A Multi-Sectoral, Multi-Household, General Equilibrium Model to Assess the Impact of a Carbon Price on the Australian Economy

By

Gaspe Ralalage Lakmini Disna Sajeewani

BSc. (Agriculture), MSc. (Economics)

A thesis submitted for the degree of

Doctor of Philosophy

School of Business

University of New England, Armidale, NSW

July 2012
Dedicated to my mother, Nanda Liyanaarachchi

and father, Gaspe Ralalage Chandrasiri

who toiled to educate and guide me in the right path.
Acknowledgements

I would like take this opportunity to thank all who have given me support and guidance throughout to complete this thesis. First and foremost, I would like to express my greatest gratitude to my principal supervisor Professor Mahinda Siriwardana and co-supervisors Dr. Judith McNeill and Dr. Stuart Mounter. Professor Siriwardana’s encouragement to pursue a PhD degree started well before I formally undertook the program in 2009. Once I commenced my research, he guided me decisively to understand quite complex CGE modelling theory and provided me with every possible help needed to overcome difficulties in developing the database and the model for this study. Dr. Judith McNeill has been an extraordinary supervisor to me throughout my study period. Her support and guidance helped me tremendously to structure chapters as she patiently read each chapter many times until I met the required academic quality of the thesis.

I would like to acknowledge the financial support from the University of New England International Scholarship. Additionally, this study was facilitated by the funding from the Australian Research Council Grant under the Discovery Project DP0986306. At the very beginning I received a training grant from the South Asian Watch on Trade, Economics and Environment to attend a CGE modelling course in Kathmandu, Nepal which helped me immensely to understand the theoretical structure of the database used in the CGE model – the Social Accounting Matrix. I was given the opportunity to expose my research to academic audiences by the Conference Travelling Grant from the School of Business to attend a domestic conference and the Travelling Grant from the Institute of Rural Futures (IRF) to attend an international conference. Furthermore, the CGE modelling course and the Database course conducted by the Centre of Policy Studies (CoPS) in the Monash University gave me the latest theoretical and technical expertise to undertake this study.

I am very thankful to Dr. Xianming Meng (Sam) whose support has been a major input towards the success of this study. Whenever I encountered methodological issues, he would always check for errors although he was very much engaged in his own PhD at that time. Furthermore, I am thankful to Professor Mark Horridge and Professor Ken Pearson at the CoPS for providing me with necessary data as well as resolving some technical issues. I especially thank Dr. Ian Patrick for recommending me to obtain IRF funds to attend to an international conference in the last month of my candidature. Furthermore, my appreciation is extended to staff of Higher Degree Research team, staff of the Institute of Rural Futures and staff of the Business School for their support throughout my study period. I would also like to
acknowledge my employer in Sri Lanka, the Socio Economic division of the Department of Agriculture where I was encouraged to pursue a PhD program.

Most importantly, I would like to appreciate the editorial assistance given by David Wysel. His attention to detail on language, illustrations and consistency benefitted the completeness of this thesis. Furthermore, I would like to thank Emeritus Professor Partrick Hutchinson, Dr. Joy Hardy and Mrs. Cathy Coleman for their early stage support in proof reading some of my chapters.

I am very much grateful to Cheryl and Garry Cooper for their personal and friendly support from the time I came to Australia in 2007. They made me feel as if this country was my second home. I am also very much grateful to my uncle M.S. Jayasinghe and my aunty Mallika Karunaratne for supporting my education in many ways. Furthermore, it would have been very hard for me to undertake this long period of study without the support from my loving husband Shammi Rajapakse. Last but not least, I sincerely thank my loving parents and my loving parents-in-law for being by our sides during this whole time, not complaining, but supporting always.
Abstract

Australia ratified the Kyoto Protocol in 2007 and became legally committed to a reduction of greenhouse gas emission levels of 8 percent below 1990 levels. In order to achieve this target, the Australian government announced a tax of $23 per tonne of CO\textsubscript{2}-e as a starting carbon price which commenced from 1 July 2012. The economic implications of this carbon price have been projected by the Australian Treasury using a suite of Computable General Equilibrium (CGE) models and various other sector specific models. However, the present study shows an alternative possibility of projecting such impacts using a less complex, but more descriptive CGE model of the Australian economy titled A3E-G. With an explicit tax, the A3E-G model is capable of handling endogenous substitution among energy inputs and alternative allocations of resources among energy and capital. The A3E-G model has been calibrated using an Environmentally-extended Social Accounting Matrix (ESAM). The ESAM is one of the first SAMs constructed for carbon price modelling in Australia.

The A3E-G model is used to analyse the macroeconomic, sectoral and household effects of three alternative carbon prices ($10, $23 and $35) to achieve emission reduction targets for the Australian economy. The policy experiments reveal that high carbon emission cuts are possible at higher carbon prices. A carbon price of $23 reduces GDP by 0.6 percent and real consumption by 0.17 percent and increases the consumer price index by 0.71 percent in the short-run. This policy increases energy prices, especially electricity prices by 24 percent in the short-run and 9 percent in the long-run. The employment impacts of the policy reveal intermediate production, transport workers and labourers and related workers are seriously affected by the carbon price as there is a reduced employment level of 1.37 and 0.98 percent respectively.

Household impacts are found to have a proportional to progressive tax incidence in the short-run and a progressive tax incidence in the long-run. These results are due mainly to the differences between the ownership of factors of production by various household groups. The revenue recycling simulations show an increase in economic efficiency and household welfare without increasing emissions. All compensation policies tend to increase household welfare (measured as utility change and equivalent variation) towards higher income groups.
Table of Contents

Declaration .................................................................................................................. ii
Acknowledgements .................................................................................................... iv
Abstract .................................................................................................................. vi
Table of Contents ..................................................................................................... vii
List of Tables ........................................................................................................... x
List of Figures .......................................................................................................... xi
Glossary ..................................................................................................................... xii

CHAPTER I Introduction ........................................................................................... 1
  1.1 Background of the study ....................................................................................... 2
  1.2 Statement of the problem .................................................................................... 5
  1.3 Research objectives ............................................................................................ 8
  1.4 Methodology ....................................................................................................... 9
  1.5 Contribution to the literature ........................................................................... 10
  1.6 Outline of the thesis ........................................................................................ 11
CHAPTER II Australia’s Energy Sector: Implications for Greenhouse Gas Emissions and
Mitigation Policies .................................................................................................... 14
  2.1 The supply of energy in Australia .................................................................... 14
  2.1.1 Energy industry contribution to the economy ............................................. 18
  2.1.2 Australia’s electricity supply industry ......................................................... 19
  2.2 Australia’s energy consumption ...................................................................... 20
  2.3 Greenhouse gas emissions from the energy sector ........................................... 24
  2.4 Development of a greenhouse gas mitigation policy framework in Australia ... 30
  2.5 Conclusion ....................................................................................................... 36
CHAPTER III Use of Computable General Equilibrium Models in Environmental Policy
Analysis ..................................................................................................................... 37
  3.1 Fixed coefficient models in environmental policy analysis .............................. 37
  3.2 Computable General Equilibrium (CGE) models .............................................. 41
    3.2.1 Use of CGE models in environmental policy analysis .............................. 43
    3.2.2.2 Dynamic CGE models ........................................................................ 52
    3.2.3 CGE models of trade and environment ..................................................... 56
    3.2.4 CGE models of natural resources ............................................................... 58
  3.3. Australian CGE models for greenhouse gas control policies ....................... 59
    3.3.1 Australia’s Treasury carbon price modelling .......................................... 65
  3.4 Conclusion ....................................................................................................... 67
CHAPTER IV An Environmentally-Extended Social Accounting Matrix (ESAM) for
Australia ..................................................................................................................... 69
  4.1 General introduction to a Social Accounting Matrix (SAM) ............................ 70
  4.2 Classification of accounts used in the macro-SAM ............................................ 72
  4.3 Compiling a macro-SAM of Australia ............................................................... 77
    4.3.1 Input-output data ...................................................................................... 77
    4.3.2 Activity/industry account ....................................................................... 79
    4.3.3 Commodity account ............................................................................... 79
    4.3.4 Taxes on the product account ................................................................. 80
    4.3.5 Tax on the production account ............................................................... 81
    4.3.6 Labour account ....................................................................................... 81
List of Tables

Table 2.1 Composition of energy in the production, imports and exports in Australia, 2008-09 .......................... 15
Table 2.2 Reserves of major energy commodities in Australia, 2010 ........................................................................ 16
Table 2.3 Energy related industries in Australia 2006-07 to 2008-09 ........................................................................ 18
Table 2.4 Total and per capita greenhouse gas emission comparison of Annex 1 countries, 2008 .......................... 28
Table 4.1 Schematic representation of the macro-SAM ....................................................................................... 73
Table 4.2 Aggregate IO table for Australia 2004-05 ($Am) ...................................................................................... 79
Table 4.3 Account for activities ($Am) .................................................................................................................. 79
Table 4.4 Account for commodities ($Am) .............................................................................................................. 80
Table 4.5 Account for taxes on products ($Am) ......................................................................................................... 80
Table 4.6 Account for production tax ($Am) ............................................................................................................. 81
Table 4.7 Account for labour ($Am) ........................................................................................................................ 81
Table 4.8 Account for capital ($Am) ........................................................................................................................... 82
Table 4.9 Interest flows of institutions ($Am) ........................................................................................................... 83
Table 4.10 Dividend flows of institutions ($Am) ......................................................................................................... 86
Table 4.11 Reinvested earnings on FDI flows ($Am) ..................................................................................................... 87
Table 4.12 Natural asset flow ($Am) ........................................................................................................................ 88
Table 4.13 Non life insurance flows of institutions ($Am) .......................................................................................... 89
Table 4.14 Current transfer flows of institutions ($Am) ............................................................................................. 90
Table 4.15 Social assistance benefit flows ($Am) ......................................................................................................... 91
Table 4.16 Income tax flows ($Am) ............................................................................................................................ 92
Table 4.17 Total income flows of all institutions ($Am) ............................................................................................... 93
Table 4.18 Account for consolidated capital ($Am) .................................................................................................. 94
Table 4.19 The macro-SAM of Australia for 2004-05 ($Am) .................................................................................... 95
Table 4.20 Disaggregating electricity supply sector ................................................................................................. 99
Table 4.21 Remapping of factor payments ................................................................................................................. 101
Table 4.22 Proportion of household disposable income by quintile (2009-10) ......................................................... 104
Table 4.23 Income distribution of all working households by occupation, 2001 ......................................................... 105
Table 6.1 Carbon emission matrix for 2005 CO\textsubscript{2}-e (1000 tonne) ................................................................. 156
Table 6.2 Armington elasticities for the model ......................................................................................................... 158
Table 6.3 Capital for Energy substitution elasticities by sector ................................................................................... 160
Table 6.4 Average expenditure elasticities and Frisch parameters ........................................................................... 162
Table 6.5 Household expenditure elasticities ........................................................................................................... 164
Table 7.1 Macroeconomic effects under various carbon prices in Australia ................................................................. 172
Table 7.2 Long-run cost of electricity (Scenario 4) ..................................................................................................... 177
Table 7.3 Projections of percentage change in industry outputs under various carbon prices ............................... 180
Table 7.4 Sectoral CO\textsubscript{2}-e emissions (percentage change relative to the baseline) .............................................. 183
Table 7.5 Sectoral effects of employment ................................................................................................................ 187
Table 7.6 Percentage change projection in occupational groups under various carbon prices ............................... 188
Table 7.7 Projected post tax real income effects among household deciles ............................................................... 190
Table 7.8 Percentage change in household real consumption under various carbon prices .................................. 191
Table 7.9 Macroeconomic results of the carbon price revenue recycling experiments ............................................. 193
Table 7.10 Percentage changes in post tax income by household decile ................................................................. 195
Table 7.11 Percentage change in household utility .................................................................................................... 198
Table 7.12 Equivalent variation as a percentage change in post tax income ........................................................... 199
Table 7.13 SSA of Scenario 2: 50 percent variation in all parameters ........................................................................... 201
List of Figures

Figure 2.1 Distribution of Australia’s major non-renewable energy resources ........................................17
Figure 2.2 Electricity generation by fuel 2008-09 ..................................................................................19
Figure 2.3 World electricity prices, selected countries, 2009 a ..............................................................20
Figure 2.4 Australian energy flows, 2008-09, unit Petajoules ...............................................................21
Figure 2.5 Energy consumption by industry from 2006-07 to 2008-09 ..................................................22
Figure 2.6 Primary energy consumption by fuel......................................................................................23
Figure 2.7 The annual growth in energy consumption .............................................................................23
Figure 2.8 Energy intensity of consumption ..........................................................................................24
Figure 2.9 Greenhouse gas emission by sectors, 2008 .......................................................................25
Figure 2.10 Percentage change in greenhouse gas emissions by sectors from 1990 to 2008 ..............26
Figure 2.11 CO₂-e emissions from electricity generation by fossil fuels, 2008 ...............................26
Figure 2.12 Per capita energy emissions factors, 2008 .....................................................................27
Figure 2.13 Percentage contribution of per capita emissions by sector, 2008 ..................................29
Figure 2.14 CO₂ emissions per kWh from electricity and heat generation, average 2008 ..............29
Figure 5.1 Linearisation error .............................................................................................................111
Figure 5.2 Structure of production of goods and services .................................................................116
Figure 5.3 Structure of household demand ..........................................................................................131
Figure 6.1 Core structure of the database ............................................................................................151
Figure 7.1 The short-run closure .........................................................................................................167
Figure 7.2 The long-run closure ..........................................................................................................169
Figure 7.3 Percentage changes of average electricity prices under short-run carbon price ..........176
Figure 7.4 Short-run and long-run marginal abatement cost (MAC) curves ......................................178
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3E-G</td>
<td>Economy-Energy-Emission CGE model</td>
</tr>
<tr>
<td>ABARE</td>
<td>Australian Bureau of Agricultural and Resource Economics</td>
</tr>
<tr>
<td>ABS</td>
<td>Australian Bureau of Statistics</td>
</tr>
<tr>
<td>ANA</td>
<td>Australian National Accounts</td>
</tr>
<tr>
<td>ANZSIC</td>
<td>Australian New Zealand Standard Industrial Classification</td>
</tr>
<tr>
<td>ASNA</td>
<td>Australian System of National Accounts</td>
</tr>
<tr>
<td>CCAP</td>
<td>Change in Capital</td>
</tr>
<tr>
<td>CES</td>
<td>Constant Elasticity of Substitution</td>
</tr>
<tr>
<td>CET</td>
<td>Constant Elasticity of Transformation</td>
</tr>
<tr>
<td>CGE</td>
<td>Computable General Equilibrium Model</td>
</tr>
<tr>
<td>CO₂-e</td>
<td>Carbon Dioxide equivalent</td>
</tr>
<tr>
<td>CPRS</td>
<td>Carbon Pollution Reduction Scheme</td>
</tr>
<tr>
<td>CPI</td>
<td>Consumer Price Index</td>
</tr>
<tr>
<td>DCCEE</td>
<td>Department of Climate Change and Energy Efficiency</td>
</tr>
<tr>
<td>ESAM</td>
<td>Environmentally-extended Social Accounting Matrix</td>
</tr>
<tr>
<td>ETS</td>
<td>Emissions Trading Scheme</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GEMPACK</td>
<td>General Equilibrium Modelling Package</td>
</tr>
<tr>
<td>HES</td>
<td>Household Expenditure Survey</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>IO</td>
<td>Input-Output</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>LES</td>
<td>Linear Expenditure System</td>
</tr>
<tr>
<td>MPCCC</td>
<td>Multi Party Committee on Climate Change</td>
</tr>
<tr>
<td>NGGI</td>
<td>National Greenhouse Gas Inventory</td>
</tr>
<tr>
<td>ROW</td>
<td>Rest of the World</td>
</tr>
<tr>
<td>SAM</td>
<td>Social Accounting Matrix</td>
</tr>
<tr>
<td>SSA</td>
<td>Systematic Sensitivity Analysis</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
</tbody>
</table>