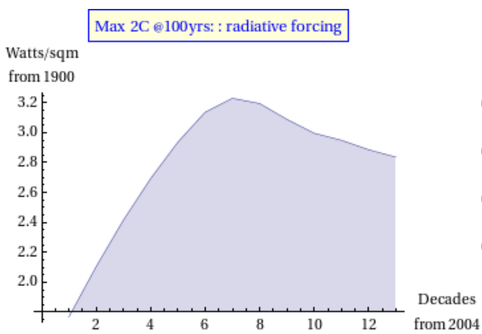

Fig 16 Radiative Forcing Arising from the Concentration of Carbon in the Atmosphere

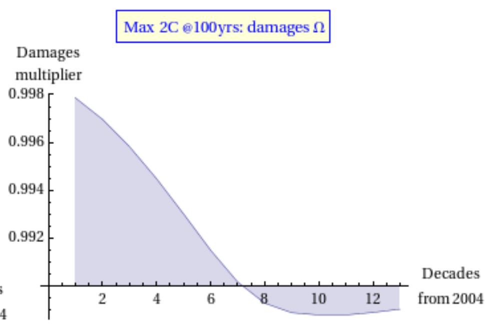

Fig 17 Economic Damage Multiplier Arising from the Effects of Global Warming

The second most important illustration is Figure 17, which is the economic damage feedback multiplier. This is a function of atmospheric temperature rise and asymptotically approaches 0.989, which is a reduction of economic output of about 1.1%.

Industry activities

Figures 18 to 22 show the level of industry activity by commodity by region. These are complemented by Figures 23 to 25 that cross-tabulate to show industry activity by region by commodity.

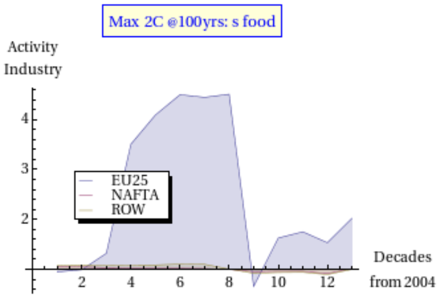

Fig 18 Regional Activity of the Food Sector

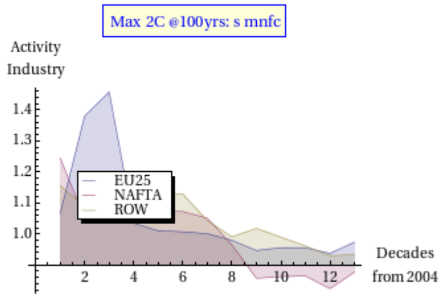

Fig 19 Regional Activity of the Manufacturing Sector

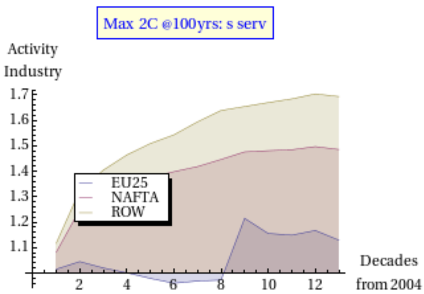

Fig 20 Regional Activity of the Services Sector

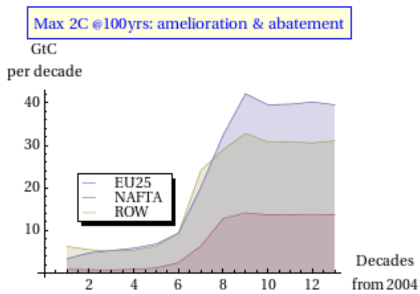

Fig 21 Regional Activity of the Abatement Sector

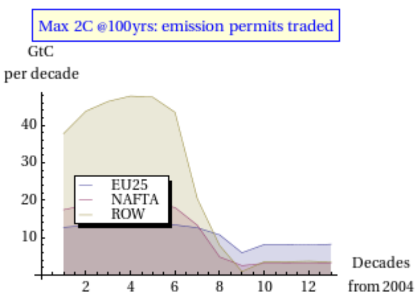

Fig 22 Regional Emissions Trading

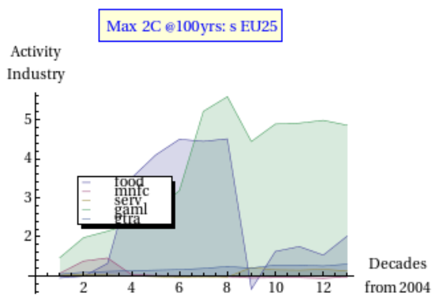

Fig 23 EU25 Sector Activity Levels

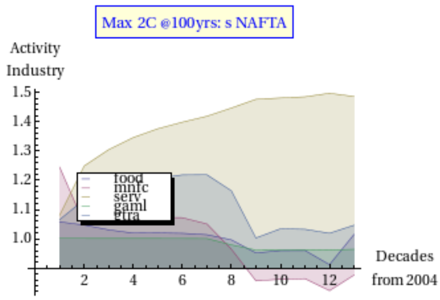

Fig 24 NAFTA Sector Activity Levels

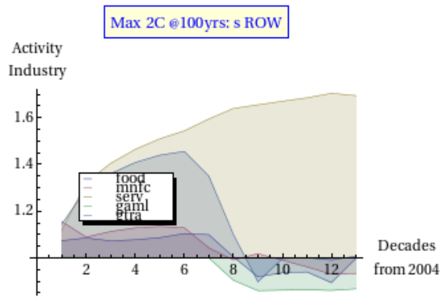

Fig 25 Rest Of World Sector Activity Levels

3.1.6 Specialisation

A major feature of the industry activity illustrations, for example in Figure 18 (above), is that for a time the EU25 becomes a food bowl for the Rest of the World (ROW). The activity of the sector is very strong, increasing from 1 to 4.5 times over six decades. It also exhibits a volatile profile by dropping to 0.65 at decade 9 and then returning to 2 times by decade 13.

Specialisation is not the result of a fixed input-output coefficient schema. It occurs because of trade substitution in resource extensive sectors of factor abundance, guided by the general equilibrium that maximises value-added per unit of labour resource (ten Raa 2005, pp.48-9, 110-1 & 127-8). Production is switched to the most viable location until this process becomes limited by a binding constraint. Higher cost sectors are deactivated. This occurs because of the knife-edge in the Theorem of Complementary Slackness. Sectors are either active, with zero slack and have positive shadow prices for inputs; or are closed with positive slack and zero price for inputs.

The presence of specialisation in Sceptre's super-free trade model is not regarded as weakness but as a generic issue inherent in neoclassical modelling and starkly apparent following optimisation. It is not a matter of suppressing specialisation. Indeed, the well-known Ricardian benefits that derive from multiplying the volume of free trade are due to a general equilibrium optimisation of bilateral specialisation with trade partners (Romer 1994). This has been observed in the off-shoring of Western jobs to Asia and China. The real issue is when and how to control specialisation into a practical range.

The only approach taken in Sceptre to model this policy of 2C at 100 years is to limit trade deficits. It is acknowledged that this is less than perfect because specialisation may still occur in one commodity if production of another is relinquished.

In cases where policy studies have specific requirements it will be necessary to better control specialisation. Saturating consumer utility before too much specialisation occurs is a synthetic method of achieving this. A carefully constructed nonlinear contemporaneous utility function is required (ten Raa 2005, p.175). Various non-linear objective functions were evaluated in the course of Sceptre's development. However, a simple yet effective general purpose saturating utility function that addressed excessive EU25 food production was not forthcoming. Ultimately, other social welfare considerations led to the selection of Sceptre's objective function as set out earlier.

Two better methods for controlling specialisation are to employ additional engineering or ecological infrastructure constraints and the use of differential technology propagation. Infrastructure constraints are specific to the specialised commodity. For example, food production in the European Union would be limited by the availability of arable land. Such a constraint may be implemented in the same way as a labour constraint with resource data drawn from GTAP's land use database or Mathematica's Country database. In other regions or countries where farming is on marginally viable land such as Australia or China, a better constraint may be water resources.

Differential technology propagation would change value-added functions and the pattern of substitution. For example, the differential propagation of HIV pharmaceutical technology and future green energy technologies are major concerns of developing countries. In relation to limiting EU food specialisation, it might be that genetically modified crops in NAFTA and the Rest of the World would act to reduce the resource extensibility of EU food production.

3.1.7 Total Factor Productivity

Figure 19 (above) shows manufacturing industry activity in all regions rapidly increasing and then declining. The rapid increase is due to growing output for all regions, while the decline is due to technological progress through increased factor productivity, leading to more output for the same amount of input and industry activity.

3.1.8 Carbon sector activity

Figures 21 and 22 (above) show the outputs of the augmented carbon sectors, the amelioration and abatement sector and emission permits trading sector respectively. It may be noted that in decade 6 the trading of emissions permits switches over to physical amelioration and abatement. A feature of the illustration is the strong growth in EU25 emissions (for the reasons discussed above) and in the region's equally strong amelioration and abatement. Total emissions dealt with by both processes rises from 78 GtC in the first decade to 99 GtC in decade 13.

3.1.9 Commodity Export

Figures 26 to 29 (below) show the export outputs for each commodity. A positive amount is a net import while a negative amount is a net export. No Services export activity is shown because Services (for example electricity and water) has been defined as a nil-export commodity in this study.

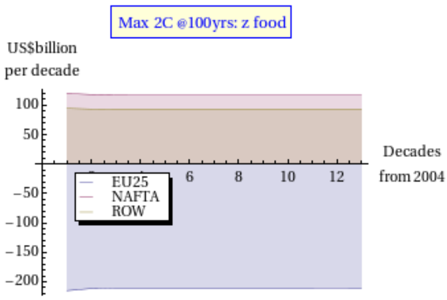

Fig 26 Food Exports

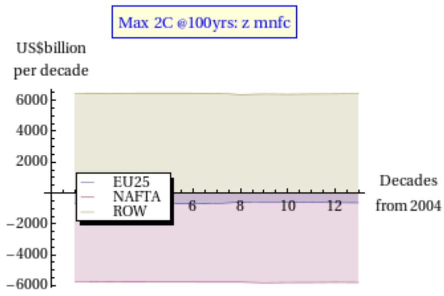

Fig 27 Manufacturing Exports

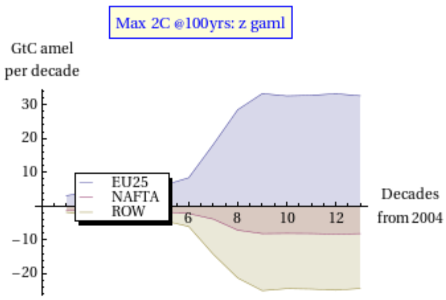

Fig 28 Amelioration & Abatement Services Exports

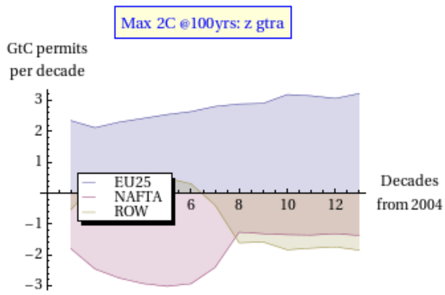

Fig 29 Traded Emissions Permits

It may be noted in Figure 26 that EU25 is a net exporter of food to NAFTA and ROW, as has been recognised in its specialisation. The EU25 is quiescent in the export of manufacturing. Figure27 shows NAFTA exporting manufactured products to ROW.

In order to achieve its food expansiveness, Figure 29 shows that the EU25 imports emissions permits from NAFTA and after decade 6 begins to import significant amounts of emissions permits from the ROW. However the dominant feature in Figures 28 and 29 is that after decade 6, EU25 imports large amounts of both amelioration and abatement services and emissions permits.

3.1.10 Aggregate investment and capital accumulation

Figures 30 and 31 show aggregate investment and capital in absolute terms, which are mainly used for comparisons across scenarios.

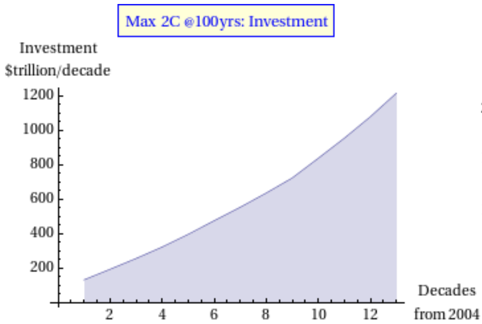

Fig 30 Aggregate Investment per decade

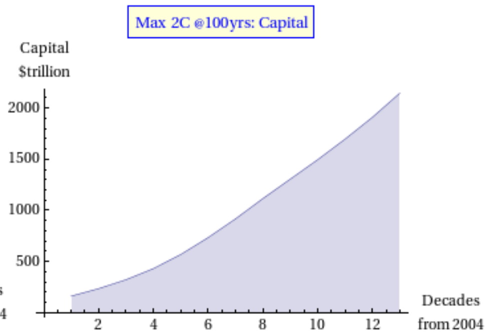

Fig 31 Aggregate Accumulated Capital

The table below compares a "business as usual" scenario with no climate constraint to the 2°C policy case. it may be seen that the 2°C limit reduces accumulated capital in decade 13 by 11% or US$280 trillion.

Table 4 Investment and capital accumulation

Investment and capital accumulation (in decade 13)		
2004 US$ trillions	**Business as Usual**	**Policy Case 2C**
Investment per decade	1,229	1,214
Accumulated capital	2,424	2,143

Source: Sceptre

Figures 32 to 34 (below) show the investment activity for each region by commodity. This is a plot of the multipliers of the existing investment vectors. Cross-tabs of investment activity for each commodity by region are shown in Figures 35 to 37.

These activities are the multiple of existing investment vectors, which are:

Table 5 Initial investment per decade

Initial investment (per decade) 2004 US$trillion			
US$ per tonne Carbon	**Food**	**Manufacturing**	**Services**
EU25	0.07	9.30	11.30
NAFTA	0.32	10.30	14.60
ROW	0.24	12.60	23.00

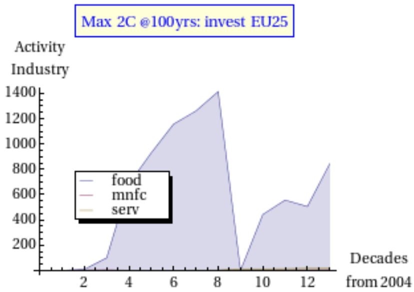

Fig 32 EU25 Sector Investment Activity Levels

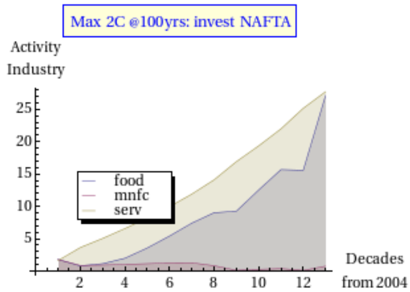

Fig 33 NAFTA Sector Investment Activity Levels

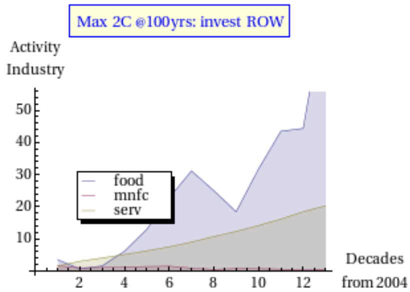

Fig 34 ROW Sector Investment Activity Levels

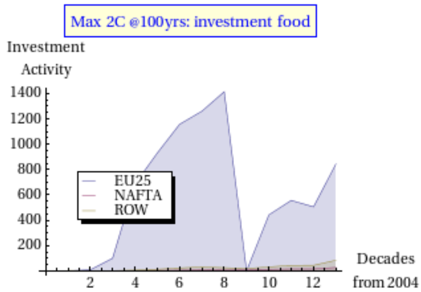

Fig 35 Food Sector Investment Activity Levels

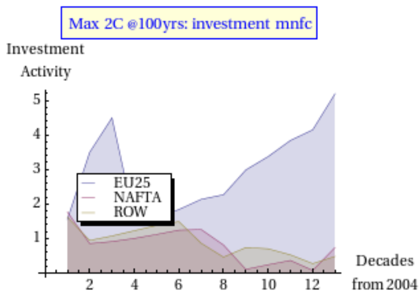

Fig 36 Manufacturing Sector Investment Activity Levels

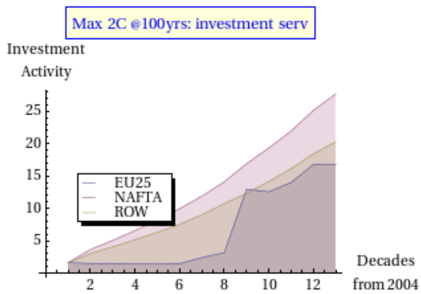

Fig 37 Services Sector Investment Activity Levels

In Figure 32, the EU's small investment vector is increased by very large multiples for its specialisation in food. Figures 33 and 34 show that NAFTA and ROW also grow their food investment by more than 25-fold and 50-fold, respectively.

There is only sustaining investment in manufacturing in all regions. However, investment in services in both NAFTA and ROW grows the same 25-fold as NAFTA's food investment.

Figures 38 to 40 (below) show the net accumulated investment in each region by commodity. As expected, Figure 38 shows EU25 accumulated investment in the food industry is high. These figures also exhibit the feature that investment in services rises strongly due to the demands of amelioration and abatement.

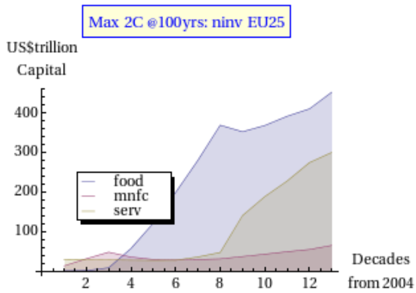

Fig 38 EU25 Sector Investment per decade

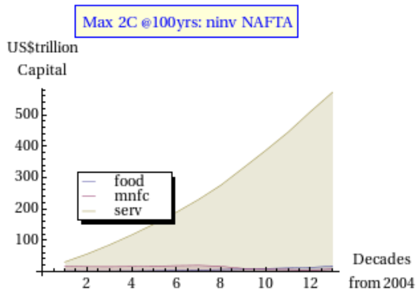

Fig 39 NAFTA Sector Investment per decade

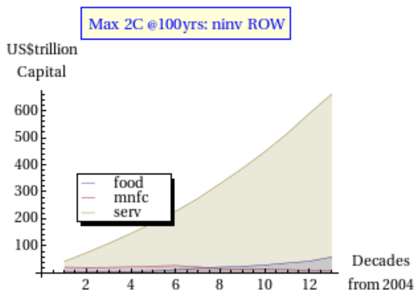

Fig 40 Rest of World Sector Investment per decade

3.1.11 Marginal cost of global economic expansion

Pursuant to the Theorem of Complementary Slackness, each binding constraint has a resource productivity and zero slack, while the opposite is true for each non-binding constraint. In Sceptre, approximately 2% of the original 996 constraints have slack of zero. In the above 2C policy scenario, the two key binding constraints are for temperature rise, the EU25 food commodity, the damage feedback function and the emissions control rate.

One disadvantage of Mathematica's interior point optimisation function is that it does not expose the Karush-Kuhn-Tucker (KKT) multipliers, the nonlinear equivalent of Lagrange multipliers, from the underlying C++ code. For Sceptre's large scale optimisations, the lack of direct access to KKT results necessitates calculation of the multipliers from first principles. This task has two disadvantages. Firstly, task can take quite a long time. Secondly, results may not be unique or identical to those implicit in the original interior point optimisation.

The KKT multiplier for a constraint represents the productivity of the resource, which is the change in the objective function for a unit change in the resource of the constraint. As

Sceptre's objective function is the net present value of the unbiased or unweighted sum of country expansion factors, the KKT multipliers or shadow prices are given in terms of Net Present Value of economic expansion rather than in dollars.

A KKT multiplier of 33.6 is found for the 2°C temperature rise constraint. This implies that a 33.6 increase in the value of the objective function will result if the temperature rise is relaxed by one unit, from 2°C to 3°C at decade 10. However, the shadow price is strictly applicable as a differential only at the one point of 2°C in decade 10. It will vary through the unit rise of 1°C. So it is usual to express prices in terms of incremental increases. For example, an increase of one-hundredth of a unit of the resource, 0.01°C or 0.5%, leads the objective function to rise by 0.336. This is a 5.11% rise compared to the optimisation value of 6.574. Therefore, the output elasticity is approximately 10x (5.11% / 0.5%).

To obtain absolute prices in dollars from shadow prices given in terms of population adjusted expansion factors, the objective function needs to be mapped to one where expansion factors are multiplied by the weighted proportions of consumption in each country. This provides the following conversion ratios:

Table 6 Value of the Objective function

Value of Objective Function	
Raw Expansion Factor Basis	**Dollar Weighted Equivalent**
6.57	US$759 trillion
1 (or per unit)	US$116 trillion

Source: Sceptre

From the table, it may be noted that the dollar value of the objective function is about 100 trillion times the expansion value. Therefore a relaxation of the temperature constraint by 0.01°C and consequent increase of 0.336 in the Net Present Value of the expansion factors is worth about US$38.8 trillion. This is almost equal to the single year GDP US$40.97 trillion (GTAP7, 2004 values).

3.2 Results comparing 2°C at 2100, Hansen/Gore 350ppm and 25%-2020/60%-2050

The application of Sceptre to two differently characterised policy goals is shown below. The first is the proposal of James Hansen and Al Gore to return the atmospheric concentration of CO_2 concentration to 350ppm. The second is Australia's suggestion that global emissions be reduced 25% by 2020 (from 1990 levels) and 60% by 2050.

Hansen/Gore proposal to return atmospheric CO_2 to 350ppm

The Tällberg Foundation, Al Gore, James Hansen and others have emphatically pleaded for world governments to return the atmospheric concentration CO_2 to 350 ppm from 380 ppm in 2009. The emissions, atmospheric temperature rise and ocean temperature rise are shown in Figures 45 and 46. In contrast to the 2°C rise in the 2°C policy case, the 350ppm policy case shows a marginal temperature rise of only 1°C, which is about 0.2° from the current position.

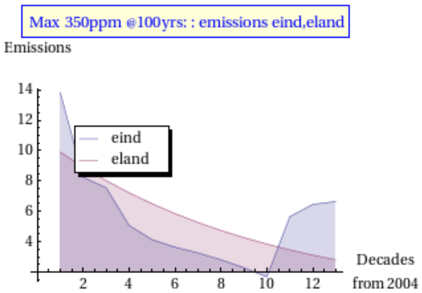

Fig 45 Hansen/Gore Policy of Limiting the Maximum Atmospheric Concentration of CO_2 to 350ppm - Industrial (eind) and Other Emissions (eland)

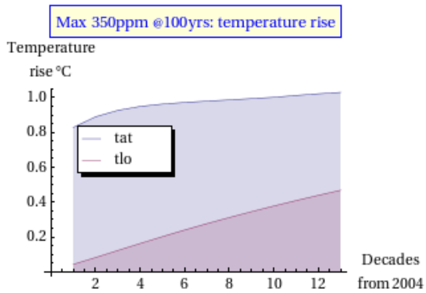

Fig 46 Hansen/Gore Policy of Limiting the Maximum Atmospheric Concentration of CO_2 to 350ppm - Atmospheric (tat) and Lower Ocean (tlo) Temperature Rise

Figure 45 shows the phenomena of a rising tail of industrial emissions following reduction to nearly zero at 10 decades. Policy makers could well introduce an additional policy that requires achievements in industrial emission reductions to be maintained. However, in order to retain simplicity, this additional policy has not been modelled here so the figure will demonstrate only the effects of the primary policy.

The value of the objective function for a policy goal of 350ppm shows that constraint imposes an increased cost on the economy compared to the Base Case of a 2°C temperature rise. However, this increased cost is only in the order of US$15-20 billion. This is nowhere near the twenty-fold cost of radically ceasing all emissions immediately, which some policy makers have seen as analogous to a 350ppm policy.

It is interesting to note that 350 ppm policy case limits EU25's resource expansive food production, which as we saw had become a very strong effect with the 2°C policy (the 2°C policy case has a delayed requirement for emissions control but otherwise is similar to a concentration limit of 450 ppm).

Policy to reduce emissions by 25% by 2020 and 60% by 2050
Sceptre shows that this policy results in two distinct reductions in industrial emissions as shown in Figure 43. This is an interesting policy approach because the objective function shows a marginally lower cost than the 2°C policy, while temperature rise is contained to about 1.7°C, albeit continuing to slowly increase, as shown in Figure 44.

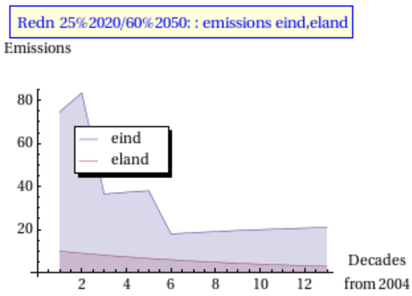

Fig 43 Policy of 25% Reduction in Emissions by 2020 and 60% Reduction by 2050 - Industrial (eind) and Other Emissions (eland)

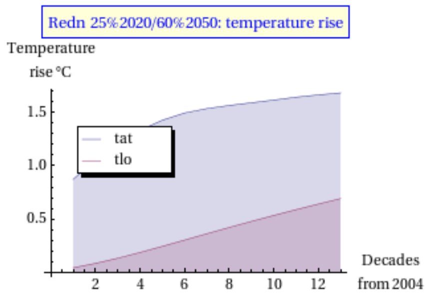

Fig 44 Policy of 25% Reduction in Emissions by 2020 and 60% Reduction by 2050 - Atmospheric (tat) and Lower Ocean (tlo) Temperature Rise

5. Discussion

Increasingly, Western societies are embracing Service Science trust strategies to solve issues of the global commons relating to the securities of air, food, water, energy and safety. Various Western governments are finding themselves on the cusp of extraordinary challenges in shifting their policy frameworks from unconstrained growth to constrained growth. Exacerbating the anxieties associated with this new uncharted future have been financial and social stresses associated with the 2009 Global Financial Crisis.

This research introduces techniques from finance and computable general equilibrium (CGE) into Input Output analysis, informed by a consistent political economic framework of Service Science, to aid policy development under constrained growth. A new type of neoclassical climate policy model has been developed, which has been called Sceptre, an acronym for Spatial Climate Economic Policy Tool for Regional Equilibria. It is an innovative methodological technique for intertemporal computable general equilibrium that includes the interaction between prices and quantities, and settles an equilibrium across regional industry sectors and between regions.

Sceptre applies the Service Science concept of benchmarking to multiregional Input Output modelling. Benchmarking is a form of Data Envelopment Analysis (DEA) where all economies simultaneously seek to be the best they may be given the nature of their production functions and national factor endowments. The results of this research have demonstrated that Sceptre is effective in understanding the diverse effects that global climate constraints may have on regional industries. Sceptre's comprehensive regional production tableaus and trade linkages show that von Neumann knife-edge effects will propagate quickly to regional industries through global trade. This has important ramifications for regional economic welfare and trade competitiveness, as well the price and rate of emissions control in each region.

In the Western democratic process, citizens expect Government policy makers to understand the dynamics of economies in terms of decades and plan for long term welfare. The Sceptre policy tool assists policy makers in developing a sensitive understanding of their local industry dynamics within global equilibrium over an intertemporal period of nominally 10 decades. Sceptre provides insights into understanding robustly different policy scenarios and political perspectives that are valuable in developing an appreciation of the emerging realities for traditional specialisations and industry employment profiles. In turn, these insights suggest changes in the importance of national endowments, attitudes to self-reliance and strategic needs for evolving geopolitical alliances based on trade.

From the perspective of policy analysis, Sceptre's methodology in projecting, pricing and making the most of constrained resources is a comprehensive approach to globalised markets with full attention to commodity production technologies and population labour dynamics. In addition to the usual neoclassical labour resource constraint, Sceptre is stablised by a labour purchasing power constraint that closes the model for households, a cap on trade deficits and most importantly a new form of constraint that embodies the whole of an accumulating commodity stocks and flows model where intertemporal capital is governed by Sales/Assets ratios. It has the compelling advantages of consistency, flexibility, transparency and the potential for ubiquity because of its underlying general purpose deployment platform.

6. Conclusion

This paper has defined a new framework for Service Science as game theory trust strategies for complex organisations and for public policy in managing the global commons. Policy tools for modelling international symbiosis and sharing of common resources were shown to comprise the techniques of general equilibrium and optimisation.

The provenance of the stocks or B matrix in intertemporal modelling was investigated. A framework accounting model using Sales/Assets resource constraints was shown to provide improved modelling ability since sales in a given period are only dependent upon the assets in the period.

Weaknesses of traditional CGE approaches were discussed. The Sceptre policy tool was shown to address these issues. Comprehensive geophysical and economic results from using Sceptre for a 2°C temperature rise policy goal were presented. Sceptre was also used to compare a 2°C temperature rise policy goal with Hansen/Gore's 350ppm policy goal and an Australian suggestion for a 25% reduction in emissions by 2020 and 60% by 2050.

5. Notes and references

‡1 It is interesting to note that the use of DuPont analysis completes a full circle in Leontief and CGE modelling. The Physiocrat Pierre Samuel du Pont de Nemours, who became a prominent American industrialist, advocated low tariffs and free trade
‡2 As there have been changes in the collection and classification of data between GTAP5 and GTAP7, a more reliable analysis would require extended econometric analysis using supplementary data sources
‡3 Attributed to the Franciscan friar William of Ockham (1285-1349)

Armington, P.S., 1969. A Theory of Demand for Products Distinguished by Place of Production (Une théorie de la demande de produits différenciés d'après leur origine)(Una teoría de la demanda de productos distinguiéndolos según el lugar de producción). *Staff Papers-International Monetary Fund*, 159-178.

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Event	**18th International Input-Output Conference**
Author	**Stuart John Nettleton**
Title	**The Service Science of Climate Change Policy Analysis: applying the Spatial Climate Economic Policy Tool for Regional Equilibria**
Category	**CGE and econometric input-output modeling**
Co-Authors	
Accepted	**yes, accepted**
Abstract	**3071 chars (max: 5000 chars)**

The use of Computable General Equilibrium modelling in evidence-based policy requires an advanced policy making frame of reference, advanced understanding of neoclassical economics and advanced operations research capabilities. This paper examines developments in neoclassical economic models for the analysis of strategy and policy. Regions and industries have the ever-present challenge of building a future where production is competitive and employment is durable. In this context, the inhibitor effects of potential climate constraints on regional industries and bilateral trade is currently a topic of major concern to polity. Threats often bring opportunities and these are sometimes major disruptions to traditional industry structure. Therefore of equal interest to some policy makers are the strategic opportunities that a window of superior domestic productivity and resource expansiveness may bring to nations seeking a transformative boost in export performance. The Spatial Climate Economic Policy Tool for Regional Equilibria (Sceptre) is an intertemporal, multiregional general equilibrium model for investigating regional and industry strategies in the presence of global policies such as carbon emission constraints. In its simplest

mode, Sceptre translates global climate policies to regional and commodity effects. This is achieved by bringing together traditional markets for commodities with new markets in carbon commodities. These new markets are emission permits trading and a technology function for carbon abatement and amelioration. A general equilibrium is settled by optimising a social welfare function, in the mode of a Negishi format, within a nonlinear economic-climate feedback loop. Both the technology function for carbon abatement and amelioration and the economic-climate feedback loop have precedent in William Nordhaus' DICE model. The social welfare function comprises regional economic expansion factors, which are developed in a multiregional context using a data envelopment or benchmarking technique successfully applied by Thjis ten Raa to single period national and bilateral models. In a novel intertemporal innovation, Sceptre draws together disciplines of economics and finance by substituting resource constraints with Dupont sales to asset ratios in order to dynamically link and mediate the stocks and flows of each commodity. This avoids the issue in Ramsey models that investment is merely an uncontrolled residual of production and consumption, and the issue in the Leontief B-matrix approach that final industry assets are cannibalised. Regionally aggregated Make and Use matrices drawn from GTAP's Social Accounting Matrices are used in the underling economic model as regional-commodity production function tableaux. Outputs for policy consideration include global geophysical climate effects, regional and industry activity levels, bilateral trade flows, potential resource expansiveness, investment, labour and regional and industry rate of transition from carbon trading to carbon amelioration and abatement.

Full paper	102_20100429011_100429SNSceptre.pdf
Days for presentation	**Sun, 20/Jun/2010** **Mon, 21/Jun/2010** **Tue, 22/Jun/2010** **Wed, 23/Jun/2010** **Thu, 24/Jun/2010**

Fri, 25/Jun/2010

send a message to the editors

18th International Input-Output Conference
20-25 June 2010 • Sydney Australia

Conference Book

Left: Sydney Harbour Bridge during the September 2009 dust storm

Right: Aerial view of Broken Bay, directly north of Sydney

18th International Input-Output Conference 20-25 June 2010 • Sydney Australia

18th International Input-Output Conference — 20-25 June 2010 • Sydney Australia

WELCOME MESSAGE

On behalf of the University of Sydney, I welcome you to the 18th International Conference on Input-Output Economics to be held in Sydney from 20-25 June 2010.

The theme of this conference will be "Re-thinking economic growth towards sustainability and wellbeing”; it reflects important concerns that many people harboured throughout the past few years, but also reflects a major challenge we are facing: To avert dangerous environmental change whilst being able to ensure well-being for the world’s people.

Input-output techniques have proven extremely versatile and powerful tools for decision-makers. In particular, environmental applications of input-output models have enjoyed enormous popularity in recent years. However, we still have a lot to do in making input-output tools more widely known across non-expert circles, and remove barriers to the development of understanding and appreciation of, and trust in the results that input-output models provide.

This conference provides great opportunities. To the researcher, it brings an environment in which exciting new ideas can be aired and discussed. For the practitioner, it provides a forum in which the strengths of our input-output technique can be demonstrated to people searching for solutions to their problems. For students, it is perhaps the best opportunity to get to know well-known academics, and look for exchange programmes and scholarships. For members of the corporate and governance worlds, it may even represent a hunting ground from which to pluck young bright talents.

I invite you to read our attractive programme, register your participation, and experience for yourself the friendly and stimulating atmosphere that is so typical of every input-output conference.

I also invite you to take the opportunity of your visit to look beyond the conference. The University of Sydney is Australia’s first university, and features a beautiful campus as well as world-class research and education. The city of Sydney with its blue shining harbour and golden beaches is a true jewel that one should see once in a lifetime. And why not spend a few more weeks and travel around the amazing Australian continent that is home to unique wonders one cannot experience anywhere else.

I look forward to seeing you in Sydney in 2010.

Manfred Lenzen
Professor of Sustainability Research
Chair of the Local Organising Committee

18th International Input-Output Conference 20-25 June 2010 • Sydney Australia

The 18th International Input-Output Conference in Sydney took more than 2 years to organise, starting from the initial bid to the International input-output Association (IIOA), to finally putting in place all procedures required for a successful event.

This conference would not have happened without the support of volunteers in the Local Organising Committee (LOC), and members of the Scientific Program Committee (SPC). On behalf of the LOC and SPC Chairs, the IIOA and all conference delegates, a heartfelt thank-you to a dedicated and effective team!

Local Organising Committee

Chair: Manfred Lenzen

Acting Chairs: Jodie Gonzalez Jennings and Elaine Fillie

Committee members:

Christopher Dey
Winton Evers
Lachlan Feggans
Barney Foran
Alejandro García
Arne Geschke
Bonnie McBain
Daniel Moran
Joy Murray
Shelly Page
Marguerite Pettit
Fabian Sack

For your assistance, local committee members will be recognisable at the conference in a white shirt with the main conference logo printed on the back.

The members of the Scientific Program Committee are listed in the Book of Abstracts.

With many thanks

Printing for the conference provided by Fuji Xerox Australia on responsibly procured paper.

The LOC is also very grateful for the support of Winton Evers:

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José M. Rueda-Cantuche
Institute for Prospective and Technological Studies
Joint Research Centre's European Commission, Spain

Co-chair:

Klaus Hubacek
University of Leeds, United Kingdom

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18th International Input-Output Conference

CONFERENCE PROGRAM

20/Jun/2010 - 25/Jun/2010

International Input-Output Association
Vienna, AUSTRIA
www.iioa.org

SESSION PLAN

Sun, 20/Jun/2010

17:00 - 20:00 *Welcome Reception and Registration*

Mon, 21/Jun/2010

08:30 - 09:00 *Late registrations only*

09:00 - 09:30 *Opening Ceremony and Welcome to Country*
Eastern Avenue Lecture Theatre
Geoffrey J. D. Hewings (President of the IIOA),
José M. Rueda-Cantuche (Chair of the SPC),
Klaus Hubacek (Co-chair of the SPC),
Manfred Lenzen (Chair of the LOC),
Jodie González Jennings (Co-chair of the LOC)

09:30 - 10:30 Plenary Session 1

- Location: **Eastern Avenue Lecture Theatre**
  Topic: **Sustainability in Economics**
  Chair: Joerg Beutel

1. Is there entropy in an economy? Revisiting an early concept of sustainability introduced by Nicholas Georgescu-Roegen
   by *Utz Peter Reich*

10:30 - 11:00 *Coffee Break*

11:00 - 12:30 Parallel Session 1

- Location: **Eastern Avenue Lecture Theatre**
  Topic: **World Input-Output Database I: Contruction issues**
  Chair: Erik Dietzenbacher

1. Joint Estimation of Supply and Use Tables
   by *Umed Temurshoev, Marcel P. Timmer*

2. An Empirical Evaluation of Methods to Estimate Use Tables of Imports
   by *Bart Los*

3. The construction of input-output tables and the use of supply-use tables in input-output analyses: a review
   by *José Manuel Rueda-Cantuche, Joerg Beutel*

- Location: **Lecture Theatre 1, School of Physics**
  Topic: **Water input-output analysis**
  Chair: Cristina Sarasa

  1. A regional inventory of water demand and water pollutant discharge in the Yangtze River and China as a whole based on an inter-regional input-output analysis model
     by *Tomohiro Okadera, Masataka Watanabe, Nobuhiro Okamoto*

  2. Interregional Virtual Water Trading in Japan: the applied idea to identify the characteristics of Virtual Water Trading using the Input-Output Approach.
     by *Hideo Fukuishi*

  3. Water Rates and Responsibilities of Direct, Indirect and End-Users in Spain
     by *Cristina Sarasa, Julio Sánchez Chóliz, Rosa Duarte Pac*

- Location: **Lecture Theatre 2, School of Physics**
  Topic: **Analysis of factor inputs**
  Chair: Joost Reyes Santos

  1. The change of the capital and labor input for China's economy
     by *Duan Yu Wan, Cuihong Yang*

  2. The bias in accounting for national income changes when pervasive processing trade is present
     by *Jiansuo Pei, Erik Dietzenbacher, Jan Oosterhaven*

  3. Extension of Input-Output Analysis to Portfolio Diversification
     by *Joost Reyes Santos*

- Location: **Lecture Theatre 5, School of Physics**
  Topic: **Climate policy issues: tools**
  Chair: Stuart John Nettleton

  1. A micro-founded Hybrid Input-Output framework
     by *Stefano Merciai*

  2. Alternative Approaches to Designing Climate Policy Response: An Australian Case Study
     by *Suwin Sandu*

  3. The Service Science of Climate Change Policy Analysis: applying the Spatial Climate Economic Policy Tool for Regional Equilibria
     by *Stuart John Nettleton*