Dissertation

Benchmarking Climate Change Strategies Under Constrained Resource Usage

in Fulfilment of the Requirements for the Degree of
Doctor of Philosophy

Presented to the Faculty of Engineering & Information
Technology
of
The University of Technology, Sydney (Australia)

Stuart Nettleton

B.Eng. (Hons II, Division I), Sydney University, 1974
M.Eng.Sci., University of New South Wales, 1978
M.B.A. (Alan Knott University Medal), Macquarie University, 1982
Graduate Diploma, Australian Institute of Company Directors, 2005
Certified Practising Accountant & Fellow of CPA Australia

12 February 2010

Supervisor: Assoc. Prof. Deepak Sharma, PhD

Introductory remarks

Revision Number 330, published on 12 February 2010
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Importance of the glossary. Before starting with the first chapter it is recommended to peruse the Glossary on page iii, following the Table of Contents.

Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

signature (Stuart Nettleton)

Sydney, 12 February 2010

Abstract

This doctoral dissertation presents evidence based research into climate change policy. The research technique of political economy is used to investigate policy development. A major change in the Anglo-American growth paradigm from unconstrained to constrained growth is identified. The implications of this change for climate policy are identified. The political economy of climate change policies is expressed in a new Spatial Climate Economic Policy Tool for Regional Equilibria (Sceptre). This is an innovative benchmarking approach to computable general equilibrium (CGE) that provides a spatial analysis of geopolitical blocs and industry groupings within these blocs. It includes international markets for carbon commodities and geophysical climate effects. It is shown that climate constrained growth raises local policy issues in managing technology diffusion and dysfunctional resource expansive specialisations exacerbated by the creation of global carbon markets.

Acknowledgements

Discipline in the pursuit of enlightenment

Anon. Shinto Philosopher

A doctoral dissertation that covers so many interdisciplinary subjects and takes several years to complete could not be written without the support of many colleagues at the University of Technology Sydney. I would like to thank Assoc. Professor Deepak Sharma for his wise mentorship, perspicacity, candour and friendship. Deepak introduced me to the world of Input Output analysis and general equilibrium modelling, encouraged me in the pursuit of philosophy and political economy, and kept me focused by regularly drawing the discussion back to policy implications.

Deepak's Energy Policy Program has been a jewel of the Faculty of Engineering and Information Technology for eighteen years. I was fortunate to participate in the Energy Modelling module, which provided an excellent foundation to Input Output analysis and resource infrastructure policy. This was complemented by practical studies in Policy Research through the Australian Technology Network (ATN) of Universities LEAP program.

Although my other mentors William Nordhaus and Thijs ten Raa would at present know me only from published comments in the Mathematica support group or through a few emails, they have had a profound influence on my research. William Nordhaus' 2007 book A Question of Balance showed me best practice in assessing climate change policies. Thijs ten Raa's 2006 book The Economics of Input Output Analysis provided a refreshing and exciting paradigm for computable general equilibrium modelling that elevated Input Analysis to a completely new level. My head became filled with exciting new ways to understand the world. My passion to do this led me to an almost singular obsession in implementing Thijs ten Raa's concepts in a Nordhaus-like intertemporal economic-climate model.

Daniel Lichtbau at Wolfram is another dear mentor who constantly amazed me at his knowledge of Mathematica optimisation, ability to obtain answers to esoteric questions from the mysterious halls of Wolfram and his tireless perseverance in responding to me as I pushed many of the limits of Mathematica and its algorithms.

My doctoral assessment examiners Emeritus Professor Rod Belcher, Professors Stuart White and Joe Zhu, Dr. Gul Ismir and Chair, Professor Jie Lu, provided incisive and balanced comment at a critical stage in the formation of my proposal. I am most grateful for their constructive comments on the scope of this policy research and their support and guidance.

My colleague Ravin Bagia systems dynamics perspective and always cheerful disposition led to many interesting insights and new ideas. I sincerely hope that Ravin and I can fulfil our plan to develop critical mass in funded policy research using the methods shown in this dissertation.

Lastly, the understanding of my family has made this work possible. My thanks go to my children. To my daughter for deftly wielding her existential blade with elegance and grace and to my son for his practical demonstration of that secret of life that Herculean perseverance along with a good heart brings extraordinary success.

Above all, the patient indulgence of my wonderful partner, Julie, has been beyond the pale of duty and has made this work worthwhile and enjoyable. Julie was the first to read this dissertation and see those things my eyes passed over too quickly. I am truly grateful and humbled by her confidence and ever encouraging smile for me to persevere with yoga.

Table of Contents

Glossary

Abbreviations

Acronym	Meaning
ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
APEC	Asia Pacific Economic Forum
BAU	Business As Usual
bbl	Barrel of oil (159 litres)
BP	Before (the) Present
Btu	British Thermal Unit (about 1.06×10^3 Joules)
C	(degrees) Celsius
CCS	Carbon capture & storage
CDM	Clean Development Mechanism
CEPII	Centre d'Etudes Prospectives et d'Information Internationales
CFCs	Chlorofluorocarbons
Computed General Equilibrium (CGE)	"Computed" means "ascertained or arrived at by calculation or computation; (also) performed or controlled by a computer; computerized" (OED, 2009). A Computed General Equilibrium (CGE) is the result, outcome, state or output of a "Computable General Equilibrium (CGE) model" following calculation or computation. This dissertation draws no distinction between models that are able to be computed and models that have been computed and are represented by their computed state. Therefore the terms "Computed General Equilibrium", "Computable General Equilibrium" and the acronym "CGE" have the same meaning.
Computable General Equilibrium (CGE) model	"Computable" means "Capable of being computed, calculable; solvable or decidable by (electronic) computation" (OED, 2009). A Computable General Equilibrium (CGE) model is "A general equilibrium model of the economy so specified that all equations in it can be solved analytically or numerically. Computable general equilibrium models are used to analyse the economy-wide effects of changes in particular parameters or policies" (Black et. al.. 2009). See also Computed General Equilibrium (CGE) above.
CH4	Methane
CO2	Carbon Dioxide
CO2e	Carbon Dioxide equivalent see Gt CO_2
Cognitive Behavioural Therapy (CBT)	"A cognitive therapy that is combined with behavioural elements (see behaviour therapy). The patient is encouraged to analyse his or her specific ways of thinking around a problem. The therapist then looks at the

Acronym	Meaning
	resulting behaviour and the consequences of that thinking and tries to encourage the patient to change his or her cognition in order to avoid adverse behaviour or its consequences. CBT is successfully used to treat phobias, anxiety, and depression (it is among the recommended treatments for anxiety and depression in the NICE guidelines)" (Martin, 2007)
COP	Conference of the Parties (of the UNFCCC)
COP15	UNFCCC November 2009 meeting in Copenhagen, Denmark
CRS	Constant returns to scale such that production can be increased or decreased without affecting efficiency
CSIRO	Australian Commonwealth Scientific and Industrial Research Organisation
Data Envelopment Analysis (DEA)	Data Envelopment Analysis is a linear programming technique typically used to measure the technical (in)efficiency of decision making units compared to the units with best practice
DICE	Dynamic Integrated Model of Climate and the Economy
DMU	A decision making unit in Data Envelopment Analysis (DEA)
Effectiveness	The extent to which outputs of service providers meet the objectives set for them
Efficiency	The degree to which the observed use of resources to produce outputs of a given quality matches the optimal use of resources to produce outputs of a given quality. This can be assessed in terms of technical efficiency (conversion of physical inputs such as labour and materials into outputs), allocative efficiency (whether inputs are used in the proportion which minimises the cost of production) and dynamic efficiency (degree of success in altering technology and products following changes in consumer preferences or productive opportunities)
EU	European Union
EU25	Twenty five countries of the EU in 2004, prior to its 2007 expansion to Bulgaria and Romania
ETR	Ecological/ Environmental Tax Reform
ETS	Emissions trading scheme, which may be either a differential structure as introduced in European Union countries, or an absolute structure where emitters must purchase emissions permits in order to pollute the atmosphere with greenhouse gases
gg	Grammes (grams)
G5	Major emerging economies, comprising Brazil, India, China, Mexico and South Africa
G8	Group of 8, comprising Canada, France, Germany, Italy, Japan, Russia, United Kingdom, United States
G20	Group of 20, comprising Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, United Kingdom, United States,

Acronym	Meaning
	European Union. In September 2009, the G20 announced it would be the world's peak economic policy body, replacing the G8.
gC	Grams of Carbon (see GgC)
Gg	Giga-grammes (grams)
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GHG	Greenhouse Gases
Global warming potentials	CO_2 (1), CH_4 (21, although a recently detected reaction with aerosols now suggests 33), N_2O (310), CF_4 (6,500), C_2F_6 (9,200), SF_6 (23,900), HFC-143a (3,800), HFC-23 (11,700), HFC-125 (2,800), HFC-134a (1,300), HFC-143a (3,800)
GJ	Gigajoules
Gt	Gigatonnes
GtC	Gigatonnes of Carbon
Gt CO2	Gigatonne of CO_2 (3.67 Gt CO_2 has the same carbon content as 1 GtC. The factor of 3.67 represents the ratio of the molecular weight of CO_2 , which is 44.009, to the atomic weight of carbon, which is 12.011, see Oak Ridge National Laboratory (Carbon Dioxide Information Analysis Center 1990, Table 3) and Clark (1982, p467))
GTAP	Global Trade Analysis Project (Purdue University)
GTEM	Global Trade & Environment Model
HCFC	Hydro-Chloro-Fluoro-Carbon
HFC	Hydro-Fluoro-Carbon
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
IMAGE	Integrated Model to Assess the Greenhouse Effect
IPCC	Intergovernmental Panel on Climate Change, based in Geneva, Switzerland. In 2007, the IPCC and Al Gore shared the Nobel Peace Prize
IRIO	Interregional Input Output Model (see also MRIO)
Kyoto Protocol	The Kyoto Protocol stems from a 1992 United Nations Conference on Environment and Development in Rio de Janeiro (Brazil), which considered climate change regulations and a United Nations Framework Convention on Climate Change in Berlin (Germany) the same year. In 1995, a Conference of the Parties in Berlin proposed a new protocol to replace the ambiguous agreement reached in 1992. In 1997, at the 3rd session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in Kyoto, Japan, the Berlin proposal became the Kyoto Protocol. Its target was that by 2008–2012 the net emissions of 6 greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC and SF_6) would be reduced by 5.2% of the 1990 emission levels of these gases. While each signatory to the Kyoto Protocol decides how it will implement the agreements of the

Acronym	Meaning
	Treaty, the Kyoto Protocol offers mechanisms to achieve targeted reductions in greenhouse gases including international and local emissions trading schemes (ETS), emissions sinks (the development and management of forests and agricultural soils), joint implementations (where one company invests in another's facility and shares reductions in emissions), clean development mechanisms (where companies invest in reducing greenhouse pollution in developing countries), bubbling (collectively attaining targets), etc.
Linear program	Programming algorithms to maximise or minimise an objective function subject to a set of linear mathematical constraints
MAD	Mutually assured destruction
Mb	millions of bytes of random access memory (RAM) or file size
MEF	Major Economies Forum comprising Australia, Brazil, Canada, China, Germany, the European Union, France, the United Kingdom, India, Indonesia, Italy, Japan, Mexico, Russia, South Africa, South Korea and the USA.
MJ	Million (10^6) Joules or Mega Joules
MBTU	Thousand (10^3) BTU (where M is the Roman Numeral for one thousand)
MMBTU	Million (10^6) BTU
Moral Hazard	"The observation that a contract which promises people payment on the occurrence of certain events will cause a change in behaviour to make these events more likely. For example, moral hazard suggests that if possessions are fully insured, their owners are likely to take less good care of them than if they were uninsured. The consequence is that insurance companies cannot offer full insurance. Moral hazard results from asymmetric information and is a cause of market failure" (Black et al. 2009)
MRIO	Multiregional Input Output Model (see also IRIO)
NGO	Non-Governmental Organisation
N2O	Nitrous Oxide
NOAA	United States of America National Oceanic & Atmospheric Administration
NOX	Nitrogen Oxides
NPV	Net Present Value
OECD	Organisation for Economic Cooperation and Development
PCA	Principal components analysis
PJ	Peta Joule(s)
ppm	Parts per million, used here as a measure of the concentration of greenhouse gases in the atmosphere (1 ppm of CO_2 in the atmosphere = 2.123 GtC in the atmosphere, which assumes an atmospheric mass of 5.137×10^{18} kg, see references for "Gt CO_2")
Principal -	"The problem of how person A can motivate person B to act for A's benefit

Acronym	Meaning
Agent Problem	rather than following self-interest. The principal, A, may be an employer and the agent, B, an employee, or the principal may be a shareholder and the agent a director of a company. The problem is how to devise incentives which lead agents to report truthfully to the principal on the facts they face and the actions they take, and to act for the principal's benefit. Incentives include rewards such as bonuses or promotion for success, and penalties such as demotion or dismissal for failure to act in the principal's interests" (Black et al. 2009)
Prisoner's dilemma	"A two-player game that illustrates the conflict between private and social incentives, and the gains that can be obtained from making binding commitments. The name originated from a situation of two prisoners who must each choose between the strategies 'Confess' and 'Don't confess' without knowing what the other will choose. The important feature of the game is that a lighter penalty follows for a prisoner who confesses when the other does not. The game is summarized in the pay-off matrix where the negative pay-offs can be interpreted as the disutility from imprisonment" (Black et al. 2009)
Production frontier	A curve plotting the minimum inputs required to produce a given quantity of output
Productivity	The ratio of physical output produced from the use of a quantity of inputs (see also TFP)
quad	Quadrillion BTU, equivalent to 1.055×10^{18} Joules
quadrillion	One thousand million (10^{15}) i.e. Peta
R&D	Research & Development
Sceptre model	Spatial Climate Economic Policy Tool for Regional Equilibria (the model of this doctoral research and described in this dissertation)
Slacks	In a linear program solution, the extra amounts by which an input (output) can be reduced (increased) to attain technical efficiency after all inputs (outputs) have been reduced (increased) in equal proportions to reach the production frontier
SO2	Sulphur Dioxide
SRES	United Nations' IPCC "Special Report on Emissions Scenarios"
tt	Tonnes
TJ	Terajoules
TFP	Total Factor Productivity is the ratio of the quantity of all outputs (weighted by revenue shares) to the quantity of all inputs (weighted by cost shares)
UK	United Kingdom
UKMO	United Kingdom Meteorological Office
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change, based in Bonn

Acronym	Meaning
USOSTP	United States Office of Science and Technology Policy
USGCRP	United States Global Change Research Program
USA or U.S.	United States of America (America)
WHOSTP	White House Office of Science and Technology Policy
WMO	World Meteorological Organisation
WWF	World Wildlife Fund

Mathematical Symbols

Symbol	Meaning
∀	For each/all/any of
∂	Partial differential
Δ	Difference
∈	Is an element of
∏	Cartesian product of
∑	Sum of
≤	Less than or equal to
≥	Greater than or equal to

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Preface

You must become the change you wish to see in the world.

Mahatma Gandhi

Putting pen to paper on this dissertation in April 2008, it occurred to me that it has never been a more poignant time for a comprehensive review of climate change strategies, which is the subject of this dissertation. Oil had reached US$120 per barrel on its way to US$150 per barrel, the contract prices of Australian coking coal for steel smelting had just tripled to US$305 per tonne, steaming coal for power generation up 130% to US$125 per tonne, iron ore up 65% to US$120 per tonne, following a 35% rise the previous year, and third world food riots were occurring due to rice and corn production being diverted to ethanol for transport. American President George W. Bush had just taken the unusual step of invalidating vehicle tailpipe emissions controls in States like California and announced significantly lower standards.

Three wildly divergent views about the future were circulating in Western markets about the commodity price spiral. The first was that it was merely a trading bubble due to speculators and it would burst. The second view was that the emergence of a prosperous middle class in China and India had a ravenous demand for animal protein and cars. This meant the world was now in a new era of high resource demand and prices. However, the world would adapt, as always. We could be sanguine because the world had previously coped with similar dire exigencies and would produce the necessary resources, so commodity prices would fall. The third scenario was that the world had reached or passed peak-oil production and was in a new era of scarce food, energy and metals, and this meant a continuation of rapidly increasing demand and high prices.

Such questions about the impact of resource scarcity on world economic growth had not been asked since I was an undergraduate in the 1970s. Adam Smith's invisible hand had solved the crises. Western birth rates declined, economic growth in Japan and Europe subsided and the Club of Rome's dire Malthusian projections did not eventuate.

Yet in April 2008 a new dimension of Climate Change had emerged into a major market factor in my home country, Australia. In its first day in office, Australia's new Rudd Labour Government had just ratified the Kyoto Protocol.

In Australia, as in many Western countries, there is unquestioned support for local protection of air and water quality, and the control of polluting goods such as waste, noise and smoking. Support for regional level protection is considerably less overwhelming because it usually has some implication in trading-off local employment or amenity for the good of people elsewhere in Australia. For example, management of the Darling, Murray and Snowy Rivers means the environment gains and farmers lose water. Forestry workers lose jobs when old growth forests are protected in Tasmania.

Notwithstanding the increasing attention to greenhouse gas pollution at the Government level, apathy at best exists among industry and consumers. There is little respect for the scientific evidence of Intergovernmental Panel on Climate Change, released in 2007, which shows that climate change threatens the very basis of our civilisation. Nor is there respect for Al Gore's call to action to avert it.

There appears to be an overwhelming lack of consensus in Australia, or in any Anglo-American country, for carbon taxes or similar market mechanisms to increase the price of goods and processes that contribute to global warming. In fact, despite increasing evidence that Australia was in a long term drought attributable to climate change, the former Prime Minister John Howard claimed to be a "non-believer in climate change". Perhaps even more disturbing, he legitimated uncritical scepticism amongst Australia's political conservatives and greatly empowered already strong industry lobby groups like Clean Coal to argue against any tilt in policy toward the environment.

These examples suggest that as the issues become geographically and culturally broader, citizens of Western democracies rapidly lose interest in protecting the commons from being despoiled. As a result, any change to environmental policies in Western countries is a very difficult thing. The vast majority of individuals and business ask "Why me, why should I be charged

more and my business or livelihood be disadvantaged for some theoretical concept called climate change?" Indeed, following a fuel revolt in 2000, the Constitutional Court of France declared environmental taxes unconstitutional. As a result, the European Union emissions trading scheme introduced in 2004 included neither a tax on carbon nor the requirement for companies to bid for permits to pollute. To date, America has steadfastly refused to affirm the Kyoto Protocol. At the time of concluding this thesis, its pending Waxman Markey Bill is not as strong as legislation in the United Kingdom and European Union.

Nor is there understanding in Europe about combining fiscal and environmental policy into a holistic solution where environmental tax revenues are recycled into reduced labour and income taxes. Perhaps it is not surprising that people living in areas of long term structural unemployment are uninterested in the argument that recycling environmental taxes into lower labour taxes increases economic growth and creates extra jobs. People in Europe simply want fiscal and environmental policies kept separate.

In April 2008, I made a submission to the Garnaut Review suggesting a moderate carbon tax on carbon-adders as the first stage of a market based emissions trading scheme that would ultimately lead to a market for emissions trading consistent with that of other major Western democracies (see Appendix 1). My submission also proposed that a carbon-added tax be imposed on imports in the same way as a goods and services tax (GST) is applied. Between April 2008 and October 2009, European policy has come full circle to align with my proposal: France introduced a carbon tax and together with Germany was planning duties on the untaxed carbon embedded in imports.

There remains much division over policies to ameliorate and abate the consequences of global warming. As I was drawing this dissertation to a conclusion in August 2009, the opposition party in Australia used its upper house majority to vote down the Government's Carbon Pollution Reduction Scheme.

The end of my dissertation has coincided with the 80th anniversary of the start of the Great Depression. I reflect on the past few years and am amazed at the dazzling panoply of world events in the period: China and India burst onto the

world stage as global leaders, America became a debtor nation with multi-trillion dollar deficits, a global financial crisis of almost Great Depression proportion came and went in just one year, as did a swine-flu pandemic.

Yet climate change policy remains in disarray as the United Nations' COP15 Copenhagen meeting approaches, Governments flounder and people remain *blasé* or cognitively dissonant about scientific evidence. Climate sceptics abound and mock the melting of the Arctic, Greenland and Antarctic ice-caps that threaten many metres of sea rise, a shift in the earth's axis of rotation, widespread earthquakes, tsunamis and volcanic eruptions from shifting tectonic plates and the release of methane deposits from the sea beds and permafrost.

Every day, almost every newspaper carries the latest stories of my research topic and the policy imbroglio in climate change. It is at the same time satisfying and disturbing that my research into benchmarking climate change policies remains poignant and needed.