CHAPTER I
Introduction

Scientific evidence suggests that greenhouse gases, especially carbon dioxide (CO_2) emissions from anthropogenic activities, have significantly contributed to climate change. These gases have the capacity to trap heat in the atmosphere and the resulting phenomenon is called 'global warming'. During the last 150 years, global surface temperatures have risen by 0.74 ± 0.18^{0}C with 11 of the last 12 years ranked the warmest years of the earth (Intergovernmental Panel on Climate Change (IPCC), 2007a). Furthermore, the *Fourth Assessment Report* (IPCC, 2007b) concluded that greenhouse gas increase was the extremely likely cause (more than 90 percent) for this warming since the mid 20th century and extremely unlikely (less than 5 percent) to be due to natural variability. As a result of this temperature increase, various climate models predict increased precipitation, sea level rise, increased frequency of extreme weather events and changes to many other natural characteristics of the global environment.

The consequences predicted as a result of global warming alarmed national governments around the world. Accordingly, 172 countries participated at the *Earth Summit* in 1992 to establish an environmental treaty called the United Nations Framework Convention on Climate Change (UNFCCC *Article 3,* 1992, p 4) with the ultimate objective of '*stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*'. Furthermore, the countries participating in the environmental treaty acknowledged that developed countries should take the lead in combating climate change. Those countries agreed to cut their emissions on the basis of '*common but differentiated responsibilities and respective capabilities*' (p 4). The actions and responsibilities defined under this treaty can be regarded as one of the major political movements towards protecting the global environment. Next, the establishment of the IPCC in 1988 aimed to fulfil rapidly growing demand for current and new knowledge about climate change science to the policy makers in public and private sectors.

In order to strengthen the emission reduction commitments set under the UNFCCC, the *Kyoto Protocol* (UNFCCC, 1998) was adopted in December 1997. Followed by extensive negotiations, the Kyoto Protocol became effective in February 2005. Accordingly, 37 industrialised countries and the European community became legally committed to stabilise greenhouse gas emissions to an average of 5 percent against 1990 levels over the five year period 2008-2012. In short, the Kyoto Protocol is what '*operationalises'* the Convention.

The emissions reduction mechanisms set under the Kyoto Protocol follow a market based approach. While the Protocol encourages countries to meet their emission reduction targets through national measures, it also offers additional measures by way of three market based mechanisms. These are called Kyoto mechanisms, namely Emissions Trading, Clean Development Mechanism, and Joint Implementation. By setting binding emissions reduction commitments, the greenhouse gas emissions - most prevalently CO_2 - became a new commodity. As a result, greenhouse gas emissions are viewed as a classical example of a market failure. Thus, the previously ignored external cost (climate change) of greenhouse gas emissions could be internalised into the private decisions of both producers and consumers. In summary, a market mechanism is expected to activate an emissions price (a carbon price) that would ultimately lower the emissions levels.

1.1 Background of the study

Reducing emissions means many changes to the current production and consumption patterns in an economy. Even though the expected environmental benefits are positive, there may be significant negative social and economic consequences from such an emissions reduction policy. Basically, emission reduction measures change equilibrium supply and the demand schedules of an economy. These changes are mainly driven as a direct response to increased prices in the economy. Because an emission price or carbon price directly raises the price of carbon based energy (fossil fuel), costs will be greatest for those firms and economies that produce the most emissions.

There are two common approaches to introduce a carbon price, namely a cap-and-trade system and an emissions tax (carbon tax). Both these strategies create a price for carbon which results in higher prices of fossil fuels. The only difference is that while a cap-and-trade system directly controls the quantity of emissions and leaves the prices to vary, an emissions tax controls the price and leaves the quantity to vary. Therefore, market based systems create an incentive on producers of fossil fuels and on energy consumers to lower their emissions levels by manipulating either the price or the quantity of carbon released from economic activities. As generally agreed by most economists, these strategies are the least costly way of mitigating emissions and implementing a reduction target (Garnaut, 2008a, 2011; Pezzey, 1992; Rose and Stevens, 2001) as compared to rigid command and control measures.

Market based approaches generally change the relative prices of goods and services in a market. Therefore, a policy shock by way of a carbon price leads to change in a given market's equilibrium allocation of resources and factors. If an analysis is only focussed on the changes in a single market after a policy change, a partial equilibrium model may be used. However, a carbon price shock not only affects one single market, it reverberates throughout the whole economy. For example, changes in relative prices will lead to a shift away from high carbon intensive production and processes towards low carbon intensive production and processes. Such a change will inevitably lead to change the economic structure and product mix, resource allocation and the distribution of income arising from several markets simultaneously.

A Computable General Equilibrium (CGE) model is an effective tool for analysing the interactions between different markets and how they adjust to a policy shock. CGE models are a very complex mathematical representation of an economy. For instance, once the determinants of demand and supply of every market and their cross linkages are specified, a CGE model then recalculates a 'new' equilibrium set of prices after the policy shock. This is the ability of CGE models to simultaneously determine changes in quantities of goods supplied and demanded, and their prices. As a result, a CGE model is capable of finding solutions in an aggregated multi-sectoral and multi-agent setup.

The literature applying CGE models to environmental policy is relatively scarce. This is especially so by comparison with CGE applications to tax policy, development policy and trade policy. However, in recent decades there have been many attempts to incorporate greenhouse gas emissions accounts, factor substitution functions and distributional consequences to the CGE modelling framework. The range of issues that CGE models have been developed to analyse are: economic impacts of environmental policies (Beghin et al., 1997; Jogenson and Wilcoxen, 1990; Vennemo, 1997); sectoral and macroeconomic impacts of CO_2 emissions and air pollution (Boyd et al., 1995); deforestation (Persson and Munasinghe, 1995); land use (Cruz and Repetto, 1992); ancillary benefits of reduction in air pollution (Dessus and O'Connor, 2003); economic impacts of market instruments for greenhouse gas reduction (Rose and Oladosu, 2002); and economic impacts of emission tax policies (Devarajan et al., 2009, 2011).

The main source of data for CGE modelling is derived from IO tables and national accounts. This data can be also combined in the framework of a Social Accounting Matrix (SAM). Keuning (1994, p 22) describes a SAM as '*the presentation of a sequence of accounts in a matrix that elaborates the interrelationships between economic flows (and stocks), by adopting in each account the most relevant statistical unit and classifications of these units*.' Because SAM combines IO data with income distribution data, many CGE models have been calibrated using a SAM database in order to assess distributional implications arising from environmental policies. In recent years, SAMs of many countries were further extended (see for example, for Indonesia Resosudarmo and Thorbecke (1996), for China Xie (2000), for Bolivia Alarcon et al. (2000), and for Brazil Lenzen and Schaeffer (2004) with environmental accounts. These SAMs are generally identified as Environmentally-extended SAMs (ESAMs) and serve as potential databases for calibrating CGE models.

1.2 Statement of the problem

Greenhouse gas mitigation policy is one of the most contentious political issues in Australian history. Even though Australia is largely under the threat of severe climate change consequences (Garnaut, 2008a), many stakeholders including political parties, industry groups and consumer groups oppose introducing a '*price based*' climate change policy as a means of reducing those predicted climate change consequences. These groups argue such an action would create detrimental impacts on many Australian industries, exports, and also consumers because the Australian economy is heavily reliant on fossil fuel energy sources. As such, the most preferred method of reducing emissions for those groups is using subsidies to induce development of low-emissions technologies. However, such measures need continuous monitoring and evaluation systems and substantial government spending to bring significant technological advancements. On the other hand, nuclear energy is a better alternative although there are concerns on safety issues (Owen, 2006). Furthermore, the Uranium Mining, Processing and Nuclear Energy Review (Australian Government, 2006) highlights that nuclear power would not be competitive with coal-fired generation unless carbon emissions are priced. The Australian government has been making many attempts to develop a consistent and effective greenhouse gas policy that is beyond the subsidies for selected industries and consumers, and that includes carbon pricing.

Pricing carbon has now been on Australia's political agenda over the past decade. In 2006, the Australian states (but not the Federal government) established the states and territories

National Emissions Trading Taskforce (NETT). This was one of the significant milestones of Australia's attempt to reduce emissions using price signals (Australian Government, 2007). The Taskforce proposed to introduce a national emissions trading scheme. Next, in 2008, the Australian Government announced the Carbon Pollution Reduction Scheme (CPRS) which proposed a cap-and-trade emissions trading scheme as had the NETT Taskforce (Australian Government, 2008a). The CPRS scheme was intended to commence on the first year with a fixed carbon price of \$10/t CO_2-e and gradually start to increase.

Meanwhile, the Australian Treasury in partnership with other leading climate change economic modellers and the Garnaut Climate Change Review undertook comprehensive modelling projects to investigate the potential economic impacts of emissions reduction in Australia. Accordingly, the Treasury examined various emission reduction scenarios in which Australia and the world follow pathways to a low-pollution future (Australian Government, 2008a). Most importantly, modelling undertaken by the Treasury is centered on three top-down CGE models namely Global Trade and Environment Model (GTEM), G-Cubed model and the Monash Multi-Regional Forecasting (MMRF) model. Finally, a series of bottom-up sector specific models for electricity generating, transport, land use change and forestry, and household micro simulation models have been integrated in order to obtain projections at sector specific levels and household distributional levels.

In 2011, the Australian Treasury once again undertook a comprehensive modelling exercise to assess the impacts of carbon pricing at the global, national, state, industry and household levels. The models used under this project are similar to those used in the 2008 modelling (Australian Government, 2011a). However, model simulations were conducted under two carbon price scenarios, namely a core price (\$20/t CO_2-e) and a high price (\$30/t CO_2-e) assuming Australia will face different prices from 1 July 2012. Only the household impacts were modelled using the \$23/t CO_2-e price. In the same year, updated macroeconomic and sectoral impacts were projected using a broad based carbon price of $23/t CO_2-e instead of modelling with $20/t CO_2-e (Australian Government, 2011b).

As it appears, the Treasury modelling is very complex. It has developed modelling scenarios integrating many CGE models as well as sector specific models. This is because the Treasury argues that no single model can adequately capture the global, national, state, industry, and household dimensions of the cost of climate change mitigation policy in Australia. For instance, the MMRF model is a single country dynamic model which is rich in industry details (Adams et. al., 2010) whereas the GTEM model is a global model which is capable of providing insights into Australia's key international trading partners (Pant, 2007). However, use of this kind of complex modelling framework demands various assumptions about global prices, technological changes, productivity changes, household tastes and preferences etc. Since these models have different assumptions with respect to supply responsiveness of various Australian industries, the Treasury has taken extra care when integrating these models to obtain internally consistent projections. However, the Treasury does not provide details of how this linking is done.

Moreover, all the above CGE models have been calibrated with IO databases with an aggregate household sector representing the consumers in the economy. The micro simulation model (PRISMOD - Price Revenue Incidence Simulation Model), supplements the disaggregated household level details. However, the PRISMOD only captures the flows of goods between industries and final consumers and it does not explain income flows between these institutions. An alternative way of obtaining distributional consequences of carbon price policy is to calibrate a CGE model with a SAM database. For instance, a CGE model calibrated with a conventional IO table only captures sectoral interdependence in a detailed production account whereas a SAM based model elaborates and articulates the generation of income by activities of production and the distribution and redistribution of income between social and institutional groups (Round, 2003). Towards this end, Pang et al. (2007) attempted to construct an aggregate SAM for Australia for the year 1996-97. Because this database is in its aggregate form, the distributional story of the household income and expenditure after a policy shock cannot be projected.

Therefore, two main research issues have been identified under this project. First, there is a need for a less complex but more descriptive CGE model which is capable of simulating impacts on disaggregated industries and on households under a carbon price policy. Second, there is a need for constructing a disaggregated SAM database to calibrate the CGE model in order to measure distributional consequences of a carbon price policy.

1.3 Research objectives

The central objective of this study is to develop an economy-wide, energy and emissions focussed, static CGE (titled A3E-G) model to analyse the direction and magnitude of the carbon price impacts at the macroeconomic, sectoral and household levels in Australia. As mentioned earlier, a carbon price may affect both the supply and demand sides of the economy because fossil fuels are the main source of energy in Australian production and consumption activities. These types of simultaneous impacts can be best modelled in a CGE framework (Wing, 2004). The CGE model developed for this purpose is a static, single country (Australian) model which allows for a more detailed and reliable analysis in terms of sectoral scope and household distributional levels. In relation to the model calibration, an Environmentally-extended Social Accounting Matrix (ESAM) will be developed for Australia. The ESAM database presents with disaggregated energy sectors, electricity generating sectors, occupational groups and household groups in Australia. As such, the CGE model is capable of projecting not only the macroeconomic and sectoral implications of a carbon price policy but also the household distributional impacts of the carbon price policy. Therefore, the A3E-G model calibrated with an ESAM database will be useful to check and serve as a complement to the projections made by other Australian CGE models of greenhouse gas emission related policies.

Accordingly, the following are the specific objectives of this research project:

1. To provide an analysis of the Australian energy sector and its implications on greenhouse gas emissions and mitigation policies.
2. To review the existing literature on CGE models related to environmental policies in general, and carbon pricing policies in particular.
3. To construct an ESAM database that serves as the main database for the A3E-G model calibration.
4. To develop a static, A3E-G model of the Australian economy to carry out carbon price policy simulations.
5. To construct the A3E-G model database structure with carbon emissions accounts and various elasticity parameters.
6. To simulate short-run and long-run impacts of a carbon price on the macroeconomic, sectoral, employment and household levels.
7. To measure the welfare implications of a carbon price on different household groups under various revenue recycling options.
8. To conduct sensitivity analysis on the parameters employed in order to verify statistical accuracy of projections.

1.4 Methodology

The proposed model to be used in this study is a generic version of the Johansen-type CGE model (Dixon et al., 1977,1982; Johansen, 1974). In the model, the production function in each sector is modelled under a nested Leontief or constant returns to scale production technology. The assumptions of a classical CGE approach are profit maximisation of the producers and utility maximisation of the consumers. The interactions with each agent bring markets into equilibrium where prices are competitively determined. The CGE model endogenously determines relative product and factor prices. In this way, CGE models usually explain equilibrium levels of resource allocations and growth of an economy. By including a carbon price - the CGE model constructed under this study - the A3E-G model recalculates equilibrium prices and quantities of factors and commodities. This is based on the assumption that a price on carbon will influence the decision making process of both producers and consumers.

Some of the key characteristics embedded in the A3E-G model are as follows. The model treats non-energy commodities and energy commodities separately (see similar type modeling structures in Devarajan et al., 2009, 2011; Telli et al., 2008, Yusuf, 2007). Next, the model allows price-induced substitution between capital and energy and between different energy commodities. A carbon emission accounting and carbon price mechanism incorporated into the model allows solving for another equilibrium state after a carbon price shock. Furthermore, unlike the standard ORANI-G model - a static CGE model of the Australian economy - developed by Dixon et al. (1977), the A3E-G model contains equations explaining both income and expenditure of the households, corporations, government and the rest of the world. Basically, ORANI-G is based on the IO database while A3E-G is based on the ESAM database which has additional accounts for income distribution of Australian households.

1.5 Contribution to the literature

The study contributes to the literature in at least four important ways. Firstly, the proposed methodology develops a static, single country A3E-G model with disaggregated energy sectors and enhanced capital-energy substitution possibilities in the production structure. This disaggregated approach serves as a better tool for modelling carbon price impacts on the Australian macro economy, sectors and households.

Secondly, the distributive implications of a carbon price are simultaneously projected using a highly disaggregated household sector in the model with a detailed specification of household income and expenditure accounts. In previous studies, the distributive effects of a carbon price in Australia have been primarily examined using a micro simulation model which extracts aggregate household level projections from the main CGE model. In contrast, the A3E-G model captures all the economy wide effects with respect to different household groups based on their income and expenditure patterns.

Thirdly, the model has the capability of projecting impacts on the macroeconomic and on households from various revenue recycling policies. This is a very important departure in CGE modelling as the revenue raised from the carbon price can be effectively used to reduce the burden on households and extremely affected industries.

Finally, the A3E-G is calibrated using an ESAM for Australia. To the author’s knowledge, this ESAM database will be the first database in Australia that explicitly employs social accounts to analyse the impact of a carbon price on household income distribution. Moreover, there are 35 sectors in the ESAM, classified on the basis of their carbon emissions. Modelling the sectors in this way is essential to identify the responsiveness to the carbon price mechanism in the economy.

1.6 Outline of the thesis

The remainder of this thesis is outlined as follows.

Chapter II outlines the background picture on energy and associated greenhouse gas emissions in the Australian economy. The Australian energy sector contributes quite significantly to the economy in terms of industry value added, employment and gross capital formation but is one of the largest greenhouse gas emitters. As a result, development of greenhouse gas abatement policies in the economy has been subjected to many challenges over time and is discussed briefly in this chapter.

Chapter III surveys the literature on SAM based models and CGE models for environmental policy analysis in general, and uses of CGE models in climate change policy analysis in particular. The CGE models used in climate change policy analysis are further categorised with respect to their static or dynamic nature and the static models are further surveyed under various uses. Finally, the chapter surveys the use of CGE models for greenhouse gas control policies in Australia.

Chapter IV presents the detailed procedure for constructing an ESAM for Australia. Since there has not been an ESAM constructed for the purpose of carbon price modelling in Australia, this chapter provides a transparent procedure enabling greater replicability for future ESAM construction. The chapter describes how the Australian ESAM for the year 2004-05 with 35 industries, 35 commodities, nine labour groups and 10 household groups is constructed. The particular policy change being analysed in this thesis is the imposition of a carbon price, so the sector classification is based on the relative importance of carbon emissions in the economy. The detailed household income and expenditure accounts presented in this ESAM enable accurate assessment of the distributional impacts of the carbon price as well as the welfare implications of revenue recycling options.

Chapter V provides a detailed description of the A3E-G model equations with respect to production structure, gross fixed capital formation, household demands, export and government demands, equilibrium market clearing prices including carbon price equations and income distribution equations. This model is a variation from the standard ORANI-G type model and incorporates changes into the production structure definitions and purchaser price definitions. Additionally, the A3E-G model is calibrated using an ESAM database which incorporates detailed income distribution equations by various institutions.

Chapter VI provides the additional data requirements necessary to calibrate the model. It is necessary to compile an investment matrix, a tax matrix, a carbon emissions matrix and various elasticity parameters.

Chapter VII presents various carbon price scenarios to be implemented using the A3E-G model under a short-run economic environment. This discussion is then extended by comparing one short-run carbon price scenario with the long-run carbon price scenario. The simulation outcomes are presented with respect to macroeconomic effects, industry effects and household effects. Next, options are presented for how the revenue from the carbon tax might be recycled back to the economy. These options include lump-sum transfers, income tax reductions and a reduction in GST. Finally, the sensitivity of the parameters is tested using the systematic sensitivity analysis (SSA), a facility given in the RUNGEM program of the GEMPACK software.

Chapter VIII draws together the major findings of this study, the contribution to the literature and provides suggestions for further research.

CHAPTER II

Australia's Energy Sector: Implications for Greenhouse Gas Emissions and Mitigation Policies

Introduction

There is a strong correlation between Australia's energy sector and greenhouse gas emissions. This is because Australia's energy is derived mainly from emissions intensive, fossil energy resources. At the same time, the abundant endowments of fossil energy resources and relatively cheap electricity prices have been the source of a competitive advantage for energy intensive industries. As a result, while the energy sector continues to play an important role in the economy it has been subjected to international attention on environmental issues, particularly greenhouse gas emissions. In fact, Australia's heavy dependence on carbon intensive energy sources and high level of per capita emissions has challenged past and present governments to design efficient greenhouse gas mitigation policies that are capable of meeting international commitments as well as maintaining competitiveness of the domestic economy.

This chapter is organised as follows. Section 2.1 discusses Australia's energy supply with respect to production, resource availability, and contribution to the economy. Section 2.2 discusses Australia's energy consumption patterns. Section 2.3 deals with emissions resulting from energy use. Section 2.4 discusses the evolution of greenhouse gas mitigation policy in Australia against the background of an economy heavily reliant on fossil fuel energy sources.

2.1 The supply of energy in Australia

An abundant and reliable supply of energy resources ensures Australia is competitive in supplying energy for its domestic needs as well as for the world energy needs. As reported in IEA (2009), Australia is the world's ninth largest energy producer accounting for 2.4 percent of the world's energy production. In 2008-09, Australia produced 17769 Petajoules (PJ) of energy and exported 78 percent in energy content terms (Table 2.1). The remaining 22 percent was consumed locally. Additionally, 1904 PJ of energy was imported in 2008-09 which constituted crude oil (944.4 PJ), LPG (25.7 PJ) and petroleum products (933.9 PJ).

Table 2.1 Composition of energy in the production, imports and exports in Australia, 2008-09

Energy type	Production (PJ)	% Share	Imports (PJ)	% Share	Exports (PJ)	% Share
Black coal	8903.9	50.1	-	-	7410.7	53.7
Brown coal	668.2	3.8	-	-	-	-
Crude oil	1028.1	5.8	944.4	49.6	617.1	4.5
LPG	104.1	0.6	25.7	1.3	64.2	0.5
Natural gas	1915.9	10.8	-	-	838.3	6.1
Uranium	4846.1	27.3	-	-	4753.6	34.4
Petroleum products	-	0.0	933.9	49.0	125.8	0.9
Renewable energy	302.7	1.7	-	-	-	-
Total energy	17769.0	100.0	1904.0	100.0	13809.7	100.0

Source: Based on data from the ABARE (2010)

Australia's main production of energy commodities derives from black and brown coal, uranium and natural gas. Coal dominated and accounted for 54 percent of the production in 2008-09. From the total black coal production (8903.9 PJ), around 83 percent was exported. Brown coal contributed 3.8 percent of domestic production and all production was retained locally. Uranium is the second largest energy commodity produced in Australia contributing 27 percent to domestic production and 34 percent to exports. Australia does not process uranium or use nuclear power and almost all uranium production was exported (98 percent). Natural gas production was 1915.9 PJ which qualified as the third largest energy commodity produced in Australia. Crude oil and liquefied petroleum gas (LPG) represented 6 percent of total energy production and 51 percent of total energy imports. Other major imports of energy are petroleum products which constituted 49 percent of total energy imports. Renewable energy commodities represented 1.7 percent of total energy production in 2008-09.

The production and exports of energy are derived from the existing reserves of energy in Australia. As shown in Table 2.2, the ratio of economic demonstrated reserves to current production is estimated at 108 years for black coal, 554 years for brown coal, 85 years for natural gas and 152 years for uranium. This resource base is capable of meeting both domestic and export demand over the next 20 years and beyond (Geoscience Australia, 2010).

Table 2.2 Reserves of major energy commodities in Australia, 2010

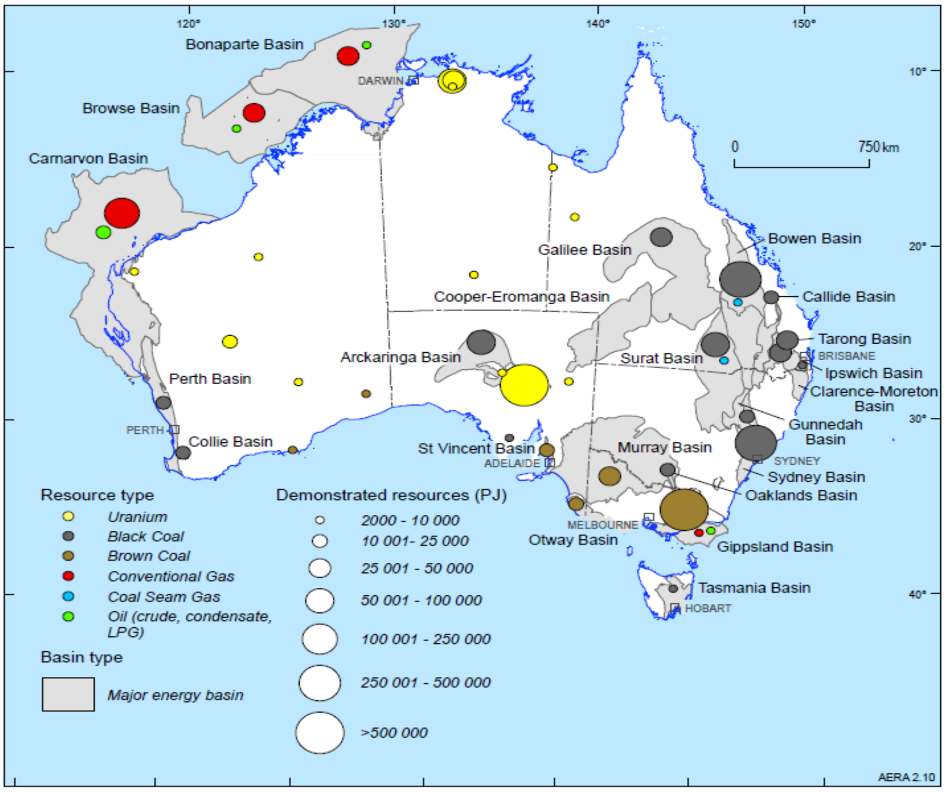
Energy source	Unit	EDR	Annual production	Resource life (yrs)[a]	Share of world %
Black coal	10^9t	45.2	0.4	108.2	10.6
Brown coal	10^9t	37.1	0.1	554.6	8.9
Crude oil	10^9L	195.0	19.4	9.8	0.3
Natural gas	m^{12}	3362.6	36.0	85.6	na
Condensate	10^9L	na	6.3	48.2	na
LPG	10^9L	153.8	na	36.8	1.6
Uranium	10^3t	1296.1	8.4	152.3	47.5

Sources: Based on data from the ABS (2010) *Australian System of National Accounts*, Cat. No. 5204, ABARE (2010) (p 4)
[a]- 5 year lagged moving average, EDR (Economic Demonstrated Reserves), na- not available

The abundant resources of coal underpin exports and low cost domestic electricity production which is one of the major reasons for the comparative advantage enjoyed by energy intensive industries in Australia over time. Furthermore, Australia has an opportunity to discover and develop renewable energy resources which include wind, solar, geothermal, hydroelectricity, ocean energy and bioenergy resources due to Australia’s geology and geographical characteristics (Geoscience Australia, 2010). At present hydro, wind, biomass and solar energy are used in heating and electricity generation. However, these energy resources are still largely undeveloped and currently there is no data available for proven resources (EDR) for renewable energy. Technology is expected to play a significant role in the transition toward a lower emissions economy which will inevitably improve the renewable energy resource base in Australia in the future.

Figure 2.1 shows the distribution of Australia’s energy resources across the country. Black coal resources are found in most states. The largest black coal resources are located in the Bowen-Surat and Sydney basins in Queensland and New South Wales respectively. These two states contribute around 95 percent of Australia's black coal reserves. Coal seam gas deposits are located close to the black coal deposits of Queensland and New South Wales.

Figure 2.1 Distribution of Australia's major non-renewable energy resources



Note: Resources containing more than 2000PJ
Source: Geoscience Australia (2010)

The biggest reserves of brown coal are located in Victoria contributing 96 percent of identified brown coal resources. Australia's petroleum resources, namely crude oil, condensate and LPG resources can be found off the coasts of Western Australia, the Northern Territory and Victoria. Among these three states or territories, Western Australia possesses 64 percent of crude oil, 75 percent of condensate and 58 percent of LPG resources. Significant deposits of conventional gas are also located close to oil deposits in Western Australia and in the Northern Territory. The world's largest uranium deposits are located in South Australia – the Olympic Dam deposit. Significant uranium deposits can be also found in the Northern Territory and Western Australia.

2.1.1 Energy industry contribution to the economy

The Australian energy industry contributes significantly to the economy in terms of employment generation, gross industry value added and gross fixed capital formation. The energy related industries exclude uranium production because uranium energy is not used in Australia's energy related activities. Accordingly, the energy industry is comprised of coal mining, oil and gas extraction, petroleum and coal products manufacturing, electricity supply and gas supply industries (Table 2.3). The total energy industry contributed $87 billion to the industry value added in 2008-09 employing 103,000 workers.

Table 2.3 Energy related industries in Australia 2006-07 to 2008-09

Industry	Employment ('000)		Industry value added ($b)		Gross fixed capital formation ($b)	
	2006–07	2008–09	2006–07	2008–09	2006–07	2008–09
Coal mining	26.0	34.0	15.3	37.9	5.4	7.7
Oil & gas extraction	10.0	12.0	22.4	28.9	6.5	12.6
Petroleum & other	8.0	7.0	2.6	1.2	0.5	1.0
Electricity supply	44.0	48.0	15.4	17.8	8.7	10.9
Gas supply	2.0	2.0	1.2	1.1	0.6	0.6
Total energy	90.0	103.0	56.9	86.9	21.8	32.6
All Industries	10435.8	10664.9	1007.0	1171.9	305.7	355.3
% share of energy	0.9	1.0	5.6	7.4	7.1	9.2

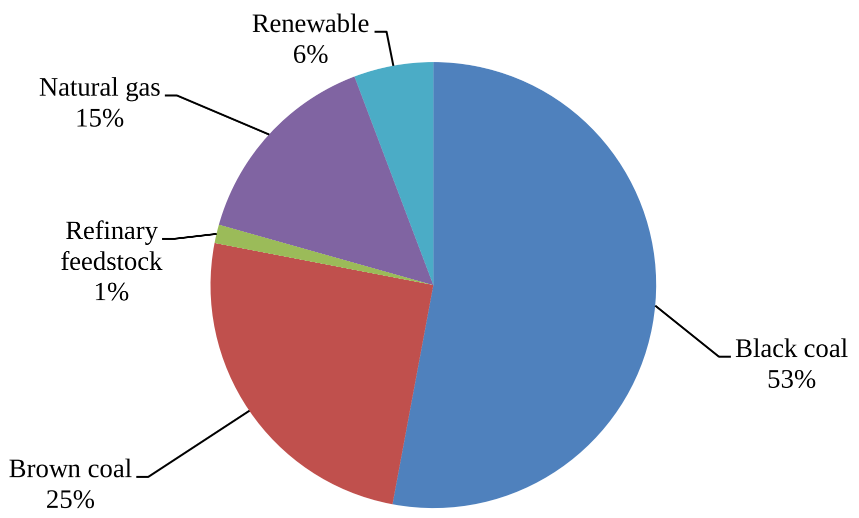
Sources: Based on data from the ABS (*2010*) *Australian Industry*, Cat. No. 8155; *Australian System of National Accounts*, Cat. No. 5204; *Australian Labour Market Statistics*, Cat. No. 6105.

The electricity supply industry employed 48,000 workers which was around 47 percent of the total workforce employed in the energy sector. The electricity supply and coal mining industries together employed 80 percent of the total workers employed in the energy sector. The share of the energy sector to the gross fixed capital formation in 2008-09 was 9.2 percent. The oil and gas extraction sector contributed to the highest share of industry gross value added in 2006-07. In 2008-09, the coal mining sector contributed to the highest share of industry value added contributing $37.9 billion.

2.1.2 Australia's electricity supply industry

The electricity supply industry is the largest energy industry in Australia. Coal dominates Australia's electricity production. In 2008-09, black coal and brown coal accounted for 53 percent and 25 percent respectively of total electricity generation in Australia. This reflects Australia's abundance of coal reserves and is a major reason for Australia's relatively cheap electricity. Natural gas and renewable energy sources contributed 15 percent and 6 percent respectively to the generation of electricity in 2008-09 (Figure 2.2).

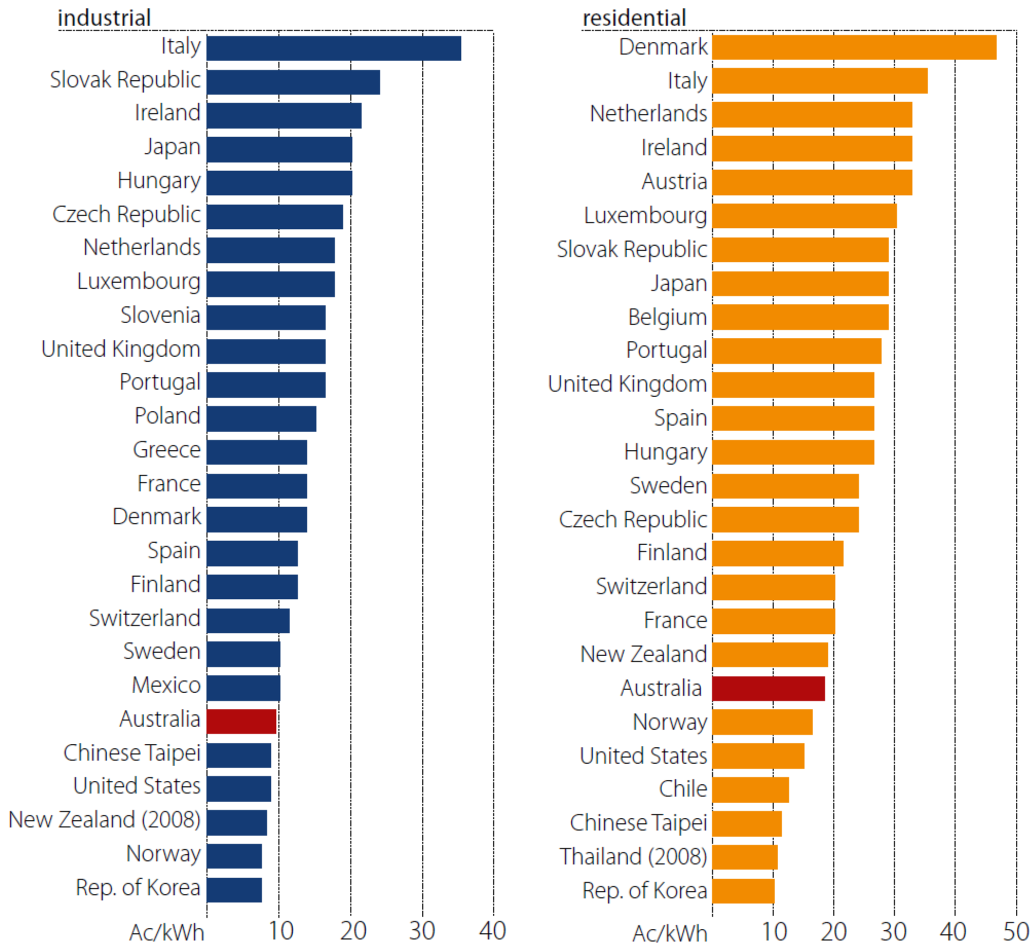
Figure 2.2 Electricity generations by fuel 2008-09



Source: Based on data from the ABS (2010) *Australian Industry*, Cat. No. 8155

Because of the fact that most of Australia's electricity is produced using low cost energy resources (especially coal), Australia's industrial and residential electricity prices have been among the lowest in most of the OECD countries (see Figure 2.3). Only a small number of industrial countries ranked industrial electricity prices to be slightly higher than Australian prices, namely United States, New Zealand, Norway and Republic of Korea. Generally, residential electricity prices are higher than industrial electricity prices for almost all countries. Australia's residential electricity prices are still ranked well below those in most of the European countries.

Figure 2.3 World electricity prices, selected countries, 2009 a

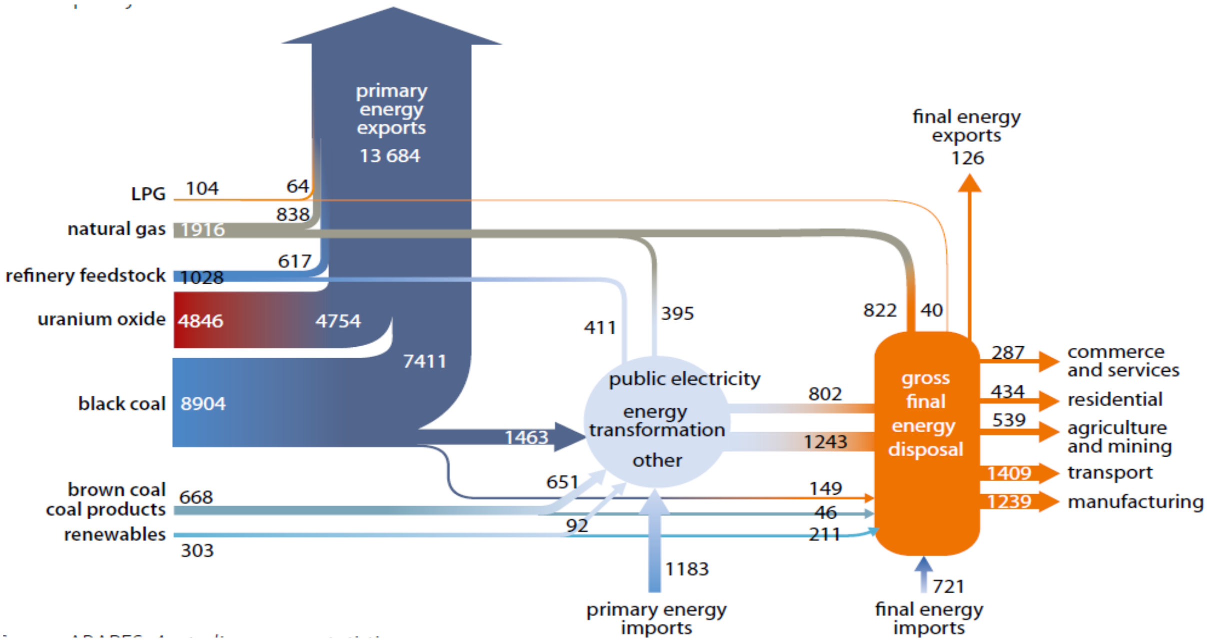


Note: Australian prices estimated using 2004 prices from IEA Energy prices and taxes, and ABS index of electricity prices for households and business.
Sources: IEA, Energy prices and taxes, 2010; Copied from Energy in Australia, ABARE (2011) p 26

2.2 Australia's energy consumption

Australia's energy consumption comprises primary energy consumption and electricity consumption. Primary energy is generally transformed in refineries and power plants for use as petroleum and electricity before being used by industries or households (Figure 2.4). Australia's primary energy consumption was 5773 PJ in 2008-09 by all major industries and households. Australia ranks as the twentieth largest primary energy consumer and fifteenth on a per capita basis (ABARE, 2011). The major energy using industries are electricity generating, manufacturing and construction, and transport, which together accounted for an average of 78 percent of Australia's energy consumption. The electricity generating sector was the largest user of domestic energy consuming 30 percent of total energy in 2008-09. The mining and residential sectors are the second and third largest energy consumers respectively in the economy.

Figure 2.4 Australian energy flows, 2008-09, unit Petajoules

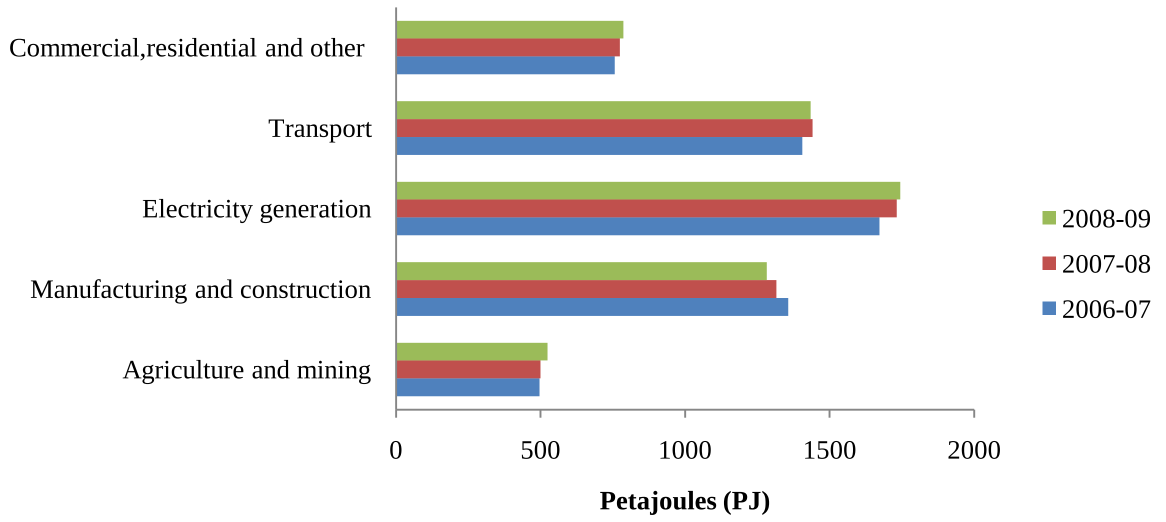


Source: Energy Australia, ABARE (2011) p15

As shown in Figure 2.5, energy consumption in agriculture and mining, electricity generating, transport, commercial, residential and other sectors has increased, while energy consumption in the manufacturing and construction sectors has declined during 2006-07 to 2008-09. The increase in energy consumption in the agriculture and mining sector was largely the result of the continued robust export demand for energy commodities. The decrease in energy consumption in the manufacturing and construction sector resulted from reduced demand in the iron and steel, chemicals, textiles, clothing and footwear industries (ABARE, 2010).

Australia's primary energy consumption consists of coal, oil and gas. In 2009-10, coal accounted for around 37 percent of the primary energy consumed in Australia. Oil represented the second largest primary fuel source accounting for 35 percent. Gas and renewable energy sources accounted for 23 percent and 5 percent respectively of total primary energy consumption.

Figure 2.5 Energy consumption by industry from 2006-07 to 2008-09

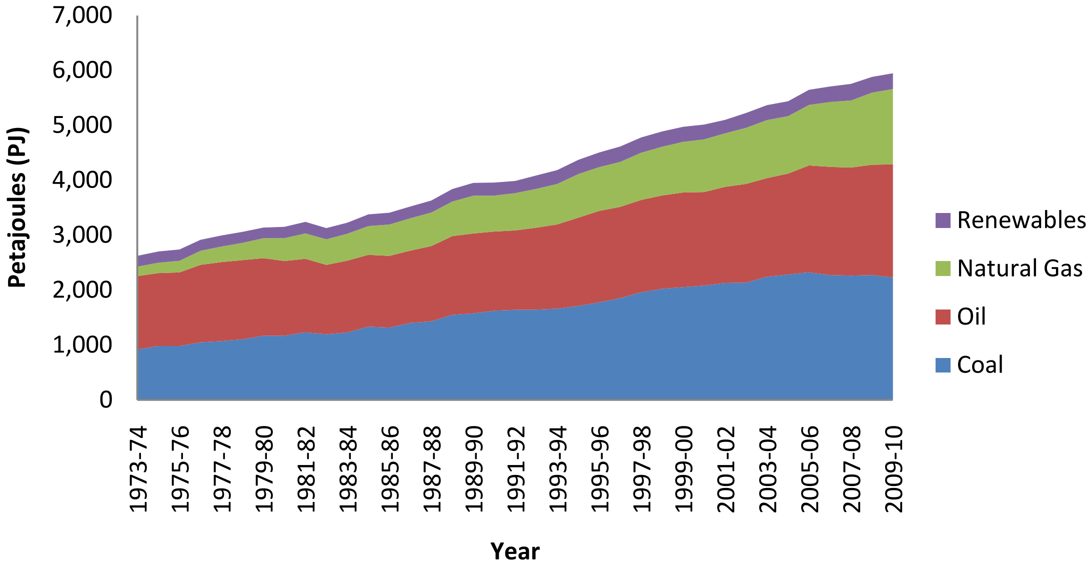


Source: Based on data from the ABARE (2010)

Figure 2.6 shows primary energy consumption by fuel during 1973-74 to 2009-10. The share of coal and oil in Australian energy consumption gradually increased until 2005-06 and has remained constant thereafter. In contrast, the share of natural gas has increased significantly in the past 30 years and there is a potential for this trend to continue in the future. According to the ABARE projections, gas consumption is projected to rise by 3.4 percent a year and to double in demand by 2029-30 (ABARE, 2011). According to the ABARE projections, the current renewable energy demand of 5 percent is expected to rise by 8 percent in 2029-30 with the implementation of renewable energy target programs. A strong growth is expected to occur in the development of wind energy.

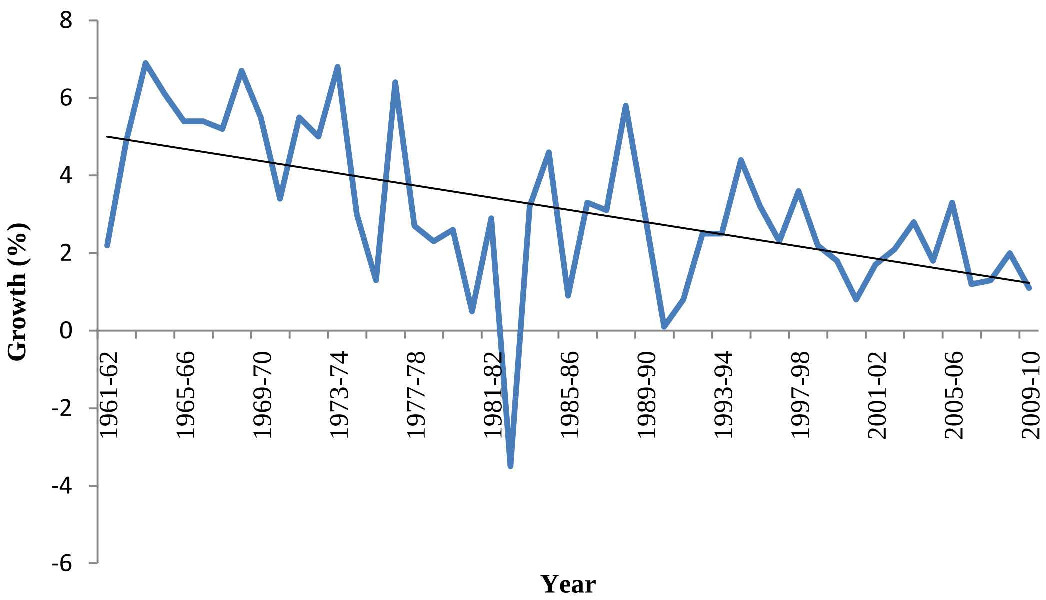
The growth of total primary energy consumption has gradually slowed during the past five decades. This is due mainly to changes in Australia's economic structure, effects of technological developments, government policies on energy efficiency in energy conversion and final consumption sectors (ABARE, 2010). As shown in Figure 2.7, energy consumption grew by 5 percent annually during the 1960s and fell during the 1970s to an average of 4 percent a year. A further decline in growth of energy consumption to around 2.3 percent per year can be seen during the 1980s. This downward trend continued until the 1990s and falling further since 2000 to an average of 1.8 percent.

Figure 2.6 Primary energy consumption by fuel



Source: Based on data from the ABARE (2010)

Figure 2.7 The annual growth in energy consumption

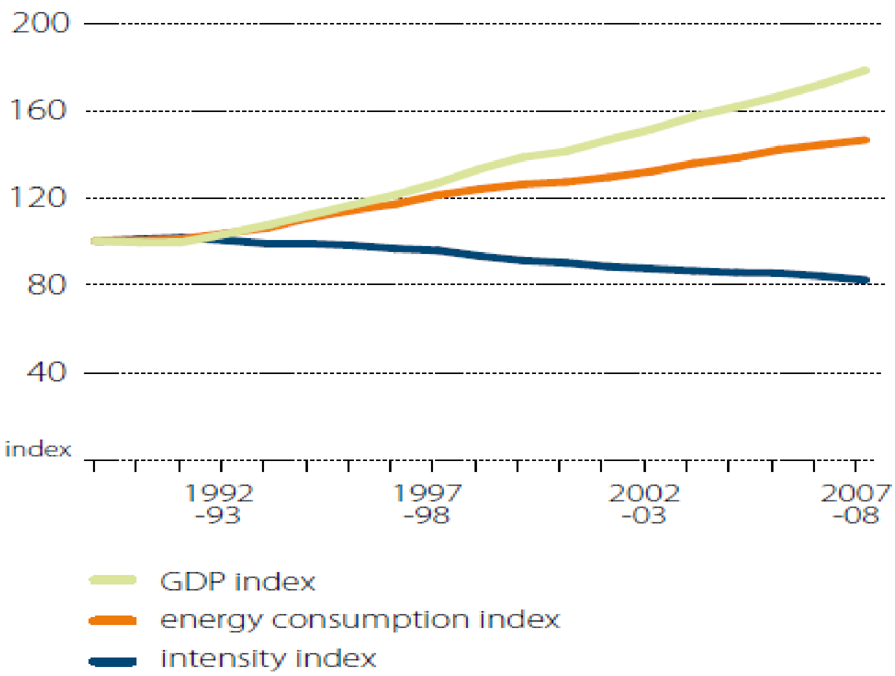


Source: Based on data from the ABARE (2010).

This declining pattern of energy consumption can be measured in terms of energy intensity (energy consumption per unit of gross domestic product). There can be seen a gradual decline in energy intensity (intensity index) over the period from 1989-90 to 2006-07 (Figure 2.8).

This is due mainly to a rapid growth of less energy intensive sectors such as the commercial and services sectors during the last two decades. The other major reason is the increase in energy efficiency over the last two decades due to both technological change and fuel switching programs. In recent years, the Australian and State Governments have implemented various policies at both a national and state levels that have had a direct impact on improving the energy efficiency technologies (ABARE, 2011).

Figure 2.8 Energy intensity of consumption



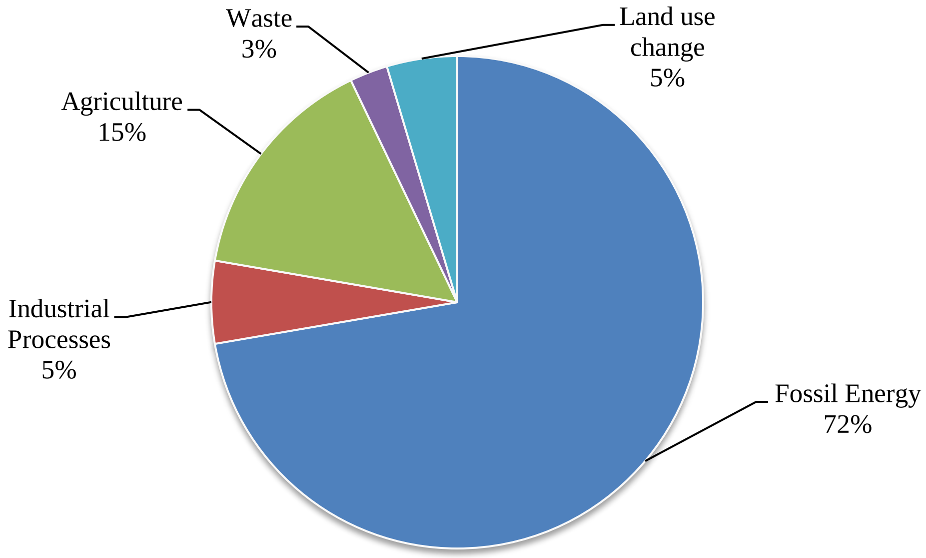
Source: Copied from Australian energy projection to 2039-30, ABARE (2011), P 8

2.3 Greenhouse gas emissions from the energy sector

The energy sector contributes the majority of Australia's emissions. Energy emissions are mainly derived from stationary energy, transport and fugitive[1] sectors. In 2008, the production and consumption of energy accounted for 72 percent of Australia's net emissions or 416.6Mt of CO_2-e (equivalent). Other emissions arise from industrial processes (5 percent), agriculture (15 percent), waste (3 percent), and land use changes (5 percent) (see Figure 2.9).

[1] Fugitive emissions arise from fuel emissions associated with the production, processing, transport, storage, transmission and distribution of fossil fuels such as black coal, oil and natural gas (DCCEE, 2008 p 15).

Figure 2.9 Greenhouse gas emissions by sectors, 2008



Source: Based on data from the DCCEE (2008)

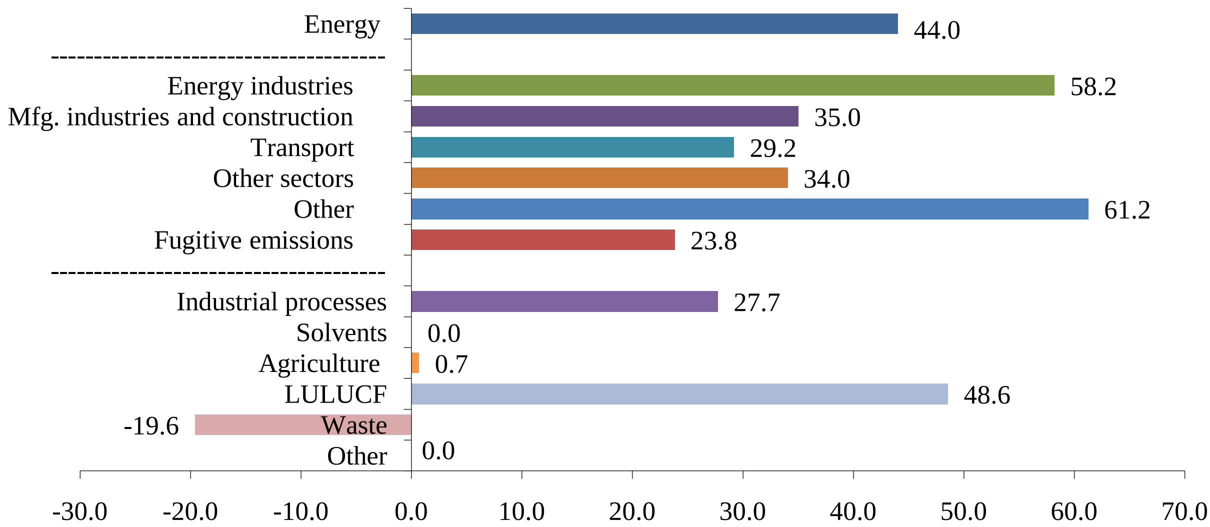
In 2008, Australia's total emissions were 549.5 Mt of CO_2-e[2], a 31.4 percent increase on 1990 emission levels. The sectoral breakdown of emissions shows that Australia's emissions have increased in the energy sector and in the industrial processes sector. The total percentage increase in emissions in the energy sector during 1990 to 2008 was 44 percent, comprising 58 percent increase in energy industries emissions, 35 percent increase in manufacturing and construction emissions, 29 percent increase in transport emissions, 34 percent increase in other sector emissions (commercial, residential), 61 percent increase in other (not elsewhere classified) emissions and 24 percent increase in fugitive emissions (Figure 2.10). Agricultural emissions increased slightly by 0.7 percent while waste emissions have significantly declined by 19.6 percent over the period. The reduction in emission in the waste sector (3.5 Mt CO_2-e) was mainly driven by increasing patterns of recycling and enhanced methane recovery (DCCEE, 2008).

Within energy industries emissions, electricity generation contributed 204.3 Mt of CO_2-e or 90 percent of total energy related emissions in 2008 (Figure 2.11). These emissions mainly arise from combustion of fossil fuels in the generation of electricity. In 2008, the share of

[2] Excludes emission due to land use and forestry activities.

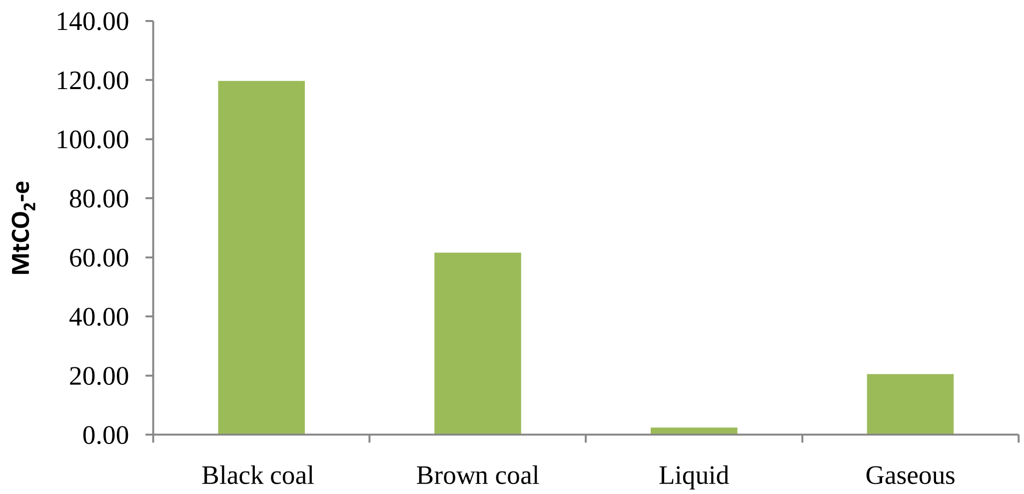
black coal and brown coal constituted 88 percent of the total emissions accrued to electricity generation. Emissions from natural gas and crude oil in electricity generation accounted for only 0.1 percent of the total emissions.

Figure 2.10 Percentage change in greenhouse gas emissions by sectors from 1990 to 2008



Source: Based on data from the UNFCCC (2008)

Figure 2.11 CO_2-e emissions from electricity generation by fossil fuels, 2008



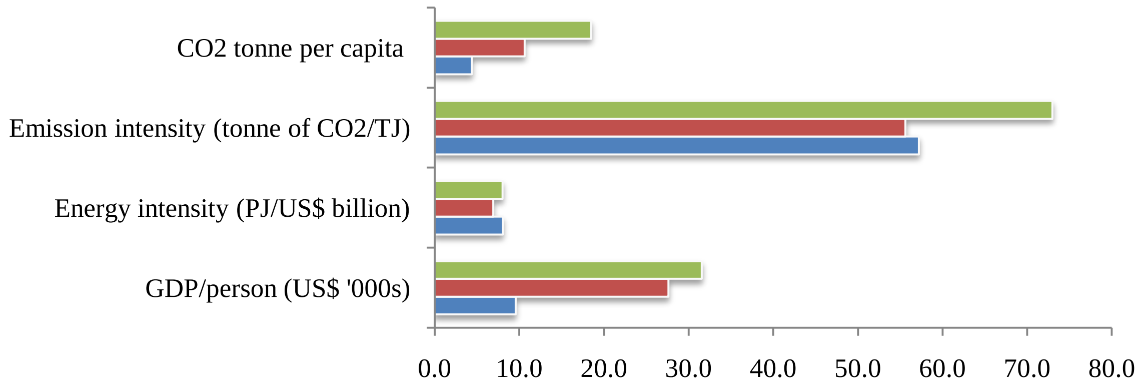
Source: Based on data from the DCCEE (2008)

Australia's emissions intensive energy use has attracted international attention on environmental grounds. In most instances, per capita emissions associated with energy is used as an indicator to compare Australia's carbon emission position with rest of the world. Energy associated per capita emissions can be obtained as a product of per capita GDP, energy intensity of the economy and emissions intensity of energy (Garnaut, 2008);

$$CO_2 per\ capita = GDP\ per\ capita \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

Figure 2.12 compares per capita energy emissions factors of Australia, OECD (Organisation of Economic Co-operation and Development) average and the world average. The energy intensity, measured as total primary energy consumption per dollar of GDP did not account significantly for high per capita emissions. For instance, energy intensity remained stable until 1980 at 10 PJ/US$ billion and has fallen by 2.5 percent a year from 1990 to 2008. On the other hand, emissions intensity has significantly contributed to high per capita emissions in Australia due to the dominant role played by the fossil fuels in the economy.

Figure 2.12 Per capita energy emissions factors, 2008



	GDP/person (US$ '000s)	Energy intensity (PJ/US$ billion)	Emission intensity (tonne of CO2/TJ)	CO2 tonne per capita
Australia	31.6	8.0	73.0	18.5
OECD	27.6	6.9	55.6	10.6
World	9.6	8.0	57.2	4.4

Note: all financial values are measured in 2000 US$, purchasing power parities.
Source: Based on data from the IEA (2008)

Because of its small population, Australia emits only 1.5 percent of the world's total greenhouse gas emissions. Nevertheless, Australia's per capita greenhouse gas emissions are the highest among all major greenhouse gas emitting countries in the world. Table 2.4

includes seven major greenhouse gas emitting countries with respect to total emissions and per capita emissions. These countries are listed as Annex I countries[3]. With respect to total greenhouse gas emissions, the United States ranks the highest among all Annex I countries and Australia ranks highest with respect to per capita emissions. Countries such as Luxembourg, Canada, and New Zealand report high per capita emissions due to small populations as compared to countries like the European Community (a group of countries), Russia, and Japan which produce larger total amounts of greenhouse gas emissions but rank low with respect to per capita emissions.

Table 2.4 Total and per capita greenhouse gas emission comparison of Annex 1 countries, 2008

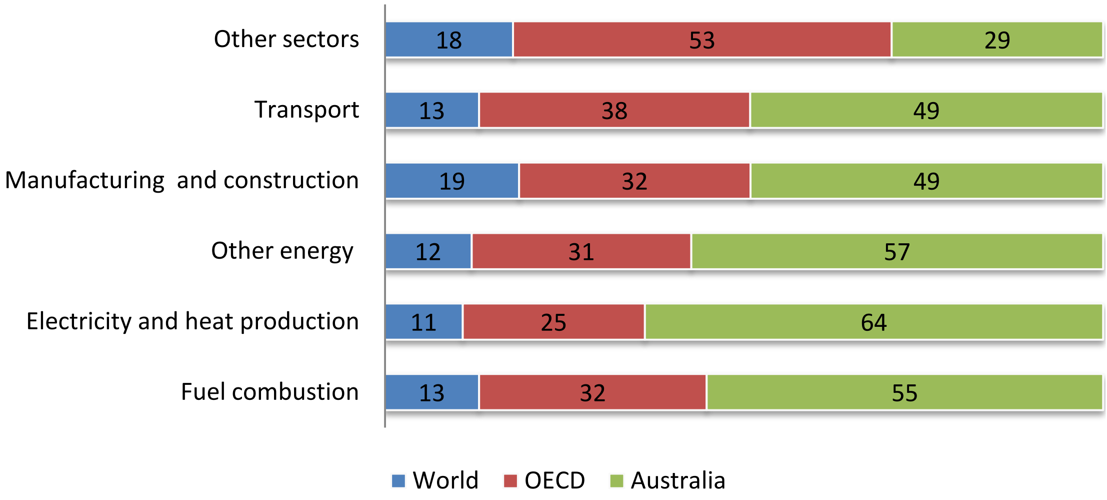
Country	Mt CO_2-e	Rank	Mt CO_2-e per capita	Rank
Australia	549.5	8	25.7	**1**
Luxembourg	12.5	37	25.6	**2**
United States	6924.6	**1**	22.8	**3**
Canada	734.4	6	22.0	4
New Zealand	74.7	23	17.5	5
Russian Federation	2229.6	**3**	15.7	6
European community	3970.5	**2**	10.1	22
Japan	1281.8	4	10.0	23

Source: Based on data from CAIT–UNFCCC (2008)

Figure 2.13 illustrates the percentage contribution of per capita greenhouse gas emissions by Australia, average OECD and average world. This demonstrates the reason for exceptionally high emissions intensity in Australia as compared to OECD and world averages. As shown, Australia generates relatively high per capita emissions due to fuel combustion, electricity and heat production and other energy related industries. Australia's percentage contribution of per capita emissions due to electricity and heat production was two-thirds of both OECD and world averages. This is due mainly to high carbon emissions reported per kilowatt hour of generated electricity as compared to average OECD and the world (see Figure 2.14).

[3] Annex 1 countries include the industrialised countries that were members of OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economic transition.

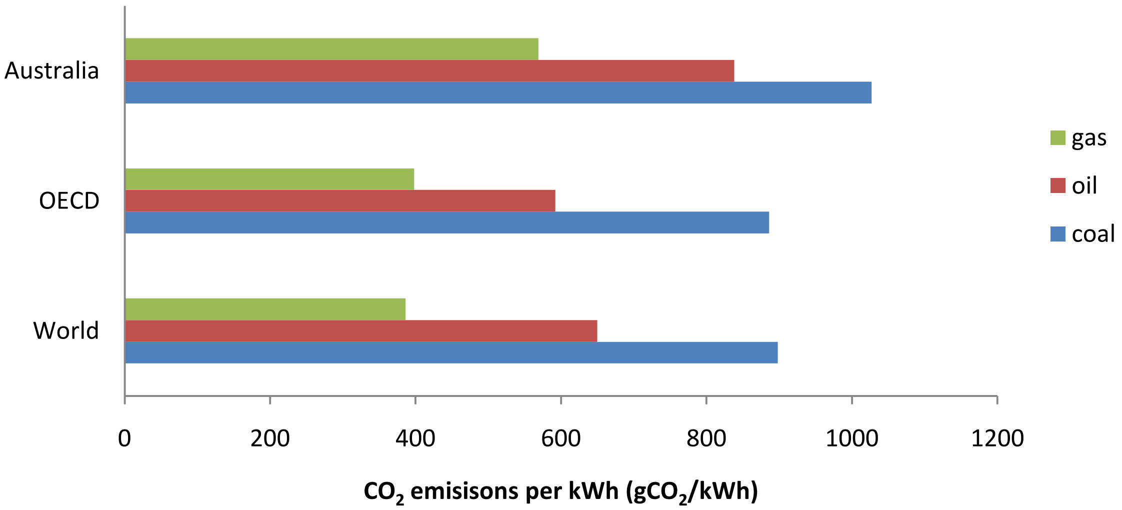
Figure 2.13 Percentage contribution of per capita emissions by sector, 2008



Source: Based on data from the IEA (2008)

The emissions intensity of electricity and heat generation is significantly higher in Australia for all three major fossil fuels (coal, gas and oil) per kilowatt hour (kWh). It is 14 percent and 16 percent higher for electricity generated using coal, 29 percent and 42 percent higher for electricity generated using oil, and 47 percent and 43 percent higher for electricity generated using gas than world and OECD averages respectively (Figure 2.14).

Figure 2.14 CO_2 emissions per kWh from electricity and heat generation, average 2008



Source: Based on data from the IEA (2008)

There are only three OECD countries with electricity systems using coal that are more emissions intensive than Australia – Belgium, New Zealand and Turkey. There are also only eight countries in the world with higher emissions intensive electricity systems than Australia – Bahrain, Botswana, Cambodia, Cuba, India, Kazakhstan, Libya and Malta (Garnaut, 2008).

2.4 Development of a greenhouse gas mitigation policy framework in Australia

Australia's greenhouse gas mitigation policy has a direct impact on its energy sector and the economy. As discussed earlier, this is because emissions largely result from the use of emissions intensive fossil energy sources and the significant role played by the energy sector in the economy. As noted Australia is a small contributor to the world greenhouse gas emissions in total, but per capita emissions are highest among many OECD countries and the world. The resultant consequences of greenhouse gas emissions i.e. global warming are widely spread throughout the world irrespective of the emitters. Therefore, Australia is legally committed under international agreements on climate change - UNFCCC (United Nations Framework Convention on Climate Change) and the Kyoto Protocol - to take measures to control emissions.

Development of a greenhouse gas mitigation policy began to emerge on the Australian political and policy landscape during the mid-1980s. In 1992, Australia ratified the UNFCCC and became the eighth sovereign state to ratify the Convention. In the same year, the Australian government adopted a National Greenhouse Response Strategy (NGRS) which set out a range of voluntary low and no-cost measures to achieve emission reduction targets. Since then, many changes have happened within the Australian political parties towards implementing a carbon tax policy. During the evolution of a carbon tax policy in Australia, various energy sector lobbying groups have had a strong influence. For instance, the energy, mining and transport sectors lobbied the Federal Government not to implement a carbon tax when it was introduced under the NGRS program. Later, the NGRS program was replaced by a new package called *Greenhouse 21*. As a result of this lobbying pressure, this package also failed (Christoff, 2008). Next, when the Government leadership changed to John Howard in

1996, Australia's national climate policy was redefined on the basis of protecting '*Australia's national interests*'. This emphasised supporting fossil fuel energy use and exports and the development of energy intensive manufacturing industries such as aluminium and magnesium smelting.

In 1997, the Prime Minister's *Safeguarding the Future* package set out measures re-emphasising the importance of protecting Australia's national economic growth and energy security. The Australian Greenhouse Office (AGO) was established and given responsibility for innovative market based climate change policy measures - one of these being the Mandatory Renewable energy Target (MRET). The MRET was designed to promote Australian electricity retailers and wholesale electricity customers to source a specified fraction of their electricity from renewable energy. The market design of this scheme is based on a 'baseline and credit' approach which includes tradable renewable energy certificates each representing 1MWh of eligible generation.

Australia's unique economic circumstances in relation to energy were among the key reasons why Australia joined with the United States calling for binding targets on developing countries. At the Kyoto negotiations, Australia's particular national circumstances were considered and Australia's allowable emissions reduction target was extended. Accordingly, Australia's reduction in emissions level was allowed to be 8 percent above the 1990 emissions over the Protocol's first commitment period of 2008-12. In order to make compliance easier, Australia and all other Annex B countries[4] were allowed to trade permits between countries (emissions trading) and to use offset credits from emission reduction projects in developing countries (clean development mechanism - CDM). Furthermore, Australia could extract concessions from the '*Australian Clause*' whereby land use-changes (i.e. deforestation) since 1990 were allowed to be added into the initial assigned amount. Although these arrangements

[4] Annex B – Group of countries included in the Kyoto Protocol that have agreed to a target for their greenhouse gas emissions, including all the Annex 1 countries (as amended in 1998) except Turkey and Belarus.

seemed to significantly reduce the burden on Australia to meet its first commitment period goal, Cabinet declared in 1998 that it would not ratify the Protocol unless the United States did so. The fear of losing Australia's comparative advantage enjoyed by the energy sector appeared to be the central issue for this decision. This was also evident in the then Prime Minister's address to the Business Council of Australia in 2006 (BCA, 2006, p 4):

> *"We have made it very clear that we won't ratify the Kyoto agreement – we took that decision some years ago because we feared that ratifying that agreement could have damaged the comparative advantage of this country enjoyed as a result of our abundance of fossil fuels and the importance of Australia's export and general performance"*.

At the time, the Labor Party (the then opposition party to the Government) supported the ratification of the Kyoto Protocol. This was seen on several initiatives taken at the State and Territory Government levels. For instance, the New South Wales (NSW) and Victorian State Labor Governments implemented measures to limit greenhouse gas emissions in their states. The NSW government established the NSW Greenhouse Gas Abatement Scheme which is the world's first greenhouse gas Emissions Trading Scheme (ETS). Several State Governments followed mandatory emissions reduction targets and the Queensland government implemented the *13%* Gas Scheme. All these initiatives were focussed on establishment of a National Emissions Trading Scheme (NETS) and in 2006 the first report of NETS was released by the Labor Party. The NETS contained an emissions reduction policy that puts Australia on a pathway to reduce emissions by around 60 percent compared with 2000 levels by the middle of the century. However, the then Australian Government position was still not to implement any form of an ETS.

The Labor State and Territory Governments were left alone to implement an ETS at the State level until the then Prime Minister announced the establishment of a joint government business Task Group on Emissions Trading in December 2006. The Task Group terms of reference emphasised Australia's special interest on preserving the energy sector (Australian Government, 2007, p 1);

> *"Australia enjoys major competitive advantage through the possession of large reserves of fossil fuel and uranium. In assessing Australia's further contribution to reducing greenhouse gas emissions, these advantages must be preserved".*

In parallel to the Government's action on the climate change mitigation plan, the Labor Party commissioned a report from Professor Ross Garnaut. Professor Garnaut was to examine the impacts of climate change on the Australian economy and to recommend medium to long-term policies and policy framework to improve the prospects of sustainable prosperity. The terms of reference of the Garnaut Review outlined the intended tasks to be undertaken and to report to the Governments of the eight States and Territories of Australia and, if invited to do so, to the Prime Minister of Australia. The final report was published in 2008. The Review described Australia's mitigation effort as a contribution towards an effective global agreement on mitigation and recommended Australia to implement an ETS with a transitional fixed price period from 2010 to 2012. This fixed price was recommended to continue until a comprehensive international agreement on mitigation was commenced. The ETS described by Garnaut (2008a) was an economically 'pure' ETS and contained the following features - broad sectoral coverage, no free allocation of permits, no price caps, quantitative limits of the use of international offsets, and limited transitional arrangements to the coal industry.

After the change of the government in 2007, the then Prime Minister Kevin Rudd ratified the Kyoto Protocol marking a significant milestone of Australia's action towards reducing greenhouse gas emissions. The new Government re-introduced the ETS policy under a new name - the Carbon Pollution Reduction Scheme (CPRS). Many design features of the CPRS were based on Garnaut recommendations. However, the Government acquiesced to industry lobbyists. Accordingly, and quite contrary to the Garnaut recommendations, the Government indicated a generous assistance package for polluters which included the following three main elements (Australian Government, 2008b).

1. Free permits to most Emissions Intensive Trade Exposed (EITE) activities.
2. Limited amount of assistance to coal-fired electricity generators to 'ameliorate the risk of adversely affecting the investment environment' (p 370).
3. Creation of two specific industry adjustment funds, the Climate Change Action Fund and the Electricity Sector Adjustment Scheme.

This industry assistance package was further relaxed in the CPRS White Paper (Australian Government, 2008c) which extended the 'limited amount' of assistance to coal-fired electricity generators giving $130.7 million free permits over five years. Amendments made in May 2009 to the CPRS proposed a further $750 billion in transitional assistance to the coal industry. Furthermore, free permits to EITE sectors were extended by 25 percent in the CPRS Bill 2009. All these arrangements were to please the industry lobbying groups and were contrary to the theoretical rationale of carbon pricing. Garnaut (2008, p 331) stated that '*free permits are not free. Although they may be allocated freely, their cost is borne elsewhere in the economy - typically by those who cannot pass on the cost to others (most notably, households)*'. When Garnaut was interviewed by the Sydney Morning Herald on 19 December 2008, he re-emphasised his argument against the Australian Government action saying that '*never in the history of Australian public finance has so much been given without public policy purpose by so many, to so few*'.

The CPRS was planned to be implemented in 2010. However, fierce divisions existed within the Australian Parliament. There were three groups within the Government: one group was the climate sceptics who opposed carbon pricing under any circumstances; a second group wanted the ETS to be delayed until other major emitters introduced similar measures; and the last group supported ETS. Furthermore, there was persistent pressure from industry lobby groups who attracted the support from climate sceptics. Finally, as a consequence of all these issues, the CPRS start date was deferred until 1 July 2011.

In 2010, Professor Ross Garnaut was once again commissioned by the Australian Government to provide an independent update to his 2008 Climate Change Review. This time the Garnaut Climate Change Review - Update 2011 released a series of papers which focus on new developments and consider whether the case for the conclusions drawn in 2008 has been strengthened or weakened. In particular, the updated paper six - carbon pricing and reducing Australia's emissions - once again confirmed that a market based approach with economy wide carbon pricing through an ETS or a carbon tax would be cheaper than regulatory approaches to reduce emissions. Furthermore, an ETS with a fixed carbon price was recommended initially over a floating price in order to allow firms to become familiar with compliance under the scheme. The recommended starting point for Australia's carbon price was in the range of $20 to $30 per tonne of carbon dioxide equivalent in 2012.

With regard to industry assistance on EITE sectors, Garnaut updated paper six stating that the CPRS Green Paper and White Paper were based on arbitrary and approximate judgments. Based on a principled approach, he suggested that the rates of assistance for moderately emissions intensive and highly emissions intensive industries should be 60 and 90 percent respectively. The CPRS White paper proposed these values to be 66 percent and 94.5 percent respectively. By reducing the industry assistance, EITE industries were expected to face a carbon price between $2.60 and $10.40 per tonne of CO_2-e assuming a carbon price started at around $26 per tonne. Therefore, rather than not paying a carbon tax such an arrangement is expected to encourage those EITE sectors to pay for their emissions.

In 2010, the new Prime Minister Julia Gillard entrusted the development of a carbon price policy in Australia to a Multi-Party Climate Change Committee (MPCCC). The objective of the Committee was to explore options for implementing a carbon price and building consensus on how Australia will tackle the challenge on climate change (DCCEE, 2010). The MPCCC comprises representatives of the Government, the Australian Greens and two independent Members of Parliament. The MPCCC released the *Clean Energy Agreement* in 2011 which contained measures to reduce carbon pollution, provide opportunities for innovation and investment in clean technologies, and reward improved land use management. The MPCCC proposed a fixed carbon price of $23 per tonne to be introduced from 1 July 2012. The fixed carbon price will be transformed into a fully flexible cap-and-trade scheme in the fourth year of the mechanism. The domestic trading scheme will be then linked to international carbon markets. The MPCCC recommendations were adopted and the *Clean Energy Legislation Package* passed by the Senate on 8 November 2011. The Legislation sets out ways and means of introducing a carbon price in Australia to reduce carbon pollution and move forward to a clean energy future.

2.5 Conclusion

This chapter set out the characteristics of Australia's energy sector with respect to supply and consumption. The energy sector is the biggest contributor to greenhouse gas emissions in Australia. This is because the majority of energy is produced from emissions intensive coal. As a result, Australia ranks highest in per capita emissions among the OECD and world averages. The Australian government announced its decision to implement a carbon price mechanism which is identified as one the most cost-effective and economically responsible ways of reducing Australia's carbon pollution. Given the background of carbon emissions associated with the energy sector and the current mitigation policy in Australia, the next chapter presents a discussion on alternative ways of modelling carbon price impacts on an economy. This discussion will show the theoretical rationale for selecting a computable general equilibrium approach to carbon price policy analysis.

CHAPTER III

Use of Computable General Equilibrium Models in Environmental Policy Analysis

Introduction

The objective of this chapter is to review the literature on the use of Computable General Equilibrium (CGE) models related to environmental policy analysis. The impact of government policies to control environmental problems such as air pollution, water quality and deforestation have been extensively analysed using CGE models, which are much more capable of indicating associated social and economic costs of many sectors in the economy compared to partial equilibrium models. Partial equilibrium models only estimate the cost of environmental policies by taking substitution processes in the production, consumption, and market clearing conditions in a given sector into account. CGE models allow for adjustment in all sectors, enabling interactions between many markets (goods and factors), and many institutions (household, government, corporations, rest of the world).

Section 3.1 discusses the use of fixed coefficient models namely input-output models and social accounting matrix based models in the environmental policy analysis. These models serve as precursors to the development of CGE models in many ways. The basic concepts of CGE models and applying these concepts in environmental policy analysis are discussed in Section 3.2. Section 3.3 includes a detailed review of Australian greenhouse gas abatement policies using various types of CGE models.

3.1 Fixed coefficient models in environmental policy analysis

Fixed coefficient models namely Input-Output (IO) models and Social Accounting Matrix (SAM) based models take fixed coefficients in production and consumption as well as market clearing conditions into account. However, models of this type treat substantial components of economic systems as exogenous (e.g. the volumes of final demand, labour supply) and hold relative prices constant. Therefore, these models are not capable of capturing price adjustments, non-linear substitution possibilities or supply and demand interactions that exist in a real world economy. However, these fixed coefficient models explain the inter-industry linkages of an economy that is embedded in CGE models. Basically, understanding the inter-industry linkages are important to incorporate environmental externalities resulting from private production processes into economic systems.

The theory of externalities in environmental economics characterises pollution as a public 'bad' associated with the production of private goods. Leontief (1970) explained a methodology to incorporate such externalities into the conventional IO model and to eliminate pollution from the economic system. For instance, the amount of pollution released from an industry depends on the technological characteristics of that particular industry. As such, the technical interdependence between the level of desirable and undesirable outputs can be explained in terms of structural coefficients. Leontief demonstrated this idea using a hypothetical two-sector economy which produces agricultural and manufacturing commodities. For instance, when the technical coefficients associated with the undesirable outputs are incorporated into the structural matrix[5] of the manufacturing sector, the decrease or increase in the level of pollutants can be realised as a change in intermediate demand, change in final demand or combination of the two. Accordingly, it is important to determine appropriate levels of technical input and output coefficients associated with pollutants. Therefore, Leontief's study provides an insight to understand how to incorporate externalities (public 'bad') into an economic system within the framework of an IO model, and various ways of internalising those externalities.

The development of a SAM paved the way to extend an IO table with additional information on institutions and production factors. This idea was pioneered by Sir Richard Stone (1961)

[5] Structural matrix shows the various levels of input requirements to produce one unit of output.

who integrated IO data with national accounts data. Since then, many SAM based models have been developed especially for developing countries. The interaction between the economy and the environment is considered as an important issue and there can be seen many studies incorporating conventional SAM with other environmental related issues. In the following discussion, SAM based models are reviewed in relation to developing interactions between the environment and the economy.

Resosudarmo and Thorbecke (1996) developed a SAM based model to link the economy to the environment and to obtain feedback from the environment to the economy. The improved environmental quality data on household incomes by different socio-economic classes is used to obtain feedback from the environment to the economy. For this purpose, they extended the SAM of Indonesia to include the link between production activities, ambient level air pollutants, and associated human health problems. This consolidated social and environmental accounting matrix is used to analyse the impact of policies designed to improve air quality on household incomes. The constrained fixed-price multiplier results suggest that policies designed to reduce the amount of pollutants in the air would improve the income distribution of household groups, especially the urban households. Improved air quality reduces household expenditure on health services, giving more chance to spend on other goods and services. As a result, domestic production expands employing more factors of production. Because factors (labour) are supplied from households, this effect improves household income.

Similar to the above approach, Xie (2000) also developed an Environmentally-extended SAM (ESAM) to provide linkages between the economy and the environment. The environmental component of this ESAM includes pollution related information such as pollution abatement sectors, sectoral payments for pollution cleanup, pollution emission taxes, pollution control subsidies, and environmental investments. The numerical ESAM presents 1990 Chinese data which included seven production sectors, three types of pollution (wastewater, smog dust, and solid waste) and three corresponding pollution abatement sectors. The intermediate input of the pollution abatement sectors were separated from those of the production sectors by following Leontief (1970). Next, the cleanup services of the three pollution sectors were estimated in the activity matrix, and payments for pollution (emission taxes) were represented in the factor account. Finally, the pollution abatement investment is transferred to the production sectors as investment consumption demands in the activity account. The advantage of using the ESAM over a conventional SAM in the multiplier and structural path analysis is that the ESAM provides simulation results with respect to the effect of a policy shock on pollution related activities.

In the case of Brazil, Lenzen and Schaeffer (2004) extended the common structure of a SAM to combine environmental and social accounts. Extensions to the conventional SAM include additional entries for non-renewable energy combusted energy content of fuel in the production or household consumption and carbon contents of combusted fuel in physical units. The multipliers calculated from this SAM not only show the interactions between the structure of production and distribution of income, but also the effects on energy resources and on the environment after a policy shock. Income multiplier analysis reveals that poor income groups spend more on energy and electricity which generates more carbon emissions. Because there is a strong correlation between electricity and carbon emissions, the gap between rich and poor could be further widened.

Likewise, various environmental issues have been integrated into SAMs of many countries. For instance, Weale (1997) incorporated land clearing and degradation, logging damage, and depletion of oil reserves into an Indonesian SAM. These indicators are incorporated as physical accounts and multipliers because these indicators evaluate additional requirements of exports that would match with increases in imports in order to maintain the balance of payments. Alarcon et al. (2000) described a methodology to extend the Bolivian SAM with social indicators (housing information) and environmental indicators (greenhouse gas emissions and fuel use). Morilla et al. (2007) used the Spanish Social Accounting Matrix and Environmental Accounts (SAMEA) to derive domestic production multipliers, emissions of greenhouse gases and consumption of water. These SAM structures suggest the vast possibility of incorporating environmental indicators into economic systems in order to evaluate environmental and economic efficiency.

The usefulness of SAMs extended with environmental indicators can be further enhanced by replacing fixed coefficients with production functions and demand models. This can be achieved in a general equilibrium framework which captures substitution effects of price and income changes. The following sections discuss the theoretical background of the CGE models and their uses in analysing environmental policies.

3.2 Computable General Equilibrium (CGE) models

CGE models are different from the Leontief type IO and SAM based models because in a CGE model technological coefficients are flexible and determined by relative prices. As such, a comprehensive analysis of policy options can be undertaken by combining IO or SAM with some parametric values into a CGE model, in order to capture the substitution effects of price and income changes. In a more generalised form, Dervis et al. (1982) defined a CGE model to be '*one where all prices are adjusted until the decision is made in the productive sphere of the economy being consistent with the final demand decisions made by the household and other autonomous decision makers*'(p 136).

More precisely, CGE models are concerned with converting the Walrasian general equilibrium structure of an abstract representation of an economy into a realistic model of an actual economy (Shoven and Whalley, 1984). Therefore, a CGE model is capable of handling not only perfectly competitive models with instantaneous market clearing but also compatible with imperfectly competitive behaviour with price distortions caused by government interventions. The inclusion of a Walrasian general equilibrium structure into CGE modelling is further elaborated in the recent work of the Global Trade Analysis Project (GTAP) of Hertal (1997), and the work of Ginsburgh and Keyzer (1997).

The first CGE model developed by Johansen (1960) is a multisectoral growth (MSG) model that combines the dynamic Leontief-type model with macroeconomic production and consumption functions. This model is an ideal example of the extension of the IO model with relative price-driven substitution possibilities. Johansen used a fixed coefficient assumption for the modelling of demand for intermediate goods but employed the linear logarithmic of the Cobb-Douglas production functions to model the substitution between capital and labour. The fixed coefficient assumption of household behaviour was replaced by a system of demand functions including Frisch parameters. Many models were inspired by Johansen's pioneering work (see for example, Dixon et al., 1982; Powell and Lawson, 1990; Vincent, 1990).

A related approach involves combining an IO model with macro functions based on econometric studies (see Hudson and Jorgenson, 1974, 1977; Jorgenson, 1984; Jorgenson and Wilcoxen, 1990). These models are used to develop econometric models of producer behaviour with a system of demand functions for inputs of capital, labour, energy and materials in each industrial sector. Each system is a stochastically specified sub-model showing quantities of input demanded as a function of prices and output. This branch of CGE models emphasise issues particularly related to energy and environmental policy (see for example, Bergman, 1988,1990; Conrad and Henseler-Unger, 1986; Lee et al., 1994).

Apart from differences between theoretical specifications of CGE models, CGE models can be further classified along various other dimensions. One such dimension is by geographic scope; single-country, multi-country and global models. Single country models are more appropriate in evaluating country-specific impacts (sectoral, household) of a policy change whereas multi-country and global models are suitable for evaluating impacts that are of concern by two or more countries. CGE models can also be classified depending on the inclusion of a time dimension, static or dynamic. A static CGE model replicates data for a single period whereas a dynamic model generates a time path for the variables included in the model.

There is a large body of literature on the use of CGE models investigating a variety of policy issues including tax policies, development issues, agricultural programs, international trade, energy and environmental policies etc. The focus of this study is to include a review of CGE models used in environmental policies. The following sections review the literature on CGE models designed to analyse environmental policies in general and the use of different types of CGE models to evaluate specific environmental policies in particular.

3.2.1 Use of CGE models in environmental policy analysis

The development of CGE models to address the economic impacts of environmental policies has become a popular policy analysis tool in recent years (Adams et al., 2007; Beghin et al., 1997; Cruz and Repetto, 1992; Forsund and Storm, 1988; Jogenson and Wilcoxen, 1990). Many anthropogenic environmental issues such as emissions of greenhouse gases, acid rain, deforestation, and waste disposal may interact directly with the production and consumption activities in the economy. Therefore, environmental policies designed to control air and water pollution, and deforestation raise the cost of output and distort factor markets implying higher social costs than the costs indicated by the partial equilibrium models (Conrad, 1999)[6]. CGE models estimate the cost of these policies while allowing simultaneous adjustments in all sectors of the economy.

[6] See for more comprehensive analysis of use of CGE models, partial equilibrium models and macroeconomic models for environmental policy analysis.

CGE models are useful whenever there are large numbers of production sectors and households, or when there are distortions in the economy. Generally, environmental policies generate direct impacts on few sectors of the economy while other sectors are also affected indirectly. Under such circumstances, a CGE model allows interactions between disaggregated industries, households and other institutions and between both the supply and demand sides. Therefore, a CGE model is capable of simulating impacts with respect to the economy as a whole as well as to a particular sector.

It is agreed on the basis of scientific evidence that the biggest contributors to the global warming are the developed countries who have been responsible for emitting greenhouse gases since industrialisation. Since the inception of the Kyoto Protocol, many global CGE models have been developed to identify the effects of ‘carbon leakage’ a phenomenon caused as a result of emission sources migrating from abating to non-abating countries. This has been found to be a major obstacle to unilateral emissions reduction policies. Accordingly, the development of regional or multi-country CGE models aims to analyse regional/multi-country environmental issues, or analyse the coordination of national policies within the region (see for example DICE (Nordhus, 1992; 1994), the Global 2100 model of Manne (1994), Manne and Richels (1994), the MERGE model of Manne et al. (1995), the OECD GREEN model of Burniaux et al. (1992).

By using a CGE model for environmental policy analysis, a policy maker cannot only assess the impacts of a particular policy on the economy but can also assess the interactions of several policies even under existence of distortionary taxes. For example, CGE models can be used to explain how the environmental taxes interact with other distortionary taxes, and how the revenues can be recycled back into the economy (most commonly discussed as double dividend hypothesis).

More specifically, almost all environmental problems are wider in terms of geographic, time and economic scope. This demands measures with potentially significant effects on the allocation of resources. As a result, the acceptance of the CGE models in the area of environmental policy analysis has been very prominent. Section 3.2.2 reviews the use of various CGE models related to climate change as a result of emissions of carbon dioxide and other greenhouse gases into the atmosphere.

3.2.2 CGE Models of greenhouse gas emissions

Since industrialisation, atmospheric concentration of greenhouse gases has drastically increased as a result of anthropogenic activities (IPCC, 2007b). These so called human induced greenhouse gas emissions are largely a consequence of the burning of fossil fuels. Basically, emission reduction policies will have varied impacts on those economies that are heavily reliant on fossil fuel related activities. As such, economists and policy makers need to be particularly aware of what the cost of reduction would be, the time frame for achievable outcomes, when to commence reduction, and which sectors will ultimately be affected or benefited by these changes.

The most popular market based approaches to emissions reduction are a carbon tax and a cap-and-trade system. This has links to the well-known Pigovian tax, a concept that has been discussed in the literature on public intervention by means of a taxation mechanism (Bovenberg and Goulder, 1996; Parry, 1995; Parry and Goulder, 1999). Economists have analysed implications of emissions reduction by way of taxes or cap-and-trade schemes using various types of CGE models. These models can be broadly categorised into static and dynamic models. The following sections review CGE models which fall into these categories broadly under the climate change policy modelling.

3.2.2.1 Static CGE models

Static CGE models deal with issues pertaining to a single year. Models of this type are useful to analyse immediate impacts of a policy shock on the macro economy, on sectors, and on household groups. Since the time factor does not come into modelling, the IO or SAM data combined with behavioural parameters (elasticities) for a single year is sufficient to derive macroeconomic and sectoral impacts. The following sections discuss uses of static CGE models to evaluate macroeconomic impacts, distributional impacts, and the double-dividend hypothesis of environmental policies in question.

Macroeconomic impacts

Devarajan et al. (2009; 2011) explored the possible economic impacts of alternative tax policies designed to mitigate CO_2 emissions in South Africa. The CGE model developed for this purpose represents energy use, energy taxes, and CO_2 emissions. The production structure of the model treats composite energy (coal, petroleum, electricity and gas) as a primary input and then allows composite energy to substitute imperfectly with capital. In order to evaluate the economic cost of carbon, CO_2 coefficients have been derived for each energy input. A carbon tax acts mainly as a factor tax since energy inputs are modelled as a primary factor in the production process. The model is simulated to cut 15 percent emissions under assumptions about two elasticity scenarios; a reference case and a rigid case. In the reference case, the elasticity of substitution among energy is set at 0.2 and between energy and capital is set at 0.4. In the rigid case, these values are halved. Results reveal that the carbon tax impact on GDP and consumption is less than 1 percent under both elasticity scenarios. The required carbon tax rates to achieve this level of emission cut are $22 per metric tonne under the rigid case and $13 per metric tonne under the reference case as measured in 2003 US dollars. The other two alternative taxes, namely sales tax on energy and sales tax on energy intensive sectors are found to be less efficient in terms of welfare. For example, the carbon tax reduced household welfare by 0.3 percent whereas a tax on energy intensive sectors reduces household welfare by 2.7 percent.

Similar to this study, Wissema and Dellink (2007) compared the effectiveness of a carbon tax and a uniform energy tax on the Irish economy. The carbon tax rate differentiates according to the energy factor of each energy source. The uniform energy tax is levied on all energy sources. They employed a static CGE model with seven energy commodities, 19 other commodities, a government, an investment agent, a foreign agent, and a single representative household. The model is calibrated with an energy SAM which has specified a detailed energy sector and an emissions matrix. The study revealed that a carbon tax is more effective in reducing emissions. However, uniform carbon and an energy taxes provide an incentive to reduce the use of energy, and to change the sectoral structure of the economy towards less energy-intensive production. In order to meet the target of 25.8 percent emissions reduction, Wissema and Dellink found the uniform tax rate needs to be higher (35 Euros per tonne of CO_2) than the carbon tax rate (10 Euros per tonne of CO_2).

In order to rectify the existing environmental tax system in Malaysia, Al-Amin et al. (2009) proposed an applied CGE model to evaluate the impacts of a new carbon tax policy. The objective of their study was to design a tax policy which enabled Malaysia to reach maximum benefits of trade and economic development while reducing further environmental degradation. The SAM for Malaysia is calibrated to the year 2000. In the simulations, three carbon tax rates are imposed on domestic products. Successively higher carbon taxes result in 1.21, 2.34 and 3.40 percent reduction in carbon emissions with incremental negative implications on production, consumption, investment, savings and exports. These results suggest a necessity for a trade-off policy between the environment and the economy. The larger cuts in emissions require higher carbon taxes which decrease GDP at an increasing rate. Therefore, the authors recommend the Malaysian government impose a 1.21 percent emission reduction which decreases GDP by 0.82 percent. Other main economic indicators, namely fixed capital investment, investment share of nominal GDP, and the government revenue increase by 0.43, 1.39 and 26.60 percent under this policy.

Usually, permit trading is viewed as equivalent to carbon taxation as both policies are incentive based and provide the least cost-mitigation measures (Pezzy, 1992). The Kyoto Protocol includes several flexibility mechanisms that can be linked to international permit trading. However, the Protocol does not specify ways and means of implementing a permit trading mechanism *within* a country. In order to further reduce the burden of permit trading on an economy, Rose and Oladosu (2002) defined an alternative permit trading scheme with various assumptions about permit allocations, industry coverage, revenue recycling, carbon mitigation and sequestration. With the use of a static long-run CGE model, they simulated the economic impacts of these alternative market instruments across industries and income groups in the US economy. This model is characterised by 41 production sectors, 4 factors of production, 10 household income groups and 2 government types. Simulation results indicate that a carbon permit price of $128 per tonne is feasible in order to comply with Kyoto targets, without exerting much pressure on the domestic economy. However, when alternative permits are considered, the price of a permit could be significantly reduced. For example, carbon sequestration and methane mitigation policies reduce the permit price to $43 and $33 per tonne of CO_2 respectively. These findings offer an insight for other countries to design alternative domestic mitigation policies along with a carbon mitigation policy in order to reap maximum benefit of environmental policies.

Bergman (1991) discussed general equilibrium effects associated with emission control programs aimed at reducing emissions of SO_2, NO_2 and CO_2. In order to estimate the emission control cost of pollutants in the Swedish economy, Bergman developed a static CGE model which specified emissions and markets for tradable emission permits. The production sectors of the model are classified into three types. The assumptions are based on the nature of price taking behaviour of the commodities in international markets under the standard Heckscher-Ohlin theorem and the Armington assumption. On the demand side, domestic, private and public consumption, and domestic gross investment are aggregated into the domestic end-use sector. Capital, labour, electricity and natural resources are the domestic, intersectorally mobile factors of production in the model. Some distinction between 'old' and 'new' capital in these sectors is specified in order to highlight capital intensive, electricity intensive, and emission intensive sectors. The production technology is represented by a nested CES-Leontief production function and the elasticities of substitution are taken to be the same for all sectors. Emissions are considered as generating from two sources - fuel combustion and industrial processes. The former is made proportional to fuel use while the latter is made proportional to the gross output. The simulation results suggest that the emission constraints imposed in the policy case have general equilibrium effects, with significant impacts on relative factor prices and the sectoral allocation of resources.

Distributional impacts

Analysis of distributional impacts of a CO_2 emissions reduction policy is necessary to identify which income group is most affected or which would benefit most. In most instances, distributional impacts are different between developed and developing countries. The majority of studies carried out in developed countries show that a carbon tax policy is regressive, while developing country studies indicate that a carbon tax policy is not necessarily regressive and, in some instances, can be progressive. In order to analyse this issue, Hamilton and Cameron (1994) employed a hypothetical carbon tax simulation model for Canada, including a CGE model, a cost-push model, a detailed energy disposition account, and a micro-simulation model of household expenditures. The CGE model suggests a carbon tax of US$101.56 per tonne of carbon is the most efficient policy. The cost-push model and a detailed energy disposition account are then used to simulate the direct and indirect effects of a carbon tax on domestic prices, particularly prices paid by final consumers. These price changes are applied to individuals, families, and households in a micro-simulation model. According to the cost-push model, the study reveals that consumer expenditure is most significantly affected by the tax. Furthermore, the micro-simulation model reveals that the distributional consequences of the carbon tax are moderately regressive.

In contrast to the regressive view of a carbon tax policy, Yusuf and Resosudarmo (2007) suspected that such a policy may actually have progressive impacts on households due to changes in factor prices or levels of employment after a policy change. They employed a general equilibrium model with some modifications to the standard ORANI-G model in order to investigate the distributional impacts of a carbon tax on Indonesian households. This model incorporated substitution possibilities of energy commodities, a CO_2 emission accounting framework, and multiple household income and expenditure accounts. The model is calibrated using a SAM with disaggregated households for the year 2003. In their simulation strategy, carbon tax revenue (US$32 per tonne of CO_2) is recycled through uniform cuts on commodity tax and uniform income transfer options. These simulation results suggest that the uniform tax cut is expansionary for all commodities, as far as macroeconomic impacts or aggregate welfare is concerned. The distributional impacts of the carbon tax are progressive in rural areas whereas in the urban areas impacts largely depend on how the revenue from carbon tax is recycled. Overall, the net impact nationwide is progressive under all scenarios. Therefore, this study encourages developing countries to reduce their carbon emissions as it is possible for them to benefit from desirable distributional implications while contributing to the global carbon mitigation action.

Similarly, Oladosu and Rose (2007) found a carbon tax was progressive in terms of the distribution of personal income. By employing a static, regional CGE model with four types of economic activities (production, consumption, trade, and investment) the authors simulated the aggregate, sectoral, consumption and income distribution impacts of a carbon tax policy. With regard to income distribution impacts, short-run results are more favourable towards the first four income classes. The last five income groups suffered most. The only exception is the decrease in demand for fuel/utilities and transportation across all income groups. Measures of welfare impacts on a carbon tax show a relatively improved outlook for lower income households in terms of percentage change in the per capita income. Furthermore, the Gini coefficient declined by around 0.15 percent in the short and long term, indicating that the carbon tax is mildly progressive.

Double dividend hypothesis

The double dividend hypothesis in environmental taxation promotes the recycling of revenues from environmental taxes to reduce other distortions in the tax system. In the first dividend, an environmental tax contracts demand for the polluting agent which reduces associated pollution. The second dividend is achieved if the revenue is recycled back to the economy to reduce other forms of distortionary taxes. For instance, a regular tax creates welfare losses while a pollution tax creates welfare gains after correcting for an externality (see for example, Baumal and Oates, 1988; Lee and Misiolek, 1986). Early surveys of double dividend hypothesis can be found in Bosello et al. (2001), Bovenberg (1995), Bovenberg and Goulder (1998, 1999), Goulder (1995), and Schob (1997).

Labandeira et al. (2004) proposed a methodology to explore the double dividend arising from environmental taxes. They employed a static, energy-focussed CGE model of a small open economy with four energy commodities (coal, oil, gas, electricity) in the production factor specification. The CO_2 emissions data were obtained for each sector. With the introduction of a carbon tax, sectors with high carbon emissions contracted (for example electricity, transport, and chemicals). When the carbon tax is revenue neutral (i.e. the tax revenue is used to cut labour taxes), the most immediate effects are seen on the reduced marginal wage rate paid by employers and increased labour demand. The social welfare gain, measured as equivalent variation in real terms, experiences a 256 million Euro increase which provides an environmental improvement (first dividend) of 221 million Euro and a fiscal improvement (second dividend) of 35 million Euro.

McKitrick (1997) considered five revenue recycling policies namely lump-sum transfer to households, goods and services tax reduction, corporate income tax reduction, personal income tax reduction, and payroll tax reduction to implement a double dividend case of the carbon tax in Canada. A static CGE model is used to assess carbon emission control policies by calculating coefficients which relate fuel use to CO_2 release. Other than fuel, certain manufacturing industries such as ammonia and cement production are also considered as major emitters of CO_2. The carbon tax rate is determined endogenously in order to achieve a 12.5 percent emissions reduction against the base year 2000. Results indicate that the carbon tax revenue recycled through lump-sum transfer to households, GST reduction and corporate income tax reduction scenarios are not welfare improving. However, the case of a carbon tax recycled through payroll tax reductions and personal income tax reductions do generate welfare improvement. The McKitrick study gives a broader theoretical insight for analyses of double dividend environmental taxation under alternative revenue recycling options.

3.2.2.2 Dynamic CGE models

In most instances, the impact of climate change policies will be felt over a long period once policy adjustments regarding technology, production and consumption have taken place. These changes will determine investment policies in the economy as dynamic general equilibrium models are employed to evaluate various macroeconomic, sectoral and other impacts in those economies.

Conrad and Schroder (1991) employed a dynamic applied general equilibrium model to measure the trade-offs between various goals of environmental and economic policy. They modelled the impact of abatement activities on economic growth and on environmental quality. The treatment of capital as a quasi-fixed input and the introduction of adjustment costs in changing capacities, allows the model to differentiate the short-run equilibrium state from the long-run equilibrium state. Economic effects of an emission standard and a uniform emission tax are compared employing a dynamic CGE model. The model is calibrated using data from 1985 through to 1996 using an extended IO table with additional matrices for emission coefficients and abatement activities. Conrad and Schroder found that an emission tax reduces unemployment and increases social welfare through redistribution of revenue collected from taxes whereas environmental standards contribute to a high unemployment rate. Furthermore, emission taxes reduce emissions through input substitution and as a result require less pollution abatement activities. They demonstrated numerically the superiority of emissions taxes over command-and-control regulations.

The dynamic CGE model developed by Telli et al. (2008) used estimates of average population growth, investment behaviour, and total factor productivity growth for 15 years. Ten production sectors are defined in the dynamic CGE model which included four energy sectors and six greenhouse gas emission intensive sectors. A carbon tax is introduced on production, on intermediate input usage, and on consumption. The revenue of these taxes is directly added to the government revenue pool. The study focussed on implementing tax and quota based instruments with and without an investment policy. All policy scenarios were projected over the period of 2003-2020 after calibrating the parameter values for the base-run reference scenario. The study found a taxation policy produced viable results in comparison to a quota based policy. However, these energy/carbon taxes suffer from very adverse employment effects. Therefore, this study suggests the necessity to reduce the existing tax burden on producers to achieve an effective environmental policy.

Zhang (1998) focussed on modelling the energy sector and its linkages to the Chinese economy using a time recursive dynamic CGE model. The model has 10 production sectors, with disaggregated energy sectors by coal, oil, natural gas and electricity. The energy composite and the capital-labour composite derive the primary factor composite under the constant elasticity of substitution assumption. At the top level, the primary factor composite and intermediate inputs are combined using Leontief production functions to derive gross output. The explicit time dimension in the model allowed for autonomous energy efficiency improvement that is unrelated to price increases in the economy. Other features of this CGE model included endogenous substitution among energy inputs with alternative allocation of resources and endogenous determination of foreign trade and household consumption. The simulation results of the baseline scenario depict a rapid growth of the economy until the year 2010, followed by increases in energy consumption and CO_2 emissions. When a carbon tax is introduced to reduce year 2010 emissions by 20 and 30 percent, the Gross National Product (GNP) reduces by 1.5 and 2.8 percent and welfare drops by 1.1 and 1.8 percent respectively. These results confirm that the associated GNP and welfare losses tend to rise more sharply as the degree of emission reduction increases. The model also incorporated a mechanism to reduce the adverse effect of carbon tax through revenue recycling.

The calibration approach to CGE modelling specifies the nature of substitutability among inputs by assumption. In contrast, an econometric approach uses empirical evidence to determine substitutability among inputs. Glomsrod et al. (1992) employed an econometric approach to analyse the impacts of greenhouse gas emissions restrictions on the economy. In order to estimate the overall cost of CO_2 emissions control policy, they used a carbon tax model (modified MSG) and two sub models of emissions to air and non-economic welfare. Emissions are calculated based on projections of fuel use and industrial process activity from the MSG model. Supply of fuel is set exogenously and the carbon tax is set endogenously. The model compared a baseline scenario to a control scenario after 10 years, assuming that no other country introduced similar measures. The carbon tax showed an increasing trend over the years and the impact on the economy is seen by declining GDP, imports, exports, private consumption and investments. The overall export sector contracted due to a contraction in oil and gas exports and traditional exports. However, the economy is restructured towards non-exporting sectors and labour intensive sectors over time. From the consumption point of view, substitution away from heating fuel, petrol and the purchase of cars are observed. Non-economic welfare has substantially increased due to the reduction in fossil fuel use which emits a number of pollutants including CO_2.

Moving further deep into pollution abatement modelling, Dessus and O'Connor (2003) noted that the primary benefits of climate change policy are mostly global and have a very weak influence on a particular country. In contrast, ancillary benefits of climate change policies are confined to the domestic country and simply observable during short time spans. In order to investigate such ancillary benefits of a climate change policy, Dessus and O'Connor developed a dynamic CGE model for the Chilean economy. The model is calibrated using the 1992 SAM which is updated to 1995 and with the results simulated for the years 1995, 2000, 2005 and 2010. The model provides for substitutions among four energy commodities (coal, refined petroleum, gas and electricity) and includes a matrix of sectoral emission coefficients for six air pollutants. The indirect benefit associated with the pollution abatement is indicated by human mortality which is calculated outside the CGE model. Policy simulations are conducted to determine the amount of CO_2 emission reduction without welfare loss after considering indirect benefits, the optimal level of carbon tax, and the tax impact on energy prices and real GDP. Their findings suggest that the resulting welfare benefits exceed the cost associated with the carbon tax policy. Furthermore, the sale of carbon credit at the world market price is recommended to reduce the welfare losses associated with the carbon tax policy.

3.2.3 CGE models of trade and environment

Most studies that have addressed the role of international trade and its effects on the environment found that trade liberalisation harms the environment unless accompanied by appropriate mitigation policies (Antweiler et al., 2001; Li, 2005; Machando et al., 2001). Similarly, Anderson and Blackhurst (1992) and Cordon (1997) claimed that the most favoured nation status trade liberalisations will always improve global economic welfare, even in the presence of environmental externalities, provided that optimal environmental policies are in place.

For a small open developing country like Malaysia, Jaffar et al. (2008) suspected that a carbon tax would significantly reduce the economic growth under a backdrop of trade liberalisation. This idea was modelled using a static CGE model calibrated to the 2000 SAM of Malaysia. Three simulation scenarios are implemented: the impact of a more aggressive trade liberalisation policy; the output-specific carbon tax; and the combination of the two scenarios. An aggressive trade liberalisation policy scenario where tariff and export duties are halved causes household consumption and carbon emissions to increase. However, this policy decreases net exports, government revenue and GDP. The output-specific carbon tax scenario increases government revenue while allowing substitution between energy commodities. The combined policy scenarios indicate that revenue raised from a carbon tax is greater than the decline in consumption. The study shows that further trade liberalisation positively affects household consumption and carbon emissions and negatively affects exports, government revenue and GDP. Because the revenue raised from the carbon tax outweighs the loss in consumption, the authors recommend returning the tax revenue back to consumers via either a tax rebate or reducing the existing tax burden on consumers.

When the impacts of environmental externalities such as resource depletion and water and air pollution are considered, further attempts to liberalise trade are questionable. Strutt and

Anderson (2000) tested whether trade liberalisation increases environmental deterioration, using Indonesia as a case study. For this purpose, they employed a modified version of the global CGE model (GTAP) to project structural changes of the economy with and without trade reforms. The environmental module is incorporated to measure the effects of changes in economic activity on air and water pollution in Indonesia. The findings of this case study suggest that trade policies improve the environment with respect to air and water quality and reduce the depletion of natural resources.

International trade in carbon emission rights is another prospective area of environmental policy analysis. This is because these CO_2 restrictions could lead to dislocate sectors which produce energy-intensive goods to countries where there are no such carbon restrictions (the concept called 'carbon leakage'). Perroni and Rutherford (1993) tested whether CO_2 restrictions on the use of fossil fuel affect international trade and the pattern of comparative advantage. A static CGE model calibrated to a bench mark equilibirum year 2020 is employed with the expectation that trade in carbon emission rights may play a significant role during that time. This model contains four internationally traded commodities: oil, basic intermediate materials, carbon rights and an aggregate non-basic, non-energy product. All these commodities are homogenous and freely traded in international markets. The model estimated a global carbon tax rate of $274 per tonne when emission rights are tradable, and a carbon tax rate of $344 per tonne when emission rights are non-tradable. The model results also confirm that carbon taxes depress international oil prices and create incentives for trade in natural gas between economies.

The Joint Implementation (JI) is a supplementary instrument enabling countries ratified under the Kyoto Protocol to curb emissions at a cheaper cost. Bohringer et al. (2003) explored the possibility of undertaking a JI between Germany and India, allowing Germany to buy part of its emissions reduction from India. They investigated whether an environmental tax reform *cum* JI provided employment and overall efficiency gains as compared to a domestic mitigation policy. The simulations are carried out using a large-scale CGE model with the assumption that Germany will be able to implement a JI with the Indian electricity sector. The model allows for substitution among energy goods and carbon intensive non-energy goods. A sector specific resource (fossil fuel) is treated as one of the factors of production other than labour and capital in both countries. As one might expect, JI significantly lowers the level of carbon taxes to achieve a certain level of emission reduction in Germany. Furthermore, JI reduces the negative effects on labour demand and triggers direct investment demand for energy efficient power plants in Germany. On the other hand, JI offers scarce capital goods for India in order to generate electricity more efficiently. As a result, prices of electricity will be much lower providing substantial welfare gains to its consumers.

3.2.4 CGE models of natural resources

From an economic perspective, environmental problems most often arise due to lack of well-defined and enforceable property rights. Climate change is one of the examples of this principle. The other example is the depletion or degradation of natural resources. Depletion or degradation of natural resources is a main concern for those economies which are highly dependent on natural resources like forests, fisheries, water, and land (for agriculture and grazing).

Xie and Saltzman (2000) employed a multi-sector CGE model to analyse the economic impacts of environmental policies such as pollution taxes and subsidies. For this purpose, they first developed an ESAM of the Chinese economy. The model integrated various pollution control activities with economic activities. Hence, the profit maximising and utility maximising behaviour of the producer and the consumer is redefined to include pollution emission and pollution control activities. The simulation results indicate that as the tax rate goes up, there is a steady decrease in production and a steady increase in the price index. As a result, the unemployment rate increases and pollution generation decreases. The impacts are reversed when a subsidy is given to the industry which generates pollution. Interestingly, subsidies decrease the output of less polluting or pollution-free sectors, such as agriculture and services. This is because capital intensive energy and mining sectors become more cost effective due to a reduction in their pollution abatement costs. As a result, these sectors compete with tight capital resources in the economy.

A CGE model with a broader specification of natural resources was developed by Abler et al. (1999). The natural resource components of the model included deforestation and overfishing. Environmentally related problems such as pesticide usage, wastes, and greenhouse gas and air pollution are also incorporated. The model is calibrated to a SAM using data for Costa Rica for 1985-89. Each indicator is assumed to be a linear function of variables specified in the CGE model. Even though this study mainly focussed on assessing the parameter uncertainty of CGE experiments, the model characteristics are essentially related to environmental CGE modelling. A series of Monte Carlo experiments are used to find parameter uncertainty of the environmental indicators due to economic policies, namely trade liberalisation and government spending. The results show that the deforestation and depletion of fish stock increase both under trade liberalisation and increased government spending policies.

3.3. Australian CGE models for greenhouse gas control policies

Dixon et al. (1977) pioneered the ORANI model which is a large CGE model of the Australian economy with more than 100 industry sectors. Deviating from the well-known Johansen class multisectoral models, ORANI allows for one industry to produce more than one commodity, an appropriate definition for modelling Australian agriculture. ORANI is the first model developed to analyse the effects of tariff cuts on industries, occupations and regions in Australia. Due to the flexibility in the reclassifying of variables between the exogenous and endogenous categories, ORANI showed the potential to be used for analysing various alternative policy scenarios.

McDougall (1993a) produced short-run costs of Australia's greenhouse gas abatement by employing an enhanced version of the ORANI multisectoral model (Adams and Dixon, 1992). This version contained a detailed fossil fuel use structure. Since the model did not specify the flexibility of fuel mix and energy use by all economic activities, the required tax rate needed to reduce carbon dioxide emissions to the target level over the long-run (20 percent below 1988 by the year 2005 as per given in the Toronto target) is estimated using another purpose-built ORANI model. A carbon tax of $19 per tonne is applied to domestic fuel usage which excludes exports and domestic non-fuel use. The results show that the carbon tax raises output prices, especially prices of energy intensive commodities. The impact on export competitiveness in trade exposed industries, both export-oriented and import-competing, is seen by the contraction in export volume (-0.6 percent). Given the fixed domestic absorption assumption, the fall in exports led to a fall in GDP by 0.9 percent. The estimated employment loss is 1.2 percent. In response to a rise in consumer prices, wages fell by 1.9 percent. The sectors adversely affected are metal production, mining and electricity, gas and water for which outputs contracted by 6.5, 5.8 and 3.4 percent respectively. However, less energy-intensive industries benefit from the tax induced change in the composition of household consumption. Employment impacts are unevenly distributed with a significant fall in plant and machine operators and drivers (-2.9 percent) and labourers and related workers (-1.5 percent).

The ORANI-E is another enhanced version of the ORANI model of the Australian economy. This model contains several energy specific enhancements embedded into the database as well as into the theoretical structure of the model (Dixon, et al., 1982; Powell and Snape, 1993). In the database, fossil fuel is disaggregated into six commodities and the electricity industry into seven industries with six types of generating technologies and one end-use electricity supply industry. The production structure uses the flexible nesting facility to model energy and capital substitution, inter-fuel substitution, and substitution between different electricity generating technologies. This version of ORANI-E is used to simulate the long-run effects of an energy tax which is levied on fossil fuels on consumption (McDougall, 1993b). The main simulation represents the introduction of an energy tax while two alternative energy related taxes are introduced for comparison namely a carbon tax and a tax on petroleum products. The results show that both the carbon and energy tax reduce carbon emissions and fossil fuel energy consumption. The energy tax is only 70 percent as effective as the carbon tax. However, the petroleum product tax is not as effective in reducing emissions or reducing energy consumption. With regard to macroeconomic effects, both energy and carbon taxes reduce national consumption by 0.07 percent and real GDP by 0.5 percent. The outputs of the mining, metal products and electricity, gas and water sectors reduce under both energy and carbon taxes. Therefore, McDougall concluded that a broad-based energy tax would be comparable in effectiveness to a carbon tax. Both taxes induce emission abatement through fuel switching whereas a petroleum tax cut excludes cheaper fossil fuels giving rather ineffective policy outcomes.

The MONASH model (Adams et al., 1994), the successor to the ORANI model is a dynamic single region model that has been used to model the impacts of policy changes for year-to-year growth patterns. Asafu-Adjaye (2004) employed an aggregated version of the MONASH model to simulate the impacts of environmental policies in the Australian economy. Two environmentally related policies are analysed using this model: a forest conservation policy which applies downward shocks of 10 and 5 percent on wood exports; and a CO_2 emissions reduction policy which imposes an annual sales tax of 1 percent on utilities. Results are forecast for seven years and are divided into two periods - the short-run (years 1-3) and the long-run (years 4-7). The results show that taxes on wood chips and utilities contract real output, real consumption and aggregate employment in the short-run. However, in the long-run, there is a growth in real output by 6 percent, real consumption by 4.4 percent, and aggregate employment by 6.4 percent. The above results confirm that following a period of adjustment these policies lead the economy to expand as a response to input substitution and an increase in the productivity of input use.

The dynamic single region MONASH model and the comparative static Monash Multi-Regional (MMR) model have been used to develop the MMRF-Green (Adams et al., 2000a) model which is a dynamic, multi-sectoral, multi-regional CGE model with detailed environmental specifications of the Australian economy. The environmental capabilities of the model include an energy and gas emissions accounting module, equations describing inter-fuel substitution in electricity generating by regions, and mechanisms for the endogenous take-up of abatement measures in response to greenhouse policy measures. However, the expression of the substitution effect is only operational under a dynamic long-run simulation setting. In a static simulations setting when the technology is assumed to be unchanged, all these substitution effects disappear.

The MMRF-Green model is used to simulate the effects of a domestic cap-and-trade permit system with auctioned permits to meet Kyoto Protocol commitments (Adams et al., 2000b). A tax rate of $44.33 per tonne of CO_2 equivalent emissions (assuming a zero transaction cost for a permit price) is applied on fuels and output of industries that release emissions. The tax revenue is recycled back into the economy as a uniform reduction in *ad valorem* taxes on household consumption, similar to the sale of permits. The effects of the emissions tax on economic variables and on emissions are measured for the period 2003-04 to 2011-12, in percentage deviations relative to the baseline projection. The short-run simulation results show reduced investment (mainly in the construction sector) and, therefore, reduced employment. In the long-run, a decline in wages stimulates producers to substitute labour for capital. The study identified sectoral impacts from the emissions reduction policy in the long-run. Accordingly, electricity generating technology is substituted away from high emission technologies (black coal and brown coal) to low emission technologies (gas and oil). The changes in generating mix and abatement possibilities built into the model result in a rise in fuel prices. This mainly contracts exports of energy-intensive industries (aluminium) and domestic demand for energy (oil and natural gas). The agriculture and mining sectors are negatively affected by the policy as the model incorporates a tax on activity-related emissions.

Other CGE models namely GTEM and G-cubed are also used as potential tools for climate change policy modelling in Australia. Since both these models are global CGE models, Australia is represented as one of the regions in the model structure. The GTEM has evolved from the MEGABARE model developed by ABARE (1996) and the static GTAP model (Hertal, 1997). MEGABARE is a dynamic CGE model of the world economy which was developed to address climate change policy issues. It contains 50 industries and 45 countries. In the production structure, the MEGABARE contains intermediate inputs, energy inputs and three factors of production (land, labour, and capital), with substitution possibilities allowed between labour and capital. A unique feature of the MEGABARE is its use of the technology bundle approach in modelling electricity, iron and steel production. This approach permits substitution between energy intensive technologies in response to changes in relative prices to ensure emission abatement.

Using an aggregated (16 commodities and 19 regions) version of the MEGABARE model, Kennedy et al. (1998a) analysed two policy options of particular relevance to Australia: independent abatement; and abatement with an international scheme of tradable emission quotas. In the model, a carbon tax is imposed on carbon dioxide emissions and the revenue from the tax is assumed to be returned back to the economy as a lump-sum transfer. The study claims that the emissions trading scheme will reduce economic costs to Annex B countries compared to individual abatement efforts. Furthermore, coal, iron and steel and non-ferrous metal production are less affected under the emissions trading scheme. This study suggests countries enter into an internationally tradable emissions trading scheme in order to reduce economic costs associated with structural change and sectoral impacts induced by abatement policies.

Following a strong critique of the MEGABARE (see for a detailed discussion on the possible drawbacks displayed in the MEGABARE model is found in Hamilton and Quiggin, 1997) a new model evolved. This new model is titled GTEM and was derived from the MEGABARE and the static GTAP model (Hertel, 1997). The GTEM model is also a multi-commodity, multi-regional, dynamic CGE model, with a better specification of the greenhouse module. The wider coverage of emission accounts provides better estimation of carbon equivalent leakages (that is partial offsetting of emissions reductions in abating countries by increases in emissions in non-abating countries). Kennedy et al. (1998b) and Fisher (1999) used the GTEM model to simulate impacts of a carbon tax under two policy environments: independent abatement and a scheme of international tradable emissions quotas. The results find that international trading would substantially reduce the cost of meeting Annex B countries targets specified under the Kyoto protocol.

The G-Cubed model developed by McKibbin and Wilcoxen (1992) and updated by McKibbin and Wilcoxen (1995) is also used in greenhouse gas policy analysis in Australia. It is a dynamic inter-temporal general equilibrium model in which the world is divided into 8 regions. Australia is one of the regions, and each region has five energy and seven non-energy sectors. The model provides an analysis for both short-run and long-run growth forecasts of macroeconomic policy. Furthermore, all agents including consumers, producers, and investors are assumed to be engaged in a forward looking optimising behaviour. The key characteristic of this type of modelling is the consideration of the adjustment path equilibrium and the use of macroeconomic models explaining individual behaviour and sectoral composition. Key insights drawn from the studies using the G-Cubed model find that a carbon tax in Australia will lead to a significant reduction in real economy-wide output in the short-run (McKibbin, 1997).

3.3.1 Australia's Treasury carbon price modelling

The Australian Treasury used a suite of three top-down CGE models namely GTEM, G-Cubed and MMRF to analyse climate change mitigation policies in Australia. While MMRF is a detailed model of the Australian economy with state and territory level detail, the two other models are global models with Australia represented as one of the regions. Several bottom-up sector specific models of electricity generating, road transport, agriculture and forestry sectors and household distribution complement the macro results drawn from these CGE models. The detailed modelling framework and results are included in the Treasury modelling reports (Australian Government, 2008a; 2011a).

In 2008, the Australian Treasury examined various macroeconomic, sectoral and household impacts under four alternative scenarios of emission reduction, relative to a reference case by employing GTEM, MMRF and G-Cubed models (Australian Government, 2008a). The scenarios are drawn positioning Australia within the context of global action to reduce greenhouse gas emissions and to stabilise greenhouse gas concentrations at 450-550 parts per million (*ppm*) around the year 2100. Two scenarios (CPRS-5 and CPRS-15) examine the potential cost of a medium to long term transformation of the Australian economy assuming a multi-stage global action, where all countries participate in a global emissions trading scheme gradually from 2010 to 2025. The other two scenarios are drawn from the Garnaut Climate Change Review (Garnaut-10 and Garnaut-25) and these scenarios assume that all countries will participate in an emissions trading scheme from the year 2013 (Garnaut, 2008).

The four policy scenarios use market-based policy mechanisms to reduce greenhouse gas emissions around the world, including Australia. An emissions pathway (expressed in CO_2-e emissions) is constructed for each scenario within the models with an assumption of 4 percent growth of emissions price per year from a specific starting point. The Treasury estimates using GTEM show that the lower the emissions level, the higher the starting emissions price. For example, CPRS-5 and Garnaut-10 scenarios are consistent with the stabilisation of greenhouse gases at around 550 *ppm* CO_2-e in the year 2100, with corresponding emission prices of US$23 and US$27 per tonne of CO_2-e, respectively. In the other two scenarios, CPRS-15 and Garnaut-25, the starting prices of emissions are US$32 and US$47 respectively, where the CPRS-15 scenario is consistent with stabilisation at around 510 *ppm* CO_2-e, and the Garnaut-25 scenario is consistent with stabilisation at around 450 *ppm* CO_2-e in the year 2100. These emission estimates are similar to MMRF estimates for Australian permit prices. However, the G-Cubed estimates are largely different from the GTEM and MMRF for the same emissions scenarios. A lower emission price in the G-Cubed model is due mainly to the forward-looking behaviour of the model which brings technological substitution forward. Thus, the G-Cubed model forecasts low transaction costs. However, the G-Cubed model suggests a higher per dollar mitigation cost in early years and, as a result, the economic costs of mitigation are comparable between all three models.

In 2011, the Treasury once again undertook a modelling exercise using two carbon price scenarios ($20 and $30) to be implemented in 2012-13 (Australian Government, 2011a). In the core policy scenario ($20), Australia's gross national income is expected to grow at an average rate of 1.1 percent per year from 2010 to 2050. In the meantime, the expected emissions reduction is substantial with the introduction of a carbon price and Australia is expected to meet the emissions reduction target of 5 percent below 2000 levels in 2020 and 80 percent below 2000 levels in 2050. As expected, carbon pricing drives a structural change towards low carbon emission-intensive products and production processes, and away from more emission-intensive sectors. In the estimation of household impacts, the Treasury used a $23 carbon price in 2012-13, and the impact on the overall price level is 0.7 percent. After incorporating some elements of the *Clean Energy Future* policy package agreed by the Multi-Party Committee on Climate Change (MPCCC), the Australian Treasury produced another updated analysis using a $23 carbon price across the board (Australian Government, 2011b). The updated modelling report provides detailed results covering 50 industry sectors with detailed sectoral analysis of electricity generating, road transport, and land sectors.

The Australian Treasury has been updating the assumptions involved in the carbon tax model over the past few years. Basically, the results drawn from these models are largely subject to the degree of integration among the models and the way they are integrated. Furthermore, the cost and impacts of climate change are predicted over longer time periods and the modelling is based on assumptions for Australia and for the rest of the world about carbon and energy commodity prices, GDP and population growth, productivity and technological development, changes in household taste and preferences, and emissions.

3.4 Conclusion

This chapter has reviewed the existing literature on the design of CGE models in environmental policy analysis. It began with the emphasis of using fixed coefficient models in the environmental policy analysis, mainly because these models serve as the precursors to the development of CGE models. Next, the chapter discussed some of the important theoretical features embedded into CGE models and the uses of these features when designing the specific environmental policy focus. Furthermore, the chapter described uses of static and dynamic CGE models in addressing macroeconomic impacts, distributional impacts and double dividend hypothesis of environmental taxation. Finally, CGE models designed for the greenhouse gas abatement policy analysis in Australia were reviewed with particular attention to the large scale CGE models used by the Australian Treasury.

It appears that environmental CGE models have made significant progress in terms of the size and complexity over the recent past. The modelling capacity of these models is so vast that they can be developed further to include more real world features, with more realistic specification of the production structures, technological advancements, income generating processes of economic agents etc. Such features demand more sophisticated database structures but if the data are available and can be compiled, it can be calibrated using ESAM databases. The ESAM presented in this study incorporates features of a SAM as well as carbon emissions data of the sectors and, thus, becomes an ideal tool to obtain simultaneous impacts of the environmental policies on various sectors as well as on the income distribution of the various household groups in the economy. Accordingly, Chapter VI presents a detailed discussion regarding the construction of an ESAM database for Australia which serves as the main database for calibrating the A3E-G model developed under this study.

CHAPTER IV

An Environmentally-Extended Social Accounting Matrix (ESAM) for Australia

Introduction

In this chapter, the procedure of constructing an Environmentally-extended Social Accounting Matrix (ESAM) for Australia for the purpose of carbon price modelling is explained. To the author's knowledge, the ESAM described in this chapter will be the first energy and emissions-focussed social accounting database for Australia. The ESAM presents disaggregated energy sectors, electricity generating sectors, disaggregated household sectors and disaggregated labour groups. The economy-energy-emissions focussed CGE model (A3E-G) that will use this database is described in Chapter V.

This chapter is organised as follows. Section 4.1 provides a general introduction to the Social Accounting Matrix (SAM) database. Section 4.2 explains schematic features of the SAM and various accounts used in the SAM. In Section 4.3, following a top-down approach, the macro-economic SAM (macro-SAM) is presented. The macro-SAM gives an aggregated perspective of the flow of funds in an economy without an institutional or sectoral breakdown. Section 4.4 presents the steps in constructing the micro-SAM. The micro-SAM disaggregates sectors and institutions according to the research objectives and the availability of data. The micro-SAM can be viewed as the ESAM of Australia. Details of the approach used in disaggregating activity/commodity account, aggregated household account and aggregate labour account are presented in this section.

4.1 General introduction to a Social Accounting Matrix (SAM)

A SAM depicts a 'snapshot' of a country's economic structure for a particular year. It is a matrix of the accounts of production, factors and institutions providing a statistical and analytical database for modelling and policy simulations. Sir Richard Stone[7] (1961) pioneered the development of the SAM framework and addressed the matter of integrating disaggregated production accounts into the national accounts of a country. A SAM was first constructed by the United Nations in 1968 to organise macro-economic data systems in the United Kingdom (Pyatt and Round, 1985). Early contributions to social accounting matrices can be found in the studies of King (1985), Pyatt (1985, 1988, 1991a, 1991b), Pyatt and Roe (1977), Pyatt and Round (1977, 1979, 1985), Pyatt and Thorbecke (1976), Reinert and Roland-Holst (1997) and Thorbecke (2003).

A SAM contains not only the important inter-industry matrix of the input-output (IO) table[8] but also includes more detail on the inter-institutional transfers in an economy. These institutions include factor markets, households, corporations, government and the rest of the world (SNA, 1993). Therefore, many studies have suggested the use of a SAM as an essential database for CGE modelling (see for example, Robinson (1988) and Taylor (1990) for a comprehensive survey on SAM-based CGE modelling). This is because a SAM includes additional detail on sectors that are often regarded as part of 'final demand' (for example households or government) of an IO table.

The rationale behind the SAM is traditional double entry book-keeping such that each transaction is recorded as a receipt in one account and expenditure in another account. As noted by Reinert and Roland-Holst (1997), the fundamental principle of double-entry accounting procedure makes up the macroeconomic accounts of any country. Hence, balanced

[7] A Nobel prize winner for the development of the SNA (System of National Accounts)

[8] The input-output table was developed by Wassily Leonteif in the 1930s. It presents the production side of the economy, with a specific focus on the intermediate input requirements and final outputs of industries.

accounts are obtained from all included parties thus satisfying Walras' law (Reinert and Roland-Holst, 1997; Zavkiew, 2005). This law states that if *k-1* accounts are balanced, then the k^{th} account must balance. This condition is fulfilled in the SAM framework because the total value of each row must be equal to the total value of the corresponding column. This feature essentially portrays some of the most important market clearing conditions to be satisfied in CGE modelling. The market clearing condition is explicitly satisfied as SAM necessitates the balance in supply of the commodity to demand for the commodity (intermediate demand and final demand). The factor market also necessitates the balance between factor costs to producers and wages and capital rent paid out as income. In addition, all institutions exhaust income over expenditure satisfying the budget constraint, while industries satisfy a zero profit condition where costs equal revenues. Thus, the SAM provides the basic and necessary conditions required for the applied general equilibrium modelling (see for example Dervis et al., 1982; Johansen, 1960; Shoven and Whalley, 1972).

In the social accounting transactions of the economy, each row records details of receipts by each particular account while the columns record corresponding expenditures (Pyatt and Round, 1985). Production leading to the generation of income is allocated to institutional sectors. The widely used institutions in a SAM framework are households, government, corporations and the rest of the world (ROW). By incorporating these institutional accounts, the SAM shows the distribution of factorial income leading to disposable income of institutional sectors which is then either spent or saved. These accounts are known as the 'current account' of institutions that represent income sources, expenditure patterns and generation of savings. Institutional savings constitute a part of capital formation in the economy.

4.2 Classification of accounts used in the macro-SAM

This section provides a brief overview of the production and institutional accounts used in a standard macro-SAM. The schematic macro-SAM framework involves the following accounts: industries; commodities; factors (labour, capital); current accounts of the institutions (divided into households, corporations and government); the ROW; and the consolidated capital (CCAP) account. The basic structure of the macro-SAM framework is shown in Table 4.1. The following explains the accounts presented in each row and column of Table 4.1.

Row 1 shows how activities/ industries use intermediate goods and factor services to produce commodities. The expenditure of these activities is shown in **Column 1** which includes the purchase of intermediate commodities ($\sum IC_{ij}$) both domestic and imported, payments to factors of production in the form of wage payments ($\sum PW_i$), capital rent ($\sum K_i$), and production taxes payable to the government ($\sum PT_i$). The receipts to the activities are derived from the sales of commodities ($\sum VD_i$). Receipts are equal to the industry costs ($\sum VX_i$). The account identity can be represented as follows:

Receipts : $$\sum \boldsymbol{VX_i} = \sum \boldsymbol{VD_i} \quad (4.1)$$

Outlays : $$\sum \boldsymbol{VX_i} = \sum \boldsymbol{IC_{ij}} + \sum \boldsymbol{PW_i} + \sum \boldsymbol{K_i} + \sum \boldsymbol{PT_i} \quad (4.2)$$

Table 4.1 Schematic representation of the macro-SAM

Receipts \ Outlays		1 Activity	2 Commodity	3.a Labour	3.b Capital	4.I Households	4.II Government	4.III Corporations	5 ROW	6 CCAP	Total demand
1	Activity		Sales (VD_i)								Production (VD_i)
2	Commodity	Intermediate demand (IC_{ij})				Household consumption (DH_i)	Government consumption (DG_i)		Exports (DE_i)	Investment (DI_i)	Commodity demand (VT_i)
3.a	Labour	Wages (PW_i)							Remittances (FW_f)		Labour income
3.b	Capital	Capital Rent (K_i)									Capital income
4.I	Households			Household labour (W_h)	Distributed profits (K_h)	Transfers (TRN_{hh})	Transfers (TRN_{gh})	Transfers (TRN_{ch})	Transfers (TRN_{fh})		Households income (Y_h)
4.II	Government	Value added taxes (PT_i)	Tariffs, indirect taxes (CT_i)		Taxes on profits (K_g)	Income tax (TRN_{hg})	Transfers (TRN_{gg})	Corporate taxes (TRN_{cg})	Indirect export taxes (TE_i)		Government income (Y_g)
4.III	Corporations				Non distributed profits (K_c)	Transfers (TRN_{hc})	Transfers (TRN_{gc})	Transfers (TRN_{cc})	Transfers (TRN_{fc})		Corporations income (Y_c)
5	ROW		Imports (M_i)	Foreign labour (W_f)		Transfers (TRN_{hf})	Transfers (TRN_{gf})	Transfers (TRN_{cf})	Transfers (EX_{ff})		External income (Y_f)
6	CCAP					Household savings (S_h)	Government savings (S_g)	Corporation savings (S_c)	Foreign savings (S_f)	Capital transfers (S_{cc})	Total savings (S)
	Total supply	Industry costs (VX_i)	Domestic supply (VS_i)	Labour outlays	Capital outlays	Households expenditure (E_h)	Government expenditure (E_g)	Corporations expenditure (E_c)	Foreign exchange earnings (E_f)	Total investment (I)	

Row 2 presents commodities which are the outcome of the production units (activities). These commodities are used by various sectors and institutions in the economy. The commodity demand is comprised of intermediate demand by respective industries, final consumption demand by the households ($\sum DH_i$), by the government ($\sum DG_i$), and by the ROW as exports ($\sum DE_i$). The residual demand forms the consolidated capital ($\sum DI_i$) which forms the investment side of the economy. Outlays to the commodity account are shown in **Column 2** which is comprised of commodity sales to industries, indirect commodity tax (sales tax and import tariff) payments ($\sum CT_i$) and imports ($\sum M_i$). Accordingly, the commodity account defines Gross National Product (GNP) from the expenditure side of the economy. When the total supply and demand of goods and services in the economy is expressed as VS and VT, the following accounting identity can be displayed.

Income : $$\sum \boldsymbol{VT_i} = \sum \boldsymbol{IC_{ij}} + \sum \boldsymbol{DH_i} + \sum \boldsymbol{DG_i} + \sum \boldsymbol{DE_i} + \sum \boldsymbol{DI_i} \quad (4.3)$$

Expenditure : $$\sum \boldsymbol{VS_i} = \sum \boldsymbol{VD_i} + \sum \boldsymbol{CT_i} + \sum \boldsymbol{M_i} \quad (4.4)$$

Row 3a and 3b represent factor accounts. These accounts in the SAM represent the value addition to the production process in the economy which typically includes labour and capital sub-accounts. The receipts to the labour account (Row 3a) are derived from the sales of labour to the production activities in the form of wage payments and foreign remittances (FW_f). The receipts to the capital account (Row 3b) are derived from the sales of capital to the production activities in the form of capital rent. In turn, these revenues are distributed among various agents in the economy (see **Column 3a and 3b**). Total labour supply is accrued to the households (W_h) and to the ROW (W_f). Outlays of the capital account are comprised of distributed profits to households (K_h), taxes on profits to the government (K_g), and non-distributed profits to corporations (K_c). The left side of the following equation identities represents the receipts while the right side denotes outlays of those accounts.

Labour account : $\sum \boldsymbol{PW_i} + \boldsymbol{FW_f} = \boldsymbol{W_h} + \boldsymbol{W_f}$ (4.5)

Capital account : $\sum \boldsymbol{K_i} = \boldsymbol{K_h} + \boldsymbol{K_g} + \boldsymbol{K_c}$ (4.6)

Row 4.I shows how households receive factor income from labour income and distributed profits as well as transfers from various institutions namely intra-household transfers (TRN_{hh}), government transfers (TRN_{gh}), corporate transfers (TRN_{ch}), and ROW transfers (TRN_{fh}). To balance the accounting identity in the SAM, the household income must be equal to the household expenditure. Thus, the generated income is spent (**Column 4.I**) on consumption of goods and services, intra household transfers, payment of direct taxes to the government (TRN_{hg}), transfers to corporations (TRN_{hc}) and transfers to ROW (TRN_{hf}). The residual income is saved (S_h) and this forms the capital account of the household. The general form of the accounting identity of the aggregate household account is presented as follows:

Income : $\boldsymbol{Y_h} = \boldsymbol{W_h} + \boldsymbol{K_h} + \boldsymbol{TRN_{hh}} + \boldsymbol{TRN_{gh}} + \boldsymbol{TRN_{ch}} + \boldsymbol{TRN_{fh}}$ (4.7)

Expenditure : $\boldsymbol{E_h} = \sum \boldsymbol{DH_i} + \boldsymbol{TRN_{hh}} + \boldsymbol{TRN_{hg}} + \boldsymbol{TRN_{hc}} + \boldsymbol{TRN_{hf}} + \boldsymbol{S_h}$ (4.8)

Row 4.II shows receipts to the government account that are derived mainly through tax collections from various industries and institutions in the economy. Formally, the macro-SAM shows how the government revenue is collected from production taxes, commodity taxes, taxes on profits (capital rent), direct income taxes paid by households, intra-government transfers (TRN_{gg}), corporate taxes (TRN_{cg}) and export taxes ($\sum TE_i$). The government account *per se* allocates its current expenditure (**Column 4.II**) on buying goods and services, transfers to households, transfers to corporations (TRN_{gc}), inter-government transfers and transfers to the ROW (TRN_{gf}). The remaining income is saved (S_g) which is transferred to the capital account in the form of a budget deficit or a surplus. The accounting identity of the government account is presented as follows:

Income : $Y_g = \sum PT_i + \sum CT_i + K_g + TRN_{hg} + TRN_{gg} + TRN_{cg} + \sum TE_i$ (4.9)

Expenditure : $E_g = \sum DG_i + TRN_{gh} + TRN_{gg} + TRN_{gc} + TRN_{gf} + S_g$ (4.10)

Row 4.III shows receipts to the corporation account which is derived from: rent on capital; non-distributed profits (K_c); transfers from households; government; intra-corporate transfers (TRN_{cc}); and transfers from foreigners (TRN_{fc}). The expenditure side (**Column 4.III**) of the corporation account consists of dividend payments to households, corporate tax payments to the government, inter-corporate transfers and transfers to the ROW (TRN_{cf}). The residual income forms corporate savings (S_c). The mathematical expression of this identity is:

Income : $Y_c = K_c + TRN_{hc} + TRN_{gc} + TRN_{cc} + TRN_{fc}$ (4.11)

Expenditure : $E_c = TRN_{ch} + TRN_{cg} + TRN_{cc} + TRN_{cf} + S_c$ (4.12)

Row 5 shows transactions between domestic accounts and the ROW accounts. Receipts to the ROW account are comprised of imports of goods and services for intermediate consumption, wages paid for hiring foreign labour, transfers from all domestic institutions, and intra ROW transfers (EX_{ff}). Expenditures to this account (**Column 5**) are obtained as exports of goods and services, foreign remittances, foreign transfers to domestic institutions and external transfers including re-exports. The remaining income is transferred to the capital account (S_f) which is the current account deficit/surplus of a country. The equations derived for this identity are presented as follows:

ROW Income : $Y_f = \sum M_i + W_f + TRN_{hf} + TRN_{gf} + TRN_{cf} + EX_{ff}$ (4.13)

ROW Expenditure : $E_f = \sum DE_i + FW_i + TRN_{fh} + \sum TE_i + TRN_{fc} + EX_{ff} + S_f$ (4.14)

Row 6 presents the receipts to the CCAP account which is composed of savings from households, government and corporations and from the rest of the world. These savings are channelled into investment (**Column 6**) as gross fixed capital formation and changes in inventories of domestic and imported goods and services ($\sum DI_i$) (i.e. gross fixed capital formation and the changes in inventories) and capital transfers (S_{cc}) of the institutions. The mathematical identity of this account is presented as:

Savings (income) : $\boldsymbol{S = S_h + S_g + S_c + S_f + S_{cc}}$ (4.15)

Investment (expenditure) : $\boldsymbol{I = \sum DI_i + S_{cc}}$ (4.16)

4.3 Compiling a macro-SAM of Australia

This section presents steps in constructing the macro-SAM of Australia for the year 2004-05. The macro-SAM incorporates real world data[9] to the flows identified in the schematic framework of Table 4.1. It traces the circular flow of incomes from product markets through factor payments to institutions and back to product markets through expenditure on final goods. Thus, macro-SAM requires data related to final consumption and expenditure by different sectors of the economy and by various institutions, and the generation of income and formation of capital by these institutions. These data were obtained from the Australian Bureau of Statistics (ABS). Data related to final consumption and expenditure by different sectors of the economy and by institutions were obtained from Australian National Accounts: Input-Output Tables (ANA: IO tables) (ABS, 2008a). Data related to the generation of income and formation of capital by different institutions was obtained from the Australian System of National Accounts (ASNA). From the ASNA accounts, income and capital accounts of institutions, namely households, financial corporations (f), non-financial corporations (nf), the government and external sectors were obtained for year 2005 (ABS, 2008b).

4.3.1 Input-output data

The 'Use' table (Table 2 of the ANA: IO tables), shows usage of commodities by industries and other final users in the economy. The flows in the 'Use' table are comprised of both

[9] At the time of compiling the SAM for Australia the most recent complete data set was for the year 2004-05.

domestic and imported commodity demands. In order to derive demand for each domestic commodity, the demand for each imported commodity is recorded in the 'Imports' table (Table 3 of the ANA: IO tables) was subtracted from the 'Use' table. Table 4.2 presents the aggregate IO table derived from both 'Use' and 'Imports' tables[10]. The first row of Table 4.2 shows how the output of total goods and services of the economy was disbursed among industries and different final demand categories. For example, the entry of 787878 in the first column represents total purchases of domestic commodities by industries (intermediate consumption). The other entries which are primary inputs to the intermediate demand are compensation of employees (431118), gross operating surplus (364726), commodity tax (14350), production tax (26016), and intermediate use of imports (103347). The value of total intermediate consumption and primary inputs determines the total production (inputs/supply) of the economy which was 1727435. The total value added inputs which includes factors of production (431118+364726) and indirect taxes less subsidies (75781) and production taxes (26016) derive the Gross Domestic Product (GDP) of the economy which was 897642 in the year 2004-05. This feature of the IO system shows the close relationship with the national accounts of a country (O'Connor and Henry, 1975).

The final demand for domestic output consists of consumption by households (429220), government (160578) and CCAP (189505 - the gross fixed capital formation by private, public, and government sectors and the changes in inventories) and exports (160256). The intermediate demand and the final demand constitute the total demand for production which is equivalent to the total supply. Labour and capital are allocated only to intermediate demand while indirect taxes less subsidies and imports are allocated to intermediate and final demand sectors as appropriate.

[10] All numbers in the cells in Table 4.1 are in million of Australian Dollars ($Am) valued at basic prices (Production cost excludes margin and taxes on products). For the purposes of this report the units are not shown throughout the text.

Table 4.2 Aggregate IO table for Australia 2004-05 ($Am)

	Industry uses	Final demand				Total demand
		Households	Government	CCAP	Exports	
Total intermediate uses	787878	429220	160578	189505	160256	1727435
Compensation of employees	431118					431118
Gross operating surplus, mixed income	364726					364726
Taxes less subsidies on products	14350	46334		13702	1395	75781
Taxes less subsidies on production	26016					26016
Imports	103347	45473	1921	33534	5911	190188
Australian production (Total supply)	1727435	521028	162499	236741	161651	2809354

Source: Adapted from ANA: IO tables (ABS, 2008a)

4.3.2 Activity/industry account

The receipts to the activities account are derived from the sale of commodities. The corresponding outlays are comprised of intermediate commodity demand from both domestic and imported sources (891225 = 787878+103347), labour demand (431118), capital demand (364726) and production tax (26016). These values were directly obtained from Table 4.2. The following Table 4.3 displays the accounting composition of this account.

Table 4.3 Account for activities ($Am)

Item	Receipts	Item	Outlays
Sale of goods and services	1713085	Intermediate consumption	891225
		Labour	431118
		Capital	364726
		Production tax	26016
Total	1713085	Total	1713085

Source: Compiled from Table 4.2

4.3.3 Commodity account

The receipts to the commodity account are intermediate demand from production activities, total final consumption demand from households (474693 = 429220+45473) and from the government (162499 = 160578+1921), exports (160256) and formation of capital (223039 =

189505+33534). Corresponding outlays to the commodity account are commodity sales, commodity taxes less subsidies and total imports (184275 = 103347+45473+1921+33534). These values were obtained from Table 4.2 and the accounting composition is presented in Table 4.4.

Table 4.4 Account for commodities ($Am)

Item	Receipts	Item	Outlays
Intermediate consumption	891225	Sale of commodities	1713085
Household consumption	474693	Commodity tax less subsidies	14350
Government consumption	162499	Total imports	184275
Exports	160256		
Capital stock	223039		
Total	1911712	Total	1911712

Source: Compiled from Table 4.2

4.3.4 Taxes on the product account

The product tax account displays the taxes less subsidies paid by industries and other institutions to the government account. Values corresponding to receipts were obtained from Table 4.2. The outlay of this account is received by the government account which is equivalent to what was recorded in the ASNA government account. The following accounting identity is displayed for this account in Table 4.5.

Table 4.5 Account for taxes on products ($Am)

Item	Receipts	Item	Outlays
Intermediate commodity tax	14350	Collection of tax income by the government	75781
Household tax on commodities	46334		
Export tax on commodities	1395		
Tax on capital goods	13702		
Total	75781	Total	75781

Source: Compiled from Table 4.2 and ASNA government account (ABS, 2008b)

4.3.5 Tax on the production account

The tax on the production account is one of the value added components in the production process. As recorded in Table 4.2, the other taxes less subsidies on production were 26016. The amount of subsidy given for production was 12519 as recorded in the ASNA government account. Thus, receipts and outlays to the production tax account are given in Table 4.6.

Table 4.6 Account for production tax ($Am)

Item	Receipts	Item	Outlays
Production tax by industries	26016	Gross production tax to government	38535
Production subsidy by government	12519		
Total	38535	Total	38535

Source: Compiled from Table 4.2 and ASNA government account (ABS, 2008b)

4.3.6 Labour account

The aggregate labour account interacts with the activity account, households account and the ROW account. The activity related compensation of employees is obtained from Table 4.2. Foreign remittances of 1127 were obtained from the ASNA external account which was allocated as a receipt to the labour account. The outlays related to this account were obtained from both household and external accounts of the ASNA. Accordingly, total labour income accrued to households and to the ROW was 430914 and 1331 respectively (see Table 4.7).

Table 4.7 Account for labour ($Am)

Item	Receipts	Item	Outlays
Compensation of employees by activities	431118	Labour payment receipts by household	430914
Compensation of employees by ROW	1127	Labour payment receipts by ROW	1331
Total	432245	Total	432245

Source: Compiled from Table 4.2 and ASNA household and external account (ABS, 2008b)

4.3.7 Capital account

The capital account records gross operating surplus of the production activities which are owned by various domestic institutions in the economy. The capital used in the production activities is recorded in Table 4.2 while the capital resources owned by domestic institutions are recorded in respective ASNA institutions accounts. The receipts and outlays of the capital account are given in Table 4.8.

Table 4.8 Account for capital ($Am)

Item	Receipts	Item	Outlays
Capital used in production activities	364726	Household own capital	145065
		Non-financial corporation own capital	177436
		Financial corporation own capital	26580
		Government own capital	15645
Total	364726	Total	364726

Source: Compiled from Table 4.2 and ASNA institutions accounts (ABS, 2008b)

4.3.8 Institutions accounts

Income flow transactions between household, corporations[11], government and ROW are derived from the respective ASNA accounts. The total income flow accrued to each institution is an aggregate of interest flows, dividend flows, reinvested Foreign Direct Investment (FDI) flows, natural assets flows, non-life insurance flows, current transfer flows, social assistance flows and income tax flows. The procedure for computing total income flows between these institutions is presented in the following Steps 1 to 9.

4.3.8.1 Step 1: Interest flows

As shown in Table 4.9, *Stage 1* all receipts and outlays accrued to respective institutions were recorded among the institutions based on primary information as given in the ASNA institution accounts. The residual receipts and outlays were recorded as unallocated.

The total receipts by the household account were 59246 which constitute property income receivable on interest (25649) and imputed interest (33597). It was assumed that the property income attributable to insurance policy holders (1085) as recorded in the non-financial

[11] Financial (f) and non-financial (nf) corporation accounts.

corporation account was paid by the financial corporations and the property income attributable to insurance policy holders (26241) as recorded in the financial corporation account was received by both households and non-financial corporations. Thus, part of the property income attributable to the household account by the financial corporation account was derived (25156 = 26241-1085).

Table 4.9 Interest flows of institutions ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household	0	0	50792	8454	0	59246	0
Corporate (nf)		0	6264			13214	6950
Corporate (f)			0			87882	87882
Government	0	0	2663	0	0	2663	0
External	0	0	22508	0	0	22508	0
Outlays	55143	28578	82227	13543	6022		
Unallocated	55143	28578	0	5089	6022		
Stage II							
Household	0	0	50792	8454	0	59246	
Corporate (nf)	5784	0	6264	533	631	13214	
Corporate (f)	49358	28578	0	4555	5390	87882	
Government	0	0	2663	0	0	2663	
External	0	0	22508	0	0	22508	
Outlays	55143	28578	82227	13543	6022	185513	

Source: Computed from ASNA institutions accounts (ABS, 2008b)

Next, the interest payment on unfunded superannuation liabilities as recorded in the government account was taken directly as a receipt to the household account which was 8454. The remaining unallocated interest of 25636 = 59246-(25156+8454) was considered as an outlay from the financial corporation account to the household account. Finally, the total interest income attributable to the household account by the financial corporation account was 50792 = 25156+25636. The household account records property income payable into three categories, namely interest payable on dwellings (41481), interest payable on consumer debt (7078) and interest payable on unincorporated enterprises (6584). Therefore, the total outlay accrued to the household account was 55143 and this was recorded as unallocated.

The total outlay accrued to the financial corporation account was 82227 which was the sum of property income payable as interest (55986) and property income attributable to insurance policy holders (26241). The property income receivable by the government was 2663 and property income receivable by the external account was 22508 as recorded in the ASNA accounts. These values were allocated as outlays from the financial corporation account. The remaining outlay of 6264 = 82227-(50792+2663+22508) was allocated as a receipt to the non-financial corporation account. The total property income receivable to the financial corporation account was 87882 and this amount was recorded as unallocated.

The total receipt to the non-financial corporation account was 13214. Since 6264 has already been allocated into the financial corporation account, the remaining 6950 = 13214-6264 was recorded as unallocated. The total property income payable as interest by the non-financial corporation account was 28578 and this was recorded as unallocated.

The total receipt to the government account was 2663 and this was allocated to the financial corporation account. The total outlay from the government account was 13543 which was the sum of property income payable on unfunded superannuation liabilities (8454) and on other interest (5089). Since 8454 has already been allocated into the household account, the remaining 5089 = 13543-8454 was recorded as unallocated.

The total receipt to the external account was 22508 and this was allocated to the financial corporation account. The total outlay to the external account was 6022 and this was recorded as unallocated.

Once all initial interest flows between institutions have been allocated, the next task was to allocate all unallocated flows into respective institutions (see *Stage II* of Table 4.9). Firstly, the unallocated receipt of 6950 to the non-financial corporation account was distributed among household, government and external accounts based on proportions of unallocated receipts and total outlays. Accordingly, the receipt to the household account was 5784 = 6950x55143/(55143+5089+6022), the receipt to the government account was 533 = 6950x5089/(55143+5089+6022) and the receipt to the external account was 631 = 6950x6022/(55143+5089+6022). Finally, the remaining unallocated receipts to the financial corporation account were allocated among the household, non-financial corporation, government and to the external accounts as 49358, 28578, 4555, and 5390 respectively.

4.3.8.2 Step 2: Dividend flows

Stage I of Table 4.10 shows receipts and outlays accrued to institutions as recorded in the respective institution accounts in the ASNA. Property income receivable as dividends were obtained for all institutions and property income payable as dividends were obtained for financial and non-financial corporation accounts and for the external account. Initially, all these transactions were recorded as unallocated receipts and outlays.

Next, these values were allocated proportionately based on unallocated receipts and outlays (see *Stage II* of Table 4.10). Firstly, unallocated dividend receipts to the financial corporation (1824) and to the non-financial corporation (14559) were allocated proportionately to the external account as outlays. Accordingly, the outlay from the external account to the financial corporation account was 4339 = 4883x14559/(14559+1824) and the outlay from the external account to the non-financial corporation account was 543 = 4883-4339.

Secondly, unallocated dividend receipts to other institutions were distributed among the financial and non-financial corporation accounts based on unallocated dividend outlay proportions. Accordingly, dividend income received by the household account from the non-financial corporation account was 15656 = 19929x42506/(42506+11599) and from the financial corporation account was 4272 = 19929-15656.

Table 4.10 Dividend flows of institutions ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household						19929	19929
Corporate (nf)						1824	1824
Corporate (f)						14559	14559
Government						8626	8626
External						14050	14050
Outlays	0	42506	11599	0	4883		
Unallocated	0	42506	11599	0	4883		
Stage II							
Household		15656	4272			19929	
Corporate (nf)		1005	274		543	1824	
Corporate (f)		8028	2190		4339	14559	
Government		6776	1849			8626	
External		11037	3012			14050	
Outlays	0	42506	11599	0	4883		

Source: Computed from ASNA institutions accounts (ABS, 2008b)

Receipt of dividend income to the government account from the non-financial corporation account was 6776 = 8626x42506/(42506+11599) and from the financial corporation account was 1849 = 8626-6776. Dividend income received by the external account from the non-financial corporation account was 11037 = 14050x42506/(42506+11599) and from the financial corporation account was 3012 = 14050-11037. Finally, the residual unallocated outlays accrued to the non-financial corporation account (9034) and the financial corporation account (2465) was allocated between those two institutions based on unallocated receipts and outlay proportions. Accordingly, dividend flow accrued to the non-financial corporation account from the non-financial corporation account was 1005 = 1280x9034/(9034+2465) and from the financial corporation account was 274 = 1280x2465/(9034+2465). The remaining unallocated outlays were residually allocated to the financial corporation account and to the non-financial corporation account as 2190 and 8028 respectively.

4.3.8.3 Step 3: Foreign Direct Investment (FDI) flows

The transaction of FDI flows were recorded in the financial and non-financial corporation accounts and in the external account (See Table 4.11). Firstly, all receipts and outlays of FDI were recorded as unallocated receipts and outlays under respective institutions. Next, all receipts or outlays of FDI accrued to the financial and non-financial corporation accounts were assumed as outlays or receipts made by the external account (see *Stage II*).

Table 4.11 Reinvested earnings on FDI flows ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household						0	0
Corporate (nf)						6997	6997
Corporate (f)						2577	2577
Government						0	0
External						17182	17182
Outlays	0	12672	4375	0	9709		
Unallocated	0	12672	4375	0	9709		
Stage II							
Household							
Corporate (nf)					6997	6997	
Corporate (f)					2577	2577	
Government						0	
External		12672	4375		135	17182	
Outlays	0	12672	4375	0	9709		

Source: Computed from ASNA institutions accounts. (ABS, 2008b)

4.3.8.4 Step 4: Natural asset flows

Receipts to the natural asset flows were recorded in the household account (19), non-financial corporation account (67) and in the government account (3583). Corresponding outlays were recorded in the household account (412) and in the non-financial corporation account (3257).

Firstly, these transactions were recorded under *Stage I* of the Table 4.12. Since there were only three institutions dealing with natural asset transactions, the outlay from the household account to the government account was, firstly, allocated as 412 and then, the rest of the receipts were allocated as outlays from the non-financial corporation account to the household account as 19, non-financial corporation account as 67 and to the government account as 3171 (see *Stage II* of Table 4.12).

Table 4.12 Natural asset flow ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household						19	19
Corporate (nf)						67	67
Corporate (f)						0	0
Government						3583	3583
External						0	0
Outlays	412	3257	0	0	0		
Unallocated	412	3257	0	0	0		
Stage II							
Household		19				19	
Corporate (nf)		67				67	
Corporate (f)						0	
Government	412	3171				3583	
External						0	
Outlays	412	3257	0	0	0		

Source: Computed from ASNA institutions accounts (ABS, 2008b)

4.3.8.5 Step 5: Non-life insurance flows

Receipts and outlays of the non-life insurance flows to the household, non-financial corporation, financial corporation and to the external accounts are shown in Table 4.13. Initially, all these values were recorded as unallocated (see *Stage I*). Next, non-life insurance payments accrued to the household account (25491) and to the external account (1980) were allocated as receipts to the financial corporation account. The remaining receipt of 4274 accrued to the financial corporation account was allocated as an outlay from the non-financial corporation account (31745-(25491+1980)). It was then assumed that the non-financial corporations only incur non-life insurance payments to households and to financial corporations. Therefore, the remaining outlay of 1925 accrued to the non-financial corporation account was allocated as a receipt to the household account (6200-4274).

Table 4.13 Non life insurance flows of institutions ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household						23326	23326
Corporate (nf)						5153	5153
Corporate (f)						31745	31745
Government						0	0
External						1926	1926
Outlays	25491	6200	28480	0	1980		
Unallocated	25491	6200	28480	0	1980		
Stage II							
Household		1925	21401			23326	
Corporate (nf)			5153			5153	
Corporate (f)	25491	4274			1980	31745	
Government	0					0	
External		0	1926			1926	
Outlays	25491	6200	28480	0	1980		

Source: Computed from ASNA institutions accounts (ABS, 2008b)

Since households also receive non-life insurance claims from the financial corporation, the balance of receipt of 21401 = 23326-1925 was allocated as an outlay from the financial corporation account. Finally, the remaining outlays of the financial corporations were allocated to the non-financial corporation account and to the external accounts as receipts of 5153 and 1926 respectively. By doing this, all unallocated receipts and payments of non-life insurance claims were successfully allocated between institutions involved in the economy.

4.3.8.6 Step 6: Current transfer flows (not elsewhere classified)

Table 4.14 records current transfer flows accrued to the household, non-financial corporation, government and the external accounts. Initially, direct flows were allocated to the external account as 842 and to the non-financial corporation account as 68 from the government account and all other receipts and outlays were recorded as unallocated (see *Stage I*). In *Stage II*, the remaining flows were allocated based on unallocated receipt and outlay proportions of each corresponding institution. Accordingly, receipts to the household account from households were 1646 = 13244x2330/(2330+3077+12201+1136)and from the non-financial corporation were 2174 =13244x3077/(2330+3077+12201+1136). Receipts to the government account from the non-financial corporation account were 570 = 3041x3077/ (3077+ 12201+ 1136) and from the government account were 2260 = 3041x12201/ (3077+12201+1136).

Table 4.14 Current transfer flows of institutions ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household				68		13244	13244
Corporate (nf)						68	68
Corporate (f)						0	0
Government						3041	3041
External				842		2391	1549
Outlays	2330	3077	0	12201	1136		
Unallocated	2330	3077	0	11291	1136		
Stage II							
Household	1646	2174		9030	393	13244	
Corporate (nf)						68	
Corporate (f)						0	
Government	0	570		2260	210	3041	
External	683	332		842	532	2391	
Outlays	2330	3077	0	12201	1136		

Source: Computed from ASNA institutions accounts (ABS, 2008b)

Once these transactions were allocated, the remaining outlay of 9030 from the government account (12201-(842+2260+68)) was allocated to the household account. The remaining receipt of 394 to the household account (13244-(1646+2174+9030)) was then allocated to the external account. The remaining receipt of 210 to the government account was residually allocated to the external account (3041-(570+2260)). All remaining outlays were allocated to the external account as receipts from the household account as 684 (2330-1646), from the non-financial corporation account as 333 = 3077- (2174+570) and from the external account as 533 = 1136-(393+210).

4.3.8.7 Step 7: Social assistance benefits flows

Table 4.15 shows the social assistance benefit transaction between the institutions involved. As shown, the household account records secondary income receivable as social assistance benefits while the government account records secondary income payable as social assistance benefits in cash to residents as 75073.

Table 4.15 Social assistance benefit flows ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household				75073		75073	75073
Corporate (nf)						0	0
Corporate (f)						0	0
Government						0	0
External						0	0
Outlays	0	0	0	75073	0		
Unallocated	0	0	0	75073	0		
Stage II							
Household				75073		75073	
Corporate (nf)						0	
Corporate (f)						0	
Government						0	
External						0	
Outlays	0	0	0	75073	0		

Source: Computed from ASNA institutions accounts (ABS, 2008b)

4.3.8.8 Step 8: Income tax flows

The income tax receipts were recorded in the government and in the external accounts while income tax payments were recorded in the household, non-financial corporation, financial corporation and in the external accounts. Initially, all these values were recorded as unallocated (Table 4.16, *Stage I*).

Table 4.16 Income tax flows ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External	Receipts	Unallocated
Stage I							
Household						0	0
Corporate (nf)						0	0
Corporate (f)						0	0
Government						164697	164697
External				0		320	320
Outlays	121319	33955	8592	0	1152		
Unallocated	121319	33955	8592	0	1152		
Stage II							
Household						0	
Corporate (nf)						0	
Corporate (f)						0	
Government	120999	33954	8592		1152	164697	
External	320			0		320	
Outlays	121319	33955	8592	0	1152		

Source: Computed from ASNA institutions accounts (ABS, 2008b)

Next, outlays from the households in the form of income tax payments (118052) and other taxes on income and wealth payments (2947) were allocated to the government account as receipts which were 120999 = 118052+2947. The current taxes on income and wealth paid by the financial corporation account were allocated to the government as receipts of 8592. Because the total government receipt from resident corporations was 42546, the income tax paid by the non-financial corporation was derived as 33954 = 42546-8592. Income tax paid by non residents was then considered as a transaction between the government and the external account which was 1152. Finally, external account receipts of current taxes on income and wealth were allocated as an outlay to the household account which was 320.

4.3.8.9 Step 9: Total income flows

Finally, total income flows between institutions were derived by adding each category of income flow shown in Steps 1 to 8 (derived from *Stage II* of the above transaction Tables 4.9 to 4.16). The gross savings accrued to each institution were computed after subtracting total income (receipts) from total payment (outlay) of each institution as recorded in ASNA accounts. (For example gross savings of household account 41093=245788-204695). The gross savings of each institution forms part of the consolidated capital account in the economy. Table 4.17 completes the inter-institutional transactions shown in the macro-SAM for Australia (see Table 4.19)[12].

Table 4.17 Total income flows of all institutions ($Am)

	Household	Corporate (nf)	Corporate (f)	Government	External
Household	1646	19775	76465	92558	393
Corporate (nf)	5785	1073	11691	602	8172
Corporate (f)	74850	40881	2191	4555	14286
Government	121411	44472	13104	2260	1362
External	1003	24043	31821	842	668
Total (outlay)	204695	130243	135273	100817	24882
Total (receipt)	245788	206088	163334	137556	81207
Gross savings	41092	75845	28071	36739	56325

Source: Computed from ASNA institutions accounts (ABS, 2008b).

4.3.9 Consolidated capital (CCAP) account

The investment side of the CCAP account constitutes the gross fixed capital formation and change in inventories (223036). The savings side of the CCAP account was derived from gross savings and capital transfers of all institutions in the economy. As the gross savings of

[12] Note that re-exports (5911) were added into the intra transaction of the external account (678+5911= 6578).

institutions (see Table 4.17) in the economy has been computed, the next task was to compute capital transfers accrued to each institution. The total capital transfers of all institutions in the economy were 10282. This was derived from each institution's capital account in the ASNA (Household capital transfer - 4463, corporate capital transfer - 3474, government capital transfer - 1194 and external capital transfer - 1151). Finally, a non-flow (1334) was included after adding all institutions net lending/net borrowing flows. The derived CCAP entries are shown in Table 4.18. Finally, the numerical macro-SAM for the year 2004-05 was compiled and is presented in Table 4.19[13].

Table 4.18 Account for consolidated capital ($Am)

Item	Receipts/savings	Item	Outlays/Investment
Household savings	41093	Capital stock	223036
Non-financial corp. savings	75845	Tax and subsidies	13704
Financial corp. savings	28071		
Government savings	36739		
ROW savings (external)	56325	Non flow items	1334
Capital transfers (all institutions)	10282		
Total	248356	Total	248356

Source: Computed from each ASNA institution's capital account (ABS, 2008b) and Table 4.2

[13] A non-flow of 1329 was added into the corporation receipts as a balancing item.

Table 4.19 The macro-SAM of Australia for 2004-05 ($Am)

Receipt \ Outlay		1	2	3.a	3.b	3.c	4	5.I	5.II	5.III	6	7		
		Activity	Commodity	Labour	Capital	Production tax	Commodity tax	Household	Government	Corporations	ROW	CCAP	Non flow	**Total demand**
1	Activity		1713085											**1713085**
2	Commodity	891225						474693	162499		160256	223036		**1911712**
3.a	Labour	431118									1127			**432245**
3.b	Capital	364726												**364726**
3.c	Production tax	26016							12519					**38535**
4.	Commodity tax		14350					46334			1395	13704		**75783**
5.I	Household			430914	145065			1646	92558	96240	393			**766816**
5.II	Government				15645	38535	75781	121411	2260	57576	1362			**312571**
5.III	Corporation				204016			80634	5157	55836	22459		1329	**369431**
6	ROW		184277	1331				1004	842	55864	6579			**249896**
7	CCAP							41093	36739	103916	56325	10282		**248356**
	Non flow											1334		
	Total supply	**1713085**	**1911712**	**432245**	**364726**	**38535**	**75781**	**766815**	**312574**	**369432**	**249896**	**248356**		

Note: Some row and column totals do not add up due to rounding errors.

4.4 Construction of the micro-SAM for Australia (ESAM)

The procedure of constructing a micro-SAM for Australia is described in this section. Constructing the micro-SAM involves a process where the main accounts contained in the macro-SAM and their non-zero entries are disaggregated to provide a more detailed picture of all flows in the economy. The level of disaggregation depends on the research objective and the availability of data. The main objective of constructing the database under this study is to analyse the impact of the carbon price on various production sectors, labour groups and households groups in Australia. Accordingly, sectors were re-classified into 35 based on the level of CO_2 emissions, labour was disaggregated into nine occupational groups and households were disaggregated into 10 income classes. This micro-SAM is viewed as the ESAM for Australia.

4.4.1 Preparation of IO table

As discussed in Section 4.3.1, the 'Use' and 'Imports' tables were used to derive input-output data in the micro-SAM for Australia (ABS, 2008a). In the 'Use' table, there are 109 commodities being used by 109 industries of which several commodities are being used by each industry as intermediate inputs. Unfortunately, missing entries were noticed in some rows of the 'Use' table. For example, there were no final demand or total sales values available for the commodities namely services to agriculture, hunting and trapping, services to mining, water transport, and air and space transport. Those entries were not reported in the 'Imports' table as well. These missing entries were restored with the use of the 'Make' table (Table 1 of the ANA: IO table) which shows total domestic production (output of commodities) by each industry at basic prices. Once intermediate use of domestic commodities was obtained (by subtracting the 'Import' table from the 'Use' table), the overall import/domestic ratios were used to deduce total imports including those missing commodities. The total final demand was then calculated as a residual and was distributed between those missing commodities according to the best judgment. Missing entries of imported use were finally distributed proportionately to the domestic use. This procedure is closely similar to the procedure undertaken by Horridge (2002) in preparing the 1996-97 Australian IO table for a CGE database.

4.4.1.1 Disaggregating energy sectors

There are several sectors in the IO table identified as energy sectors, namely coal, oil-gas and petroleum-other coal product sectors. These sectors were further disaggregated into several subsectors in order to assess the Australian energy sector responses to a carbon price policy in detail. For this purpose, the detailed IO product report published by ABS (2008c) was used to disaggregate the coal sector into *black* coal and *brown* coal, the oil-gas sector into *oil* and *gas*, the petroleum-other coal product sector into automotive petrol (*autopetrol*), kerosene (*kerosnpetrol*), liquid petroleum gas (*liqgaspetrol*) and other petroleum and coal products (*otherpetrol*) sectors.

The detailed IO product report records sales data of black coal (all types including briquettes) and brown coal (lignite, including briquettes) for 109 industries and all other final demand categories. Firstly, these sales data were used to calculate share of sales corresponding to black and brown coal. Secondly, these shares were used to disaggregate the coal sector in the IO table into *black* and *brown* coal sectors. In the cost side, sale of black coal was allocated into cost of black coal and sale of brown coal was allocated into cost of brown coal. All other intermediate input costs were split using the total sales shares of black and brown coal sectors. This was based on the assumption that the technology for production for each industry was the same within each group.

The oil-gas sector was disaggregated into four sub-sectors in the detailed IO product report, namely crude oil (including condensate), liquefied natural gas, natural gas (in the gaseous state) and liquefied petroleum gas (natural coal, gas and similar other than petroleum gases and other gaseous hydrocarbons not elsewhere classified). For this study, two broad sectors were considered, namely oil (crude oil including condensate) and gas (all other gaseous sub sectors). Firstly, using the detailed IO product report, sales of crude oil, liquefied natural gas, natural gas and liquefied petroleum gas were obtained for 109 intermediate industries and other final demand categories. Secondly, these sales were aggregated into oil and gas sectors. The share of sales calculated for these sectors were used to split the existing oil-gas sector into *oil* and *gas*. In the cost side, the sale of oil was allocated into cost of oil while sale of gas was allocated into cost of gas. All other intermediate costs were split according to the share of sales obtained for the oil and gas sectors.

The petroleum-coal products sector was disaggregated into eight sub-sectors in the detailed IO product report, namely automotive petrol, kerosene, liquefied petroleum gas, benzole, lubricating heavy petroleum and bituminous oils, refined tar, paper and paperboard impregnated, and other petroleum and coal products. For the purpose of this study, the following sectors were considered: automotive petrol (*autopetrol*) sector; kerosene (*kerosnpetrol*) sector; liquefied petroleum gas (*liqgaspetrol*) sector; and all other petroleum products (*otherpetrol*) sector. Similarly, to the procedure described above, the share of sales for each sub-category was calculated and used to split the petroleum-coal sector into the four above mentioned sub-sectors. Finally, in the cost side, sales of each sub-sector were allocated to corresponding costs and all the other intermediate costs were split according to the share of sales of each sub-sector.

4.4.1.2 Treatment of the electricity supply sector

The existing IO table contains one electricity supply industry producing electricity as one commodity in Australia. In this study, the electricity supply sector was disaggregated into five generating industries (*black coal, brown coal, oil, gas and renewable energy industry*) and one *commercial electricity supply* industry. For this purpose the electricity supply industry was disaggregated into two sectors - electricity generating and commercial electricity supply - by using the industry revenue data published in the Australian industry reports of the IBISWorld (2010). Next, the electricity generating sector was further disaggregated into five sub-electricity generating industry (black coal, brown coal, oil, gas and renewable energy) using the shares of energy data, published in ABARE (2005). Table 4.20 shows percentage shares calculated from these two sources.

Table 4.20 Disaggregating electricity supply sector

Electricity Sector	Industry Revenue $million in 2009	% share	Fuel Type	Petajoules in 2004-05	% share
Electricity generating	13850	40.22	Black coal	469	54.28
Commercial electricity	20583	59.77	Brown coal	187	22.64
			Oil	11	1.27
			Gas	128	14.81
			Renewable	69	7.98
Total	34433	100.00	Total	864	100.00

Sources: IBISworld (2010) and ABARE (2005) p 42.

The modified electricity sector assumes that all the existing sales to intermediate demand are supplied by the commercial electricity supply sector. However, existing sales to the same industry (initially the electricity supply) were derived from five generating types (black, brown, oil, gas and renewable energy) and commercial electricity supply. In order to do this, existing sales were first split into electricity generating and the commercial electricity sector based on industry revenue shares. Accordingly, 60 percent of existing shares were allocated to the commercial electricity sector and the rest was allocated to the electricity generating sector. Next, using the energy shares of different generating types, the aggregate electricity generating sector was disaggregated into five generation classes. Sales of electricity generating were disaggregated into electricity generating black coal, brown coal, oil, gas and renewable energy sectors. The residual sales (supply) were allocated into the commercial electricity supply sector. On the cost side, it was assumed that each generator sells only to the respective electricity generating sector. Other remaining intermediate costs accruing to respective electricity generating sector and to the commercial electricity supply sector were split based on the share of sales of each electricity generating sector and commercial electricity supply sector.

4.4.1.3 Re-computing factor payments

The existing 'Use' table does not separate land use as a factor of production. The land factor plays a significant role in the production of agricultural commodities and it is included in the modelling of almost all ORANI type models of Australia. Therefore, it is important to derive usage of land in the production activities. For this purpose, factor payments appearing in the IO table were re-computed and three factors were derived, namely *labour*, *capital* and *land* following the method explained by Horridge (2002). Accordingly, value added components in the IO table namely compensation of employees and gross operating surplus & mixed income were split into intermediate value added components (see Table 4.21 Column 2).

The data needed to split two of these value added components into three intermediate categories which were not readily available in the literature and were not computed for this study. Instead, data from the ORANI database developed at the Centre of Policy Studies (Horridge, 2002) was used to compute proportions of these intermediate categories. Using these proportions, monetary values of the intermediate categories were computed. Next, as shown in Table 4.21 Column 3, those intermediate categories were added into the SAM categories. Accordingly, intermediate categories of wages and salaries and imputed wages were aggregated to form factor *labour,* and intermediate categories of fixed capital and working capital were aggregated to form the factor *capital*. Finally, the remaining intermediate category of land is taken as the factor *land*.

Table 4.21 Remapping of factor payments

IO categories	Intermediate categories	SAM categories
Compensation of employees	a. Wages and salaries	1. Labour = a+b
Gross operating surplus and mixed income	b. Imputed wages	2. Capital = c+d
	c. Fixed capital	
	d. Working capital	
	e. Land	3. Land = e

Source: ORANI-G database (Horridge, 2002).

4.4.1.4 Disaggregating labour factor payments

Next, the aggregate labour account in the macro-SAM was further disaggregated using the census of population and housing customised data report (ABS, 2009). This report provides data on persons employed and mean weekly individual income by occupation and by industries[14] for the year 2005-06. The total average weekly income earned by nine occupations for 67 industries was derived by multiplying the number of persons employed by the mean weekly income. These 67 industries were then mapped with the industries in the re-constructed IO table (119 industries[15]) and a wage bill matrix was derived. The labour vector was then split into nine occupational groups using the shares of the wage bill matrix.

[14] Occupations are classified by 1 digit (ASCO Ed) and industries by 2 digit (ANZSIC, 1993)
[15] Total number of industries after disaggregating energy and electricity supply sectors

The following occupation groups are included in the macro-SAM:

1. Managers and administrators (MGR);
2. Professionals (PRF);
3. Associate professionals (APR);
4. Tradespersons and related workers (TRD);
5. Advanced clerical and service workers (ACL);
6. Intermediate clerical, sales and service workers (ICL);
7. Intermediate production and transport workers (IPR);
8. Elementary clerical, sales and service workers (ECL); and
9. Labourers and related workers (LBR).

4.4.2 Disaggregating household expenditure and income

The aggregate household account in the macro-SAM was disaggregated into 10 (deciles) income groups. For this purpose, it was necessary to disaggregate household expenditure and income presented in the macro-SAM to distinguish expenditure and income earning by each decile. The main source used to disaggregate the aggregate household account in the SAM was the household expenditure survey (HES) conducted by the ABS. Since the published data contains only household quintiles, household expenditure data by deciles was requested (ABS, 2006a). At the time of compiling the micro-SAM for Australia, it was only possible to obtain HES data in deciles for the year 2003-04. It was assumed that household characteristics have remained unchanged since then.

4.4.2.1 Household final consumption expenditure

The first task of disaggregating household expenditure involves mapping the consumption expenditure given in the HES data according to the classification given in the IO table (Khan, 1989). The first observation made at this stage is that commodities classified in the HES data did not coincide with the commodities classified in the IO table. Usually, HES classifies commodities that correspond to household wants, while the IO classifies commodities that are closely linked to the production system (Keuning and Ruijter, 1988). It was also noted that there were more commodities classified in the HES than in the IO table. Fortunately, there was an official mapping between those two classifications submitted to the Treasury by the ABS in 2005 (IOPC-2005 vs. HES-2003/04 correspondence table provided to the Treasury on 27 June 2008). This internal unpublished source has also acknowledged that some expenditure items classified to one HES code can be represented by more than one IOPC (ABS 2006b). Therefore, on some occasions commodities purchased as final goods by households are considered as sales from various industries in the IO classification. This official concordance report has mapped 1946 IOPC commodities with HES commodities. Based on this database, a household consumption share matrix was constructed for 119 commodities by 10 household income groups.

4.4.2.2 Other household expenditure and savings

The rest of the components of household expenditure as shown in the macro-SAM for Australia consist of intra-household transfers, transfers to government, corporations and ROW and gross savings. These aggregate expenditure items were disaggregated among ten deciles based on the expenditure shares of miscellaneous services (category 1302) of the HES table (ABS, 2006a).

4.4.2.3 Household income

The final step of disaggregating the household account in the macro-SAM is to detail the income generating process of the 10 household groups. As given in the macro-SAM, household income constitutes labour income, capital income (including land income) and transfers from other institutions.

Table 4.22 gives the household disposable income by quintile with respect to the main source of household income (ABS, 2011). Accordingly, household income is sourced from zero or negative income, wages and salaries, own unincorporated business income, government pensions and allowances, and other income. In order to obtain the proportion of household income by deciles, it was necessary to map household income sources in Table 4.22 with household income sources given in the macro-SAM and then to distribute income shares among household deciles. Using these income shares, the monetary values of aggregate household income sources were distributed among 10 household income deciles.

Table 4.22 Proportion of household disposable income by quintile (2009-10)

Main source of household income	Lowest	Second	Third	Fourth	Highest
Zero or negative income	2.0	0.0	0.0	0.0	0.0
Wages and salaries	11.9	51.7	80.1	87.0	86.0
Own unincorporated business income	3.5	5.2	5.6	5.9	5.9
Government pensions and allowances	74.5	34.1	4.0	0.0	0.0
Other income	8.2	9.0	10.3	8.1	8.1
Total	100.0	100.0	100.0	100.0	100.0

Source: ABS (2011), p 23

Finally, household labour income was disaggregated among nine occupation groups as identified above in Section 4.4.1.4. In order to perform this task, household income distribution by different labour categories was required. Table 4.23 shows the income distribution of all working households by occupations in 2001 (Yates, 2006). As shown, working households have been classified into seven income groups. Therefore, mapping of household income deciles with seven household groups was required in order to construct a household income distribution matrix by deciles and by nine occupation categories.

Table 4.23 Income distribution of all working households by occupation, 2001

	Income distribution of all working households						
Occupation	$0-399	$400-599	$600-799	$800-999	$1000-1199	$1200-1499	$1500+
MGR	5	7	8	9	12	11	49
PRF	3	5	8	11	14	12	47
APR	3	8	12	12	13	14	37
TRD	5	12	16	17	14	15	22
ACL	5	10	17	13	11	13	30
ICL	9	15	16	13	12	14	20
IPR	5	14	18	16	13	14	19
ECL	15	20	16	14	11	11	13
LBR	13	21	18	14	11	10	12
All	6	11	13	13	13	13	31

Source: Yates et al. (2006) p 21

4.5 Conclusion

In this chapter, the main focus has been to describe the procedure of compiling a macro-SAM and a micro-SAM for Australia. The micro-SAM is obtained by disaggregating some non-zero entries in the macro-SAM based on the research objectives. Accordingly, a micro-SAM with 119 sectors, nine occupation categories and 10 household groups was derived. This SAM constitutes the highly disaggregated Australian SAM at the sectoral, household and occupational level. Next, these 119 sectors were aggregated into 35 sectors while preserving the importance of the energy sector details. The 35 sectors, 10 household groups and nine occupation groups containing SAM can be regarded as the ESAM for Australia. The procedure of aggregating 119 sectors into 35 sectors is explained in Chapter VI. This ESAM database is used to calibrate the CGE model developed under this study (A3E-G). Hence, this comprehensive database provides a considerably improved research infrastructure for carbon price modelling in Australia.

CHAPTER V

An Economy-Energy-Emission Computable General Equilibrium Model of the Australian Economy (A3E-G)

Introduction

In this chapter, the theoretical structure of the Computable General Equilibrium (CGE) model designed to assess the impact of a carbon price in the Australian economy is outlined. As discussed earlier in Chapter I, a carbon price exerts direct and indirect impacts on many sectors of the economy, therefore, a CGE model is an ideal tool for analysing such impacts as compared to a partial equilibrium model. Many Australian studies including the Treasury model have used CGE models to analyse the economic impacts of a carbon price because the task of CGE models in this particular area is highly demanding. This is due mainly to the fact that the implications of such a policy are rather complicated to analyse. For example, Arrow (2005) noted that there is no real alternative to a CGE model when repercussions of proposed policies are widespread.

The rest of this chapter is organised to discuss the extended features of the CGE model used for this study. Section 5.1 outlines the general features of the CGE model developed and named, A3E-G model. In Section 5.2, the industry demands for inputs by various sources are discussed. The demand functions for gross fixed capital formation are discussed in Section 5.3. In Section 5.4, the equations for demand by households are outlined, while Section 5.5 outlines equations for both export and government demand. Section 5.6 includes a discussion of carbon emissions accounts and the detailed procedure for deriving carbon emission intensities and equations necessary for implementing the carbon price mechanism in the economy. Section 5.7 presents equations for zero pure profit conditions while Section 5.8 provides a discussion for equilibrium and necessary market clearing conditions for the economy in order to implement the model. Section 5.9 includes equations to explain income distribution by various household groups, government, corporations and the rest of the world (ROW). Model closure requirements and conditions to be fulfilled in order to verify the validity of the model are discussed in Section 5.10.

5.1 A Computable General Equilibrium (CGE) model

The CGE model used in this study is based on the ORANI-G model which is an applied general equilibrium model of the Australian economy (Dixon et al., 1997). However, modifications have been included in order to incorporate energy industry details, multiple households, and a carbon price mechanism into the Australian economy. The CGE model developed under this study is titled Economy-Energy-Emission Computable General Equilibrium model (A3E-G) of the Australian economy and it contains the following distinguishing features:

1. Disaggregated energy industries;
2. Nested electricity generating structure;
3. Composite capital-energy production structure;
4. Multiple household types;
5. Various types of labour groups;
6. Leontief specification of carbon emission intensities by industries and households;
7. Income mapping equations for multiple households; and
8. Income mapping equations for government, corporations and ROW.

5.1.1 Equation systems

Similar to the ORANI-G model, the A3E-G model has a theoretical structure that explains the behaviour of producers and consumers in the economy for a given time period. It is a static model which does not have any mechanism for the accumulation of capital. The model is based on the assumption of perfect competition where no individual buyer or seller is able to influence the price. Demand and supply equations for private sector agents are derived from solutions to optimisation problems (cost minimisation, profit maximisation). In order to represent a holistic view of the economy, for a given time period, the model contains equations explaining:

- Producer demand for intermediate inputs and primary factors;
- Supplies of commodities by producers;
- Inputs demanded for the formation of capital;
- Commodities demanded by the households;
- Export demand;
- Commodities demanded by the government;
- Carbon emission intensity equations for production and consumption;
- The relationship of basic values to production costs and purchaser prices;
- Market clearing conditions for commodities and primary factors;
- Numerous macroeconomic variables and price indices; and
- Income received by various institutions and by source.

The model equations closely follow the Johansen class of general equilibrium models where equations are written as a system of linear equations. The model variables are derived to be in percentage change form. For example, as illustrated in Dixon et al. (1992), the class of general equilibrium models is one in which an equilibrium is a vector V of length n satisfying a system of equations.

$$F(V) = 0 \tag{5.1}$$

where F is a vector function of length m. The number of F functions are assumed to be differentiable with n number of variables which exceeds the number of equations m. By assigning certain (*n-m*) variables as exogenously given, the system solves for the remaining endogenous variables (*m*). This above system in (5.1) can be very large and involves a wide variety of nonlinear functional forms. Therefore, Johansen's approach is to derive a system of linear equations in which variables are expressed in changes, percentage changes or changes in the logarithms of the components of V.

The linearised version is derived from a differential form:

$$A(V)v = 0 \tag{5.2}$$

where $A(V)$ is an $m \times n$ matrix whose components are functions of V. The v is a $n \times 1$ vector of variables usually interpreted as percentage changes or changes in logarithms of the variables V. The percentage change is represented as $v = (dV/V)100$. By using equation (5.2), the changes or percentage changes of endogenous variables can be expressed as linear functions of the changes or percentage changes of exogenous (predetermined) variables. Accordingly, equation (5.2) can be rearranged in the form:

$$A_1 y + A_2 x = 0 \tag{5.3}$$

where y is the vector of percentage changes in those variables chosen to be endogenous and x is the vector of percentage changes in the predetermined variables chosen to be exogenous. A_1 and A_2 are matrices related to endogenous and exogenous columns respectively. The percentage change of endogenous variables with respect to exogenous variables can be obtained by rearranging equation (5.3) into equation (5.4).

$$y = -A_1^{-1} A_2 x \tag{5.4}$$

The equations of the model are derived from the solutions to the optimisation problems (cost minimisation, utility maximisation etc.), which are assumed to underlie the behaviour of the agents in conventional neoclassical microeconomics. The agents are assumed to be price takers with producers operating in competitive markets that prevent the earning of pure profits.

However, equation (5.4), is accurate only for small changes in Y and X. Otherwise linearisation errors may occur. It is convenient to express dY and dX as percentage changes in y and x where $y = 100dY/Y$ and $x = 100dX/X$. As illustrated in Figure 5.1, the endogenous variable Y changes as an exogenous variable X moves from X^O to X^F. The true non-linear relation between X and Y is shown by the line A and the linear first order approximation between X and Y is shown by the line B. It is observed that as the change in x or dX is larger, a greater the proportional error in y or dY occurs. However, if the changes in X are broken into a number of steps and the linear approximation technique applied to each sub-change in X, the consequent sub-change in Y can be minimised. In this way, the linearisation error can be minimised in order to reach a value of Y which is closer to Y_{exact}.

This multistep process which reduces linearisation error to derive a closer estimate of a non-linear function is called the *Euler* method - the process of using differential equations (change formulae) to move from one solution to another. The GEMPACK (computer software designed to make the linear solution process as easy as possible) developed by Codsi and Pearson (1988) offers a flexible system for solving applied general equilibrium models using a process of differential equations to move from one solution to another.

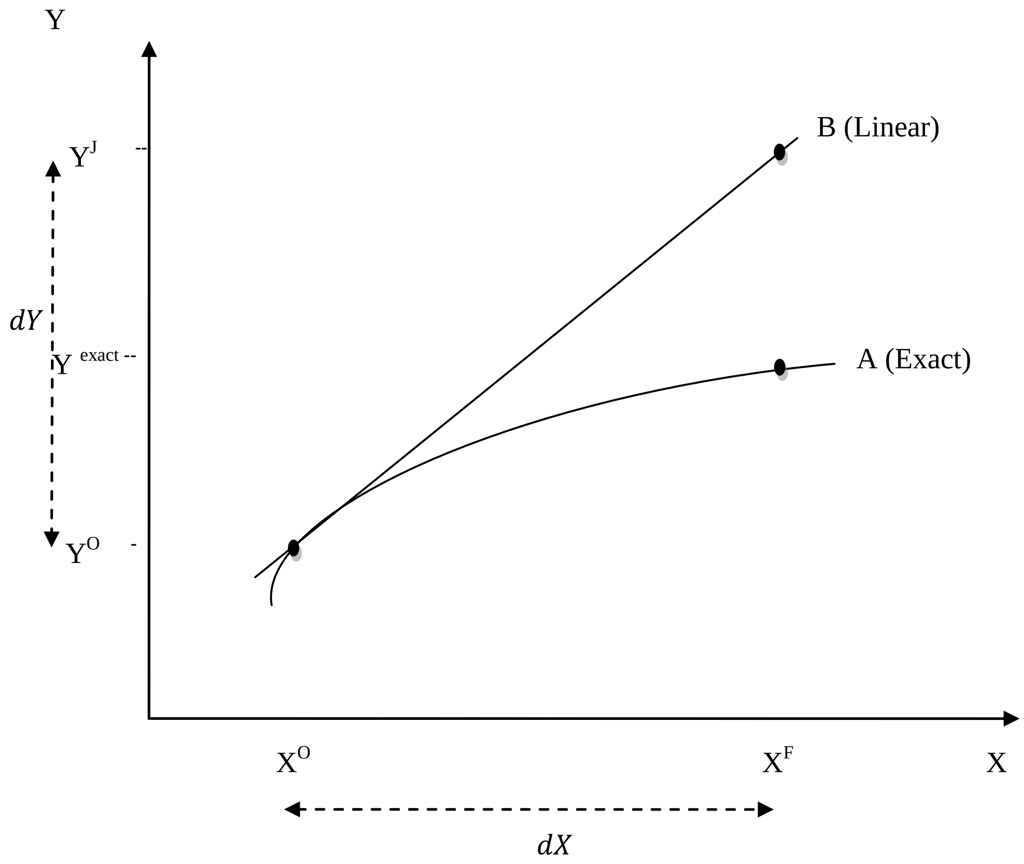
Each solution step uses an initial solution $\{Y_o, X_0\}$ formulae for the derivative matrices G_Y and G_X, and the total percentage change in the exogenous variables (x). When the user specifies the linear equations, the TABLO language (a model specific programming language) is used to update formulae for the GEMPACK to repeatedly:

Evaluate G_Y and G_X at given values of V;

Solve the linear system to find y; and

Update the data coefficients V which are functions of X and Y i.e. $V = H(X, Y)$.

Figure 5.1 Linearisation error



Source: Horridge (2003)

5.1.2 Model equation system

The equations in the model used for this study are largely adopted from the ORANI-G equation system. However, some modifications have been included into the standard ORANI-G equations in order to evaluate a carbon price mechanism in the Australian economy. For this purpose, modifications have been incorporated into the production structure equations and then to purchaser price equations. Additionally, a new set of behavioural equations are incorporated for institutions (household, government, corporations and ROW) with a detailed system of income and expenditure accounts.

The description and derivation of the linearised equation system is presented in the next sub section. Equations are mostly derived in the linearised form and occasionally derived in the level form. A notational convention is followed when writing equations in the model. For example, a lower case letter is used for the percentage change variable and an upper case letter is used for a level or ordinary change variable. The naming convention for variables closely follows the ORANI-G naming of variables. Sets represent as a subscript of a variable. For example, $X_{(is)j}$ denotes, the demand by user *j* for input *i* of type *s*. One of the digits 0 to 6 indicates *j* users. Inputs *i* are combinations of intermediate inputs, energy inputs and primary factors. Both domestic and imported sources supply commodities to the production and consumption process, therefore, *s*=1 means domestic and *s*=2 means imported. The following lists the letters that are assigned to variables and digits which are allocated to various users in the system.

A letter indicating the type of variable	
x or *q*	Percentage change of input quantity
p or p_f	Percentage change of price – in local or foreign currency
t	Power of tax
V	Level variable in nominal value of transactions
S	Input share
Digit indicating the user	
1	Current production
2	Investment
3	Household consumption
4	Export
5	Government consumption
6	Inventories
0	All users, or user distinction is irrelevant

The equations described in the model are expressed in linear functional forms which are organised into a number of blocks. Except where indicated, the variables are in percentage changes and are shown in lower case letters.

The model contains the following blocks which define equations for:

i. Demand for intermediate non-energy commodities;
ii. Demand for electricity generators to supply electricity;
iii. Demand for energy commodities;
iv. Demand for capital and energy composite;
v. Demand for labour by occupational categories;
vi. Demand for composite primary factors (labour, capital, land and energy);
vii. Supply of commodities by industries;
viii. Demand for investment goods;
ix. Household demands by income groups;
x. Export demand;
xi. Government and inventory demand;
xii. Purchaser price equations;
xiii. Market clearing equations for commodities by source; and
xiv. Income received by various institutions and by source.

5.2 The structure of production

The production structure in the model allows each industry to produce several commodities using intermediate inputs, labour of several types, land, capital and energy inputs. The combination of inputs used in the production process is different to the standard ORANI-G model as the A3E-G model treats non-energy commodities and energy commodities separately. The model then allows price-induced substitution among different energy commodities used in the production process (see similar type modeling structures in Devarajan et al., 2009, 2011; Telli et al., 2008; Yusuf, 2007). Similar to the ORANI-G structure, commodities destined for export are distinguished from those for local use. This multi-input, multi-output production specification is managed by a series of separability (nesting) assumptions. The generalised production function under the input-output separability assumption can be written as:

$$G(inputs) = X^{1TOT} = H(Outputs) \tag{5.5}$$

where X^{1TOT} is the level of industry activity.

The separability assumption reduces the number of estimated parameters required by the model. It shows the relationship between industry activity level and commodity output (H function). The relationship is derived from two nested constant elasticity of transformation (CET) aggregation functions. The G function explains the relationship between industry activity level and inputs which are derived from a sequence of nested production functions.

Figure 5.2 describes the input demand of the production function which is composed of five-layer nested Leontief and Constant Elasticity of Substitution (CES) functions. Similar to the standard ORANI model, the product-output mix of an industry is determined by Constant Elasticity of Transformation (CET) functions. The top level is a Leontief function describing the demand for intermediate inputs and composite primary factors and the rest are various CES functions at the bottom levels. The derivation of a linearised percentage change input demand function under the CES constraint is given in Appendix A.

Key modifications to the standard ORANI-G model include new input demand functions for electricity generation and energy inputs. Electricity generation in the economy is disaggregated into five generation types based on the energy sources used, namely electricity generated from black coal, brown coal, oil, gas and renewable energy sources. As the generated electricity commodity is homogenous irrespective of the type of the energy source used, the substitution among five types of generators is expressed using a CES function. This feature of the model allows electricity generation to shift from high carbon emission generators to low carbon emission generators.

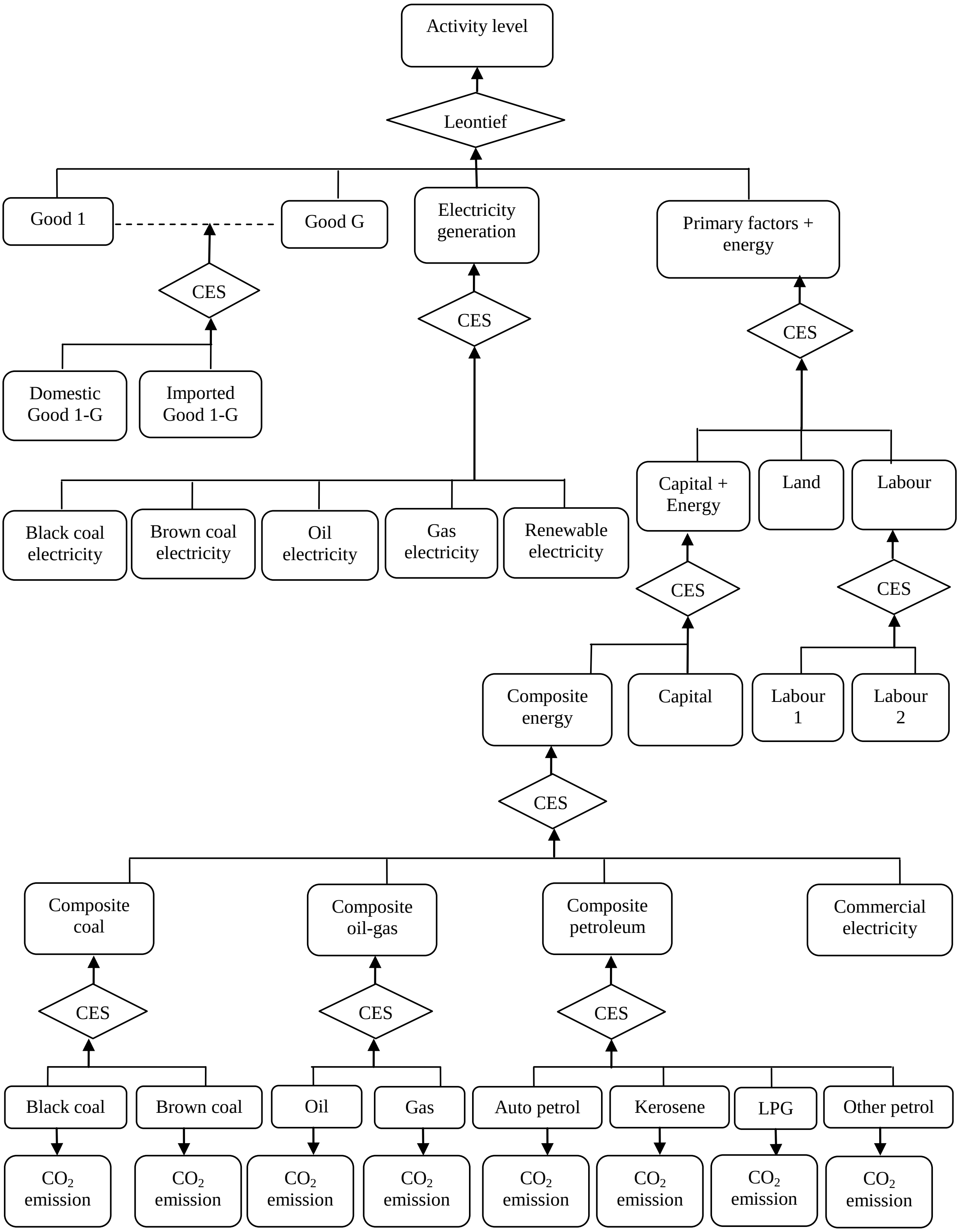
The use of a CES functional specification to form the composite electricity generation is slightly different from the Leontief functional specification used by Adams et al. (2000a; 2000b). They modelled each type of electricity generation using a Leontief function at the top level of the production function.

The energy inputs are also treated differently in the model. This modification explains that energy efficiency is positively related to the investment on energy saving devices, e.g. well-insulated housing uses less energy for air conditioning. Limited substitution possibilities are assumed between energy goods and capital and the level of substitution depends on the cost and the availability of energy saving technology. A similar approach explaining substitution between capital and an energy composite is used by many researchers such as Burniaux et al. (1992), Zhang (1998), Ahammad and Mi (2005) and Devarajan et al. (2009; 2011).

The substitution between different types of energy inputs is also described by CES functions at the bottom level. Accordingly, the model allows considerable substitution between brown coal and black coal, between oil and gas, and between auto petrol, kerosene, LPG and other petroleum. At one level above, demand for the composite energy is derived by the composite coal, composite oil-gas, composite petroleum products and commercial electricity through another CES function.

Only the commercial electricity commodity is included in the composite energy group because it is the final form of energy (electricity) which can be utilised by various sectors in the economy. This structure assumes electricity is generated by various sources and sold directly to the commercial electricity sector.

Figure 5.2 Structure of production of goods and services



As such, electricity generation is viewed as having normal composite intermediate demand (described by a Leontief function) for the electricity generating sectors and commercial electricity is treated as having energy demand for other sectors.

CO_2 emissions are made proportional to the energy inputs (except for commercial electricity) used and/or to the level of economic activity. In the model, carbon emissions are assumed to arise from stationary fuel combustion, industry activity and from household consumption. Based on the emissions data published in the National Greenhouse Gas Inventory (NGGI) of the Department of Climate Change and Energy Efficiency (DCEEE), input (stationary), output (activity) and consumption (household) emissions intensities are calculated[16]. These emission intensities are assumed fixed in the model to reflect the unchanged technology and household preferences. Therefore, once the carbon price is introduced, the model re-calculates the market equilibrium based on emissions intensities associated within each sector.

5.2.1 Industry demand for intermediate inputs

As illustrated in Figure 5.2, industries use intermediate commodities from domestic and imported sources as inputs to the current production process. In order to determine the domestic/import composition of intermediate commodity demands, the Armington (1970) assumption is used which suggests that imports are imperfect substitutes for domestic commodities. The cost minimisation problem minimises the total cost of imported and domestic good c subject to the CES production function. The solution determines the commodity demand by source:

$$x^1_{csi} = x^{1\_s}_{ci} - \sigma^1_c (p^1_{csi} - p^{1\_s}_{ci}) \qquad (5.6)$$

[16] Emission intensity is expressed as the amount of emissions per dollar of inputs (fuels), output (industry output) and household consumption.

where x_{csi}^{1} is the demand for commodity *c* by industry *i* from source *s*, $x_{ci}^{1\_s}$ is the demand for composite (domestic-import) commodity, p_{csi}^{1} is the purchaser price of commodity *c* from source *s* to industry *i*, $p_{ci}^{1\_s}$ is the price of the composite commodity, and σ_{c}^{1} is the Armington elasticity between domestic and imported commodity *c*.

The effective price of the commodity composite is derived as:

$$p_{ci}^{1\_s} = \sum_{s \in SRC} S_{csi}^{1} \times p_{csi}^{1} \tag{5.7}$$

where S_{csi}^{1} is the share of industry *i*'s purchase of domestic or imported commodity *c*. The Tablo code is given in Appendix B, Excerpt 5.5.

5.2.1.1 Industry demand for composite electricity generation

There are five electricity generating plants in the model namely black coal, brown coal, oil, gas and renewable energy. These electricity generating plants are assumed to be supplying electricity to the commercial electricity sector. The industry demand for electricity generation is modelled as a CES aggregation between different electricity generating plants.

$$x_{ci}^{1\_elcg} = x_{i}^{1elcg} - \sigma_{i}^{1elcg}(p_{ci}^{1\_elcg} - p_{i}^{1elcg}) \tag{5.8}$$

where $x_{ci}^{1\_elcg}$ is the intermediate use of electricity generation *c* in industry *i*, x_{i}^{1elcg} is the electricity generation composite demand, σ_{i}^{1elcg} is the elasticity of substitution between different electricity generation types, $p_{ci}^{1\_elcg}$ is the price of electricity generation *c* in industry *i*, and p_{i}^{1elcg} is the price of composite electricity generation.

The effective price of composite electricity generation is derived as:

$$p_{i}^{1elcg} \times V_{i}^{1elcg} = \sum_{c \in ELCG} V_{ci}^{1elcg\_s} \times p_{ci}^{1\_elcg} \tag{5.9}$$

whereV_i^{1elcg} is the value of composite electricity use in industry i and $V_{ci}^{1elcg\_s}$ is the value of each electricity generating usage in industry *i*. The Tablo code is given in Appendix B, Excerpt 5.6.

5.2.2 Industry demand for energy inputs

The energy commodities are treated separately from non-energy commodities. This allows energy substitution between different energy commodities. In order to model this effect, the coal, oil-gas and petroleum sectors are disaggregated into sub sectors which are either produced domestically or imported. The commercial electricity supply is treated as energy, while the rest of the electricity generating industries are treated as industries supplying inputs to the commercial electricity sector. The following sections present industry demand equations for different types of energy inputs.

5.2.2.1 Industry demand for composite coal energy

Industry demand for composite coal energy is modelled as a CES aggregation between black coal and brown coal. A problem of cost minimisation between black coal and brown coal derives optimum composition of black coal and brown coal used by each industry. Equation (5.10) depicts the intermediate demand for black coal and brown coal used by each industry in the percentage change form:

$$x_{ci}^{1\_col} = x_i^{1col} - \sigma_i^{1col} \times (p_{ci}^{1\_col} - p_i^{1col}) \tag{5.10}$$

where $x_{ci}^{1\_col}$ is the intermediate use of black coal and brown coal in industry i, x_i^{1col} is the composite coal demand, σ_i^{1col} is the elasticity of substitution between black coal and brown coal, $p_{ci}^{1_col}$is the price of black coal and brown coal to industry *i*, and p_i^{1col} is the price of composite coal.

The following equation derives the effective price of composite coal:

$$p_i^{1col} \times V_i^{1col} = \sum_{c \in COAL} V_{ci}^{1col\_s} \times p_{ci}^{1\_col} \tag{5.11}$$

where V_i^{1col} is the value of composite coal usage in industry *i*, $V_{ci}^{1col\_s}$ is the value of black and brown coal usage in industry *i*. The Tablo code is given in Appendix B, Excerpt 5.7.

5.2.2.2 Industry demand for composite oil-gas energy

Under a cost minimisation problem, the cost of composite oil-gas is minimised subject to the CES production functions of oil and gas. The percentage change form of equation (5.12) shows the intermediate demand for oil and gas is proportional to composite oil-gas demand and to a price term:

$$x_{ci}^{1\_oig} = x_i^{1oig} - \sigma_i^{1oig}\left(p_{ci}^{1\_oig} - p_i^{1oig}\right) \tag{5.12}$$

where $x_{ci}^{1\_oig}$ is the intermediate use of oil and gas in industry *i*, x_i^{1oig} is the composite oil-gas demand, σ_i^{1oig} is the elasticity of substitution between oil and gas, $p_{ci}^{1\_oig}$ is the price of oil and gas in industry *i*, and p_i^{1oig} is the price of composite oil-gas.

The following equation derives the effective price of composite oil-gas:

$$p_i^{1oig} \times V_{ci}^{1oig} = \sum_{c \in OILG} V_{ci}^{1oig\_s} \times p_{ci}^{1\_oig} \tag{5.13}$$

where V_{ci}^{1oig} is the total value composite oil-gas usage in industry *i* and $V_{ci}^{1oig\_s}$ is the value of oil and gas usage in industry *i*. The Tablo code is given in Appendix B, Excerpt 5.8.

5.2.2.3 Industry demand for composite petroleum inputs

The industry demands for composite petroleum inputs are modelled as a CES combination of automotive petroleum, kerosene, liquid gas petroleum and other petroleum products:

$$x_{ci}^{1\_ptr} = x_i^{1ptr} - \sigma_i^{1ptr}(p_{ci}^{1\_ptr} - p_i^{1ptr}) \quad (5.14)$$

where $x_{ci}^{1\_ptr}$ is the intermediate demand for petroleum input *c* in industry *i*, x_i^{1ptr} is the composite petroleum demand, σ_i^{1ptr} is the elasticity of substitution between different petroleum products, $p_{ci}^{1\_ptr}$ is the price of petroleum products *c* in industry *i* and p_i^{1ptr} is the price of petroleum composite.

The following equation derives the effective price of petroleum:

$$p_i^{1ptr} \times V_i^{1ptr} = \sum_{c \in PETR} V_{ci}^{1ptr\_s} \times p_{ci}^{1\_ptr} \quad (5.15)$$

where V_i^{1ptr} is the total value of composite petroleum usage in industry *i* and $V_{ci}^{1ptr\_s}$ is the value of each petroleum product usage in industry *i*. The Tablo code is given in Appendix B, Excerpt 5.9.

5.2.2.4 Industry demand for composite energy inputs

In the model, composite coal, composite oil-gas, composite petroleum products and commercial electricity are used to derive the composite energy commodity. Accordingly, the following input demand equations for composite coal, composite oil-gas, composite petroleum products and commercial electricity are derived:

$$x_i^{1col} = x_i^{1eng} - \sigma_i^{1eng} \times (p_i^{1col} - p_i^{1eng}) \quad (5.16)$$

$$x_i^{1oig} = x_i^{1eng} - \sigma_i^{1eng} \times (p_i^{1oig} - p_i^{1eng}) \quad (5.17)$$

$$x_i^{1ptr} = x_i^{1eng} - \sigma_i^{1eng} \times (p_i^{1ptr} - p_i^{1eng}) \quad (5.18)$$

$$x_i^{1ele} = x_i^{1eng} - \sigma_i^{1eng} \times (p_i^{1ele} - p_i^{1eng}) \quad (5.19)$$

where x_i^{1eng} is the industry demand for composite energy, σ_i^{1eng} is the elasticity of substitution between different energy commodities, p_i^{1eng} is the effective price of composite energy, x_i^{1ele} is the industry demand for commercial electricity and p_i^{1ele} is the price of commercial electricity.

The effective price of composite energy is derived as:

$$V_i^{1eng} \times p_i^{1eng} = V_i^{1col} \times p_i^{1col} + V_i^{1oig} \times \ p_i^{1oig} + V_i^{1ptr} \times p_i^{1ptr} + V_i^{1ele} \times p_i^{1ele} \quad (5.20)$$

where V_i^{1eng} is the total value of energy input demand in industry *i* and V_i^{1ele} is the value of electricity supply demand in industry *i*. The Tablo code is given in Appendix B, Excerpt 5.10.

5.2.3 Industry demand for composite capital-energy

The energy technology can be embodied with invested capital by treating composite energy as a primary input and allowing imperfect substitution with capital (Devarajan et al., 2009; 2011). Similarly, the A3E-G model allows input substitution between capital and composite energy subject to a CES production function. In the cost minimisation problem, firms determine optimum composition of the capital-energy composite by minimising the total cost of purchasing capital and composite energy commodities. The following equations explain industry demand for composite capital-energy.

$$x_i^{1eng} = x_i^{1enc} - \sigma_i^{1enc} \times (p_i^{1eng} - p_i^{1enc}) \quad (5.21)$$

$$x_i^{1cap} = x_i^{1enc} - \sigma_i^{1enc} \times (p_i^{1cap} - p_i^{1enc}) \quad (5.22)$$

where x_i^{1enc} is the industry demand for the capital-energy composite, p_i^{1enc} is the price of the capital-energy composite, x_i^{1cap} is the industry demand for capital, p_i^{1cap} is the price of capital and σ_i^{1enc} is the substitution elasticity between energy and capital.

Finally, the effective price of the capital-energy composite can be derived as:

$$V_i^{1enc} \times p_i^{1enc} = V_i^{1eng} \times p_i^{1eng} + V_i^{1cap} \times p_i^{1cap} \tag{5.23}$$

where V_i^{1enc} is the total value of capital-energy cost and V_i^{1cap} is the total value of capital cost to industry i. The Tablo code is given in Appendix B, Excerpt 5.11.

5.2.4 Industry demand for composite labour

The labour composite used in this model is a CES aggregation of nine occupational groups. In the cost minimisation problem, for a given labour composite, each firm is assumed to minimise total cost by employing different combinations of skill categories or occupations. For each industry, the solution determines the optimum composition of labour demand by industry (i) and by occupational group (o). The following equations determine the demand for labour composite and the effective price of labour for each industry, in percentage change form:

$$x_{io}^{1lab} = x_i^{1lab\_o} - \sigma_i^{1lab}\left(p_{io}^{1lab} - p_i^{1lab\_o}\right) \tag{5.24}$$

$$p_i^{1lab\_o} \times V_i^{1lab\_o} = \sum_{o \in OCC} p_{io}^{1lab} \times V_{io}^{1lab} \tag{5.25}$$

where x_{io}^{1lab} is the demand for labour type o by industry i, $x_i^{1lab\_o}$ is the composite labour demand, $\sigma_i^{1lab}$is the elasticity of substitution among different occupations o, p_{io}^{1lab} is the wages by industry i and occupation o, $p_i^{1lab_o}$is the effective price of labour, V_{io}^{1lab} is the total labour payments by industry i for occupation o, and $V_i^{1lab\_o}$ is the total labour bill in industry i. As expressed in equation (5.24), the changes in relative prices of occupations induce a substitution effect in favour of relatively cheaper occupation groups. The Tablo code is given in Appendix B, Excerpt 5.12.

5.2.5 Industry demand for primary factor composite

The next level of the production structure minimises the total cost of primary factors in each industry given the optimal combination of primary factor composite. Industry demand for the primary factor composite is modelled as a CES function between composite labour, composite capital-energy and land. In this case, total primary factor costs are minimised subject to the CES production functions. The solution to the optimisation problem, in percentage change form, derives input demand functions for primary factor inputs.

Industry demand for composite labour is given as:

$$x_i^{1lab\_o} = x_i^{1prim} - \sigma_i^{1prim}\left(p_i^{1lab\_o} - p_i^{1prim}\right) \qquad (5.26)$$

Industry demand for capital-energy composite is given as:

$$x_i^{1enc} = x_i^{1prim} - \sigma_i^{1prim}\left(p_i^{1enc} - p_i^{1prim}\right) \qquad (5.27)$$

Industry demand for land is given as:

$$x_i^{1land} = x_i^{1prim} - \sigma_i^{1prim}\left(p_i^{1land} - p_i^{1prim}\right) \qquad (5.28)$$

The effective price of primary factors is given as:

$$V_i^{1prim} \times p_i^{1prim} = V_i^{1lab\_o} \times p_i^{1lab\_o} + V_i^{1enc} \times p_i^{1enc} + V_i^{1lnd} \times p_i^{1lnd} \qquad (5.29)$$

and the ordinary change in total cost of primary factors is given as:

$$100 \times \Delta V_i^{1prim} = V_i^{1lnd}\left(p_i^{1lnd} + x_i^{1lnd}\right) + \sum_{o \in OCC} V_i^{1lab}\left(p_i^{1lab} + x_i^{1lab}\right) + V_i^{1enc}\left(p_i^{1enc} + x_i^{1enc}\right) \quad (5.30)$$

where x_i^{1prim} is the industry demand of primary factor composite, σ_i^{1prim} is the elasticity of substitution between primary factors, $p_i^{1prim}$is the effective cost of primary factor composite,

V_i^{1prim} is the total value of all primary factor costs, and V_i^{1lnd} is the value of land cost. The Tablo code is given in Appendix B, Excerpt 5.13.

5.2.6 Top production nest

At the top level of the production structure, intermediate non-energy commodity composite, electricity generating commodity composite and primary factor-energy composite are combined using Leontief production functions. The elasticity of substitution is set to zero in the Leontief production function and, therefore, the derived demand equations lack the price term. The solution to the cost minimisation problem for the intermediate non-energy commodity demand equation is given as:

$$x_{ci}^{1\_s} = x_i^{1tot} \tag{5.31}$$

The industry demand for composite electricity generation commodity is given as:

$$x_{ci}^{1elcg} = x_i^{1tot} \tag{5.32}$$

The demand for primary factor composite is given as:

$$x_i^{1prim} = x_i^{1tot} \tag{5.33}$$

where x_i^{1tot} is the total output produced by industry *i*. The Tablo code is given in Appendix B, Excerpt 5.14.

5.2.7 Determining industry costs and production taxes

Once the equilibrium quantity and price equations are determined at each stage of the production process, the next task is to compute levels and changes in the total cost of production. The level and changes in the total cost of production are obtained by adding level and changes of cost of primary factors and cost of purchasing intermediate inputs, production taxes and other taxes (in this case the change in output carbon tax revenue). This can be written as:

$$\Delta V_i^{1tot} = \Delta V_i^{1prim} + \sum_{C\in COM}\sum_{S\in SRC}\frac{1}{100}V_{csi}^{1pur}\,(p_{csi}^{1} + x_{csi}^{1}) + \Delta V_i^{1ptx} + \sum_{c,com}\Delta TX_{ci}^{1O} \quad (5.34)$$

where ΔV_i^{1tot} is the change in the total cost of production, ΔV_i^{1prim} is the change in the total cost of primary factors and V_{csi}^{1pur} is the value of purchase of commodity *c* from source *s* (domestic and imported) by the industry *i*. The other two variables denote ordinary change in production tax revenue (ΔV_i^{1ptx}) and ordinary change in output carbon tax revenue (ΔTX_{ci}^{1O})[17].

The following equation defines p_i^{1tot} as the percentage change in the unit cost of production for industry *i*. In other words, p_i^{1tot} is the percentage change in marginal cost given the constant returns to scale production technology. Therefore, this equation satisfies the competitive zero pure profits condition (price=marginal cost) by assuming that p_i^{1tot} is equal to the average price received by each industry.

$$V_i^{1tot}(p_i^{1tot} + x_i^{1tot}) = 100\Delta V_i^{1tot} \quad (5.35)$$

The Tablo code is given in Appendix B, Excerpt 5.15.

5.2.8 Industry output mix

The A3E-G model allows each industry to produce a mixture of all the commodities. For each industry, the mix varies according to the relative price of commodities. Under all scenarios, the producer maximizes the total revenue from all outputs subject to the constant

[17] Derivation of ΔTX_{ci}^{1O} is explained in subsection 5.6.2

elasticity of transformation (CET)[18] function. Equation (5.36) explains that an increase in a commodity price, relative to the average, induces transformation in favour of that output:

$$q_{ci}^{1} = x_{i}^{1tot} + \sigma_{i}^{1out}(p_{c}^{0com} - p_{i}^{1tot}) \tag{5.36}$$

where q_{ci}^{1} is the supply of commodity *c* by industry *i*, σ_{i}^{1out} is the elasticity of transformation, p_{c}^{0com} is the general output price of locally produced commodities and p_{i}^{1tot} is the average price received by the industry which is expressed as:

$$p_{i}^{1tot} = \sum_{c \in COM} \frac{V_{ci}^{make}}{V_{i}^{make\_c}} \times p_{ci}^{q1} \tag{5.37}$$

where V_{ci}^{make} is a matrix that records the value of commodity *c* produced by industry *i*, $V_{i}^{make\_c}$ is the total production by industry *i*, and p_{ci}^{q1} is the price of commodity *c* received by industry *i*.

Each industry is assumed to be getting the same price for a given commodity which is:

$$p_{ci}^{q1} = p_{c}^{0com} \tag{5.38}$$

The total commodity output (x_{c}^{0com}) produced by various industries is a simple summation over industries:

$$x_{c}^{0com} = \sum_{i \in IND} \frac{V_{ci}^{make}}{V_{i}^{make\_i}} \times q_{ci}^{1} \tag{5.39}$$

where $V_{c}^{make\_i} = \sum_{i} V_{ci}^{make}$. The Tablo code is given in Appendix B, Excerpt 5.16.

5.2.9 Output for local and export markets

The next three equations define how industry supplies of commodities reach both domestic and export markets. It is assumed that goods destined for export are not the same as for the

[18] The CET aggregation function is different from the CES function where in CES $\rho > -1,\ \rho \neq 0\ \ and\ \sigma = 1/(1+\rho)$ and in CET $\rho < -1,\ \ and\ \sigma = -1/(1+\rho)$

domestic market and the conversion of these undifferentiated commodities into both destinations is governed by a constant elasticity of transformation frontier.

The supply of commodities to the export market (x_c^4) is given as:

$$\tau_c(x_c^{0dom} - x_c^4) = p_c^{0dom} - p_c^e \tag{5.40}$$

where τ_c is the inverse of the elasticity of transformation between exportable and locally used commodities, p_c^{0dom} and x_c^{0dom} are the price and output of commodities supplied to the local market and p_c^e is the price of exportable commodity *c*.

The supply of commodities to the domestic market (x_c^{0com}) is defined as:

$$x_c^{0com} = \left(1 - S_c^{exp}\right)x_c^{0dom} + S_c^{exp}x_c^4 \tag{5.41}$$

The transformation maintains the zero pure profit condition, that is:

$$p_c^{0com} = \left(1 - S_c^{exp}\right)p_c^{0dom} + S_c^{exp}p_c^e \tag{5.42}$$

where $S_c^{exp}$is the sales share of commodity *c* sold in the export market. The Tablo code is given in Appendix B, Excerpt 5.17.

5.3 Investment demand

The nesting structure for the production of fixed capital is similar to the nested structure that governs intermediate inputs to current production. Fixed capital is produced using inputs from domestic and imported sources. Primary factors or other costs are not used directly as inputs to capital formation. The investment demand equations are derived in two stages. At the bottom level, the total cost of imported and domestic goods *c* are minimised subject to the CES function while at the top level the total cost of commodity composites is minimised subject to the Leontief function.

Demand for source specific inputs is very similar to the corresponding intermediate demand equations and the following equations describe source specific demand equations of demand for investment goods *c* from source *s* by industries *i* (x_{csi}^{2}):

$$x_{csi}^{2} = x_{ci}^{2\_s} - \sigma_{c}^{2}(p_{csi}^{2} - p_{ci}^{2\_s}) \tag{5.43}$$

$$p_{ci}^{2\_s} = \sum_{s,SRC} S_{csi}^{2} \times p_{csi}^{2} \tag{5.44}$$

where $x_{ci}^{2\_s}$ is the investment use of domestic-import composite, $p_{ci}^{2\_s}$ is the price of investment domestic-import composite, p_{csi}^{2} is the price of investment good *c* from source *s* to industry *i*, σ_{c}^{2} is the elasticity of substitution between domestic and imported commodities and S_{csi}^{2} is the industry cost share of good *c* from source *s*.

At the top level, the total cost of commodity composites is minimised subject to a Leontief function. The demand for composites determines the price of capital as the average cost of producing a unit which is a zero pure profits condition. The expression is:

$$x_{ci}^{2\_s} = x_{i}^{2tot} \tag{5.45}$$

$$p_{i}^{2tot} = \sum_{c \in COM} \frac{V_{ci}^{2pur\_s}}{V_{i}^{2tot}} \times p_{ci}^{2\_s} \tag{5.46}$$

where x_{i}^{2tot} is the total output for investment goods *c* by industry *i*, $V_{ci}^{2pur\_s}$ is the purchaser value of the import-domestic composite of investment, and p_{i}^{2tot} is the cost of a unit of capital. The Tablo code is given in Appendix B, Excerpt 5.18.

5.4 Household demands

The model includes 10 household groups (multiple households) and each household demand system follows a linear expenditure system. Therefore, household demands for commodity composites (domestic-imported) are aggregated by a Klein-Rubin function (Klein and Rubin, 1948-49). At the next bottom level (as shown in Figure 5.3) the domestic and imported commodity composite is modelled using the Armington aggregation. The representative household in each group is assumed to be choosing commodity *c* from source *s* to minimise the cost of achieving the optimal levels of composite commodity subject to a nested CES utility function. The solution to this optimisation problem determines the domestic-import composite of household demand which is given as:

$$x_{csh}^{3} = x_{ch}^{3\_s} - \sigma_{c}^{3} \times \left(p_{csh}^{3} - p_{ch}^{3\_s}\right) \tag{5.47}$$

where x_{csh}^{3} is the demand for commodity c from source s by household h, $x_{ch}^{3\_s}$ is the household use of the domestic-import commodity composite, σ_{c}^{3} is the household Armington elasticities, $p_{csh}^{3}$is the price of commodity c from source s by household h, and $p_{ch}^{3\_s}$ is the effective price of the domestic-import commodity composite which is defined as:

$$p_{ch}^{3\_s} = \sum_{s \in SRC} S_{csh}^{3} \times p_{csh}^{3} \tag{5.48}$$

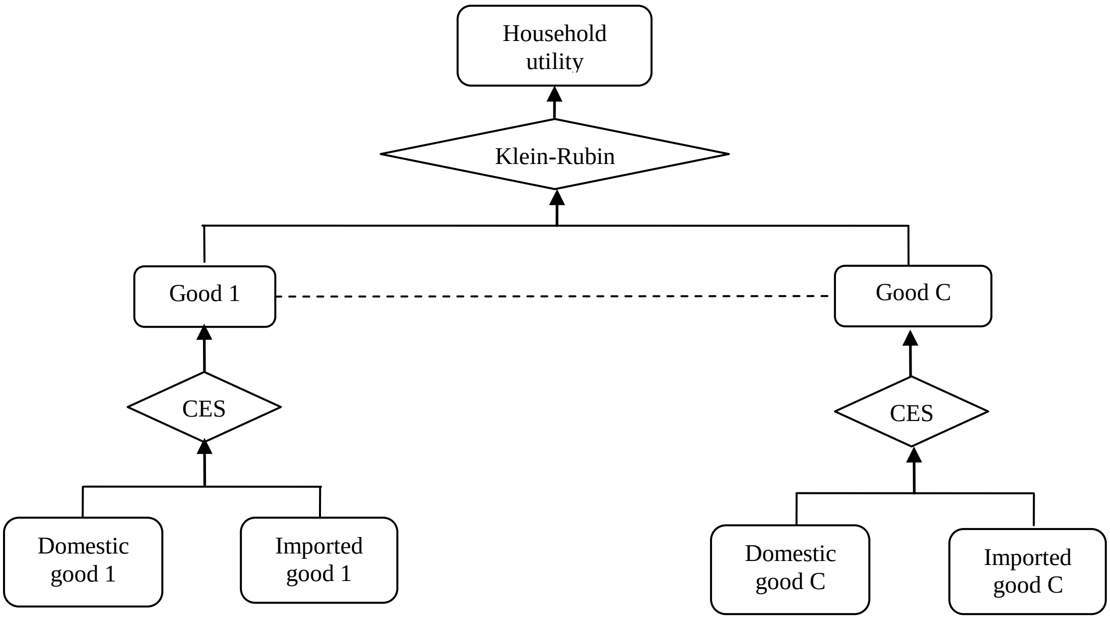
where S_{csh}^{3} is the household source share, i.e. share of household h's expenditure on commodity *c* from source *s*.

At the top level (of Figure 5.3) household demand for composite commodities are derived by maximising a Klein-Rubin utility function subjected to a household budget constraint:

$$U = \prod_{c}\left(X_{ch}^{3\_s} - X_{ch}^{3SUB}\right)^{S_{ch}^{3LUX}} \; s.t. \sum_{c} X_{ch}^{3\_s} \times P_{ch}^{3\_s} \tag{5.49}$$

where U represents the per household utility, $X_{ch}^{3\_s}$ is the total consumption of good c by household h, X_{ch}^{3SUB} is the subsistence requirements of each commodity which are purchased regardless of the price, and S_{ch}^{3LUX} is the marginal budget share of each commodity *c*.

Figure 5.3 Structure of household demand



The demand equations derived from the solution to the optimisation problem produces the linear expenditure system:

$$X_{ch}^{3\_s} = X_{ch}^{3sub} + S_{ch}^{3lux} \times V_{h}^{3lux\_c}/P_{ch}^{3\_s} \tag{5.50}$$

where $V_{h}^{3lux\_c} = V_{h}^{3tot} - \sum X_{ch}^{3sub} \times P_{ch}^{3\_s}$, $V_{h}^{3lux\_c}$ is the remaining consumer budget after subsistence expenditures are deducted from luxury or supernumerary expenditure, and V_{h}^{3tot} is the total consumption expenditure by household *h*.

In the percentage change form, the luxury demand for composite commodities can be written as:

$$x_{ch}^{3lux} = p_{ch}^{3\_s} + w_{h}^{3lux} \tag{5.51}$$

where w_{h}^{3lux} is the percentage change in total nominal luxury expenditure (V_{h}^{3lux}).

The total household demand for composite commodities can be written as:

$$x_{ch}^{3\_s} = B_{ch}^{3lux} \times x_{ch}^{3lux} + \left(1 - B_{ch}^{3lux}\right) x_{ch}^{3sub} \tag{5.52}$$

where B_{ch}^{3lux} is the ratio of supernumerary expenditure to total expenditure.

Total real consumption of households is given by:

$$x_h^{3tot} = \sum_c S_{ch}^{3\_s} \times x_{ch}^{3\_sh} \tag{5.53}$$

where $S_{ch}^{3\_s} = V_{ch}^{3pur\_sh} / V_h^{3tot}$, i.e. household budget shares.

The consumer price index (household specific) is given by:

$$p_h^{3tot} = \sum_c S_{ch}^{3\_s} \times p_{ch}^{3\_sh} \tag{5.54}$$

The household budget constraint is defined as:

$$w_h^{3tot} = p_h^{3tot} + x_h^{3tot} \tag{5.55}$$

The Tablo code is given in Appendix B, Excerpt 5.19.

5.5 Export and government demands

In the model, foreign demand for Australian export commodities is explained by two sets of export demand functions, namely individual export commodity demand and collective export commodity demand functions. The individual export group includes all the main export commodities. The downward-sloping individual export demand function is denoted in percentage form as:

$$x_c^4 = f_{qc}^4 - \gamma_c\left(p_c^4 - \varphi - f_{pc}^4\right) \tag{5.56}$$

where x_c^4 is the export volume of good c, γ_c is the constant elasticity of demand (negative parameter), P_c^4 is the price of export good c, φ is the exchange rate that converts local to foreign currency units, f_{qc}^4 and f_{pc}^4 are shift variables which allow for horizontal (quantity) and vertical (price) shifts in the demand schedule. If f_{qc}^{4} and f_{pc}^{4} are set exogenously, the equation determines the percentage change in the export demand for an individual export commodity *c* which is inversely related to the percentage change in the price of good *c*.

The other set, the commodity composition of aggregate collective exports (non-traditional) is exogenised by treating collective exports as a Leontief aggregate. The percentage change form of the collective export demand function is given as:

$$x_{c}^{4} = f_{qc}^{4} + x^{4} \tag{5.57}$$

where x^{4} is the collective export aggregate quantity. Subscript *c* = non-traditional export commodities.

The government demand (x_{cs}^{5}) is composed of both imported and domestically produced goods and services which are expressed as:

$$x_{cs}^{5} = f_{cs}^{5} + f_{g}^{5tot} \tag{5.58}$$

where f_{cs}^{5} and f_{g}^{5tot} are shift variables in which government consumption is set to be exogenously determined. By introducing an endogenous f_{g}^{5tot2} variable, government consumption is allowed to move with real aggregate household consumption (x_{h}^{3tot}).

$$f_{g}^{5tot} = x_{h}^{3tot} + f_{g}^{5tot2} \tag{5.59}$$

The Tablo code is given in Appendix B, Excerpt 5.20.

5.6 Carbon emission accounts

A3E-G has been enhanced to incorporate carbon emission accounting and a carbon pricing mechanism into various industries and consumer groups in the Australian economy. This study considers carbon emissions arising from three main sources, namely carbon emissions from stationary energy sources (input emissions), carbon emissions from production activities (output emissions) and carbon emissions from household consumption (consumption emissions). Since there are no separate carbon emissions accounts data for imported commodities, the study assumes carbon emissions are only associated with domestic commodities and processes.

5.6.1 Carbon emissions intensity

Each carbon emissions matrix is used to derive carbon emission intensities per real dollar use of energy by industries and by household groups. Input and output carbon emission intensities are derived for industries while consumption emissions intensities are derived for households. The procedure of compilation of carbon emissions matrices is discussed in Chapter VI.

Input carbon emissions intensity

$$EI_{ci}^{1I} = EM_{ci}^{1I} / X_{c,dom,i}^{1} \tag{5.60}$$

where EI_{ci}^{1I} is the input carbon emissions intensity, EM_{ci}^{1I} is the industry input carbon emissions using energy commodity *c*, and $X_{c,dom,i}^{1}$ is the quantity of domestically produced energy commodity *c* consumed by industry *i*.

Output carbon emissions intensity

$$EI_{ci}^{1O} = EM_{ci}^{1O} / X_{ci}^{o} \tag{5.61}$$

where EI_{ci}^{1O} is the output carbon emissions intensity, EM_{ci}^{1O} is the industry output carbon emissions from output *c*, and X_{ci}^{o} is the quantity of output *c* produced by industry *i*.

Consumption carbon emissions intensity

$$EI_{ch}^{3C} = EM_{ch}^{1C} / X_{c,dom,h}^{3} \quad (5.62)$$

where EI_{ch}^{3C} is the consumption carbon emissions intensity, EM_{ch}^{1C} is the household consumption emissions due to consumption energy commodity *c*, and $X_{c,dom,h}^{3}$ is the quantity of domestically produced energy commodity consumed by household *h*.

5.6.2 Carbon price (tax)

Once the input and output carbon emissions intensities of industries and consumption carbon emissions intensity of household groups are defined, the next task is to incorporate these emission intensities to design an appropriate carbon pricing mechanism. For this purpose, industry input and output carbon emissions and household consumption carbon emissions were updated, firstly, using the emissions intensities calculated above.

$$\Delta XEM_{c,i}^{1I} = 0.01 \times EI_{ci}^{1I}\left(X_{c,dom,i}^{1} \times x_{c,dom,i}^{1}\right) \quad (5.63)$$

$$\Delta XEM_{c,i}^{1O} = 0.01 \times EI_{ci}^{1I}\left(X_{ci}^{o} \times q_{c,i}^{0}\right) \quad (5.64)$$

$$\Delta XEM_{c,i}^{13} = 0.01 \times EI_{ci}^{1I}\left(X_{c,dom,h}^{3} \times x_{c,dom,h}^{3}\right) \quad (5.65)$$

where $\Delta XEM_{c,i}^{1I}$ is the change in input carbon emissions, $x_{c,dom,i}^{1}$ is the percentage change in domestic input *c* demanded by industry *i*, $\Delta XEM_{c,i}^{1O}$ is the change in output carbon emissions, $q_{c,i}^{0}$ is the percentage change in output *c* to industry *i*, $\Delta XEM_{c,i}^{13}$ is the change in consumption carbon emissions and $x_{c,dom,h}^{3}$ is the percentage change in household *h* consumption of domestic commodity *c*.

Input carbon tax by energy source and by industry

$$1000 \times \Delta TX_{ci}^{1I} = (EM_{ci}^{1I} \times \Delta P_{ci}^{1I}) + \left(P_{ci}^{1I} \times \Delta XEM_{c,i}^{1I}\right) \quad (5.66)$$

where ΔTX_{ci}^{1I} is the change in input carbon tax revenue, ΔP_{ci}^{1I} is the change in input carbon tax and P_{ci}^{1I} is the input carbon tax.

Output carbon tax by industry

$$1000 \times \Delta TX_{ci}^{1O} = \left(EM_{ci}^{1O} \times \Delta P_{ci}^{1O}\right) + \left(P_{ci}^{1O} \times \Delta XEM_{c,i}^{1O}\right) \quad (5.67)$$

where ΔTX_{ci}^{1O} is the change in output carbon tax revenue, ΔP_{ci}^{1O} change in output carbon tax and P_{ci}^{1O} is the output carbon tax.

Consumption carbon tax by household

$$1000 \times \Delta TX_{ch}^{3C} = (EM_{ch}^{1C} \times \Delta P_{ch}^{3C}) + \left(P_{ci}^{3C} \times \Delta XEM_{c,i}^{13}\right) \quad (5.68)$$

where ΔTX_{ch}^{3C} is the change in consumption carbon tax revenue, ΔP_{ch}^{3C} is the change in consumption carbon tax by household *h* and P_{ci}^{3C} is the consumption carbon tax.

The change in total carbon tax revenue (ΔTX^{co2}) is:

$$\Delta TX^{co2} = \sum_{c,COM} \Delta TX_{c}^{1I\_i} + \sum_{c,COM} \Delta TX_{c}^{1O\_i} + \sum_{c,COM} \Delta TX_{c}^{3C\_h} \quad (5.69)$$

where $\Delta TX_{c}^{1I\_i} = \sum_{i,IND} \Delta TX_{ci}^{1I}$, $\Delta TX_{c}^{1O\_i} = \sum_{i,IND} \Delta TX_{ci}^{1O}$ and $\Delta TX_{c}^{3C\_h} = \sum_{h,HOU} \Delta TX_{c}^{3C}$

5.6.2.1 *Ad valorem* carbon tax rates

The power of equivalent *ad valorem* carbon tax rates of intermediate use and final consumption are expressed as:

$$100 \times \Delta TX_{ci}^{1I} = TX_{ci}^{1I}\left(p_{c,dom}^{o} + x_{c,dom,i}^{1}\right) + \left(TX_{ci}^{1I} + X_{c,dom,i}^{1}\right) et_{ci}^{1} \quad (5.70)$$

$$100 \times \Delta TX_{ch}^{3C} = TX_{ch}^{3C}\left(p_{c,dom}^{o} + x_{c,dom,h}^{3}\right) + \left(TX_{ch}^{3C} + X_{c,dom,h}^{3}\right) et_{ch}^{3} \quad (5.71)$$

where et_{ci}^{1} is the power of equivalent *ad valorem* carbon tax on intermediate use of commodities, et_{ch}^{3} is the power of equivalent *ad valorem* carbon tax on household consumption, TX_{ci}^{1I} is the input carbon tax revenue, TX_{ch}^{3C} is the consumption carbon tax revenue, and $p_{c,dom}^{o}$ is the percentage change in the basic price of domestic commodity *c*.

In the model, carbon tax revenue is expressed in millions of dollars. The carbon emissions are expressed in million kilograms (or metric tonne). The carbon price (tax rate) is expressed as dollars per tonne. The Tablo code is given in Appendix B, Excerpt 5.21.

5.7 Price systems and zero pure profit conditions

Two sets of commodity prices are used in the model, namely purchaser prices and basic prices with two underlying assumptions, namely 1) there are no pure profits in any economic activity (producing, importing, exporting, transporting etc), and 2) basic values are uniform across users and across producing industries in the case of domestic goods and across importers in the case of foreign goods.

Basic prices to producers exclude sales taxes and basic prices to imports exclude sales taxes but include import duties. Purchaser prices (in levels) are the sums of basic prices and sales taxes (and margins[19]). Sales taxes are treated as *ad valorem* on basic prices with the sales tax variable *t*. This is expressed in the percentage change in the power of taxes in the linearised version (the power of a tax is one plus *ad valorem* rate of tax).

Percentage change in purchaser price to producers

In the model, purchaser prices to producers for domestic commodities are expressed in the percentage form as:

[19] Margin demands are not considered for this model due to the high computational difficulties in the database construction.

$$p_c^1 = p_c^0 + t_{ci}^1 + et_{ci}^1 \tag{5.72}$$

Purchaser prices of imported commodities to producers in the percentage form are expressed as:

$$p_c^1 = p_c^0 + t_{ci}^1 \tag{5.73}$$

where p_c^1 is the intermediate purchaser price, p_c^0 is the basic prices of commodity *c*, and t_{ci}^1 is the power of tax on intermediate goods *c* to industry *i* .

Percentage change in purchaser price to capital creators

$$p_{csi}^2 = p_c^0 + t_{csi}^2 \tag{5.74}$$

where p_{csi}^2 is the purchaser price of investment, and t_{csi}^2 is the power of tax on investment goods *c* to industry *i*.

Percentage change in purchaser price to households

Purchaser prices to households for domestic commodities are expressed in percentage form as:

$$p_c^3 = p_c^0 + t_c^3 + et_{ch}^3 \tag{5.75}$$

Purchaser prices of imported commodities to households are obtained as follows:

$$p_c^3 = p_c^0 + t_c^3 \tag{5.76}$$

where p_c^3 is the purchaser price to households, and t_c^3 is the power of tax on household consumption of goods *c*.

Zero pure profits in exports

$$p_c^4 = p_c^e + t_c^4 \tag{5.77}$$

where p_c^4 is the purchaser price of export commodities c, p_c^e is the basic price of export commodities, and t_c^4 is the power of tax on exports.

Zero pure profits in government consumption

$$p_{cs}^5 = p_{cs}^o + t_{cs}^5 \quad (5.78)$$

where p_{cs}^5 is the purchaser prices of commodities c from source s to the government, p_{cs}^o is the basic price of commodities c from source s, and t_{cs}^5 is the power of tax on government. The Tablo code is given in Appendix B, Excerpt 5.22.

5.8 Equilibrium and market clearing equations

The study employs a static CGE model where time does not enter into its specification and all endogenous variables are simultaneously determined. At the equilibrium, the solution constitutes a simultaneous interaction of the sectoral supply and demand functions. It is assumed that prices adjust in such a way that demand equates with supply, clearing all markets. This is known as Walras' Law which states that for a given set of prices, the sum of excess demand over all markets must be zero. Hence, the model assumes no excess demand or excess supply in the economy. Equation (5.79) equates supply (x_{r1}^0) with demand for each of the domestically produced goods, $r = 1, \ldots. g.$ Total supply is the sum over industry outputs ($r1$) (see equation (5.80)). The total demand consists of: demand for intermediate inputs to current production ($x_{(r1)j}^1$); demand for inputs to capital creation ($x_{(r1)j}^2$); demand for consumption goods ($x_{(r1)}^3$); export demand ($x_{(r1)}^4$); and government demand ($x_{(r1)}^5$).

In percentage change form, market clearing equations for domestically produced commodities can be denoted as:

$$x_{r1}^0 = \sum_{j=1}^k x_{(r1)j}^1 S_{(r1)j}^1 + \sum_{j=1}^k x_{(r1)j}^2 S_{(r1)j}^2 + x_{(r1)}^3 S_{(r1)}^3 + x_{(r1)}^4 S_{(r1)}^4 + x_{(r1)}^4 S_{(r1)}^4 + x_{(r1)}^5 S_{(r1)}^5 \quad (5.79)$$

and

$$x_{r1}^{0} = \sum_{j=1}^{k} x_{(r1)j}^{0} S_{(r1)j}^{0} \tag{5.80}$$

For supply of imported goods (x_{r2}^{0}), total demand constitutes demand for inputs to current production ($x_{(r2)j}^{1}$) and capital creation ($x_{(r2)j}^{2}$), demand for consumption goods ($x_{(r2)}^{3}$), and government demand ($x_{(r2)}^{5}$). The market clearing equations for imported commodities are:

$$x_{r2}^{0} = \sum_{j=1}^{k} x_{(r2)j}^{1} S_{(r2)j}^{1} + \sum_{j=1}^{k} x_{(r2)j}^{2} S_{(r1)j}^{2} + x_{(r2)}^{3} S_{(r1)}^{3} + x_{(r2)}^{5} S_{(r2)}^{5} \tag{5.81}$$

where the S's appearing in equation (5.79) to (5.81) are the shares of respective demand components identified on the right hand side of the equations. The Tablo code is given in Appendix B, Excerpt 5.23.

5.9 Household income distribution and other social accounts

The A3E-G model incorporates additional income mapping equations for household, corporations, government and the ROW compared to the ORANI-G model. Basically, the ORANI-G model is based on the IO database while the A3E-G model is based on an ESAM which contains accounts for income distribution. A complete description of the Australian ESAM and its accounts was explained in Chapter IV.

5.9.1 Household income, expenditure and savings

The aggregate household account has been disaggregated into ten deciles based on average weekly income/expenditure. Household income is sourced from supply of labour (different occupational groups), rent from capital and income transfers from households, government, corporations (non-financial and financial) and from the ROW. The following equation determines total household income:

$$Y_h y_h = \sum_{o \in OCCD} Y_{ho}^{lab} \, y_{ho}^{lab} + Y_h^{cap} y_h^{cap} + Y_h^{lnd} y_h^{lnd} + Y_h^{th} y_h^{th} \tag{5.82}$$

where Y_h and y_h are the value and percentage change respectively of household income, Y_{ho}^{lab} and y_{oh}^{lab} are the value and percentage change respectively of labour income received in employing occupation o, Y_h^{cap} and y_{ih}^{cap} are the value and percentage change respectively of capital income, Y_h^{lnd} and y_{ih}^{lnd} are the value and percentage change respectively of land income, and Y_h^{th} and y_h^{th} are the value and percentage change respectively of the total transfers received from households, corporations, government and from the ROW.

Household expenditure is a function of household final consumption expenditure including indirect taxes and transfers to households and all other institutions. The following equation determines total household expenditure:

$$X_h x_h = V_h^{3tot} x_h^{3tot} + X_h^{ht} x_h^{ht} \tag{5.83}$$

where X_h and x_h are the value and percentage change respectively of household total outlay, V_h^{3tot} and x_h^{3tot} are the value and percentage change respectively of household final consumption, X_h^{ht} and x_h^{ht} are the value and percentage change respectively of the total transfers made to households, corporations, government and to the ROW.

Next, household supernumerary consumption (w_h^{3lux}) is derived which is determined by the following consumption function:

$$w_h^{3lux} = y_h + p_h^{3tot} + f_h^{3lux} \tag{5.84}$$

where f_h^{3lux} is the shift coefficient of the average propensity to consume.

Finally, household savings are determined residually as follows:

$$S_h s_h = Y_h y_h - X_h x_h \tag{5.85}$$

where S_h and s_h are household savings in level and percentage change respectively.

5.9.2 Government income, expenditure and savings

The model assumes that all taxation revenue is received by the government. The components of taxation include indirect tax revenue and carbon tax revenue. Additionally, government income constitutes rent from government owned capital and transfers received from other institutions including own government transfers. The expenditure side of the government is determined by consumption expenditure, subsidy payments and transfers to other institutions including own government transfers. The following equations represent government income, expenditure and savings:

Government income:

$$Y_g y_g = \Delta V_{csi}^{0tax} + \Delta TX^{co2} + Y_g^{cap} y_g^{cap} + Y_g^{tg} y_g^{tg} \tag{5.86}$$

where Y_g and y_g are the value and percentage change respectively of government total income, ΔV_{csi}^{0tax} is the change in aggregate tax revenue, ΔTX^{co2} is the change in carbon tax revenue, Y_g^{cap} and y_g^{cap} are the value and percentage change respectively of total capital income, and Y_g^{tg} and y_g^{tg} are the value and percentage change respectively of total transfers received from household, corporations, government and ROW.

Government expenditure:

$$X_g x_g = V_{csi}^{5tot} x_{csi}^{5tot} + X_g^{sub} x_g^{sub} + X_g^{gt} x_g^{gt} \tag{5.87}$$

where X_g and x_g are the value and percentage change respectively of government total outlay, V_g^{5tot} and x_g^{5tot} are the value and percentage change respectively of government final consumption, X_g^{sub} and x_g^{sub} are the value and percentage change respectively of subsidy payments to production, and $X_g^{gt}$and x_g^{gt} are the total transfers made to households, corporations, government and to the ROW.

Government savings:

$$S_g s_g = Y_g y_g - X_g x_g \tag{5.88}$$

where S_g and s_g are goverment savings in level and percentage change respectively.

5.9.3 Corporation income, expenditure and savings

Income to non-financial and financial corporations constitutes capital income and transfers made from all institutions. Expenditure is a function of all transfers made to all other institutions. The savings of these institutions are derived residually by subtracting total income from total expenditure. The following equations display aggregate income, expenditure, and savings of financial and non-financial corporations.

Corporation income:

$$Y_c y_c = Y_c^{cap} y_c^{cap} + +Y_c^{tc} y_c^{tc} \tag{5.89}$$

where Y_c and y_c are the value and percentage change respectively of the aggregate total income of corporations, Y_c^{cap} and y_c^{cap} are the value and percentage change respectively of capital income and Y_c^{tc} and y_c^{tc} are the value and percentage change respectively of transfers received from households, government, corporations and ROW.

Corporation expenditure:

$$X_c x_c = X_c^{ct} x_c^{ct} \tag{5.90}$$

where X_c and x_c are the value and percentage change respectively of total outlays from corporations, and X_c^{ct} and x_c^{ct} are the value and percentage change respectively of the total transfers made by corporations to households, government, corporations and ROW.

Corporation savings:

$$S_c s_c = Y_c y_c - X_c x_c \tag{5.91}$$

where S_c and s_c are the value and percentage change respectively of total corporate savings.

5.9.4 Rest of the world (ROW) income, expenditure and savings

The ROW shows the linkages between domestic institutions and the ROW. The SAM of Australia shows transactions of goods and services as exports and imports, supply and demand of foreign labour and other transactions between domestic institutions with the ROW account. The ROW savings are determined residually. The following equations display income, expenditure and savings of the ROW account:

ROW Income:

$$Y_{rw} y_{rw} = V_c^{bas} x_c^{bas} + Y_{rw}^{lab} y_{rw}^{lab} + Y_{rw}^{trw} y_{rw}^{trw} \tag{5.92}$$

where Y_{rw} and y_{rw} are the level and percentage change respectively of total income accrued to the ROW, V_c^{bas} and x_c^{bas} are the level and percentage change respectively of values of imports by industries, household, government, and formation of capital in the economy, Y_{rw}^{lab} and y_{rw}^{lab} are the level and percentage change respectively of the value of labour imported, and Y_{rw}^{trw} and y_{rw}^{trw} are the level and percentage change respectively of transfers made to the ROW account by households, government, corporations and ROW.

ROW expenditure:

$$X_{rw} x_{rw} = V_c^{4tot} x_c^{4tot} + X_{rw}^{lab} x_{rw}^{lab} + X_{rw}^{rwt} x_{rw}^{rwt} \tag{5.93}$$

where X_{rw} and x_{rw} are the level and percentage change respectively of the total expenditure to the ROW, V_c^{4tot} and x_c^{4tot} are the level and percentage change respectively of the values of exports, X_{rw}^{lab} and x_{rw}^{lab} are the level and percentage change respectively of the value of labour exported, and X_{rw}^{rwt} and x_{rw}^{rwt} are the value and percentage change respectively of transfers from the rest of the ROW, government and corporations.

ROW savings:

$$S_{rw}s_{rw} = Y_{rw}y_{rw} - X_{rw}x_{rw} \tag{5.94}$$

where S_{rw} and s_{rw} are the total savings of the ROW in level and percentage change form respectively. The complete sets of SAM equations (Tablo codes) are given in the Appendix B, Excerpt 5.24.

5.10 Closing the model

The model specified above has more variables than equations. In order to close and simulate the model, certain variables have to be declared exogenous. This will ensure the number of endogenous variables to be equal to the number of equations in the model. Selection of exogenous variables can be made following some general rules. Firstly, when prices are determined endogenously, the quantities of factors or commodities are determined exogenously. When both quantity and price variables are determined exogenously, a shift variable is introduced and determined endogenously. Secondly, at least one price variable should be declared as exogenous in order to determine the absolute price level. This price is the *numeraire*. As commonly seen in the literature, the following variables were declared as exogenous in the model:

- Technical change variables, mostly beginning with the letter 'a';
- Tax rate variables, mostly beginning with 't';

- Shift variables, mostly beginning with '*f*';
- Some nominal change variables, beginning with '*del*';
- Land endowments *x1lnd*, industry capital stocks *x1cap*, number of households *qh*;
- Investment slack variable *invslack*, foreign prices *pf0cif*, inventory to sales ratios *fx6*;
- Income mapping variables, mostly beginning with '*x*'; and
- The exchange rate *phi*, which could serve as *numeraire*.

5.10.1 Homogeneity test

Validity of the model requires passing the homogeneity test. The homogeneity test is conducted by increasing a nominal variable (in this case, exchange rate *phi*) by 1 percent and holding all real variables (quantities) unchanged. This test ensures that there is no money illusion in the model; i.e. if prices were uniformly increased there would be no effect on quantity variables. From the list of automatic closure variables, the following variables were swapped to be in the exogenous list:

- Exogenise *x3toth* instead of *f3lux*;
- Exogenise *x5tot* instead of *f5tot2*;
- Exogenise *delx6* instead of *fx6*; and
- Exogenise *realwage* instead of *f1lab_io*.

Next, the exchange rate variable *phi* was shocked by 1 percent and the solution checked for any change in nominal and real variables. The solution confirmed that all nominal endogenous variables were affected equally by the shock while all endogenous real variables had zero values, unaffected by the shock. This method verified that the model was implemented correctly.

5.11 Conclusion

This chapter described the theoretical structure of the A3E-G model developed to analyse Australian economy-energy-emissions interactions. The model is an extended version of the ORANI-G model of the Australian economy. The A3E-G model is extended with equations defining intermediate input demand functions of various energy commodities, and capital-energy composite input demand functions. Purchaser price equations include additional variables explaining the carbon price mechanism in the economy (input, output and consumption carbon price). Thus, an explicit carbon price shock will change the equilibrium level of prices and quantities in the economy. Furthermore, the model incorporates new sets of behavioural equations which explain the income and expenditure patterns of the institutions in the economy. Therefore, the carbon price changes the equilibrium allocation of resources that can be effectively transferred to the institutions in the economy. Because of this feature, the model can be further used to analyse various carbon tax revenue recycling policies. While detailed application of this model is presented in Chapter VII, Chapter VI presents the database structure to implement the A3E-G model.

CHAPTER VI

A3E-G Model Database Structure

Introduction

This chapter outlines the structure of the database used in the A3E-G model. The major part of the A3E-G database is derived from the ESAM constructed in Chapter IV. The ESAM was constructed using the IO tables and social accounting data of the households, government, corporations and rest of the world (ROW). In order to complete the rest of the database, it is necessary to compile an investment matrix, a tax matrix, a carbon emissions matrix, and various elasticity parameters.

The rest of the chapter is organised as follows. Section 6.1 presents the basic database structure. Section 6.2 provides a brief note on the use of IO data and income mapping data in the database. Sections 6.3 and 6.4 discuss the procedure of compiling an investment matrix and tax matrices. Section 6.5 presents the carbon emissions accounts database and, finally, various elasticity parameters used in the model are discussed in Section 6.6.

6.1 Model database structure

The A3E-G model database structure is an extended version of the standard database structure used in the ORANI-G type models. The structure of the database is shown in Figure 6.1 ('Absorption' matrix) which shows the commodity flows by usage (IO data). The column headings are classified into the following demand categories:

1. Domestic industries divided into I industries;
2. Domestic industries of capital formation (investors) divided into I industries;
3. Households divided into H household groups;
4. An aggregate foreign purchaser of exports;

5. Government demand; and
6. Changes in inventories.

As illustrated in Figure 6.1, the ‘Absorption’ matrix contains both domestic and imported sources of commodities used as intermediate goods for current production (V1BAS), capital formation (V2BAS), household consumption (V3BAS), government consumption (V5BAS) and changes in demand for inventories (V6BAS). Entry V4BAS includes exports of domestically produced commodities assuming that re-exports demand for imported commodities are zero.

Additionally, this database shows the carbon emissions generated from domestic activities in the economy. It is assumed that emissions are not generated from imported sources. Domestic carbon emissions from input usage by industries are given by the matrix EMI1 (input emissions). These inputs are categorised into eight energy commodities in the database. Activity related emissions are shown by the vector EMO1 (activity emissions). These emissions are generated from the production sectors. The emissions related to the household consumption (consumption emissions) are shown by the matrix EMC3. The entries included in this row are in physical units (metric tonne of CO_2 equivalent emissions). Emissions data are not reported under capital formation, exports, government and inventory columns.

Taxes are involved in the delivery of domestic and imported commodities to producers, investors, households and exports. The matrices V1TAX to V4TAX contain the indirect sales taxes paid by each demand category on commodities supplied from both domestic and imported sources. Indirect sales taxes are not payable by the government or inventories accounts such that there are no entries to appear in those corresponding cells.

The value-added demand to current production is shown in the matrices of V1LAB, V1LND and V1PTX which provide a breakdown of value-added used in the current production process. The matrix V1LAB contains the wage bill of labour by occupation groups for each industry. Similarly, matrix V1CAP, V1LND and V1PTX contain the rental value of capital, the rental value of land and production taxes paid by industries.

In principle, each industry is capable of producing any of the C commodity types. The 'Make' matrix shows the value of commodity output produced by each industry. This represents each industry's capability of producing more than one commodity type (multiple products).

Tariffs on imports are assumed to be levied at rates which vary by commodity but not by user. The import tax revenues by commodities are given in the 'Tariff' vector.

The 'Social' accounts link consumption expenditure with the income sources of the institutions which own factors of production in the economy. This data is provided from the ESAM constructed in Chapter IV. The arrows originating from the factors of production show receipts of factor income by institution in the economy. All production tax and commodity taxes are received by the government whereas all wage income is received by households. Capital income is owned by all three institutions in the economy, namely households, government and corporations. The receipts to the ROW institution are shown by the arrow originating from the imported block of the 'Absorption' matrix. All these institutions spend their income on the purchase of commodities at purchaser prices which includes basic values (production costs) of commodities plus indirect taxes on sales. The sale of commodities for household demand, exports demand, and government demand corresponds to the purchase of commodities by the households, ROW and the government. The formation of capital in the economy (through investments and inventories) is equal to the savings by each of these institutions.

Figure 6.1 Core structure of the database

(i) Absorption matrix

		Domestic industries Current production	Domestic industries Capital formation	Household consumption	Exports	Government	Inventories
	Size	I	I	H	1	1	1
Basic flows	C*S	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS
Carbon emissions	C+1	EMI1+EMO1	0	EMC3	0	0	0
Product taxes	C*S	V1TAX	V2TAX	V3TAX	V4TAX	0	0
Labour	O	V1LAB					
Capital	1	V1CAP					
Land	1	V1LND					
Production tax	1	V1PTX					

C = Number of Commodities,

I = Number of Industries

H= Number of Households,

O = Number of Occupations

(ii) Social accounts

Institutions in the economy			
Corporations	Households	ROW	Government

(iii) Make matrix

Joint production matrix	
Size	I
C	MAKE

(iv)Tariff vector

Import Duty	
Size	1
C	VOTAR

6.2 Input-output data and income mapping data

The data for the model was derived from the IO table published by the Australian Bureau of Statistics of Australia in 2004-05. The IO tables contain the ‘Use’ table (domestic and imports), ‘Supply’ table, ‘Import duties’ table and ‘Domestic tax’ table. The ‘Use’’ table is comprised of an intermediate domestic use matrix, an intermediate import use matrix, vectors of final demanders and value-added components. The intermediate domestic use matrix is a 109 x 109 matrix at basic prices which shows the use of domestic commodities as intermediate inputs to the current production. The intermediate import use matrix is similar to the dimensions of the domestic matrix except it indicates the use of imported commodities as intermediate inputs.

The final demand vectors comprise households and government demand for goods and services, export demand, formation of capital (by private, public enterprise and general government) and changes in inventories. The value added components are divided into compensation of employees, gross operating surplus & mixed income and production taxes categories. These factors are used only for the current production, thus there are no entries in the household consumption, exports, capital formation and other final demand columns. The ‘Use’ table represents the major part of the ‘Absorption’ matrix in the model database.

The ‘Supply’ table records the sum of intermediate inputs (domestic and imported) and value added components used by each industry to produce its gross output. This matrix shows the production of 109 commodities by each of 109 domestic industries. The ‘Supply’ table represents the ‘Make’ matrix in the database.

These intermediate domestic and import use matrices were re-constructed in order to show energy industry details, electricity generating sector details, household sector details, and occupation details. The re-construction details are given in Chapter IV, Section 4.4. The

'Social' accounts data of the institutions shown in Figure 6.1 were derived from the ESAM constructed in Chapter IV. The following sections discuss construction of an investment matrix, a carbon emissions matrix, tax matrices, and various elasticity parameters that are required to complete the model database structure in order to implement the A3E-G model.

6.3 Investment matrix

In the existing 'Use' table for Australia, the gross fixed capital formation (GFCF) is disaggregated by commodity but not by investing industry. However, it is required to construct a data matrix which is compatible with the structure of the current database. Therefore, the GFCF column which is disaggregated by commodity, but not by investing industry, has to be re-constructed in order to include the investing industry as well. Dixon et al. (1982) explain a procedure to construct an investment matrix using a capital stock matrix, i.e. a matrix containing estimates of the value of inputs of each commodity in the capital stock of each industry. However, given time and resource constraints, this study instead used an 'Industry performance' table published by the Australian Bureau of Statistics (ABS) for the year 2006-07 which gave industry GFCF by 95 industries. Using this table, industry GFCF shares of 95 industries were calculated firstly. Secondly, these GFCF shares of 95 industries were mapped with the sectors in the re-constructed 'Use' table. Finally, the GFCF column vector by commodity in the re-constructed 'Use' matrix was converted into an investment matrix using the calculated GFCF shares. This investment matrix now gives investment by industry and by commodity.

6.4 Tax matrices

The 'Use' table reports a row vector of taxes less subsidies on products by industries in Australia. This row vector includes both domestic taxes less subsidies and import duties paid by industries. However, in order to be compatible with the model database structure, matrices of domestic taxes and import duties allocated by industries and by commodities were required. These matrices were derived from two types of IO tables, namely the 'Taxes on products' table and the 'Import duty' table.

The 'Taxes on products' table includes both domestic and import duties paid to purchase goods and services by each industry and final demanders. The 'Import duty' table records duties paid on imported commodities by each industry and final demanders. Using these two tables, the domestic tax matrix was derived by subtracting the 'Import duty' matrix from the 'Taxes on products' matrix. The 'Import duty' matrix was used to derive a vector of commodity imports valued at *c.i.f.* prices by subtracting import duties from each of the import flows demanded by industries and final demanders.

6.5 Carbon emissions matrix

The carbon emissions resulting from the production and consumption process have been incorporated into the database under three emissions categories, namely input emissions (EMI1), activity emissions (EMO1) and consumption emissions (EMC3). Input and activity emissions are related to the current production process whereas consumption emissions are related to the household consumption. These emissions data were compiled using the National Greenhouse Gas Inventory (NGGI) of the Department of Climate Change and Energy Efficiency, Australian Government (DCCEE, 2005). Accordingly, emissions related to inputs (stationary) were derived from the national greenhouse gas inventory database and emissions related to activity (output) were derived from the national inventory by economic sector database. These emissions data are subjected to the Kyoto Protocol accounting rules and are expressed in metric tonne of carbon dioxide equivalent emissions.

The national greenhouse gas inventory database reports emissions related to sector by fuel type. From this database, emissions were obtained for 35 sectors[20] and for one residential sector by 8 fuel types, namely black coal, brown coal, oil, gas, automotive petroleum, kerosene, liquid gas petroleum, other petroleum products and renewable energy sectors. This derived the input emissions matrix (EM1I) which gives emissions by 35 sectors and by 8 fuel types.

The national inventory by economic sector database reports total emissions by economic sectors in the economy. The classification of economic sectors follows the Australian and New Zealand Standard Industrial Classification (ANZSIC). From this database, activity emissions were obtained for 21 sectors and for one residential sector. Since some sectors in the model have been further disaggregated, (for example coal sector into black and brown coal), activity emissions related to those sectors were split based on GDP shares. This derived activity related emissions by 35 sectors. The activity emissions were then deducted from the total input emissions of each sector as reported in the input emissions matrix. This derived a column vector of emissions related to output by sector (EMO1).

The household related emissions were obtained from residential emissions. This is a vector of emissions related to single household units. This emissions vector was then disaggregated into 10 household groups according to the consumption shares of each household group. The resultant emissions matrix - 35 commodities by 10 household groups - is named as the consumption emissions matrix (EMC3). The carbon emissions matrix developed for this purpose is shown in Table 6.1.

[20] This sector classification was used to aggregate 119 sectors in the model database into 35 sectors

Table 6.1 Carbon emission matrix for 2005 CO_2-e (1000 tonne)

Sector	Black coal	Brown coal	Oil	Gas	Auto petrol	Kerosene petrol	L.gas petrol	Other petrol	Input emission	Activity emission	Total emissions
Agriculture	0	0	0	5	6340	0	84	0	6429	149411	155840
Black coal	1249	0	0	25	2113	0	1	1	3387	15313	18701
Brown coal	0	501	0	20	1034	0	0	0	1556	8540	10096
Oil	0	0	20	1991	79	0	3	20	2113	1748	3860
Gas	0	0	60	5972	238	0	9	59	6338	5243	11581
Other mining	734	0	0	1438	4788	0	60	23	7045	0	7045
Food, beverages, tobacco	1020	9	0	1680	1015	0	54	198	3976	773	4749
Textile, leather	53	28	0	333	14	0	12	41	481	0	481
Wood, paper, print	1079	0	0	1040	124	0	48	7	2298	182	2480
Auto petrol	0	0	0	617	54	0	63	2210	2944	246	3190
Kerosene petrol	0	0	0	309	27	0	31	1105	1472	123	1595
Liquid gas petrol	0	0	0	154	14	0	16	552	736	62	798
Other petrol	163	47	0	31	58	0	12	0	311	0	311
Chemical coal products	279	47	391	1656	340	0	689	2414	5817	4952	10769
Non metallic mineral	453	0	0	2018	58	0	84	20	2633	0	2633
Concrete, cement	2194	0	0	958	120	0	133	149	3553	4759	8312
Iron steel	1821	0	0	1439	115	0	24	0	3399	10110	13510
Other metal	5026	0	0	6913	2405	0	6	450	14800	4581	19382
Manufacturing	0	0	0	384	69	0	66	0	520	131	651
Elec. black coal	116182	0	0	0	0	0	0	0	116182	171	116353
Elec. brown coal	0	61856	0	0	0	0	0	0	61856	150	62006
Elec. oil	0	0	0	0	1804	0	0	0	1804	100	1904
Elec. gas	0	0	0	14305	0	0	1	0	14306	100	14406
Elec. renewable energy	0	0	0	0	0	0	0	0	0	0	0
Elec. commercial	0	0	0	0	0	0	0	0	0	0	0
Gas supply	0	0	0	1137	0	0	0	0	1137	2031	3168
Water supply	0	0	0	51	49	7	0	0	107	2212	2319
Construction	0	0	0	159	1658	27	12	0	1856	0	1856
Trade services	0	0	0	364	102	0	57	0	522	379	902
Accommodation	4	0	0	806	2	0	48	0	860	11087	11948
Transport road	0	0	0	0	136	0	0	0	136	27492	27628
Transport other	0	0	0	0	435	415	0	0	850	9707	10557
Business services	0	0	0	195	432	0	0	0	627	65	691
Public services	111	159	0	907	694	27	81	0	1978	736	2714
Other services	0	0	0	0	0	0	0	0	0	0	0
Residential (household)*	9	10	0	6691	1345	0	677	0	8731	45900	54631
Total	130378	62656	471	51596	25664	477	2270	7248	280759	306304	587064

Source: Based on NGGI database (DCCEE, 2005), * Household emissions were disaggregated into deciles based on consumption shares.

6.6 Elasticity parameters

Elasticity parameters explain the behavioural responses of an economic agent to changing economic conditions (mainly prices). The parameters included in this study are input and factor substitution elasticities, product transformation elasticities, export demand elasticities and consumer demand elasticities. It is a common practice in CGE modelling that these parameters are either sourced from existing literature, derived econometrically or based on the judgment of the researcher. Due to time and resource constraints this study did not perform any econometric procedure to obtain these parameters. Instead parameters were taken from the literature or author's judgment was used, where necessary. Most of the elasticity parameters were largely adopted from the existing ORANI-G databases. However, when similar parameters were not defined in the ORANI-G databases estimates from other literature or the author's own judgment were used.

6.6.1 The elasticities of substitution between domestic and foreign sources

In an open economy, domestically sold commodities can be differentiated according to their source of production, either domestically or from imports. These domestic and imported commodities are assumed to be different from each other. Accordingly, the mix of domestic and imported commodities required by domestic absorption is determined by the degree of substitutability (or differentiation) between domestic and imported commodities. The degree of similarity between these two sources is captured by the Armington elasticity (Armington, 1970). These substitution elasticities are commonly determined econometrically using time series data of prices and quantities of imported and domestic commodities. The higher the value of this parameter, the closer is the degree of substitution.

Alaouze (1977) and Alaouze et al. (1977) produced empirical estimates for a range of commodities for Australia. These estimates are centred on Armington elasticities of 2.0.

According to these estimates, elasticities of substitution between domestic and imported sources can be differentiated by end-use, namely current production, capital creation, and household consumption. Usually, these Armington values are used in many CGE studies (see for example Dee, 1989; Dixon et al., 1982; Martin, 1989). Armington elasticities of intermediate use (σ_{arm}^{1}), investment use (σ_{arm}^{2}) and household consumption (σ_{arm}^{3}) were obtained from the ORANI-G database and mapped with the 35 sectors as given in the current database. Three Armington elasticities used in this study are shown in Table 6.2.

Table 6.2 Armington elasticities for the model

Commodity	Intermediate Armington	Investment Armington	Household Armington
Agriculture	1.4	1.6	1.4
Black coal	1.7	2	1.7
Brown coal	1.7	2	1.7
Oil	1.7	2	1.7
Gas	1.7	2	1.7
Other mining	1.7	2	1.7
Food, beverage, tobacco	2.4	1.9	1.7
Textile, leather	3.4	2.8	2.9
Wood, paper, print	1.8	1.8	1.7
Auto petrol	0.4	0.4	0.4
Kerosene petrol	0.4	0.4	0.4
LG petrol	0.4	0.4	0.4
Other petrol	0.4	0.4	0.4
Chemical coal products	2	2	1.9
Non metallic mineral	1.5	1.5	1.5
Concrete, cement	0.9	1	1.2
Iron steel	0.9	0.9	1
Other metal	1.7	1.6	1.9
Manufacturing	2.4	2.6	2.9
Elec. black coal	0	0	0
Elec. brown coal	0	0	0
Elec. oil	0	0	0
Elec. gas	0	0	0
Elec. renewable	0	0	0
Elec. commercial	0	0	0
Gas supply	0	0	0
Water supply	0	0	0
Construction	0	0	0
Trade services	0	0	0
Accommodation	0	0	0
Transport road	0.8	2	1.2
Transport other	0.8	2	0
Business services	0	0	0
Public services	0	0	0
Other services	0	0	0

Source: ORANI-G database

6.6.2 The elasticities of substitution between electricity generators

Different electricity generators were modelled separately as a CES aggregation of black coal, brown coal, oil, gas and renewable energy electricity generating to derive a single composite electricity generating. Based on the author's own judgment, substitution elasticity values of 50 were assigned among different electricity generators. A high elasticity of substitution value ensures that the generated electricity is homogenous irrespective of the type of electricity generator used.

6.6.3 The elasticities of substitution between primary factors

In the present model, primary factors consist of composite labour and a capital-energy composite for non-land using industries. In the case of land using industries, primary factors include a land factor as well. Therefore, in order to calibrate the model substitution elasticities among composite labour, land, composite capital-energy and composite energy were required. In the ORANI-G database, the elasticity of substitution between labour and fixed capital is set at 0.5 for all industries which do not use land as a factor of production. For land using industries, the pair-wise substitution elasticities between land, labour and capital are also set at 0.5.

There have been many empirical studies performed to estimate substitution elasticities between capital and energy. For example, Manne and Richels (1994) estimated a capital for energy substitution elasticity value of 0.4 for the OECD regions and 0.3 for other regions. In the Global 2100 model, the same authors employed a value of 0.33 as the capital for energy substitution elasticity (Manne, 1994). Khan (1989) estimated elasticity of substitution between capital and energy of 0.175 using a two level CES production function for the manufacturing sector in Pakistan. In GTAP-E, the value of capital for energy substitution is set at 0.5 for most industries. Capital for energy substitution elasticities for other industries, namely coal, oil, gas, petroleum and coal products and agriculture/forestry/fishery industries in the GTAP-E, are set at zero (Burniaux and Truong, 2002). Similarly, low to middle range values have been assigned in the OECD-GREEN model (Burniaux et al., 1992), and the models used by Babiker et al. (1997), Rutherford et al. (1997) and Bohringer and Pahlke (1997). Table 6.3 presents findings of Bataille (1998) for capital energy substitution elasticities in Canada.

Table 6.3 Capital for Energy substitution elasticities by sector

Sector	Capital for energy substitution
Pulp and paper	0.34
Iron and steel	0.10
Industrial minerals	0.09
Chemical products	0.11
Other manufacturing	0.06
Metals	0.07
Mining	0.03
Commerce	0.34
Refinery	0.12
Residential	0.21

Source: Bataille (1998)

The above empirical estimates and the author's best judgment were used to determine appropriate capital for energy substitution elasticities by sector in this model. Some general guidelines for assembling primary factor substitution parameter values were:

- Substitution elasticities between primary factors (σ^1_{prim}) were always given values of 0.5;
- Substitution elasticities between capital and energy (σ^1_{enc}) were generally given a value of 0.1 or applied empirical estimates, where possible;
- Substitution elasticities between energy commodities ($\sigma^1_{eng}, \sigma^1_{col}, \sigma^1_{oig}, \sigma^1_{ptr}$) were given values of 0.8; and
- Substitution elasticities between occupations (σ^1_{lab}) were set at 0.5 for all industries.

6.6.4 The product – product transformation parameters

Transformation elasticities explain the possibilities of switching production between products in response to price changes. The multiproduct matrix shows production of multiple commodities by industries. For these multi-product industries, product-product transformation elasticities provide the flexibility to respond to a change in market prices by changing the output mix. Transformation elasticities of the commodities were obtained from the ORANI-G database and mapped with 35 commodities in the current database.

6.6.5 The reciprocals of the export demand elasticities

Most of the CGE models developed for Australia used the small country assumption with respect to world prices. Therefore, in most instances world prices are insensitive to export volumes from Australia. This implies setting high values for export demand elasticities of most commodities. Export elasticities for all export commodities were obtained from the ORANI-G database and mapped into commodities in the current database.

6.6.6 Household expenditure elasticities and the Frisch parameters

Estimates of the expenditure elasticities and Frisch parameters for the 35 commodities by 10 household groups were obtained from the study of Cornwell and Creedy (1997). They empirically estimated household expenditure elasticities and Frisch parameters for 14 commodities by 30 household income groups by fitting a Linear Expenditure System (LES) to Australian cross sectional budget data of consumer expenditure for the period of 1984-85. These 14 commodities were mapped into 35 commodities and 30 household groups were aggregated into 10 household groups before using those empirical estimates in the present study. Table 6.4 displays re-computed expenditure elasticities of 35 commodities and Frisch parameters for 10 household income groups.

Table 6.4 Average expenditure elasticities and Frisch parameters

Commodity	Household income deciles									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Agriculture	0.929	0.724	0.602	0.590	0.583	0.578	0.575	0.575	0.569	0.541
Black coal	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Brown coal	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Oil	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Gas	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Other mining	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Food, bvrg, tobac.	0.929	0.724	0.602	0.590	0.583	0.578	0.575	0.575	0.569	0.541
Textile, leather	1.109	1.196	1.240	1.387	1.360	1.276	1.233	1.145	1.119	1.048
Wood, paper, print	1.397	1.539	1.500	1.387	1.360	1.276	1.233	1.145	1.119	1.048
Auto petrol	1.244	1.460	1.424	1.267	1.268	1.124	1.038	0.884	0.578	0.261
Kerosene petrol	1.244	1.460	1.424	1.267	1.268	1.124	1.038	0.884	0.578	0.261
LG petrol	1.244	1.460	1.424	1.267	1.268	1.124	1.038	0.884	0.578	0.261
Other petrol	1.244	1.460	1.424	1.267	1.268	1.124	1.038	0.884	0.578	0.261
Chemical coal	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Non metallic min	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Concrete, cement	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Iron steel	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Other metal	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Manufacturing	1.236	1.325	1.289	1.233	1.214	1.207	1.186	1.133	1.143	1.035
Elec. black coal	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Elec. brown coal	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Elec. oil	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Elec. gas	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Elec. renewable	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Elec. commercial	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Gas supply	0.883	0.509	0.199	0.317	0.373	0.399	0.437	0.451	0.465	0.440
Water supply	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Construction	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Trade services	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Accommodation	1.096	1.168	1.214	1.288	1.342	1.265	1.298	1.374	1.345	1.192
Transport road	1.244	1.460	1.424	1.267	1.268	1.124	1.038	0.884	0.578	0.261
Transport other	1.244	1.460	1.424	1.267	1.268	1.124	1.038	0.884	0.578	0.261
Business services	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Public services	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Other services	0.914	0.650	0.469	0.467	0.468	0.475	0.473	0.472	0.484	0.443
Frisch Parameter	-22.6	-13.2	-9.2	-7	-5.6	-4.6	-3.9	-3.4	-2.7	-2

Source: Based on estimates of Cornwell and Creedy (1997), 1st – 10th range poorest to richest.

Once the expenditure elasticities for 35 commodities by 10 household groups were obtained, the next task was to estimate marginal budget shares (average Engle elasticity) which should be equal to 1 in each household group. The initial calculations demonstrated that the average Engle elasticities for each household group were not equal to one. Therefore, expenditure elasticities were scaled in order to satisfy that the marginal household budget shares equals to one. The relationship between marginal budget shares with the expenditure elasticities is shown in equation (6.1).

$$\varphi_{ch} = \frac{X3_{c\_sh}}{\sum c \in COM \; X3_{c\_sh}} \times EPS_{ch} \qquad (6.1)$$

where φ_{ch} the marginal household budget share of household h for commodity c, $X3_{c\_sh}$ is the commodity c consumed by household h from both domestic and imported sources s (this includes consumption expenditure, tax and margins), and EPS_{ch} is the estimated expenditure elasticity of household h for commodity c. The sum of φ_{ch} for each household h is not equal to one. Therefore, expenditure elasticities were re-computed in order to satisfy that the sum of φ_{ch} for each household h is equal to one which is denoted in equation (6.2).

$$EPS'_{ch} = \frac{EPS_{ch}}{T\varphi_{ch}} \qquad (6.2)$$

where $T\varphi_{ch}$ is the sum of φ_{ch} across all commodities consumed by each household h. The use of EPS'_{ch} instead of EPS_{ch} satisfies the condition that the marginal budget shares of each household h across all commodities is equal to 1. Table 6.5 shows household expenditure elasticities.

Table 6.5 Household expenditure elasticities

Commodity	Household income deciles									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Agriculture	0.96	0.94	0.92	0.90	0.91	0.89	0.88	0.89	0.89	0.99
Black coal	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Brown coal	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Oil	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Gas	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Other mining	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Food, bevrg, tobacco	0.96	0.94	0.92	0.90	0.91	0.89	0.88	0.89	0.89	0.99
Textile, leather	1.14	1.55	1.91	2.12	2.12	1.96	1.89	1.78	1.76	1.93
Wood, paper, print	1.44	1.99	2.31	2.12	2.12	1.96	1.89	1.78	1.76	1.93
Auto petrol	1.28	1.89	2.19	1.94	1.98	1.72	1.59	1.38	0.91	0.48
Kerosene petrol	1.28	1.89	2.19	1.94	1.98	1.72	1.59	1.38	0.91	0.48
LG petrol	1.28	1.89	2.19	1.94	1.98	1.72	1.59	1.38	0.91	0.48
Other petrol	1.28	1.89	2.19	1.94	1.98	1.72	1.59	1.38	0.91	0.48
Chemical coal prod	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Non metallic mineral	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Concrete, cement	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Iron steel	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Other metal	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Manufacturing	1.28	1.71	1.98	1.89	1.90	1.85	1.82	1.76	1.80	1.90
Elec. black coal	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Elec. brown coal	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Elec. oil	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Elec. gas	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Elec. renewable	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Elec. commercial	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Gas supply	0.91	0.66	0.31	0.49	0.58	0.61	0.67	0.70	0.73	0.81
Water supply	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Construction	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Trade services	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Accommodation	1.13	1.51	1.87	1.97	2.09	1.94	1.99	2.14	2.11	2.19
Transport road	1.28	1.89	2.19	1.94	1.98	1.72	1.59	1.38	0.91	0.48
Transport other	1.28	1.89	2.19	1.94	1.98	1.72	1.59	1.38	0.91	0.48
Business services	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Public services	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81
Other services	0.94	0.84	0.72	0.71	0.73	0.73	0.73	0.73	0.76	0.81

Source: Author's calculation from Table 6.4, 1st – 10th range poorest to richest.

6.7 Conclusion

This chapter completes the database requirements of the A3E-G model. As explained, the main source of data was the ESAM constructed for Australia in 2004-05. Additionally, this chapter explains how other data matrices, namely investment matrix, carbon emissions matrix and tax matrices were compiled. Furthermore, a discussion is included with regard to all the behavioural parameters required by the model. This database serves the purpose for calibrating the A3E-G model described in the Chapter V for the base year 2004-05.

CHAPTER VII

An Application of the A3E-G Model: The Effects of a Carbon Price in Australia

Introduction

The aim of this chapter is to conduct policy experiments using the A3E-G model. This model is designed mainly to estimate macroeconomic, sectoral and distributional effects of a carbon price policy in Australia. The model is detailed because it contains highly disaggregated energy sectors, occupational categories and household groups. The production structure allows substitution between capital and energy and substitution between different electricity generating technologies. Therefore, carbon emission accounts incorporated into the benchmark data capture the emissions intensive energy and electricity generating sectors and the model can show how these sectors respond to an explicit carbon price shock. Furthermore, the distributional implications of the carbon price policy and revenue recycling policies can be estimated directly because social accounting data have been incorporated into the model database.

The chapter is organised as follows. The assumptions for the economic environment are described in Section 7.1. Section 7.2 presents various carbon price scenarios and simulation results with respect to macroeconomic impacts, sectoral impacts, employment impacts and household distributional impacts. Various options of carbon revenue recycling policies and their effect on the macroeconomy and on different household groups are presented in Section 7.3. The sensitivity of the model outcomes for different parameter values is discussed in Section 7.4.

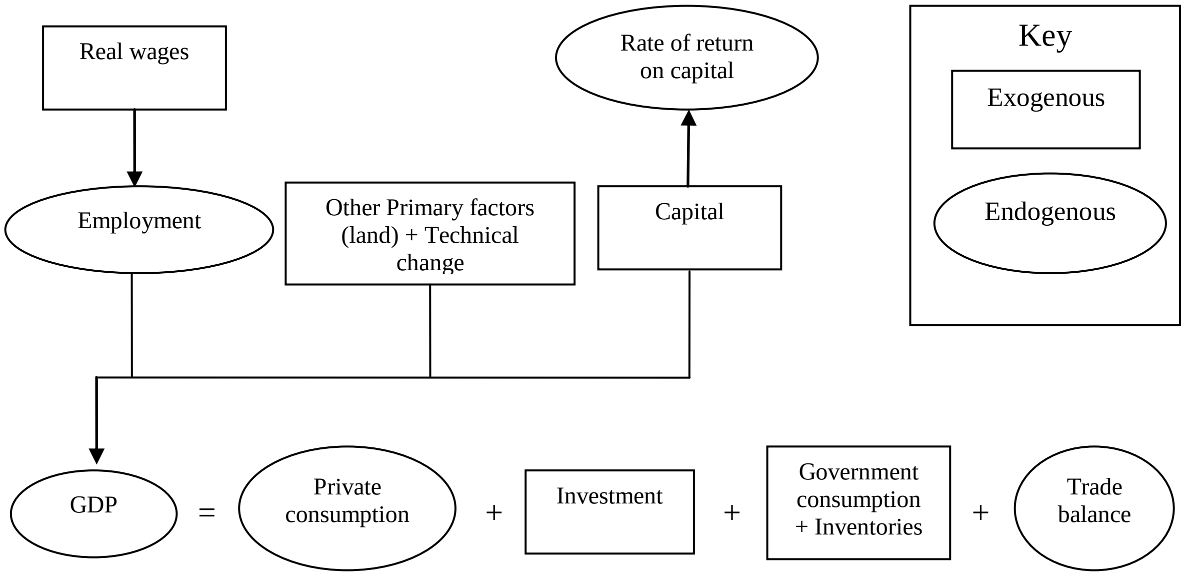
7.1 Assumptions for the economic environment

As discussed in Section 5.10 of Chapter V, certain variables in the A3E-G model are declared as exogenous in order to bring the number of endogenous variables to be equal with the number of equations. This is the standard closure requirement of the model. However, specific research questions raised under this study are analysed by swapping some of the exogenous variables with certain selected endogenous variables. Accordingly, the experiments are conducted under two different economic environments or closures – short-run and long-run. The following sections discuss the objectives of each closure and the specific variables selected for the endogenous and exogenous list. All simulations assume that there is no change in variables selected as exogenous except in the nominal changes of carbon price variables.

7.1.1 Short-run closure

The short-run closure generally assumes that the time period needed for economic variables to adjust to a new equilibrium after the policy shock is between 1 to 3 years. This short timescale assumption is achieved by fixing certain variables in the factor market. For example, and in reality, new capital stocks take time to install or the time period involved may be too long to be affected by a policy shock. Therefore, the short-run closure normally fixes the capital stocks. Furthermore, labour market rigidities are implemented by fixing real wages. Figure 7.1 shows a schematic representation of the short-run closure with key exogenous and endogenous variables in the determination of aggregate demand and aggregate supply in the economy.

Figure 7.1 The short-run closure



The aggregate demand side of the economy is represented as a function of real private consumption expenditure, real investment expenditure, real government expenditure, real demand for inventories and the balance of trade. Since one of the research objectives of this study was to find out the aggregate welfare impacts of the carbon price policy, real private consumption is determined endogenously. Similar approaches can be found in the studies of Horridge (2000) and Yusuf (2007). The rest of the closure assumptions on the aggregate demand side include exogenously determined real investment, government consumption and inventory demand variables and an endogenously determined trade balance variable.

The short-run closure assumptions affect labour and capital markets after the policy shock. These factors impact on the supply side of the economy. As mentioned above, the labour market rigidities are enforced by fixing the real wage variable. The fixed real wage is assumed by indexing nominal wages to the consumer price index (CPI). Then the aggregate employment (labour demand) becomes demand-determined. This allows aggregate employment as well as employment levels of various categories of labour to deviate from their baseline values in response to a carbon price shock. The capital market rigidities are enforced by fixing the aggregate capital. Furthermore, capital is assumed to be industry specific and unable to move across sectors. However, the rate of return on capital within each industry is determined endogenously. In addition, other primary factors such as land and technical change variables are held constant.

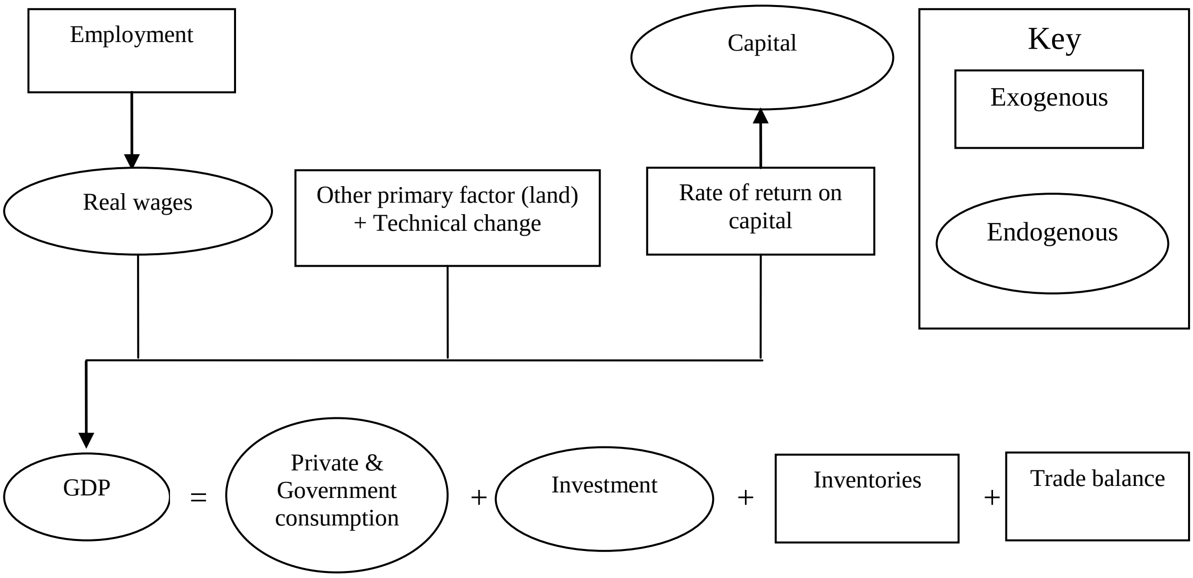
Some of the other variables are also declared as exogenous in order to simulate the model under the short-run closure. These include variables such as household tastes and preferences, number of households, all types of direct and indirect tax variables, import prices and export demand shifters. Finally, the model determines changes in domestic prices induced by the shock as changes in domestic prices relative to world prices. This is achieved by fixing the nominal exchange rate as the *numeraire*.

7.1.2 Long-run closure

The long-run closure assumptions are made in order to understand what the impact would be when certain variables take a much longer time (more than 3 years) to adjust to a new equilibrium after the policy shock. Carbon price policy may induce technological advancements and change the production structures, product mixes and consumption patterns that can best be explained under this closure assumption. Figure 7.2 shows a schematic representation of the long-run closure with key exogenous and endogenous variables in the determination of aggregate demand and aggregate supply in the economy.

As it appears, changes in the factor market assumptions are the key differences between long-run closure and the short-run closure. Accordingly, real wage is determined endogenously. As a result, the long-run cost of a carbon price shock is realised by responding to the real wage rate rather than deviating from national aggregate employment. This is the typical neoclassical closure with a full employment assumption. However, the mobility of labour among different occupational categories as well as among industries is not fixed and is determined endogenously. Also, the aggregate capital stocks are determined endogenously in such a way that fixed rates of returns are maintained. This allows producers to relocate their industry capital in order to maximise the given rate of return on capital.

Figure 7.2 The long-run closure



On the aggregate demand side, government consumption is allowed to follow private consumption and both variables move together to accommodate a balance of trade constraint. By fixing the trade balance, the long-run closure assumes the rest of the world might be reluctant to fund an increased trade deficit. Aggregate investment by industry is determined endogenously following the aggregated capital stock. Therefore, in the long-run, producers have the flexibility to determine their investment decisions as a response to price changes. Finally, inventory demand is also determined exogenously.

Similar to the short-run closure, other primary factors such as land, all technological change variables, household tastes and preferences, number of households, prices of imports (*c.i.f*), all tax variables and export demand shifters are determined exogenously. The nominal exchange rate is fixed and acts as the *numeraire*.

7.2 Carbon price policy scenarios

A carbon price is expected to drive structural change in the economy towards low emission intensive products and production processes and away from high emissions intensive products and production processes. The static A3E-G model employed in this study is capable of projecting economic impacts of an exogenous carbon price shock on the macroeconomy as well as on various sectors. However, the study does not intend to estimate the true social cost of carbon emissions in the economy but, instead, uses various carbon prices as suggested by the Australian government and by other stakeholders.

The Australian government recently announced its decision to implement a carbon price policy with a starting price of \$23/t CO_2-e (Australian Government, 2011b). This carbon price is examined in this study as the main policy scenario. In order to gauge the variation of the impact of the main policy scenario, two alternative carbon price scenarios are also examined, namely a low price scenario (\$10/t CO_2-e) and a high price scenario (\$35/t CO_2-e). These alternative prices have been proposed by leading stakeholders in the economy. The Business Council of Australia and the Australian Industry Group have both advocated a lower level starting price (\$10) of carbon that should rise modestly over time. The Grattan Institute recommended a higher level of carbon price (\$35) which may remain constant over time.

These carbon prices will be introduced as exogenous shocks within the short-run and long-run economic environments. Under the short-run closure, all three carbon price scenarios are simulated while only the main policy scenario (\$23) is simulated under the long-run closure. Because the immediate short-run impacts of the carbon price on the economy, it will be quite relevant to the current real world context. However, certain policy implications arising under the long-run closure are worth comparing with the short-run closure.

Next, these policy simulations were setup to behave in a rather similar way to the present government's carbon price policy formulations. For example, the agriculture and road transport sectors are exempted from the direct carbon price policy as announced by the government (Australian Government, 2011a). Furthermore, the revenue raised from the carbon price is added to the government consolidated revenue pool.

The carbon price affects industries and households depending on their emission levels. There are two major sources of emissions associated with industries, namely input carbon emissions and output carbon emissions. Input carbon emissions arise from the use of fossil energy sources by the production sectors, whilst output carbon emissions arise from actual production activities. Therefore, both these emission sources will be subjected to the carbon price shock. Emissions associated with household consumption are exempted from the policy shock. This is to prevent households being directly taxed by the policy because most importantly, households are already indirectly taxed as a result of increased prices of goods and services after the carbon price shock.

The following sections describe the possible effects of carbon price policies under the short-run and long-run closures. These effects are subdivided into macroeconomic effects, industry effects and household effects.

7.2.1 Macroeconomic impacts

This section discusses the projected macroeconomic effects of the carbon price policy under four different simulation scenarios. Scenario 1, Scenario 2 and Scenario 3 represent carbon prices of $10, $23 and $35 respectively under the short-run closure. Scenario 4 is the $23 carbon price under the long-run closure. Usually, these projected results are reported as percentage changes of the respective endogenous variables with respect to their base values. However, in some occasions the results are reported as absolute changes of the endogenous variables.

Table 7.1 presents the projected macroeconomic effects of carbon prices in the Australian economy. Macro variables are categorised into quantity variables, price variables and environmental variables. It appears that quantity variables, namely real GDP, aggregate employment, real household consumption and export volume have been negatively affected under all short-run carbon price scenarios and the magnitude of the effect tends to increase as the level of shock increases. Scenario 4 also projects the long-run negative impacts on these variables. Because of the closure specification, there is no impact on the aggregate employment variable under the long-run closure. On the other hand, a contraction in capital stock occurs in the long-run, however, not in the short-run.

Table 7.1 Macroeconomic effects under various carbon prices in Australia

Macro variable	Scenario 1 ($10,SR)	Scenario 2 ($23,SR)	Scenario 3 ($35,SR)	Scenario 4 ($23, LR)
Quantity variables				
Real GDP	-0.21	-0.60	-1.27	-0.67
Aggregate employment	-0.33	-0.87	-1.73	0.00
Real household consumption	-0.06	-0.17	-0.31	-0.30
Aggregate capital stock	0.00	0.00	0.00	-1.59
Export volume index	-0.98	-2.76	-6.19	-0.83
Import volume index	0.03	0.07	0.18	-0.77
Price variables				
Consumer price index	0.25	0.71	1.68	-0.34
Real devaluation	-0.26	-0.73	-1.66	0.48
Real wage rate	0.00	0.00	0.00	-1.44
Price of exports	0.10	0.29	0.66	0.11
Price of electricity	8.05	23.79	56.25	9.13
Terms of trade	0.10	0.29	0.66	0.11
Environmental variables				
Emissions reductions (Mt)	41.31	70.13	101.63	183.13
Emissions reduction (%)	-7.04	-11.94	-17.31	-31.19
Carbon revenue ($ billions)	3.06	6.39	8.67	3.73

Note: Projections in percentage changes from the base solution, SR- Short-Run, LR-Long-Run
Source: A3E-G model projections

Carbon price reduces real GDP relative to baseline

Real GDP can be determined from the expenditure side (or demand side) or from the supply side (or income side) components of GDP. The results presented in Table 7.1 show that real GDP has fallen by 0.21, 0.60 and 1.27 percent under Scenarios 1, 2 and 3 respectively. Greater GDP losses are predicted as the carbon price increases. For example, a comparison of Scenarios 1 to 3 shows that as the carbon price goes up by 250 percent, the loss in GDP increase by 500 percent. The real GDP impact under Scenario 4 is slightly higher than under the Scenario 2. Overall, these results reveal how the carbon price distortions affect economic growth. The carbon price acts as a form of tax and that reduces economic efficiency. As a result, both the expenditure side and supply side components of GDP are affected negatively. With respect to supply side components of the GDP, a carbon price increases the cost of variable factors of production which in turn reduces the incentive for producers to employ these factors in their production processes. For instance, the cost of labour increases in the short-run whereas cost of capital increases in the long-run leading to a reduction in GDP.

All short-run carbon price scenarios are inflationary leading to a proportional increase in nominal wages. The magnitude of the effect varies with the level of shock. For example, the CPI increases by 0.25 percent in Scenario 1, 0.71 percent in Scenario 2 and 1.68 percent in Scenario 3. This inflationary effect signals producers to cut labour in their production. Because the short-run assumes real wages are fixed (i.e. effectively indexing nominal wages to the CPI), labour market adjustments are fully realised from the contraction in the aggregate employment. The projected reduction in the aggregate employment is 0.33 percent in Scenario 1, 0.87 percent in Scenario 2 and 1.73 percent in Scenario 3.

In the long-run, the capital stock is variable. Because rates of return on capital are fixed, producers employ less capital in their production. The use of capital stock was reduced by 1.59 percent under the Scenario 4. On the other hand, long-run employment assumption is favourable on the national employment because in the long-run the carbon price is realised almost entirely as a fall in real wage rates and not by a fall in aggregate employment. A carbon price of $23 results in a fall in real wages by 1.44 percent. The CPI reduced by 0.34 percent which further brings favourable impacts to the economy.

Carbon price reduces the real household consumption relative to the baseline

Household consumption expenditure can be treated as an indicator of welfare or well-being. According to the argument developed by Friedman (1957), household expenditure follows the '*permanent income hypotheses*' which states that household expenditures are more stable across time than current incomes. Therefore, long-term or permanent income (as reflected in household expenditures) can be considered as a useful measure of economic well-being (Atkinson 1998). As shown in Table 7.1, real household consumption reduced under all scenarios, although in different magnitudes. Real household consumption has reduced by a much higher percentage under the long-run, Scenario 4 (-0.30 percent) as compared to the short-run, Scenario 2 (-0.17 percent). This effect can be explained as a result of changes in real incomes available for consumption. For instance, short-run household income is largely affected by the reduction in aggregate demand for employment (-0.87 percent) whereas the long-run household income is largely affected by the reduction in demand for capital stock (-1.59 percent). The loss in household real income from capital (in the long-run) seems to be higher than the loss of real income from labour (in the short-run). Therefore, real consumption in the long-run has been largely influenced by those who own more capital as compared to labour.

Carbon price reduces Australia's exports and improves terms of trade

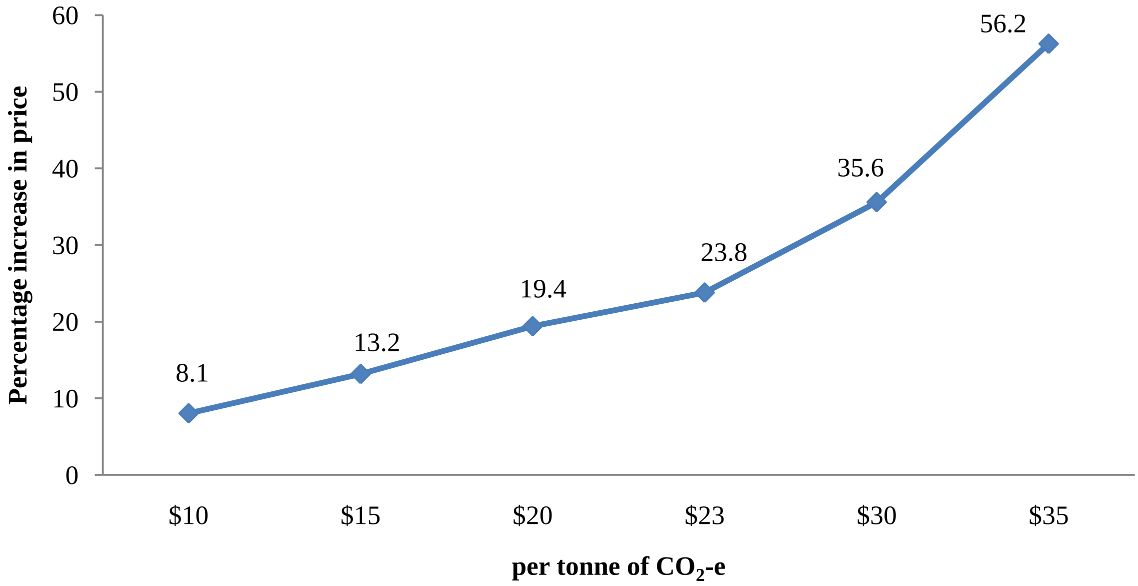
Australia's exports are significantly affected by the carbon price under all short-run scenarios. Moreover, as the carbon price increases, the negative impact on exports tends to be higher. For example, the highest reduction in exports (6.19 percent) can be seen under Scenario 3. On the other hand, import volumes have increased slightly under all short-run scenarios. As discussed earlier, a carbon price policy inflates domestic prices causing the real exchange rate to appreciate. As a result, export prices increase causing the volume of exports to decline. On the other hand, imports tend to rise in response to a currency appreciation in the economy. Furthermore, given the assumption that import prices are fixed under the closure, the rise in export prices improves the terms of trade. On the positive side, the improvements in the terms of trade, tends to offset the losses associated with the carbon price.

The impact on Australia's trade competitiveness is less severe in the long-run. Since the trade balance is determined outside the model, imports tend to move with the level of exports in order to maintain the trade deficit at the 2005 level. The export volume in Scenario 4 has reduced less significantly (-0.83 percent) compared to Scenario 2 (-2.76 percent). This indicates an improvement in Australia's trade in the face of a carbon price once the economy is given adequate time to adjust to a new equilibrium. Furthermore, a reduction in imports by 0.77 percent will bring improved opportunities for local producers. The required change in the real exchange rate to maintain the trade deficit is projected as a depreciation of the currency by 0.48 percent.

Carbon price increases energy prices, especially electricity prices

Most interestingly, inflationary effects in the economy can result in increased prices of energy commodities, especially electricity prices. Figure 7.3 shows how the carbon price has escalated electricity prices in Australia under the short-run economic environment. It is apparent that commercial electricity prices rise sharply as the carbon price increases. The electricity price increment under the main policy scenario is projected to be 24 percent. This result is not surprising as a significant proportion of Australia's electricity is generated by emissions intensive brown coal and black coal sources. The costs of production of these commodities rise sharply under a carbon policy and cost increment in these generation technologies are reflected in commercial electricity prices.

Figure 7.3 Percentage changes of average electricity prices under short-run carbon price



Source: A3E-G model projections

In contrast, the long-run costs of commercial electricity prices are much lower than the short-run prices. The increase in commercial electricity prices with a $23 carbon price under the long-run is around 9 percent. In order to explain how different electricity generators contribute to the overall commercial electricity price increase, Table 7.2 gives a breakdown of electricity generating costs using various energy sources. The electricity generation cost is projected to be lowest for renewable energy (9.7 percent) and for oil (10.6 percent), and highest for black coal (28.8 percent), brown coal (26.9 percent) and for gas (22.4 percent). This detailed analysis is possible as capital is mobile and is allowed to substitute with energy in the long-run. With a carbon price, capital will be released from emissions intensive generating plants like black coal and brown coal and will be absorbed by the less emissions intensive generating plants like renewable energy and oil. Therefore, the economy restructures in the long-run to produce electricity using less carbon emitting technologies and processes. This can be seen as a reduction in commercial electricity prices in the long-run.

Table 7.2 Long-run cost of electricity (Scenario 4)

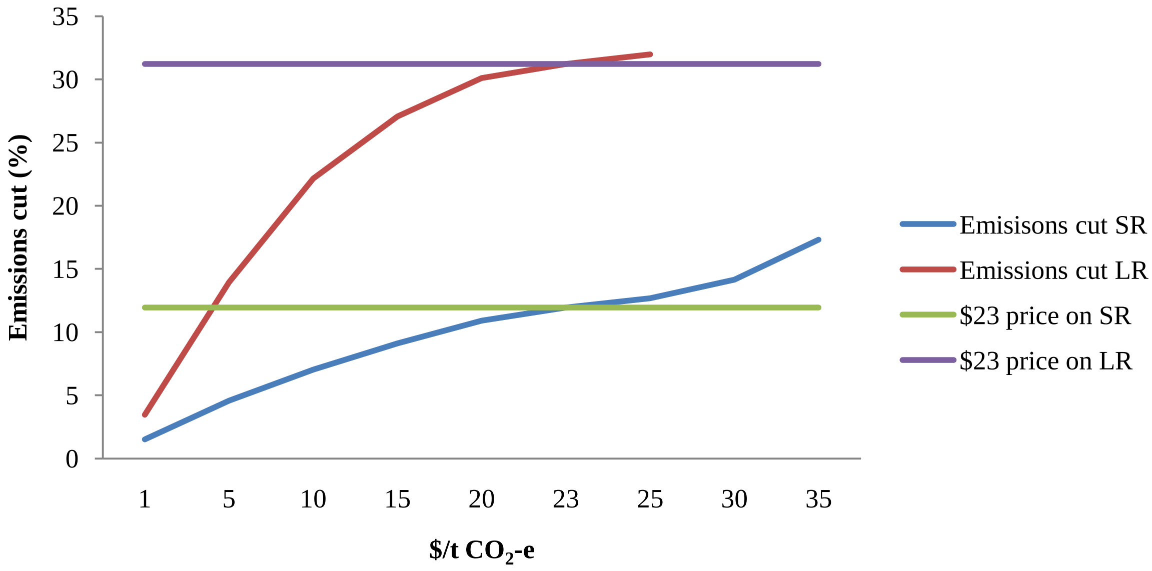
Long run cost of electricity prices	Percentage change
Commercial electricity price (average)	9.13
Electricity generating - black coal	28.81
Electricity generating - brown coal	26.91
Electricity generating - oil	10.64
Electricity generating - gas	22.45
Electricity generating - renewable energy	9.77

Note: Projections in percentage changes from the base solution
Source: A3E-G model projections

Carbon price reduces emissions and generates revenue

The main objective of a carbon price policy is to reduce emissions in the economy. Producers are expected to take abatement measures to a point where the marginal abatement cost (MAC) is equal to the carbon price. Beyond this point producers are better off to pay the carbon price rather than the cost of abatement. Figure 7.4 shows the MAC under short-run and long-run closures. Since these cost curves have been produced imposing an explicit carbon price, the true resource cost of pricing carbon is not represented. As a result, the exact point where producers are better off to pay the price rather than abatement is not given. However, these graphs do explain the sensitivity of emissions reduction at different levels of carbon prices. The rate of emissions reduction is much higher under the long-run as compared to the short-run. As shown in the graph, around 31 percent (183 Mt) emissions are cut under the long-run and around 12 percent (70 Mt) emissions are cut under the short-run when a $23 carbon price is imposed. Because the total capital stock and the aggregate investment are endogenously determined under the long-run, capital can be easily substituted with emissions intensive energy. Therefore, high cuts in emissions are observed in the long-run.

Figure 7.4 Short-run and long-run marginal abatement cost (MAC) curves



Source: A3E-G model projections

Most importantly, a carbon price generates additional revenue for the government. The revenue can be used effectively to reduce distortionary effects of the carbon price. For this reason, the Australian government (2011b) also recommends compensating low to middle income households and certain trade exposed sectors that are immediately affected by a carbon price (see *Clean Energy Act 2011*). Table 7.1 shows that a $23 carbon price would generate about $6.4 billion of revenue under the short-run and $3.7 billion of revenue under the long-run to the government. Since more emissions are abated, the revenue collected is lower in the long-run than in the short-run. This implies the success of the carbon price policy in the long term. The various ways of compensating affected household groups are discussed in Section 7.4.

7.2.2 Sectoral impacts

In a general equilibrium framework, sectoral impacts of a carbon price shock can vary significantly between sectors. For the purpose of this study, Australian industries are categorised into 35 industries. This includes disaggregated energy industries (9), electricity generating industries (5), manufacturing industries (9), services and other industries (12).

Table 7.3 presents the percentage deviations of sectoral output relative to the baseline in response to the four carbon price scenarios. The carbon price generally increases the cost of production of industries producing higher carbon emissions relative to industries producing lower carbon emissions. Accordingly, output changes after a carbon price shock can be explained largely using the percentage reduction of emissions relative to baseline of those industries (refer Table 7.4).

The changes in sectoral output arising from the imposition of the carbon price can be explained as follows. The carbon price increases the prices of directly targeted energy goods such as brown coal, black coal, oil, gas, petroleum products and commercial electricity supply. As a result, emissions associated with these sectors decrease at an increasing rate when carbon prices increase. On the other hand, a carbon price indirectly affects the prices of goods that utilise energy goods as factors of production. For instance, the commercial electricity supply price increases with the carbon price (See Table 7.1) mainly as an indirect effect brought about by increases in the cost of production of high carbon bearing fossil energy sources. The increase in prices of commercial electricity exerts further indirect impacts on electricity intensive production sectors. These kinds of combined direct and indirect effects lead high carbon emissions and energy intensive sectors to contract.

As shown in Table 7.3, significant industry output losses are projected in the brown coal, electricity generating brown coal, electricity generating black coal and commercial electricity supply sectors. Basically, these sectors (except the commercial electricity supply sector) have significantly reduced their carbon emissions (see Table 7.4).

Table 7.3 Projections of percentage change in industry outputs under various carbon prices

	Industry	Scenario 1 (SR,$10)	Scenario 2 (SR,$23)	Scenario 3 (SR,$35)	Scenario 4 (LR,$23)
1	Agriculture	-0.19	-0.53	-1.21	0.97
2	Black coal	-0.23	-0.56	-0.97	-10.86
3	Brown coal	-8.51	-24.64	-55.68	-70.20
4	Oil	-0.04	-0.11	-0.22	-1.59
5	Gas	-0.17	-0.40	-0.63	-21.94
6	Other mining	-0.11	-0.30	-0.65	-2.38
7	Food, beverages and tobacco	-0.38	-1.03	-2.15	0.21
8	Textile, clothing and footwear	-0.35	-0.97	-2.11	0.51
9	Wood, paper and printing	-0.31	-0.85	-1.77	0.24
10	Automotive petrol	-0.28	-0.53	-0.40	-1.25
11	Kerosene	-0.40	-0.87	-1.12	-1.74
12	Liquid gas petroleum	-0.51	-1.13	-1.52	-2.67
13	Other petrol and coal products	0.09	0.31	0.98	-0.95
14	All other chemical products	-0.96	-2.48	-4.73	-5.59
15	Non metallic products	-0.54	-1.46	-3.00	-0.36
16	Cement and concrete	-0.53	-1.23	-2.07	-1.77
17	Iron and steel	-1.54	-3.90	-7.22	-7.69
18	All other metal products	-0.99	-2.37	-4.41	-6.80
19	All other manufacturing	-0.39	-1.12	-2.49	0.58
20	Electricity generating - black coal	-4.38	-9.05	-6.45	-82.10
21	Electricity generating - brown coal	-4.66	-17.99	-62.53	-73.02
22	Electricity generating - oil	2.64	6.88	13.66	100.05
23	Electricity generating - gas	1.19	3.09	7.11	-36.33
24	Electricity generating - renewable energy	6.09	11.48	16.74	829.47
25	Commercial electricity supply	-2.67	-7.49	-15.75	-3.31
26	Gas supply	-0.28	-0.74	-1.46	1.43
27	Water and sewerage services	-0.18	-0.49	-0.94	-0.25
28	Construction services	0.01	0.03	0.09	-1.27
29	Trade services	-0.21	-0.58	-1.22	0.41
30	Accommodation and cafe	-0.55	-1.43	-2.73	-0.52
31	Road transport services	-0.30	-0.84	-1.90	1.11
32	Other transport services	-0.45	-1.19	-2.39	-1.91
33	Business services	-0.13	-0.35	-0.74	0.00
34	Public services	-0.16	-0.44	-0.92	-0.23
35	Other services	-0.11	-0.32	-0.64	-0.13

Source: Projections from the A3E-G model, SR- Short-Run, LR-Long-Run

The responses of the electricity generating black coal and the electricity generating brown coal sectors to different carbon price scenarios are worth discussing. Under Scenario 1, the output contracted by 4 percent for both these sectors. However, as the carbon price increases the electricity generating brown coal sector projects a notable contraction in the output as compared to the electricity generating black coal sector.

The output loss in the electricity generating black coal sector becomes smaller at $35 carbon price. These effects basically arise due to differences in the cost of production in each sector. As can be seen from the Table 7.4, emissions reduction in the electricity generating brown coal sector is relatively higher than in the electricity generating black coal sector. Under these circumstances, the sector associated with higher costs of production (in this case the electricity generating brown coal sector) releases factors of production. These factors (labour and capital) can be easily absorbed by comparatively less costly, other electricity generating technologies (in this case electricity generating black coal sector), as both these sectors share quite similar production technologies. As a result electricity generating black coal sector contracts lesser than the electricity generating brown coal sector at higher levels of carbon prices.

Similar circumstances apply to the electricity generating oil and electricity generating gas and electricity generating renewable energy sectors. This is because all these sectors show expansion in their outputs as the carbon price increases. This time, outputs of both electricity generating brown coal and electricity generating black coal sectors contract and release factors of production. Because all these generating technologies share broadly the same production structure, the released factors can be easily absorbed by the less costly generating technologies, leading to expand output in those sectors.

To summarise, the carbon price reduces the outputs of high emission intensive electricity generating technologies and increases the outputs of low emission intensive electricity generating technologies given the very high substitutability between these electricity generating technologies assumed in the model. As a result, the carbon price causes substitution in favour of low emissions technologies and processes at the expense of high emissions intensive technologies and processes.

Output contractions in the electricity generating sectors exert a direct impact on the output of the commercial electricity sector. This is mainly because of the initial assumption in the model about all generating plants supplying final electricity output to the commercial electricity sector. As discussed earlier, outputs of some electricity generating sectors, namely brown coal and black coal have contracted while outputs of electricity generating oil, gas and renewable energy have expanded under all short-run carbon price scenarios. However, the actual contribution to electricity output is much larger with coal powered generating plants as compared to other sources[21]. This explains why the commercial electricity output has reduced under all carbon price scenarios.

Among the other energy sectors, the brown coal sector records the highest output loss. This could be due to two reasons. Firstly, the direct impact (emissions reduction) increases the cost of production of the brown coal sector and, as a result, output contracts. Secondly, indirect impacts (reduced input demand) of the electricity generating brown coal and electricity generating black coal sectors have contracted output in the brown coal sector. This is because the brown coal sector is a major input supplier to coal powered electricity generation in the economy.

The other energy sectors, namely black coal, oil, gas and petroleum outputs have contracted mainly as a response to the direct impacts. This is confirmed in Table 7.4 which shows significant emissions reduction in those sectors. However, overall output losses in those

[21] Renewable energy sources contribute 6% whereas coal powered sources contribute 78% to the electricity generating (ABARE, 2005)

sectors have eased slightly due to indirect impacts. In the case of the oil and gas sectors, the increased input demand from the electricity generating oil and electricity generating gas sectors reduces the negative impacts on the oil and gas sectors. Since major input demanding sectors to the petroleum sector, namely agriculture and road transport sectors have been exempted from the carbon price shock, the petroleum sector also experiences a slight output reduction. Next, the output of the black coal sector decreases slightly as compared to output of the brown coal sector. This could be due mainly to relocating inputs (labour and capital) towards the black coal sector which has experienced decreasing emissions by lesser percentage compared to the brown coal sector due to carbon price.

Table 7.4 Sectoral CO_2-e emissions (percentage change relative to the baseline)

	Industry	Scenario 1 (SR, $10)	Scenario 2 (SR,$23)	Scenario 3 (SR,$35)	Scenario 4 (LR,$23)
1	Agriculture	-0.17	-0.49	-1.11	0.93
2	Black coal	-0.19	-0.43	-0.65	-10.96
3	Brown coal	-7.52	-19.30	-47.09	-71.48
4	Oil	-1.05	-1.83	-2.36	-3.29
5	Gas	-0.89	-1.91	-2.71	-23.50
6	Other mining	-28.95	-45.18	-52.45	-48.69
7	Food, beverages and tobacco	-7.03	-9.75	-8.86	-13.27
8	Textile, clothing and footwear	-3.75	-6.07	-3.35	-11.70
9	Wood, paper and printing	-35.94	-39.76	-41.59	-41.94
10	Automotive petrol	-6.59	-13.35	-18.41	-13.75
11	Kerosene	-13.97	-25.81	-32.74	-26.45
12	Liquid gas petroleum	-13.83	-25.63	-32.34	-26.61
13	Other petrol and coal products	-11.13	-21.25	-22.75	-26.56
14	All other chemical products	-6.83	-10.73	-12.50	-15.55
15	Non metallic products	-3.92	-7.00	-6.43	-11.97
16	Cement and concrete	-22.09	-24.66	-25.09	-25.78
17	Iron and steel	-2.78	-5.68	-8.13	-11.08
18	All other metal products	-32.00	-38.35	-39.76	-43.50
19	All other manufacturing	0.44	2.37	8.47	-3.33
20	Electricity generating - black coal	-18.59	-30.61	-32.99	-85.06
21	Electricity generating - brown coal	-10.00	-24.48	-62.27	-80.04
22	Electricity generating - oil	0.19	0.57	1.32	7.96
23	Electricity generating - gas	-0.28	0.28	3.90	-39.57
24	Electricity generating - renewable energy	0.00	0.00	0.00	0.00
25	Commercial electricity supply	0.00	0.00	0.00	0.00
26	Gas supply	-0.21	-0.54	-1.06	1.06
27	Water and sewerage services	-0.19	-0.44	-0.69	-0.40
28	Construction services	-5.90	-11.46	-14.44	-13.49
29	Trade services	-1.33	-2.89	-3.89	-3.58
30	Accommodation and cafe	-0.63	-1.53	-2.67	-1.14
31	Road transport services	-0.26	-0.76	-1.71	1.01
32	Other transport services	-0.30	-0.75	-1.29	-1.93
33	Business services	0.71	2.09	5.00	-0.76
34	Public services	-5.14	-7.55	-6.30	-11.58
35	Other services	0.00	0.00	0.00	0.00

Source: Projections from the A3E-G model, SR- Short-Run, LR-Long-Run

Overall, sectoral outputs of the other remaining sectors have contracted in the short-run. For instance, the output from the iron and steel sector reduces by 4 percent under Scenario 2. All other export oriented sectors, namely non metallic products (aluminium) and all other metal products sectors have also reduced their outputs. This could be due two reasons: one is due to increased electricity prices in the economy; another reason is that emissions associated with these sectors are comparatively high and output related emissions are also priced under the model. In contrast, a slight growth in output is seen in the construction services industry. Because construction services are relatively capital and labour intensive, the released capital and labour resources in the economy can be absorbed by this sector quite easily. Quite by contrast, the sectors exempted from the direct carbon price shock, namely agriculture and road transport services also have reduced outputs in the short-run. This is because these sectors cannot be totally excluded from an external shock due to existence of general equilibrium effects in the economy.

In the long-run, most of the emissions intensive sectors have contracted more than that observed in the short-run. Scenario 4 reveals that both electricity generating black coal and electricity generating brown coal contract by 82 percent and 73 percent respectively. Heavy output contraction in electricity generating black coal is mainly due to high emissions reduction of the sector and partly due to contraction in the output of the black coal sector by 10.8 percent. The output of the brown coal sector reduced by 70 percent which is mainly due to its own emissions reduction (71 percent), and partly due to reduced input demand from electricity generating brown coal and black coal sectors. Furthermore, outputs from the electricity generating gas and gas sectors have contracted by 36 percent and 22 percent respectively. A 100 percent expansion can be seen in the electricity generating oil sector. As a result, the corresponding input supplying oil sector has only contracted by 2 percent. The electricity generating renewable energy sector has expanded by 829 percent mainly as a result of substituting lower emissions technologies for higher emissions technologies. The overall impact on the output of the commercial electricity supply sector is -3.3 percent which has significantly improved compared to what was seen under the Scenario 2. This is mainly because of larger expansion observed in the electricity generating renewable energy (829 percent) and electricity generating oil (100 percent) sectors.

Output changes in other sectors show mixed results in the long-run. Similar to the short-run, significant output losses can be seen in the iron and steel sector and all other metal products sector in the long-run. These outputs have declined by 7.6 percent and 6.8 percent respectively. Interestingly, some less emissions intensive manufacturing sectors show positive expansion in the gross output, especially in the food, beverages and tobacco sector (0.21 percent), textile, clothing and footwear sector (0.51 percent), wood, paper and printing sector (0.24 percent) and all other manufacturing (0.58 percent) sectors. This is partly because of the comparatively smaller increase in electricity prices in the long-run. Furthermore, when factors are released from emissions intensive sectors they can be absorbed by less emissions intensive sectors. As a result, outputs of the less emission intensive sectors tend to expand. On the positive side, these sectors grow with remarkable reduction in sectoral emissions. Results also show that both the agriculture and road transport services sectors expand by 0.97 percent and 1.1 percent respectively with a slight increase in emissions.

Interestingly, the long-run effects have become favourable for sectors which have relatively fewer emissions as well as sectors that are exempted from the policy. Overall, the carbon price under the long-run scenario has significant effects on reducing emissions associated with high emissions intensive sectors while improving the growth of less emissions intensive sectors in the economy.

7.2.3 Employment impacts

The opponents to the carbon price policy speculate that the carbon tax burden would result in severe job losses in many sectors of the economy. Furthermore, there are concerns that the effects could be varied among different employment categories in Australia. Therefore, the objective of this section is to discuss how various carbon price policies impact on employment demand by industry and by occupational categories in the economy.

As shown in Table 7.5, employment changes by industry follow a similar pattern to output changes of respective industries. This relationship can be explained using the constant return to scale (CRS) production specification defined in the model. According to the CRS assumption, the change in output follows the same proportional change in labour, capital and technology. Given there is no technology or capital stock changes in the short-run, the output is mainly realised from changes in the labour demand. Therefore, in order to maintain the same proportionate change in output, the employment changes have to be greater than the output changes. For example, employment in the brown coal sector has reduced by 60 percent under Scenario 2, whereas output of this sector has reduced by 24 percent. On the other hand, the percentage change in employment has been positive in electricity generating oil (21 percent), electricity generating gas (23 percent) and electricity generating renewable energy (65 percent). Because output of these sectors expands following introduction of a carbon price, there is an increased demand for employment in those sectors.

In contrast, the projected long-run impacts on employment in these sectors are proportionately less when compared to the change in output in those same sectors. Unlike in the short-run, this effect arises because of the assumption of capital mobility between sectors. The CRS assumption is maintained by changing both labour and capital to produce a predetermined level of output.

Table 7.5 Sectoral effects of employment

	Industry	Scenario 1 (SR,$10)	Scenario 2 (SR,$23)	Scenario 3 (SR,$35)	Scenario 4 (LR,$23)
1	Agriculture	-0.36	-1.02	-2.26	1.57
2	Black coal	-1.19	-2.82	-4.78	-10.13
3	Brown coal	-30.03	-60.21	-127.50	-68.68
4	Oil	-0.39	-0.98	-1.86	-0.90
5	Gas	-1.23	-2.82	-4.36	-20.48
6	Other mining	-0.46	-1.24	-2.62	-1.67
7	Food, beverages and tobacco	0.61	-1.65	-3.42	0.94
8	Textile, clothing and footwear	-0.54	-1.50	-3.22	1.12
9	Wood, paper and printing	-0.39	-1.10	-2.32	0.78
10	Automotive petrol	-0.34	-0.67	-0.74	0.10
11	Kerosene	-0.45	-1.02	-1.44	0.08
12	Liquid gas petroleum	-0.63	-1.44	-2.12	-1.00
13	Other petrol and coal products	0.09	0.30	0.99	0.09
14	All other chemical products	-1.65	-4.17	-7.72	-4.04
15	Non metallic products	-0.71	-1.92	-3.93	0.54
16	Cement and concrete	-0.71	-1.66	-2.67	-0.11
17	Iron and steel	-2.54	-6.23	-11.01	-6.10
18	All other metal products	-1.53	-3.66	-6.71	-5.48
19	All other manufacturing	-0.54	-1.54	-3.39	-0.94
20	Electricity generating - black coal	-0.34	2.31	18.00	-76.65
21	Electricity generating - brown coal	-0.40	-8.05	-19.70	-65.24
22	Electricity generating - oil	7.36	21.49	49.87	101.60
23	Electricity generating - gas	9.40	23.22	46.50	-28.49
24	Electricity generating - renewable energy	27.99	65.17	115.81	834.56
25	Commercial electricity supply	-7.86	-18.63	-30.75	-1.56
26	Gas supply	-3.93	-9.85	-17.83	2.15
27	Water and sewerage services	-0.43	-1.11	-2.11	0.40
28	Construction services	0.04	0.14	0.30	-1.04
29	Trade services	-0.23	-0.64	-1.37	0.74
30	Accommodation and cafe	-0.69	-1.74	-3.25	0.02
31	Road transport services	-0.43	-1.23	-2.73	1.43
32	Other transport services	-0.83	-2.19	-4.31	-1.15
33	Business services	-0.25	-0.70	-1.49	0.41
34	Public services	-0.15	-0.40	-0.82	-0.06
35	Other services	-0.10	-0.28	-0.57	0.15
	Aggregate Employment	*-0.33*	*-0.87*	*-1.73*	*0.00*

Note: Projections in percentage changes from the base solution
Source: A3E-G model projections, SR- Short-Run, LR-Long-Run

Table 7.6 shows the carbon price impact on different occupational groups in the Australian economy. In the short-run, as the carbon price increases, employment levels contract in all occupational categories with some changing more than others.

Table 7.6 Percentage change projection in occupational groups under various carbon prices

	Occupational category	Scenario 1 (SR,$10)	Scenario 2 (SR,$23)	Scenario 3 (SR,$35)	Scenario 4 (LR,$23)
1	Managers and administrators	-0.37	-0.97	-1.92	0.13
2	Professionals	-0.27	-0.71	-1.40	0.14
3	Associate professionals	-0.30	-0.81	-1.59	0.15
4	Trades persons and related workers	-0.35	-0.89	-1.72	-0.67
5	Advanced clerical and service workers	-0.29	-0.79	-1.61	0.13
6	Intermediate clerical, sales and services workers	-0.32	-0.85	-1.68	0.15
7	Intermediate production and transport workers	-0.54	-1.37	-2.76	-0.52
8	Elementary clerical, sales and service workers	-0.29	-0.79	-1.62	0.43
9	Labourers and related workers	-0.37	-0.98	-1.97	0.01

Source: A3E-G model projections, SR- Short-Run, LR-Long-Run

The short-run simulation results indicate an overall decrease in derived demand for occupational labour categories following a decreased output due to a carbon price. The highest projected fall in labour demand occurs in the intermediate production and transport workers category where the projected fall is 1.37 percent under Scenario 2. Intermediate production and transport workers are engaged mostly in coal mining, oil and gas, iron ore, non-ferrous metal ores, other mining, and services to mining activities which are comparatively emissions intensive sectors in the economy. As projected, production of these sectors contracts leading to a reduction in number of employees. Both labourers and related workers and managers and administrators categories, have declined by 0.9 percent. The least affected employment group as projected under all scenarios are the professional workers category. This category projects the lowest fall compared to other categories by 0.71 percent under the Scenario 2. Basically, these workers engage in services sector activities which have been least affected by the carbon price.

As the model projects a contraction in employment across all occupational categories in the short-run, the carbon price policy sounds unattractive to every employment category in Australia. However, the long-run result changes this perspective. The projected impacts on occupational categories are positive for all occupations except trades persons and related workers (-0.67 percent), and intermediate production and transport workers (-0.52 percent). According to these estimates, trades persons and related workers and intermediate production and transport workers will be affected severely by the carbon price policy.

7.2.4 Household income distribution and consumption impacts

The social accounting data used in this model provides detailed information regarding household income patterns and expenditure sources. Household income is determined as changes in wages income (disaggregated into 9 occupational groups), capital rent, land rent, government transfers and other transfers. Wages income is received mainly by the households and comprises the major part of household income[22].

Income distribution effects are presented in Table 7.7. Overall, the impacts range from proportional to mildly progressive tax incidence under the short-run scenarios. However, the effects are not significant on deciles 1 and 2 under all scenarios. These two groups receive a significant proportion of government transfers which constitute their major source of income[23]. As a result, introduction of a carbon price may not necessarily reduce household post tax income. The rest of the income groups share the burden quite proportionately to their relative income, with middle income groups (deciles 5, 6, 7, and 8) fairing the worst. This is because in the short-run, household incomes are mainly affected from the changes in labour supply rather than changes in capital rent. Accordingly, this projection confirms that middle income households receive wage income as a major part of their total income. The post tax

[22] As given in macro-SAM for Australia, labour income constituted 56% of the total aggregate household income in 2004/05.
[23] More than 75% of the total incomes constitute government transfers for these two groups combined.

income effect on the last two income deciles (deciles 9 and 10) are relatively less than the average middle income group effect. These income groups receive a higher share of capital income relative to wage income.

Table 7.7 Projected post tax real income effects among household deciles

Household income deciles	Scenario 1 (SR,$10)	Scenario 2 (SR,$23)	Scenario 3 (SR,$35)	Scenario 4 (LR,$23)
1st	-0.05	-0.14	-0.28	-0.10
2nd	-0.07	-0.18	-0.37	-0.14
3rd	-0.24	-0.62	-1.24	-0.34
4th	-0.21	-0.55	-1.11	-0.32
5th	-0.29	-0.76	-1.51	-0.42
6th	-0.28	-0.73	-1.45	-0.38
7th	-0.28	-0.75	-1.48	-0.69
8th	-0.27	-0.72	-1.43	-0.66
9th	-0.24	-0.64	-1.27	-1.28
10th	-0.26	-0.68	-1.35	-1.36

Note: Projections in percentage changes from the base solution
Source: A3E-G model projections, SR- Short-Run, LR-Long-Run, 1st – 10th range poorest to richest.

The long-run impacts of the carbon price policy lead to a progressive tax incidence with the highest income groups (deciles 9 and 10) fairing the worst. The degree of change varies from -0.10 percent to -1.36 percent. This is mainly because the income distribution stems primarily from capital income under the long-run. Capital income constitutes a larger proportion of post tax income of rich household groups. Moreover, the post tax income changes of the rest (deciles 1-8) are somewhat less burdensome as compared to the short-run (Scenario 2). This is mainly as a result of improved labour demand in the economy under the long-run (see Table 7.6).

A carbon price changes the composition of household consumption of goods and services in the economy. A carbon price alters relative prices of commodities as industries incorporate the carbon price into their production costs. The increased prices of carbon intensive commodities will have a disproportionate impact on those households which consume more carbon intensive commodities. For instance, commodities that are required for subsistence requirements are purchased regardless of their price increase. The remaining consumption - the 'luxury' or 'supernumerary' expenditure - is altered with relative price changes.

Table 7.8 shows the percentage change in household real consumption under various carbon price scenarios. The real household consumption of each income group is negatively related to all carbon price scenarios with the magnitude of the impact rising as the carbon price increases. It is also quite clear that all short-run scenarios generate proportionate consumption reductions in the income groups of deciles 3 to 10. However, projected household consumption impacts are progressive under the long-run and the degree of change varies from -0.004 (decile 1) to -0.714 percent (decile 10).

Table 7.8 Percentage change in household real consumption under various carbon prices

Household income deciles	Scenario 1 (SR,$10)	Scenario 2 (SR,$23)	Scenario 3 (SR,$35)	Scenario 4 (LR,$23)
1st	-0.001	-0.002	-0.002	-0.004
2nd	-0.001	-0.001	-0.013	-0.010
3rd	-0.013	-0.030	-0.042	-0.034
4th	-0.021	-0.051	-0.083	-0.051
5th	-0.043	-0.107	-0.191	-0.084
6th	-0.051	-0.128	-0.231	-0.097
7th	-0.064	-0.162	-0.297	-0.194
8th	-0.073	-0.186	-0.343	-0.219
9th	-0.083	-0.211	-0.387	-0.499
10th	-0.127	-0.328	-0.621	-0.714
Aggregate	*-0.060*	*-0.170*	*-0.310*	*-0.301*

Source: A3E-G model projections, SR- Short-run, LR-Long-run, 1st – 10th range poorest to richest.

With respect to changes in patterns of energy consumption, low income households may be more vulnerable to the carbon price as compared to high income groups. For instance, the first two income groups (deciles 1 and 2) experience very slight reductions in their real consumption even as the carbon price increases. This could be due mainly to consumption of subsistence commodities being a major part of their consumption. Generally, low income households spend more than their average income on energy-intensive commodities, mainly electricity. In contrast, rich households can adjust to the relative price shifts because a larger proportion of their income may be spent on energy-intensive luxury commodities.

7.3 Revenue recycling policies

This section discusses a mechanism to reduce some of the burden on the household sector resulting from the introduction of a carbon price in the economy. A similar approach has been discussed in the *Clean Energy Act* 2011 (Australian Government 2011c) which indicated that more than 50 percent of the carbon tax revenue will be allocated to assist low and middle income households in Australia. For the present study, half of the carbon revenue is recycled under four alternative scenarios to examine the impacts on the macro-economy in general and on the household income groups in particular. For all these policy experiments, a \$23 carbon price under the short-run economic environment is used. The short-run economic environment is chosen because the immediate effects of a carbon price on Australian households are the main focus of this study. The revenue recycling policies are summarised as follows:

Recycling policy	Description
LSO	50 percent of the carbon revenue raised from \$23t/CO_2-e under the short-run is redistributed to all households based on original government transfer ratios[24].
LSE	50 percent of the carbon revenue raised from \$23t/CO_2-e under the short-run is redistributed equally among all household groups.
INC	50 percent of the carbon revenue raised from \$23t/CO_2-e under the short-run is redistributed to reduce payment of income tax[25] by households.
GST	50 percent of the carbon revenue raised from \$23t/CO_2-e under the short-run is returned to the economy by way of reducing Goods and Services Tax (GST)[26] paid by households.

[24] The original government transfer ratios are 17%, 29%, 17%, 19%, 4%, 5%, 3%, 3%, 1% and 2% to decile 1 to 10 respectively.

[25] The income tax payment is considered as a household direct payment to the government. Therefore, the compensation revenue is used to reduce payments to the government at a rate of 0%, 7%, 9%, 7%, 6%, 5%, 9%, 8%, 16% and 33% by deciles 1 to 10 respectively.

Table 7.9 summarises key macroeconomic results of these policy experiments. The policy experiments are reported along with the main policy scenario (Scenario 2) which is titled as CTX policy in the following discussion. As given in Table 7.9, the projected emissions reductions under all revenue recycling policies are closely similar to that of the CTX policy. Therefore, these recycling policies can be used effectively to improve the welfare of households without disturbing the emissions abatement effort in the economy.

The impact on real GDP has improved under all revenue recycling policies as compared to the CTX policy. Both LSE and GST policies have improved the impact on real GDP by around 60 percent compared to the CTX policy. Even though both LSO and LSE policies are lump-sum transfer options, the impact on real GDP is much higher under the LSE policy (-0.21 percent) compared to LSO policy (-0.53 percent). One possible explanation for this is that the economy is driven mostly by the spending of richer households and their consumption increases more under the LSE policy than under the LSO policy. Real GDP improves under the GST policy because the distortionary effect of the tax in the economy has reduced. The reduction in GDP under the LSO and the INC policies is 10 percent lesser as compared to the reduction in GDP under the CTX policy.

Table 7.9 Macroeconomic results of the carbon price revenue recycling experiments

Variable	CTX (Scenario 2)	LSO	LSE	INC	GST
Emissions reduction (%)	-11.94	-11.93	-11.96	-11.96	-11.74
Real GDP	-0.60	-0.53	-0.21	-0.54	-0.29
Real household consumption	-0.17	0.88	5.26	0.76	-0.05
Export volume	-2.76	-5.07	-14.68	-4.81	-1.26
Import volume	0.07	0.67	3.32	0.60	0.14
Consumer price index	0.71	1.25	3.80	1.85	-0.25
Real devaluation	-0.73	-1.28	-3.82	-1.22	-0.06

Note: Projections in percentage changes from the base solution
Source: A3E-G model projections

[26] Household payments of GST are in the proportion of 4%, 4%, 6%, 7%, 8%, 10%, 11%, 13%, 15% and 21% by deciles 1 to 10 respectively.

The CPI rises significantly under LSO, LSE and INC policies compared to CTX policy. However, under the GST policy the CPI shows a negative growth of 0.25 percent. As a result, the GST policy improves exports by 54 percent compared to the CTX policy. Overall, GST policy improves the export competitiveness in the economy as compared to other policies. All other revenue recycling policies showed deteriorating export levels. The highest reduction in exports of 14.7 percent is seen under the LSE policy. This very high fall in exports under the LSE policy resulted from the currency appreciation by 3.82 percent.

All revenue recycling policies improve aggregate household real consumption by comparison with the CTX policy. However, the reduction in GST fails to generate a noticeable impact on the household real consumption which still experiences a negative change of 0.05 percent. This is because food and exports are GST exempt and households' consumption of energy goods remain unaffected by the GST cut. The largest improvement in the household real consumption can be seen with the LSE policy which increases the aggregate household real consumption by 5.26 percent. The LSO and INC policies improve the aggregate real household consumption by 0.88 and 0.76 percent respectively. Under these three policies (LSE, LSO, INC), households have more capacity to alter their decisions toward the consumption patterns that have initially been affected by the carbon price policy. Under these circumstances improved household real consumption has given rise to a welfare gain in the economy without disturbing the carbon emissions abatement policy.

7.3.1 Distribution analysis under various recycling policies

The household distributional effects under various recycling policies in terms of percentage changes in real income, utility and equivalent variations are presented in this section. Table 7.10 shows the percentage changes of household incomes under all revenue recycling policies compared to the CTX policy. As discussed before, under the CTX policy the overall impact ranges from proportional to mildly progressive tax incidence with middle income households (deciles 5, 6, 7 and 8) affected the most.

Since a larger proportion of household incomes in deciles 1 and 2 receive government transfers, the LSO policy has significantly increased their post tax income levels compared to the baseline by 2.4 and 3.1 percent respectively. Furthermore, the projected post tax income changes are positive among the deciles 3 and 4 since these groups also receive a significant proportion of their income in the form of government transfers. The rest of the income groups (deciles 5-10) benefited less from the carbon tax revenue transferring based on the original government transfer ratios and their percent change in income remains negative, although with a slight improvement compared to the CTX policy. Therefore, progressivity of the carbon price policy becomes quite significant under the LSO policy. As such, compensating households under the LSO policy is essentially of political interest in Australia where the targeted population comprises those households with lower incomes.

Table 7.10 Percentage changes in post tax income by household decile

Household income deciles	CTX (Scenario 2)	LSO	LSE	INC	GST
1st	-0.14	2.40	1.32	-0.14	-0.05
2nd	-0.18	3.06	0.91	0.55	-0.07
3rd	-0.62	0.89	0.29	0.21	-0.23
4th	-0.55	0.80	0.15	-0.08	-0.21
5th	-0.76	-0.52	-0.16	-0.44	-0.29
6th	-0.73	-0.48	-0.17	-0.45	-0.27
7th	-0.75	-0.62	-0.21	-0.32	-0.28
8th	-0.72	-0.60	-0.26	-0.39	-0.27
9th	-0.64	-0.59	-0.18	-0.09	-0.23
10th	-0.68	-0.63	-0.33	0.06	-0.24

Source: A3E-G model projections; 1st – 10th range poorest to richest.

The LSE policy is designed to transfer carbon tax revenue equally among all household groups. Under this policy, percentage changes of the post tax income from deciles 5 to 10 have significantly improved compared to the LSO policy. However, these deciles still experience negative post tax income changes although with a lesser decline compared to the CTX policy. This is mainly because the amount of compensation is not sufficient to fill the gap created as a result of large income losses experienced by these households. In contrast, the amount of revenue received is sufficient to uplift the post tax income levels of the lowest income groups. This is seen as a positive change in the post tax income of the household group from deciles 1 to 4. There is a progressive effect under this option, although the magnitude of the effect is somewhat lesser than under the LSO policy.

The percentage change in the post tax income of decile 1 under the INC policy has not resulted in any impact compared to the CTX policy and remains as -0.14 percent. The income tax paid by this group is very small, nearly zero, thus households falling under this income group have not benefited from this policy. Interestingly, the post tax income changes in the deciles 2 and 3 have been positive. The rest of the households (deciles 4-9) still register negative percentage changes in the post tax income. The decile 10 registers a positive change in post tax income by 0.06 percent. This is because this group pays a relatively higher amount of income tax to the government and as a result the group benefits from the INC policy. Overall, the results indicate this compensation policy has benefited income groups at two ends; the richer (decile 10) and the poorer (deciles 2-3). The results are not so beneficial for middle income groups (deciles 4-9) although there is some improvement compared to the no compensation CTX policy.

Post tax income changes of the GST policy follow the same pattern to that of the CTX policy. The reduction in GST applies to value added production within each sector without distorting the relative costs of inputs. However, it does distort the composition of output to a small extent. This explains why the GST reduction affects the overall consumption level slightly less than other revenue recycling options. In this policy experiment, the GST cut has proportionately improved the post tax income of all households compared to the CTX policy but the impacts are minor as compared to lump-sum transfer options (LSO and LSE).

A carbon price affects the consumption pattern of households. As such, the percentage change in household utility can be used as a reliable indicator of welfare. With the given LES (linear expenditure system) consumption function, the change in consumption is largely realised through the change in supernumerary (luxury expenditure) consumption. Therefore, the utility of a given household group measures the likelihood of changing its supernumerary consumption. The percentage change in utility of the ten household groups is given in Table 7.11. The household utility change is progressive under the CTX policy. Once households are compensated by the LSO policy, the utility change improves towards low income household groups. This is because low income groups get more opportunities to increase their consumption of luxury commodities under this policy as compared to high income groups. However, once an equal dollar amount is given to all households (LSE policy), utility significantly increases towards higher income groups allowing these groups to consume more of the luxury goods. The INC policy has proportionately boosted the consumption level of the luxury commodities by all household groups whereas the GST policy produced less of an impact on household utility compared to the CTX policy. Still, the income groups from deciles 4 to 10 have projected negative percentage changes of utility with the GST policy. Overall, the results indicate that utility can be used as a proxy indicator to see how households respond to consumption of luxury commodities because when using a proper revenue recycling policy, household consumption patterns can be effectively changed to switch towards consumption of more efficient energy saving luxury commodities.

Table 7.11 Percentage change in household utility

Household deciles	CTX (Scenario 2)	LSO	LSE	INC	GST
1st	-0.04	6.04	3.51	2.66	0.04
2nd	-0.01	6.85	2.51	3.49	0.11
3rd	-0.27	4.78	3.03	3.32	0.08
4th	-0.35	4.52	2.41	2.85	-0.05
5th	-0.59	3.12	8.35	2.45	-0.16
6th	-0.59	3.13	7.22	2.41	-0.17
7th	-0.63	2.95	13.44	2.52	-0.20
8th	-0.63	2.95	11.49	2.41	-0.21
9th	-0.57	2.92	35.55	2.68	-0.18
10th	-0.65	2.83	21.67	2.80	-0.24

Source: A3E-G model projections, 1st – 10th range poorest to richest.

The percentage change in utility is progressive under a CTX policy and all the revenue recycling policies improve the utility levels of households in varying ways. For example, under the LSO policy, utility levels have improved towards lower income groups whereas under the LSE policy utility levels have improved towards higher income groups. However, in terms of the percentage change in utility when measured in actual dollar values, all revenue recycling policies generate significant welfare improvement towards higher income household groups (see Table 7.12). This is the monetary measure of the welfare effects of the price rise which is termed as the equivalent variation (EV). EV indicates the maximum amount that the consumer would be willing to pay to avoid a price change. From Table 7.11, it is apparent that high income households suffer more compared to low income households in monetary terms under the CTX scenario. However, when welfare is measured as EV as shown in Table 7.12, compensation has clearly improved the welfare of higher income groups compared to lower income groups.

Table 7.12 Equivalent variation as a percentage change in post tax income

Household income deciles	CTX (Scenario2)	LSO	LSE	INC	GST
1^{st}	-0.002	0.262	0.152	0.115	0.002
2^{nd}	-0.001	0.457	0.167	0.233	0.007
3^{rd}	-0.025	0.436	0.276	0.302	0.007
4^{th}	-0.043	0.548	0.292	0.346	-0.006
5^{th}	-0.086	0.447	1.196	0.351	-0.023
6^{th}	-0.103	0.549	1.266	0.423	-0.029
7^{th}	-0.130	0.606	2.757	0.517	-0.041
8^{th}	-0.147	0.688	2.684	0.562	-0.050
9^{th}	-0.160	0.820	9.977	0.753	-0.052
10^{th}	-0.260	1.123	8.602	1.112	-0.094

Source: A3E-G model projections, 1^{st} – 10^{th} range poorest to richest.

7.4 Sensitivity analysis

There are a large number of elasticity parameters introduced into the model equations and these values were obtained from the ORANI-G database, other literature and from the author's own judgements. Most often simulation results obtained from the A3E-G model rely on values assigned for key exogenous parameters. Since parameter values play a crucial role in the accuracy of the model results, it is important to find out how variations in the values of these parameters affect the model results. This is addressed by implementing a sensitivity test for the parameter values used in this study. Since the model contains a large number of elasticity parameters, it is practically impossible to conduct a simple form of sensitivity analysis (sometimes referred to as *ad hoc* sensitivity analysis) which involves selecting one or two different sets of parameter values and solving the model for each set at a time.

In contrast, a systematic sensitivity analysis (SSA) offers a more convenient way to test the sensitivity of all parameters at once. For this purpose, an SSA was performed via a Gaussian Quadrature which is a type of optimisation method. With the given distribution of M exogenous variables (parameters), Gaussian Quadrature estimates means and standard deviations of all endogenous variables by choosing the best possible N simulations. In performing the SSA, all parameters were assumed to have triangular distributions. The optimum number of simulations[27] was then determined using the Stroud Quadrature.

Table 7.13 reports the mean, standard deviation and confidence interval of the selected variables under the SSA carried out for Scenario 2. All parameters were varied by 50 percent from their mean values to check the sensitivity of the results. Overall, results reveal that the percentage change in endogenous variables is fairly robust or insensitive to a variation in parameters (exogenously determined). Furthermore, SSA mean values are not significantly different to the original simulation results. Because the standard deviations from the mean values among many endogenous macro variables are considerably low, it can be concluded with 95 percent confidence[28] that the results are generally robust with respect to 50 percent parameter variation. For example, there is a 95 percent confidence that real GDP, aggregate real consumption, aggregate employment and exports will fall and the consumer price index will rise with a $23 carbon price. However, in the case of imports, because the upper confidence interval is non-negative, it cannot be concluded with 95 percent confidence that imports will fall following a carbon price. The emissions reduction is also robust with respect to parameter variation even though the standard deviation is wide. However, some industry results are sensitive to the parameter variation. For instance, upper confidence intervals of some industries are non-negative with some high standard deviation values (see Table 7.13)

[27] This facility is offered in the RUNGEM programme of GEMPACK software

[28] The confidence interval is calculated using the Chebyshevs inequality which says that whatever the distribution of the variable in question, for each positive real number k, the probability that the value of Y does not lie within k standard deviations of the mean M is no more than $1/k^2$ and k=4.47 for 95% CI.

Table 7.13 SSA of Scenario 2: 50 percent variation in all parameters

Variable (Percentage change)	Mean	Standard dev	Confidence Interval (95%)	
			Lower	Upper
Real GDP	-0.601	0.067	-0.900	-0.301
Aggregate consumption	-0.170	0.013	-0.228	-0.112
Consumer price index	0.704	0.093	0.228	1.120
Aggregate employment	-0.875	0.083	-1.246	-0.504
Import volume	0.062	0.089	-0.336	0.460
Export volume	-2.739	0.345	-4.281	-1.197
Emissions reduction	-11.947	0.804	-15.541	-8.335
Industry outputs				
Agriculture	-0.539	0.126	-1.101	0.024
Black coal	-0.563	0.113	-1.068	-0.059
Brown coal	-24.537	1.569	-31.557	-17.523
Oil	-0.111	0.019	-0.196	-0.027
Gas	-0.404	0.061	-0.677	-0.132
Other mining	-0.307	0.068	-0.609	-0.004
Food, beverages and tobacco	-1.030	0.502	-3.274	1.213
Textile, clothing and footwear	-0.971	0.132	-1.561	-0.380
Wood, paper and printing	-0.834	0.432	-2.766	1.098
Automotive petrol	-0.507	0.106	-0.980	-0.033
Kerosene	-0.849	0.389	-2.589	0.891
Liquid gas petroleum	-1.133	0.143	-2.857	0.592
Other petrol and coal products	0.317	0.143	-0.323	0.957
All other chemical products	-2.454	0.252	-3.581	-1.327
Non metallic products	-1.441	0.145	-2.090	-0.792
Cement and concrete	-1.267	0.137	-1.880	-0.655
Iron and steel	-3.898	1.252	-9.496	1.700
All other metal products	-2.403	0.422	-4.291	-0.515
All other manufacturing	-1.112	0.138	-1.727	-0.496
Electricity generating - black coal	-8.968	0.891	-12.951	-4.986
Electricity generating - brown coal	-18.047	1.293	-23.827	-12.267
Electricity generating - oil	6.914	1.118	1.915	11.913
Electricity generating - gas	3.106	0.669	0.113	6.098
Electricity generating - renewable energy	11.663	2.858	-1.112	24.439
Commercial electricity supply	-7.443	0.444	-9.427	-5.459
Gas supply	-0.730	0.077	-1.073	-0.387
Water and sewerage services	-0.472	0.037	-0.636	-0.308
Construction services	0.031	0.011	-0.020	0.081
Trade services	-0.568	0.061	-0.841	-0.295
Accommodation and cafe	-1.399	0.134	-1.996	-0.801
Road transport services	-0.842	0.112	-1.344	-0.339
Other transport services	-1.189	0.138	-1.805	-0.574
Business services	-0.343	0.045	-0.543	-0.144
Public services	-0.440	0.058	-0.697	-0.182
Other services	-0.303	0.031	-0.443	-0.162
Household consumption by deciles				
1st decile	-0.002	0.002	-0.013	0.009
2nd decile	-0.001	0.003	-0.014	0.016
3rd decile	-0.030	0.005	-0.050	-0.010
4th decile	-0.051	0.006	-0.079	-0.023
5th decile	-0.107	0.008	-0.143	-0.071
6th decile	-0.128	0.010	-0.172	-0.084
7th decile	-0.162	0.012	-0.215	-0.109
8th decile	-0.186	0.014	-0.246	-0.126
9th decile	-0.211	0.017	-0.286	-0.136
10th decile	-0.328	0.021	-0.423	-0.233

Source: A3E-G model projections

7.5 Conclusion

Building on the model described in Chapter VI, this chapter attempted to project the macroeconomic, sectoral, employment, household impacts of a carbon price and the distributional implications arising from various revenue recycling policies using the static A3E-G computable general equilibrium model.

The study analysed the economic implications of three short-run carbon price scenarios and one long-run carbon price scenario. The main policy scenario proposed by the Australian government is a carbon price of $23 per tonne of CO_2-e. In order to gauge the extent of variation of the main policy scenario, two other carbon price scenarios were used. Accordingly, short-run simulations were drawn for $10 carbon price (Scenario 1), $23 carbon price (Scenario 2) and $35 carbon price (Scenario 3). Scenario 2 was then compared with a long-run scenario (Scenario 4) in order to understand the long term implications of the $23 per tonne of CO_2-e on the economy. All these scenarios assume that the carbon price revenues will be retained by the government. Using Scenario 2 as the control policy (CTX), four different carbon revenue recycling policies were then examined. Finally, a systematic sensitivity analysis was performed in order to test the robustness of the parameters used in the model.

CHAPTER VIII

Summary, Research Contributions and Suggestions for Further Study

Introduction

In this thesis the economic implications of carbon abatement in the Australian economy was examined by employing a Computable General Equilibrium (CGE) model as a tool. Currently, the Australian Treasury employs a large CGE modelling framework to draw projections with respect to macroeconomic, sectoral, employment and household level implications of a carbon price policy. However, as discussed in Chapter V, the CGE model developed under this study (A3E-G) is different in many aspects (eg. database structure, production structure, and carbon price mechanism) and is capable of undertaking a systematic and comprehensive analysis of the carbon price policy. This final chapter of this thesis includes a brief summary in Section 8.1 followed by a discussion of the research contributions in Section 8.2, and suggestions for further research in Section 8.3.

8.1 Summary of the thesis

Analysis of the Australian energy sector and its implications for greenhouse gas emissions and mitigation policies

Australia is endowed with abundant resources of fossil energy and has been able to establish competitive energy-intensive industries over time. Australia's major fossil based energy is derived from large reserves of coal (both black and brown coal), natural gas and oil. As a result, Australia produces the world's cheapest electricity and this is one of the key sources of Australia's economic development and prosperity. However, the use of coal and other fossil energy sources are becoming increasingly problematic because of high emission intensities associated with these resources.

Chapter II presented a discussion of the Australia's energy systems and its implications for a carbon constrained economy. Australia's agricultural and fossil energy contributes around 87 percent of Australia's total emissions. Australia's per capita emissions are the highest among all Annex I countries and the analysis shows that emissions intensity has played a significant role towards this position.

Australia's climate change mitigation policy has been the subject of intense political debate over the past few decades. This is because of the important role played by the emissions intensive energy sector in the economy and the fear of losing the comparative advantage enjoyed by the economy in relation to energy intensive exports such as coal, iron and steel products, aluminium and alumina etc. A number of policy measures have been proposed, rejected and partially implemented. The present Australian government has made a strong commitment to implement a carbon price mechanism with a starting carbon price of $23 per tonne of CO_2. The economic theory behind carbon pricing confirms that pricing carbon is the most efficient and effective means of reducing emissions.

Review of literature CGE models related to environmental policies in general and carbon price policies in particular

Chapter III contained a review of the literature of CGE models. CGE models are much more capable of indicating social and economic costs of many sectors of a policy shock as compared to partial equilibrium models. Fixed coefficient models are discussed, namely IO models and SAM models designed to estimate costs of environmental policy measures. These models explain the inter-industry linkages of an economy that are embedded in CGE models. The CGE models have the advantage that they take into account the relative price changes in an economy and determine a new equilibrium level of prices and quantities. More precisely, CGE models are concerned with converting the Walrasian general equilibrium structure from an abstract representation of an economy into a realistic model of an actual economy (Shoven and Whalley, 1984). There is a large body of literature on the use of CGE models which address various policy issues including tax policies, development policies, agricultural policies, international trade, energy policies and environmental policies. For the purpose of this study, CGE models developed to address environmental policies in general and CGE models to analyse impacts of carbon price policies in particular are reviewed. The literature survey included Australian CGE models developed for greenhouse gas policy analysis. In all, the literature reveals that the modelling capacity of the CGE models has progressed significantly in terms of accommodating complexity and realism. Further extensions to CGE models seems possible in terms of incorporating more realistic assumptions on production structures, technological advancement functions and income generating processes of economic agents etc.

Environmentally extended SAM database (ESAM) that serves as the main database for the CGE model calibration

The analysis of distributional impacts of carbon price policy in the CGE modelling framework has been facilitated by calibrating the model with an Environmentally-extended Social Accounting Matrix (ESAM). The Australian ESAM constructed in this study constitutes the most disaggregated energy sectors, electricity generating sectors, employment groups and household income groups. Since there has been no ESAM database developed for the purpose of carbon price modelling in Australia, to the author's knowledge this ESAM database will be the first energy and emissions focussed ESAM database of Australia. Many studies have suggested the use of a SAM as an essential database for CGE modelling (see for example Robinson (1988) and Taylor (1990) for a comprehensive survey of SAM-based CGE modelling).

The ESAM database described in Chapter IV provides a good research infrastructure to analyse the distributional implications arising from carbon price modelling. It explains the most transparent and detailed procedure for constructing an ESAM database of Australia for the year 2004-05 with two distinct stages - the macro-SAM and the micro-SAM. First, the macro-SAM was constructed using aggregate production, consumption and income generating activities of the institutions in the economy. Secondly, the main accounts in the macro-SAM and their non-zero entries were disaggregated to provide a more detailed picture of all flows in the economy. The level of disaggregation depends on the research objective and the availability of data. As a result, a micro-SAM was constructed with 119 sectors, nine occupation groups and 10 household groups. The 119 sector representations were finally aggregated into 35 sectors based on relative importance of carbon emissions in the economy. This micro-SAM is viewed as an ESAM of the Australian economy as it contains disaggregated energy sectors, electricity generating sectors and other emission sectors which have been disaggregated based on their carbon emission levels.

Static, energy and emissions focussed CGE model of the Australian economy to carry out carbon price policy simulations

The CGE model developed under this study is titled an Economy-Energy-Emissions CGE model (A3E-G) of the Australian economy and has incorporated modifications to the production structure and to purchaser price definitions. Additionally, a new set of behavioural equations were incorporated which explained income and expenditure patterns of institutions (household, government, corporations and rest of the world). Chapter V presented the theoretical structure of the A3E-G model designed to assess the impact of a carbon price in the Australian economy. The modified production structure in the model treated energy commodities and electricity generating sectors separately from the rest of the intermediate commodity group. Accordingly, substitutions between different types of energy inputs and electricity generating sectors were described using constant elasticity of substitution (CES) functions. Because CO_2 emission intensities were tied into each energy input, these CES functions allowed the model to substitute high emission intensive production activities and processes with less emissions intensive production activities and processes. At another level of the production structure, limited substitution possibilities were assumed between capital and the energy composite. The value of the substitution elasticity reflects the cost and the availability of energy saving technologies in the economy. The production structure used in this model is shown in Figure 5.2. The carbon emissions intensities were calculated and assumed fixed in the model to reflect unchanged technology and household preferences. These emission intensities were used to design an explicit carbon tax system under the purchaser price definitions. Finally, the model incorporated income mapping equations for 10 household groups, government, corporations and the rest of the world. As a result, the distributional implications of the carbon tax policy could not only be analysed by the spending patterns but also by income generating patterns of the institutions. Because a carbon price generally affects the markets for factors of production and types of factors with which households are endowed, these drive the direction of the distributional impact. This model is also able to calculate welfare impacts of revenue recycling policies. Finally, the model was solved directly with numerical solution techniques defined in GEMPACK software.

A3E-G model database structure with carbon emissions accounts and various elasticity parameters

Chapter VI discussed other necessary data matrices to calibrate the A3E-G model. This includes an investment matrix, tax matrix, carbon emissions matrix and various elasticity parameters. In the existing IO table, gross fixed capital formation is only disaggregated by commodity. However, it was necessary to compile an investment matrix which shows the investing industry as well in order to be compatible with the model database structure. This matrix was compiled using the 'Industry performance' table published by the Australian Bureau of Statistics (ABS). The domestic and import tax matrices were derived from the 'Taxes on products' and 'Import duty' tables of the IO tables. As shown in Figure 6.1, the database structure contains the additional row of carbon emissions. These emissions were compiled using National Greenhouse Gas Inventory (NGGI) data published by the Department of Climate Change and Energy Efficiency (DCCEE). This carbon emissions matrix has three components; a matrix of input emissions, a vector of output emissions and a matrix of household consumption emissions. Finally, various elasticity parameters required by the model were compiled. The values of the elasticity parameters were drawn from the existing literature (ORANI-G and other sources) and from the author's own judgment.

Macroeconomic, sectoral, employment and household level analysis of carbon tax policy

In Chapter III, it was argued that a Computable General Equilibrium model (CGE) approach is an ideal tool for analysing economic impacts of a carbon price. Accordingly, a static-CGE model was developed in Chapter V (named as A3E-G) and calibrated using databases constructed in Chapter IV and Chapter VI.

In Chapter VII, the A3E-G model was simulated under two economic environments or closures, namely short-run and long-run. In the short-run, the economy wide average wage rate and capital supplies were exogenously determined. In the long-run, the aggregate employment and rate of return on capital were fixed. The nominal exchange rate was the *numeraire* under both closures. The short-run closure was simulated under three carbon price scenarios, namely low price ($10), main policy ($23) and high price ($35). The main policy scenario is comparable with the Australian Government proposed carbon price. The other two scenarios were used to gauge the extent of the variation of the main policy scenario. The main policy scenario was also simulated under the long-run closure. The main findings are as follows.

Firstly, high carbon emission reductions are possible at higher carbon prices. Moreover, as the reduction in emissions takes effect, the burden on the economy increases. Therefore, a very low carbon price is not advisable from the environmental point of view and a very high carbon price is not advisable from the economic point of view. In order to give the economy an adequate time to respond to the carbon price shock, the model results indicate that a $23 carbon price as a starting carbon price for the Australia economy may be a reasonable compromise. Scenario 2 reveals that a reduction in emissions comes at a modest cost to the economy in terms of a real GDP reduction of 0.6 percent and a reduction in real consumption of 0.17 percent. This carbon price level would increase the consumer price index by 0.71 percent and this result is broadly consistent with the Treasury's finding from its modelling.

Secondly, the negative impacts of a carbon price are mainly observable in the increased price of commercial electricity. Scenario 2 (short-run) predicts a 24 percent increase in the price of electricity whereas Scenario 4 (long-run) predicts a 9 percent increase in the price of electricity. Therefore, in the long-run, the model predicts that electricity prices become less inflationary mainly as a result of changing the fuel mix of electricity generating plants.

Thirdly, carbon price impacts vary significantly between sectors. These impacts shift higher emission intensive industries to lower emissions industries. The results are more favourable for lower emissions intensive sectors and more severe for higher emissions intensive sectors in the long-run as compared to the short-run. For instance, although electricity generating black coal and electricity generating brown coal outputs have both contracted under the short-run and the long-run, there can be seen severe contractions in the long-run. These sectors register higher amounts of emissions. In contrast, the output expansion seen in the electricity generating renewable energy is significantly higher in the long-run as compared to the short-run. This sector has a zero level of emissions. Furthermore, outputs in some other less emissions intensive sectors showed a growth in the long-run especially in food, beverages and tobacco sector, textile and leather sector, and wood paper and printing sector. Sectors which were exempted from the direct carbon price impact, namely agriculture and road transport also showed some positive growth in the long-run.

Fourthly, sectoral employment has also been affected as a consequence of changes in sectoral output due to the carbon price. Similarly to the decline in sectoral output, employment in the emissions intensive sectors have declined by larger percentages compared to employment in lower emission intensive sectors. Heavy reduction in employment occurs in labourers and related workers and intermediate production and transport workers categories.

Lastly, household level impacts range from proportional to mildly progressive tax incidence in the short-run and progressive tax incidence in the long-run. This is due mainly to household incomes changing brought about by the carbon price. Households receiving a larger proportion of their income through wages are affected quite significantly in the short-run while those who receive a larger proportion of their income through capital rents are affected significantly in the long-run. However, household impacts become less significant when they receive a larger portion of their income through government transfers. Furthermore, the results reveal that low income households can be more vulnerable to carbon prices with respect to changes in patterns of energy consumption.

Welfare implications of a carbon price on different household groups under various revenue recycling options

Section 7.3 of Chapter VII discussed a mechanism to reduce some of the burden on the household sector resulting from the carbon price in the economy. For this purpose, half of the carbon tax revenue collected by the government under the short-run main policy scenario (Scenario 2, CTX policy) was recycled back to the economy to assist the household sector. There were four alternative recycling policies considered, namely lump-sum transfers based on government original transfer ratios (LSO), lump-sum transfers distributed equally among all households (LSE), income tax reduction (INC) and goods and services tax cut (GST). The macroeconomic impacts and household distributional results with respect to income, utility and equivalent variation were compared with CTX policy. The results are summarised as follows.

Firstly, all revenue recycling policies have the same emissions reductions as under the CTX policy. This effect can be seen as a positive aspect of the revenue recycling as there will be no additional burden on the environment. On the other hand, economic efficiency improves under all revenue recycling policies with a 60 percent gain in the real GDP under the LSE and GST policies compared to the CTX policy. The other two options - LSO and INC policies - improve the real GDP fall slightly as compared to the CTX policy real GDP fall. The aggregate household real consumption has also increased under all revenue recycling policies compared to the CTX policy with varying magnitudes. The highest increase in real consumption is observed under the LSE policy with a 5.26 percent increment. With respect to consumer price index changes, the GST reduction policy has changed the CPI by -0.25 percent. As a result, exports have expanded by 54 percent compared to the CTX policy. From the macroeconomic point of view, the LSE policy brings severe negative impacts on exports. This suggests that policy makers should consider the welfare implications of both the consumer and the producer when deciding the type of revenue recycling policy.

Secondly, household real incomes have improved under all compensation policies compared to the CTX policy. The compensation via LSO and LSE is favourable towards low income households resulting in progressive post tax income changes. Furthermore, the LSO policy has been found to be more favourable in uplifting post tax income of deciles 1 to 4 and the LSE policy has made significant progress of the post tax income levels of deciles 5 to 10. Therefore, both lump-sum transfer options can be recommended to improve real income of the households in Australia. The choice of the two policies determines which income group needs compensation. The INC policy has given positive income changes for the deciles 2, 3 and 10. However, the overall impacts of the INC policy have not given significant income changes in the post tax income levels of households. Similarly, the GST policy has been found to be less effective in improving post tax income levels of the households although with some improvement compared to the CTX policy.

Thirdly, changes in household utility under various recycling policies were compared with the CTX policy because household utility can be used as a good indicator of welfare. It was observed that the household utility change is progressive under the CTX policy. The revenue recycling with the LSO policy improves the utility towards low income households, whereas the LSE policy improves utility towards high income households. The INC policy has proportionately improved household utility. There was no significant effect from the GST policy on household welfare. Finally, all the compensation options have significantly improved household equivalent variation (EV) towards high income groups. The EV indicates the maximum amount that the consumer would be willing to pay to avoid a price change. Because high income groups suffered a lot in monetary terms under a carbon tax policy, it was obvious that these groups benefit most from the compensation.

Sensitivity analysis on the parameters employed in order to verify statistical accuracy of projections

The results presented in Chapter VII are robust with respect to parameter variation. This is confirmed from the SSA test which revealed a very low level of standard deviation values for most of the endogenous variables. Therefore, at 95 percent confidence intervals (calculated by Chebyshevs Inequality) the results are comparable with the original simulation results.

8.2 Research contributions

This thesis contributes to the literature on the methodology of CGE modelling for carbon tax policy analysis, distributional analysis of revenue recycling mechanisms and development of an ESAM database for Australia for carbon price modelling.

The major contribution of this study is the development of a CGE (A3E-G) model in order to analyse macroeconomic, sectoral, and household impacts of a carbon tax policy in Australia. This A3E-G model differs in many aspects from those currently being used in modelling a carbon price in the Australian economy. These include a modified energy industry specification in the production structure, behavioural equations explaining income and expenditure of the institutions and a carbon emissions accounting mechanism which modifies the purchaser price definitions in the model. As a result, the model is capable of substituting high emissions intensive production activities and processes with low emissions production activities and processes by taking carbon emissions intensities into consideration. The model then translates changes in the relative prices of factors of production to explain the income generating process of the institutions in the economy. Because the model incorporates a disaggregated household sector of 10 income classes, changes to income groups explain the distributional story of the carbon price impact. Accordingly, the model is also capable of explaining various compensation policies which are under consideration for a carbon price policy.

Another important contribution of this research is the construction of an ESAM framework. According to the author's knowledge, no ESAM has been developed in Australia giving detailed information about disaggregated energy industries, disaggregated electricity generating sector details, employment details and disaggregated household details. In this detailed ESAM framework, sectors have been disaggregated following the classification given in the NGGI database. Therefore, sectors shown in the ESAM represent the relative importance of carbon emissions in the Australian economy. In addition, the ESAM presented in this study provides a transparent procedure to replicate or update future ESAM construction. Most importantly, the ESAM provides a comprehensive and consistent equilibrium database for the initialisation and parameter specification of the A3E-G model.

8.3 Suggestions for further research

This research focussed on analysing the economic impacts of a carbon price on the Australian energy sectors, electricity generating sectors, employment groups and household groups. Following the literature survey, this task was undertaken by developing an A3E-G of the Australian economy which has been calibrated using an ESAM, carbon emissions accounts and other relevant data. Although, this model has been able to address all the objectives set under this study, further methodological and empirical work will enrich the policy relevance of this study.

Improving the model

This study employed a static A3E-G model. Projections drawn from this model can be improved by adding investment decisions by various agents in the economy. Because investment decisions are time dependent, such features will transform a static model into a dynamic model. The advantage of using a dynamic model in environmental policy analysis is the ability to incorporate decisions to invest and the purchase of more energy saving capital goods in future time periods. Accordingly, carbon price impacts on the capital accumulation and the future growth of the economy can be projected.

The A3E-G model can be extended to incorporate regional level details. By doing this improvement, carbon policy impacts can be analysed across Australian regions. The regional disparities with respect to generation of emissions and technological advancements (use of renewable energy power technologies e.g. wind, solar power) can then be considered when making regional specific projections of the impacts of a carbon price.

The current A3E-G model has a modified production structure which contains CES functions between composite energy and capital. However, some literature explains the use of CES functions between labour and composite energy and between a primary factor composite and energy. This change of functional form may give rise to different projections and future research is encouraged to address this observation.

The current model provided sectoral projections for only 35 sectors. However, the existing IO table of Australia contains 109 sectors. Although coal, oil-gas, petroleum-coal products and electricity supply industries were further disaggregated in the model, other existing sectors were aggregated. More sector specific projections could be performed if it were possible to use all 119 sectors (disaggregated sectors + existing sectors). The lack of emissions data for all 109 sectors constrained the present study to aggregate sectors into 35 sectors.

The current CGE model addresses the cost of emissions reduction in the economy. However, such emissions reduction could also result in many secondary or indirect benefits to the economy. For instance, emissions control policy contributes to the reduction of local pollutants including SO_2, NO_2 and particulates from fossil fuel burning. Further refinements of the model could take such secondary benefits into account.

Improving the data

The current CGE model has been calibrated using an ESAM database, emissions accounting data, other relevant IO data and various elasticity parameters. The ESAM database was constructed using IO data and ASNA data published by the ABS for the year 2004-05. In order to disaggregate the expenditure side of the household sector in the macro-SAM, the household expenditure survey (HES) data of the year 2003-04 were used. Assuming that household tastes and preferences remained constant during the period from 2003-04 to 2004-05, the expenditure proportions were calculated for ten income groups. However, it must be acknowledged that the accuracy of the model results could be improved by using more recent data. Recently, ABS published a 2005-06 IO table and a 2009-10 HES. Time constraints prevented recalibrating the model with these recent data but clearly an update is now warranted.

This study introduced many elasticity parameters. Parameters that have been already used in ORANI-G models were basically adapted to this study with some modifications. Other parameters were not estimated econometrically but 'borrowed' from similar studies or based on the author's own judgment. Although this practice can be regarded as a major limitation of this study, this is the common practice of many CGE modellers in this field. The SSA confirmed that the results were generally robust with 50 percent variation in all parameters used. However, some industry results were sensitive to parameter values. Therefore, further studies are suggested to improve the validity of these parameter values. These values can be estimated econometrically in order to be more appropriate into the Australian economic setting.

This study incorporated household details based on income size of ten household groups. A possible and useful extension to the model would be to build an integrated microsimulation CGE model. A microsimulation model captures household level details from survey data which has the ability to look at the distributional impacts across other socio-economic characteristic of households.

Bibliography

ABARE (Australian Bureau of Agricultural and Resource Economics). (2005). *Energy in Australia 2005*. Commonwealth of Australia, Canberra.

ABARE. (1996). The MEGABARE model: Interim documentation, Commonwealth of Australia, Canberra.

ABARE. (2010). *Energy update 2010*. Australian Government, Canberra.

ABARE. (2011). *Energy in Australia*. Commonwealth of Australia, Canberra.

Abler, D. G., Adrian, G., Rodriguez, & Shortle, J. S. (1999). Parameter uncertainty in CGE modeling of the environmental impacts of economic policies. *Environmental and Resource Economics,* 14(1), 75-94.

ABS (Australian Bureau of Statistics). (2006a). *Household expenditure survey, 2003-04 - Customized data*. Catalogue no. 6535.0, Australian Government Publishing Service, Canberra.

ABS. (2006b). *Government benifits taxes and household income, 2003-04*. Catalogue No. 6537.0, Australian Government Publishing Service, Canberra.

ABS. (2008a). *Australian national accounts: Input output table, 2004-05*. Catalogue No, 5209.0. Australian Government Publishing Service, Canberra.

ABS. (2008b). *Australian system of national accounts, 2005*. Catalogue No. 5204.0, Australian Government Publishing Service,Canberra.

ABS. (2008c). *Australian national accounts: Input output tables - product details, 2004-05,*. Catalogue No.5215, Australian Government Publishing Service, Canberra.

ABS. (2009). *Census of population and housing, 2005-06 - Customized data*. Catalogue No. 2015.0, Australian Government Publishing Service, Canberra.

ABS. (2011). *Household income and distribution, 2009-10*. Catalogue No. 6523.0, Australian Government Publishing Service, Canberra.

Adams, P., & Dixon, P. B. (1992). Disaggregating oil, gas and brown coal. *Mimeo,* Centre of Policy Studies, Monash University, Melbourne.

Adams, P., Dixon, P. B., McDonald, D., Meagher, G. A., & Parmenter, B. (1994). Forecasting for the Australian economy using the MONASH model. *International Journal of Forecasting*, 10, 181-189.

Adams, P., Parmenter, B. & Horridge, J. (2000a). MMRF-GREEN: A dynamic, multi-sectoral multi-regional model of Australia. *Centre Working Papers,* Op-94, Centre of Policy Studies/IMPACT Project, Monash University, Melbourne.

Adams, P., Parmenter, B., & Horridge, J. (2000b). Analysis of greenhouse policy using MMRF-Green. *Centre Working Papers,* Centre of Policy Studies, Monash University, Melbourne.

Adams, P. D. (2007). Insurance against catastrophic climate change: How much will an emissions trading scheme cost Australia?. *Australian Economic Review,* 40(4), 432-52.

Adams, P. D., Dixon, J., Gieseke, J., & Horridge, J. M. (2010). MMRF: Monash multi-regional forecasting model: A dynamic multi-regional applied general equilibrium model of the Australian economy. *General Working Paper,* G-223, Centre of Policy Studies, Monash University, Melbourne.

Ahammad, H., & Mi, R. (2005). Land use change modelling in GTEM - Accounting for forest sinks. *ABARE Conference Paper,* 05.13, Australian Bureau of Agricultural and Resource Economics, Canberra.

Al-Amin, Siwar, C., & Hamid, A. (2009). Computable general equilibrium techniques for carbon tax modeling. *American Journal of Environmental Sciences,* 5(3), 330-340.

Alaouze, C. M. (1977). Estimates of the elasticity of substitution between imported and domestically produced goods classified at the input-output level of aggregation.

IMPACT Working Paper, No O-13, mimeo, p 33, Avaialble from Industries Assistance Commission, Canberra.
Alaouze, C. M., Marsden, J. S., & Zeitsch, J. (1977). Estimates of the elasticity of substitution between imported and domestically produced commodities at the four digit ASIC level. *IMPACT Working Paper,* No O-11, mimeo, p 66, Available from Industries Assistance Commission, Canberra.
Alarcon, J., van Heemst, J., & de Jong, N. (2000). Extending the SAM with social and environmental indicators: An application to Bolivia. *Economic Systems Research,* 12(4), 473-496.
Anderson, K., & Blackhurst, R. (1992). *The greening of world trade issues*. Harvester Wheatsheaf, University of Michigan Press.
Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review*, 91(4), 877-908.
Armington, P. S. (1970). Adjustment of trade balances: some experiments with a model of trade among many countries. *IMF Staff Papers*, XVII(November), 488-523.
Arndt, C. (1996). An introduction to systematic sensitivity analysis via Gaussian Quadrature, *Tech. Rep.* 305, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University.
Arrow, K. J. (2005). Personal reflections on applied general equilibrium models. In T.J. Kohoe, T.N. Srinivasan and J.Whalley (Eds.), *Frontiers in Applied General Equilibrium Models*, in honour of Herbert Scarf, Cambridge, Cambridge University Press.
Asafu-Adjaye, J. (2004). A dynamic CGE model of the Australian economy: A simulation of the impacts of environmental policies. *International Journal of Applied Economics & Econometrics*, 12, 317-336.
Atkinson, A. B. (1998). *Poverty in Europe*. Oxford, Blackwell.
Australian Government. (2004). *Energy white paper: Securing Australia's energy future*. Australian Government, Canberra.
Australian Government. (2006). *Uranium mining, processing and nuclear energy: Opportunities for Australia?, Report to the Prime Minister by the uranium mining, processing and nuclear energy task force, December 2006*. Commonwealth of Australia, Canberra.
Australian Government. (2007). *Prime Ministerial task group on emissions trading: Report of the task group on emisisons trading*. Commonwealth of Australia, Canberra.
Australian Government. (2008a). *Australia's low pollution future: The economics of climate change mitigation*. Commonwealth of Australia, Canberra.
Australian Government. (2008b). *Carbon pollution reduction scheme Green paper*. Commonwealth of Australia, Canberra.
Australian Government. (2008c). *Carbon pollution reduction scheme White paper*. Commonwealth of Australia, Canberra.
Australian Government. (2011a). *Strong growth, low Pollution: Modelling a carbon price*. Commonwealth of Australia, Canberra.
Australian Government. (2011b). *Strong growth, low pollution: Modelling a carbon price - Update*. Commonwealth of Australia, Canberra.
Australian Government. (2011c). *Clean energy Act 2011*. An Act to encourage the use of clean energy, and for other purposes, ComLaw Authoritative Act, C2011A00131, downloadable from http://wwwcomlaw/gov/au/.
Babiker, M. H., Maskus, K. E., & Rutherford, T. F. (1997). Carbon taxes and the global trading system. *Working Paper*, 97-7, University of Colorado, Boulder.

Bataille, C. (1998). *Capital for energy and inter-fuel elasticities of substitution from a technology simulation model: Estimating the cost of greenhouse gas reduction.* Masters Thesis, Simon Fraser University.

Baumal, W. J., & Oates, W. E. (1988). *The theory of environmental policy, 2nd edition*. Cambridge, Cambridge University Press.

BCA (Business Council of Australia) (2006). Address to the BCA 2006 annual dinner by hon. John Howard, MP, Prime Minister of Australia, *BCA Transcript*, 1-6.

Beghin, J., Roland-Holst, D., & van der Mensbrugghe. (1997). *Trade and environment: Six country case studies from the Pacific basin*. Cambridge, Cambridge University Press.

Bergman, L. (1988). Energy policy modelling: A survey of general equilibrium approaches. *Journal of Policy Modeling*, 10(3), 377-399.

Bergman, L. (1990). Energy and environmental constraints on growth: A CGE modeling approach. *Journal of Policy Modeling*, 12(4), 377-399.

Bergman, L. (1991). General equilibrium effects of environmental policy: A CGE modeling approach. *Environmental and Resource Economics*, 1, 43-61.

Bohringer, C., Conrad, K., & Loschel, A. (2003). Carbon taxes and joint implementation: An applied general equilibrium analysis for Germany and India. *Environmental and Resource Economics,* 24, 49-76.

Bohringer, C., & Pahlke, A. (1997). Environmental tax reforms and the prospects for a double dividend - An intertemporal general equilibrium analysis for Germany. *Working Paper*, University of Colorado, Boulder.

Bosello, F., Carraro, C. & Galeotti, M. (2001). The double dividend issue: Modeling strategies and empirical findings, *Environmental and Development Economics*, 6, 9-45.

Bovenberg, L.(1995). Environmental taxation and employment. *De Economist*, 143, 111-140.

Bovenberg, L., & Goulder, L. (1996). Optimal environmental taxation in the presence of other taxes: General equilibrium analysis. *American Economic Review*, 86, 985-1000.

Bovenberg, L., & Goulder, L. (1998). Enviornmental taxation and the double divident. *Emprica*, 25, 15-135.

Bovenberg, L., & Goulder, L. (1999). Green tax reforms and the double dividend: An updated reader's guide. *Economic Journal*, 104, 444-454.

Boyd, R., Krutilla, K., & Viscusi, W. K. (1995). Energy taxation as a policy instrument to reduce CO_2 emissions: A net benefit analysis. *Journal of Environmental Economics and Management,* 29(1), 1-24.

Burniaux, J. M., Nicoletti, G., & Oliveira-Martins, J. (1992). GREEN: A global model for quantifying the costs of policies to curb CO_2 emissions. *OECD Economic Studies,* 19(Winter), 49-92.

Burniaux, J. M., & Truong, T. P. (2002). GTAP-E: An energy-environmental version of the GTAP model. *GTAP Technical Paper,* 16.

CAIT-UNFCCC. (2008). *Climate analysis indicators tool*, *Version 8*, World Resource Insitutue, www.cait.wri.org/

Centeno, M. L., (2001). *Economic policies and forest conservation in the Philippines: A computable general equilibrium approach.* PhD Thesis, University of New England.

Christoff, P.(2008). Policy autism or double-edged dismissiveness? Australia's climate policy under the Howard government. *Global Change, Peace and Security,* 17(1), 29-44.

Codsi, G. & Pearson, K. (1988), 'GEMPACK: A General Purpose Software for Applied General Equilibrium and Other Economic Modellers', *Computer Science in Economics and Management,*1, 189-20.

Conrad, K. (1999). Computable general equilibrium models for environmental economics and policy analysis. In J.C.J.M van de Bergh, (Eds.), *Handbook of Environmental and Resource Economics,* Edward Elgar, Cheltenham,1061-1087.

Conrad, K., & Henseler-Unger, I. (1986). Applied general equilibrium modeling for long-term energy policy in the federal republic of Germany. *Journal of Policy Modeling,* 8(4), 531-549.

Conrad, K., & Schroder, M. (1991). An evaluation of taxes on air pollutants emissions: An applied general equilibrium approach. *Swiss Journal of Economics and Statistics,* 127(2), 199-224.

Cordon, W. M. (1997). *Trade policy and economic welfare, Second edition*. Oxford, Clarendon Press.

Cornwell, A., & Creedy, J. (1997). Measuring the welfare effects of tax changes using the LES: An application to a carbon tax. *Empirical Economics*, 22, 589-613.

Cruz, W., & Repetto, R. (1992). *The environmental effects of stabilization and structural adjustment programs: The Philippines case.* World Resource Institute, Washington, DC.

DCCEE (Department of Climate Change and Energy Efficiency). (2005). *National greenhouse gas inventory (NGGI)*. Australian Govenrment, Canberra.

DCCEE. (2008). *Australia's national greenhouse gas inventory*. Australian Government, Canberra.

DCCEE. (2010). *Australia's emissions projections*. Australian Government, Canberra.

Dee, P. S. (1989). FH-ORANI: A fiscal ORANI with Horridge extension. *IMPACT Preliminary Working Paper*, OP-66, University of Melbourn: Melbourn.

Dervis, K., De Melo, J., & Robinson, S. (1982). *General equilibrium models for development policy*. New York, Cambridge University Press.

Dessus, S., & O'Connor, D. (2003). Climate policy without tears: CGE based ancillary benefits estimates for Chile. *Environmental and Resource Economics*, 25, 287-317.

Devarajan, S., Go, D. S., Robinson, S., & Thierfelder, K. (2009). Tax policy to reduce carbon emissions in South Africa. *Policy Research Working Paper,* 4933 (May).

Devarajan, S., Go, D. S., Robinson, S., & Thierfelder, K. (2011). Tax policy to reduce carbon emissions in a distorted economy: Illustrations from a South Africa CGE model. *The B.E. Journal of Economic Analysis and Policy*, 11(1), 1-22.

Dixon, P. B., Parmenter, B. R., Ryland, G. J., & Sutton, J. M. (1977). *ORANI, a general equilibrium model of the Australian economy: Current specification and illustrations of use for policy analysis, First Progress Report of the IMPACT Project*. Vol. 2, Australian Government Publishing Services, Canberra.

Dixon, P. B., Parmenter, B. R., Sutton, J., & Vincent, D. P. (1982). ORANI: A multisectoral model of the Australian economy. In Jorgenson, D.W. and Waelbroeck, J.W (Eds.), *Contributions to Economic analysis,* Amsterdam, North-Holland.

Dixon, P. B., Parmenter, B. R., & Powell, A. A. (1992). *Notes and problems in applied general equilibrium economics*. Amsterdam, North-Holland.

Dixon, P. B., Parmenter, B. R., Sutton, J., & Vincent, D. P. (1997). *ORANI: A multisectoral model of the Australian economy*. Amsterdam, North-Holland.

Fisher, B. (1999). The economic impacts of the Kyoto Protocol. *ABARE Conference Paper,* 99.14.

Forsund, F. R., & Storm, S. (1988). *Environmental economics and management: Pollution and natural resources*. Croom Helm, London.

Friedman, M. (1957). *A theory of the consumption function*: Princeton University Press.

Garnaut, R. (2008a). *The Garnaut climate change review, Final report*. Cambridge, Cambridge University Press.

Garnaut, R. (2008b). *Emisisons trading scheme,* Discussion Paper, 20 March, Garnaut Climate Change Review, Canberra.

Garnaut, R. (2011). *The Garnaut review 2011 Australia in the global response to climate change*. Cambridge, Cambridge University Press.

Geoscience Australia. (2010). *Australian Energy Resource Assesment*. ABARE, Canberra.
Ginsburgh, V., & Keyzer, M. (1997). *The structure of applied general equilibrium models*. Massachusetts, MIT Press Cambridge.
Glomsrod, S., Vennemo, H., & Johnsen, T. (1992). Stabilization of emissions of CO_2: A computable general equilibrium assesment. *Scandinavian Journal of Economics*, 94(1), 53-69.
Goulder, L.H. (1995). Environmental taxation and the ‘double dividend’: A readers guide. *International Tax and Public Financce*, 2, 157-184.
Hamilton, C., & Quiggin, J. (1997). Economic analysis of greenhouse policy: A layperson's guide to the perils of economic modelling. *Discussion Paper*, The Australia Institute, No 15.
Hamilton, K., & Cameron, G. (1994). Simulating the distributional effects of a Canadian carbon tax. *Canadian Public Policy*, 20(4), 385-399.
Hertal, T. W. (1997). *Global trade analysis: Modeling and applications*. New York and Melbourn, Cambridge University Press.
Horridge, J. M. (2000). ORANI-G: A General equilibrium model of the Australian economy. *IMPACT Centre Working Papers,* op-93, Centre of Policy Studies, Monash University.
Horridge, J. M. (2002). Preparation of a CGE data base from the 1996-97 Australian input-output tabels. *Centre of Policy Studies Archive*, DPMH0037, Monash University.
Horridge, J. M. (2003). ORANI-G: A generic single-country computable general equilibirum model. *Centre of Policy Studies, prepared for the practicle GE modelling course,* Monash University.
Hudson, E., & Jorgenson, D.W. (1977). *The long-term interindustry transactions model: A simulation model for energy and economic analysis*: Cambridge, Mass: Data Resources, Inc.
Hudson, E., & Jorgenson, D. W. (1974). US energy policy and economic growth, 1975-2000. *Bell Journal of Economics and Management Science,* 5(2), 461-514.
IBISWorld. (2010). *Australian industry reports*. Retrieved from www.ibisworld.come.au on 13/08/2010.
IEA (International Energy Agency). (2008). *CO_2 emissions from fuel combustion*, IEA, Paris.
IEA. (2009). *World energy outlook 2009*, IEA, Paris.
IPCC (Intergovernmental Panel on Climate Change). (2007a). Climate change 2007: Impacts, adaptation, and vulnerability. In M. Parry, O. Canziani, J. Palutikof, Can Der Linden & C. Hanson (Eds.). *Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change.*Cambridge, Cambridge University Press.
IPCC. (2007b). Climate Change 2007: The physical science basis. In S. Solomon, D. Qin, M. Manning, Z. Chen, K. B. Marquis, M. Averyt, M. Tignor & H. L. Miller (Eds.). *Contribution of working group I to the fourth assesment report of the intergovernmental panel on climate change.* Cambridge and New York, Cambridge University Press.
Jaffar, Hamid, A., Al-Amin, Quasem, A., & Siwar, C. (2008). A CGE analysis of the economic impact of output-specific carbon tax on the Malaysian economy. *Munich Personal RePEc Archive*, 10210.
Johansen, L. (1974). *A multi-sectoral study of economic growth*. Amsterdam, North-Holland.
Johansen, L. (1960). *A multisectoral study of economic growth (2nd edition)*. Amsterdam, North Holland.
Jorgenson, D. W. (1984). Econometric methods for applied general equilibrium analysis. In H. Scarf, J.Shoven, (eds) *Applied General Equilibrium Analysis*, pp.139-203. Cambridge, Cambridge University Press.

Jorgenson, D. W., & Wilcoxen, P. J. (1990). Intertemporal general equilibrium modelling of US environmental regulation. *Journal of Policy Modeling*, 12(4), 715-744.

Jotzo, F. (2010). Comparing the Copenhagen climate targets, *CCEP Working Paper*, 1-10, Centre for Climate Economics and Policy, Crawford School of Economics and Government, Australian National University, Canberra.

Kennedy, D., Brown, S., Lim, J., & Fisher, B. (1998a). Impacts of the Kyoto Protocol on the Australian mining and metallurgy industries. *ABARE Conference Paper*, 98.20.

Kennedy, D., Polidano, C., Lim, J., & Fisher, B. (1998b). Climate change policy and the economic impacts of the Kyoto Protocol. *ABARE Conference Paper*, 98.23.

Keuning, S. J., & Ruijter, W. A. (1988). Guildlines to the construction of a social accounting matrix. *The Review of Income and Wealth*, 34(1), 71-101.

Keuning, S. J. (1994). The SAM and beyond: Open SESAME!. *Economic Systems Research*, 6(1), 21-50.

Khan, A. H. (1989). The two-level CES production function for the manufacturing sector of Pakistan. *The Pakistan Development Review*, 28(1,Spring), 1-12.

King, B. B. (1985). What is a SAM? In Pyatt G.G and Round J.I. (Eds.), *Social Accounting Matrices: A Basis for Planning*,World Bank, Washington DC.

Klein, L. R., & Rubin, H. (1948-49). A constant utility index of the cost of living. *Review of Economic Studies*, 15, 84-87.

Labandeira, X., Labeaga, J. M., & Rodriguez, M. (2004). Green tax reforms in Spain. *European Environment*, 14, 290-299.

Lee, D., & Misiolek, W. (1986). Substituting pollution taxation for general taxation: Some implications for efficiency in pollution taxation. *Journal of Environmental Economics and Management*, 13, 338-347.

Lee, H., Oliveira-Martins, J., & van der Mensbrugghe, D. (1994). The OECD GREEN model: An updated overview. *Technical Paper*, No.97, OECD Development Centre.

Lenzen, M., & Schaeffer, R. (2004). Environmental and social accounting for Brazil. *Environmental and Resource Economics*, 27, 201-226.

Leontief, W. (1970). Enviornmental repercussions and the economic structure: An input-output approach. *Review of Economics and Statistics*, 52(3), 262-271.

Li, J. C. (2005). Is There a trade-off between trade liberalization and environmental quality? A CGE assesment on Thailand. *Journal of Environmenta and Development*, 14(2), 252-277.

Lluch, C. Powell, A. & Williams R. (1977). *Patterns in household demand and savings*. Oxford, Oxford University Press.

Machando, G., Schaeffer, R., & Worrel, E. (2001). Energy and carbon embodied in the international trade of Brazil: An input-output approach. *Ecological Economics*, 39(3), 409-424.

Manne, A. (1994). Global 2100: Alternative scenarios for reducing carbon emissions. *Working Paper* No.111, Stanford University.

Manne, A. S., & Richels, R. G. (1994). The costs of stabilizing global CO_2 emissions: A probabilistic analysis based on expert judgements. *The Energy Journal*, 15(1), 31-56.

Manne, A. S., Mendelsohn, R., & Richels, R. (1995). MERGE: A model for evaluating regional and global effects of GHG reduction policies. *Energy Policy*, 23, 17-34.

Martin, W. J. (1989). *Textiles and the foreign exchange regime*. Paper presented at the Textile and Clothing Conference Organized by Australian-Japan Research Centre, Australian National University,Canberra 7-8 August.

McDougall, R. A. (1993a). Short-run effects of a carbon tax. *General paper*, No G-100, Centre of Policy Studies, , Monash University.

McDougall, R. A. (1993b). Energy taxes and greenhouse gas emissions in Australia. *General paper*, No G-104, Centre of Policy Studies, Monash Univeristy.

McKibbin, W. (1997). Greenhouse abatement policy: Insights from the G-Cubed multi-country model. *The Australian Journal of Agricultural and Resource Economics*, 42(1), 99-113.

McKibbin, W., & Wilcoxen, P. (1992). G-Cubed: A dynamic multi-sector general equilibrium growth model of the global economy (Qunatifying the costs of curbing CO_2 emissions). *Brooking Discussion Paper in International Economics,* No 98, Brookings Institution, Washington, DC.

McKibbin, W., & Wilcoxen, P. (1995). The theoritical and empirical structure of the G-Cubed model. *Brooking Discussion Paper in International Economics,* No 118, Brookings Institution, Washington, DC.

McKibbin, W. J., & Wilcoxen, P. J. (2007). Managing price and targets: Why a hybrid policy is better for Australia. *Growth*, 59 (Nov), 76-85.

McKitrick, R. (1997). Double dividend enviornmental taxation and Canadian carbon emissions control. *Canadian Public Policy*, 23(4), 417-434.

Morilla, C. R., Diaz-Salazar, G. L., & Cardenete, M. A. (2007). Economic and environmental efficiency using a social accounting matrix. *Ecological Economics*, 60, 774-786.

Naranpanawa, A.K. (2005). *Trade liberalisation and poverty in a computable general equilibrium (CGE) model: The Sri Lankan case.* PhD Thesis, Griffith University.

Nordhaus, W. D. (1992). The "DICE" model: Backgroud and structure of a dynamic integrated climate-economy model of the economics of global warming. *Cowles Foundation Discussion Paper*, No. 1009. New Haven, Yale University.

Nordhaus, W. D. (1994). Rolling the DICE: An optimal transition path for controlling greenhouse gases. *Resource and Energy Economics*, 15, 27-50.

O'Connor, R., & Henry, E. W. (1975). *Input-output analysis and its applications*. London, Charles Griffin & Company Ltd.

Oladosu, G., & Rose, A. (2002). Greenhouse gas reduction policy in the United States: Identifying winners and loosers in an expanded permit trading system. *The Energy Journal*, 23(1), 1-17.

Oladosu, G., & Rose, A. (2007). Income distribution impacts of climate change mitigation policy in the Susquehanna river basin economy. *Energy Economics*, 29(1), 520-544.

Owen, A. (2006). Nuclear power for Australia? *Agenda*, 13(3), 195-210.

Pang, F., Meagher, G. A., & Lim, G. C. (2007). *An aggregated social accounting matrix for the Australian economy: Data sources and methods*. Paper presented at the Growth, Distribution and Social Accounting Matrices, Korean National Statistical Office, Daejeon, South Korea.

Pant, H. (2007). GTEM: Global trade and environment model. *ABARE Technical Report*, ABARE, Canberra, June.

Parry, I. W. H. (1995). Pollution taxes and revenue recycling. *Journal of Environmental Economics and Management*, 29 (S64-S77).

Parry, I. W. H., & Goulder, L. (1999). When can carbon abatement policies increase welfare? The fundemental role of factor markets. *Journal of Environmental Economics and Management*, 37, 52-84.

Pearson, K., & Arndt (2000). Implemeting systematic sensitivity analysis using GEMPACK, *GTAP Technical papers*. 474, Center for Global Trade Analysis, Department of Agricultural Economics, Purdue University.

Perroni, C., & Rutherford, T. F. (1993). International trade in carbon emission rights and basic materials: General equilibrium calculations for 2020. *Scandinavian Journal of Economics*, 95(3), 257-278.

Persson, A., & Munasinghe, M. (1995). Natural resource management and economywide policies in Costa Rica: A computable general equilibrium (CGE) modeling approach. *The World Bank Economic Review*, 9(2), 259-285.

Pezzey, J. (1992). The symmetry between controlling pollution by price and controlling It by quantity. *The Canadian Journal of Economics*, 25(4), 983-991.

Powel, A. A., & Snape, R. H. (1993). The contribution of applied general equilibrium analysis to policy reform in Australia. *Working Paper no G*-98, Centre of Policy Studies, IMPACT Centre.

Powell, A. A., & Lawson, T. (1990). *A decade of applied general equilibrium modelling*. Oxford, Basil Blackwell.

Pyatt, G. (1985). Commodity balances and national accounts: A SAM perspective. *Review of Income and Wealth Series*, 31(1), 155-169.

Pyatt, G. (1988). A SAM approach to modeling. *Journal of Policy Modeling*, 10(3), 327-352.

Pyatt, G. (1991a). Fundamentals of social accounting. *Economic Systems Research*, 3(3), 315-341.

Pyatt, G. (1991b). SAMs, The SNA and national accounting capabilities. *Review of Income and Wealth* 1(17), 177-198.

Pyatt, G., & Roe, A. R. (1977). *Social Accounting for development planning with special references to Sri Lanka*. Cambridge, Cambridge University Press.

Pyatt, G., & Round, J. (1977). Social accounting matrices for development planning. *Review of Income and Wealth*, 23(4), 339-364.

Pyatt, G., & Round, J. (1979). Accounting and fixed price muliplìers in a social accounting matrix framework. *The Economic Journal*, 89(356), 850-873.

Pyatt, G., & Round, J. (1985). *Social accounting matrices: A basis for planning*. Washington DC, World Bank.

Pyatt, G., & Thorbecke, E. (1976). *Planning techniques for a better future*. ILO, Geneva.

Reinert, K. A., & Roland-Holst, D. W. (1997). Social accounting matrices. In J.F. Francois and K.A. Reinert, *Applied Methods for Trade Policy Analysis: A Handbook*, Cambridge, Cambridge University Press.

Resosudarmo, B. P., & Thorbecke, E. (1996). The impact of environmental policies on household incomes for different socio-economic classes: The case of air pollution in Indonesia. *Ecological Economics*, 17, 83-94.

Robinson, S. (1988). *Multisectoral models* (Vol. 2). Amsterdam, North Holland.

Rose, A., & Oladosu, G. (2002). Greenhosue gas reduction policy in the United States: Identifying winners and losers in an expanded permit trading system. *The Energy Journal*, 23(1), 1-18.

Rose, A., & Stevens, B. (2001). An economic analysis of flexibile permit trading in the Kyoto Protocol. *International Environmental Agreements*, 1(2), 219-242.

Round, J. (2003). Constructing SAMs for development policy analysis: Lessons learned and challenges ahead. *Economic Systems Research*, 15, 161-183.

Rutherford, T. F., Montgomery, W. D., & Bernstein, P. M. (1997). CETM: A dynamic general equilibrium model of global energy market, carbon dioxide emissions and international trade. *Working Paper*, 97-3, University of Colorado, Boulder.

Schob, R. (1997). Environmental taxes and pre-existing distortion: The normalization trap. *International Tax and Public Finance*, 4, 167-176.

Shoven, J. B., & Whalley, J. (1972). A general equilibrium calculation of the effects of differential taxation from income from capital in the US. *Journal of Public Economics*, *1*, 281-322.

Shoven, J. B., & Whalley, J. (1984). Applied general equilibrium models of taxation and internaitonal trade: An introduction and survey. *Journal of Economic Literature*, 22, 1007-1051.

SNA, (1993). *System of national accounts and supporting tables*. Series F, No 2, Rev 4, United Nations, New York.

Stern, N. (2006). *The economics of climate change: The Stern review*. Cambridge, Cambridge University Press.

Stone, R. (1961). *Input-output and national accounts*. Organisation for the Economic Co-operation and Development (OECD), Paris, France.

Strutt, A., & Anderson, K. (2000). Will trade liberalization harm the environment? The case of Indonesia to 2020. *Environmental and Resource Economics*, 17, 203-232.

Taylor, L. (1990). *Socially relevant policy analysis, structuralist CGE models for the developing world*. Cambridge, MIT Press.

Telli, C., Voyvoda, E., & Yeldan, E. (2008). Economics of environmental policy in Turkey: A general equilibrium investigation of the economic evaluation of sectoral emission reduction policies of climate change. *Journal of Policy Modeling*, 30, 321-340.

Thorbecke, E. (2003). Towards a stochastic social accounting matrix for modelling. *Economic Systems Research*, 15, 155-196.

UNFCCC. (1992). United nations framework convention on climate change. http://unfccc.int/essential_background/convention/background/items/1349.php

UNFCCC. (1998). Kyoto Protocol to the united nations framework convention on climate change. http://unfccc.int/key_documents/kyoto_protocol/items/6445.php

Vennemo, H. (1997). A dynamic applied general equilibrium model with environmental feedbacks. *Economic Modelling*, 14(1), 99-154.

Vincent, D. P.(1990). Applied general equilibrium modelling in the Australian industries assistance commision: Perspective of a policy analyst. In Lars Begman, Dale W. Jorgenson and Erno Zalai (Eds). *General Equilibrium Modeling and Economic Policy Analysis*. Oxford, Basil Blackwell.

Weale, M. (1997). Environmental statistics and the national accounts. In P. Dasgupta and K.-G. Maler, (Eds.), *The Enviornmental and Emerging Development Issues*. Oxford, Clarendon Press.

Wing, S. I. (2004). *Computable general equilibrium models and their use in economy-wide policy analysis*: MIT Joint Program on the Science and Policy Global Change, Technical Note 6, Cambridge, Massachusetts.

Wissema, W., & Dellink, R. (2007). AGE analysis of the impact of a carbon energy tax on the Irish economy. *Ecological Economics*, 61, 671-683.

Xie, J. (2000). An environmentally extended social accounting matrix: Conceptual framework and application to environmental policy analysis in China. *Environmental and Resource Economics*, 16, 391-406.

Xie, J., & Saltzman, S. (2000). Environmental policy analysis: An environmental computable general-equilibrium approach for developing countries. *Journal of Policy Modeling,* 22(4), 453-489.

Yates, J., Randolph, B. & Holloway, D. (2006). Housing affordability, occupation in Australian cities and regions. *AHURI Final Report*, No. 91, Prepared for the Australian Housing and Urban Research Institute.

Yusuf, A.A. (2007). *Equity and environmental policy in Indonesia.* PhD Thesis, Australian National University.

Yusuf, A. A., & Resosudarmo, B. P. (2007). On the distributional effect of carbon tax in developing countries: The case of Indonesia. *Working Paper in Economics and Development Studies*,200605, Department of Economics, Padjadjaran Universtiy.

Zavkiew, Z. (2005). Constructing a 2001 social accounting matrix of Tajukistan. *CAMA Working Paper Series,* 20/2005, Paper Presented at the Australian National University.

Zhang, Z. (1998). Macro-economic and sectoral effects of carbon taxes: A general equilibrium analysis for China. *Economic Systems Research,* 10(2), 135-159.

Appendices

Appendix A Equation system in the model

Demands for inputs used in current production (general form)

In the process of conversion of inputs into outputs the model assumes that producers are competitive and efficient. In a competitive and efficient market, producers treat all input prices as exogenously given and choose input combinations to minimise cost at any given level of output. The derivation of a generalised input demand functions under cost minimisation problem can be shown as follows.

The cost minimisation problem is to choose, inputs $X_i, i = 1, \dots .n,$ to minimise cost,

$$C = \sum_i P_i \mathrm{X_i} \qquad \text{(A5.1)}$$

subject to a Constant Elasticity of Substitution (CES) production function

$$Y = \mathrm{A}\left[\sum_i \delta_i X_i^{-\rho}\right]^{-1/\rho} \qquad \text{(A5.2)}$$

The constrained optimization of this problem can be written as a Lagrangian function, which is;

$$Z = \sum_I P_i X_i + \Lambda Y - \mathrm{A}\left[\sum_i \delta_i X_i^{-\rho}\right]^{-1/\rho} \qquad \text{(A5.3)}$$

The first order conditions are,

$$\frac{\partial Z}{\partial X_i} = P_i - \delta_1 \mathrm{X_i}^{-(\rho+1)}.\Lambda\left[Y - A\left[\delta_i X_i^{-\rho}\right]^{-(1+\rho)/\rho}\right] = 0 \qquad \text{(A5.4)}$$

and

$$\frac{\partial Z}{\partial X_k} = P_k - \delta_k \mathrm{X_k}^{-(\rho+1)}.\Lambda\left[Y - A\left[\delta_k X_k^{-\rho}\right]^{-(1+\rho)/\rho}\right] = 0 \quad where\ k = 1, \dots \mathrm{n} \qquad \text{(A5.5)}$$

$$\frac{P_k}{P_i} = \frac{\delta_k \mathrm{X_k}^{-(\rho+1)}}{\delta_i \mathrm{X_i}^{-(\rho+1)}} \qquad \text{(A5.5.1)}$$

$$\frac{P_k}{P_i} = \frac{\delta_k \mathrm{X_i}^{(\rho+1)}}{\delta_i \mathrm{X_k}^{(\rho+1)}} \qquad \text{(A5.5.2)}$$

Hence, $X_i^{-\rho} = \left(\frac{\delta_i P_k}{\delta_k P_i}\right)^{-\rho/(1+\rho)} \mathrm{X_k^{-\rho}}$

Substitute this above expression in the production function to obtain

$$Y = A\left[\delta_i \left(\frac{\delta_i P_k}{\delta_k P_i}\right)^{-\rho/(1+\rho)} \mathrm{X_k^{-\rho}} + \delta_k X_k^{-\rho}\right]^{-1/\rho} \qquad \text{(A5.6)}$$

$$Y = A\left[\sum_i \delta_i \left(\frac{\delta_k P_i}{\delta_i P_k}\right)^{\rho/(1+\rho)}\right]^{-1/\rho} . X_k \qquad \text{(A5.7)}$$

Finally derive the input demand function of X_k have the form,

$$X_k = Y \frac{1}{A}\left[\sum_i \delta_i \left(\frac{\delta_k P_i}{\delta_i P_k}\right)^{\rho/(1+\rho)}\right]^{1/\rho} \qquad \text{(A5.8)}$$

That is

$$X_k = Y\left(\frac{1}{A}\right) \delta_k^{1/(1+\rho)} P_k^{-(1/(1+\rho))}\left[\sum_i \delta_i^{1/(1+\rho)}\ P_i^{(\rho/(1+\rho))}\right]^{1/\rho} \qquad \text{(A5.9)}$$

Logarithmic differentiation of the function

$$\frac{dX_k}{X_k} = \frac{dY}{Y} - \frac{1}{1+\rho}\frac{dP_k}{P_k} + \frac{\frac{1}{\rho}\left(\sum_i \delta_i^{1/1+\rho}\frac{\rho}{1+\rho}P_i^{\frac{\rho}{1+\rho}-1}dP_i\right)\times\left[\sum_k \delta_k^{1/1+\rho}P_k^{\rho/1+\rho}\right]^{\frac{1}{\rho}-1}}{\left[\sum_k \delta_k^{1/1+\rho}P_k^{\rho/1+\rho}\right]^{1/\rho}} \quad \text{(A5.10)}$$

Where $\frac{dX_k}{X_k} = x_k$, $\frac{dY}{Y} = y$ and $\frac{dP_i}{P_i} = p_i$

So that,

$$x_k = y - \left(\frac{1}{1+\rho}\right)p_k + \frac{\frac{1}{\rho}\left(\sum_i \delta_i^{1/1+\rho}\frac{\rho}{1+\rho}P_i^{\rho/1+\rho}p_i\right)}{\sum_k \delta_k^{1/1+\rho}P_k^{\rho/1+\rho}} \quad \text{(A5.11)}$$

$$x_k = y - \left(\frac{1}{1+\rho}\right)p_k + \frac{1}{\rho}\sum_i \frac{\delta_i^{1/1+\rho}P_i^{\rho/1+\rho}}{\sum_k \delta_k^{1/1+\rho}P_k^{\rho/1+\rho}} \times \frac{\rho}{1+\rho}p_i \quad \text{(A5.12)}$$

where

$S_i = \left(\delta_i^{1/(1+\rho)}P_i^{\rho/(1+\rho)}\right)/\left[\sum_k \delta_k^{1/(1+\rho)}P_k^{\rho/(1+\rho)}\right]$ and $\sigma = \left(\frac{1}{1+\rho}\right)$

Thus,

$$x_k = y - \sigma p_k + \sum_i S_i \times \sigma p_i \quad \text{(A5.13)}$$

$$x_k = y - \sigma(p_{k-} \sum_i S_i\, p_i) \quad \text{(A5.14)}$$

and if define $p_{ave} = \sum_i S_i\, p_i$

$$x_k = y - \sigma(p_k - p_{ave}) \quad \text{(A5.15)}$$

The economic interpretation of the above equation states that the percentage change in the use of input *k* is proportional to the percentage change in output and to a price term.

Appendix B Tablo code excerpts

Dimensions of the model

The commodity, industry, occupation, household classifications of the A3E-G model described is given in the Excerpt 5.1. There are 35 industries and commodities which are named as IND and COM in the SET statements. Subsets of commodities are named as GCOM, COAL, OILG, PETR, and ELEC. ElCG is a subset of GCOM. These elements of the commodities derive from two sources, domestic and import which are given under SRC statement. Labour category is disaggregated into 8 domestic skill-based occupations and is given in the set OCCD. OCCD is a subset of OCC. Set OCC contains additional foreign employment group. There are 10 household groups and are described by the set HOU.

Excerpt 5.1 Definition of sets and subsets in the model

```
Set                                                                     !Index!
COM # Commodities# read elements from file BASEDATA header "COM"(agricind,blcoal,brcoal,
oil,gas,alminig,fodbvtbac,txtlhr,wdprprt,autoptrl,keroptrl,lgasptrl,otherptrl,allchem,nonmetal,cmtconc
t,iornsteel,allmetal,allmanufc,elcblcoal,elcbrcoal,elcoil,elcgas,elcenew,cmelecsup,gassup,watersup,con
stserv,tradeserv,acmcafe,roadtrans,othrtrans,albuserv,alpubserv,alothserv);  ! c !
SRC # Source of commodities # (dom,imp);   ! s !
IND # Industries # read elements from file BASEDATA header "IND" (agricind,blcoal,brcoal,
oil,gas,alminig,fodbvtbac,txtlhr,wdprprt,autoptrl,keroptrl,lgasptrl,otherptrl,allchem,nonmetal,cmtconc
t,iornsteel,allmetal,allmanufc,elcblcoal,elcbrcoal,elcoil,elcgas,elcenew,cmelecsup,gassup,watersup,con
stserv,tradeserv,acmcafe,roadtrans,othrtrans,albuserv,alpubserv,alothserv);! i !
OCC # Occupations # read elements from file BASEDATA header "OCC" (MangAdm,Prfesonl,
AsPrfesonl,TradRelate,AdClrical,IntClrical,IntProd,EleClrical,LabourRelate,Foreing);  ! o !
set OCCD #domestic occupation# read elements from file basedata header "OCCD" (MangAdm,
Prfesonl,AsPrfesonl,TradRelate,AdClrical,IntClrical,IntProd,EleClrical,LabourRelate);
HOU # Households # read elements from file BASEDATA header
"HOU"(Decile1,Decile2,Decile3,Decile4,Decile5,Decile6,Decile7,Decile8,Decile9,Decile10);
GCOM # non energy commodities # read elements from file BASEDATA header
"GCOM"(agricind,alminig,fodbvtbac,txtlhr,wdprprt,allchem,nonmetal,cmtconct,iornsteel,allmetal,allmanuf
c,elcblcoal,elcbrcoal,elcoil,elcgas,elcenew,gassup,
watersup,constserv,tradeserv,acmcafe,roadtrans,othrtrans,albuserv,alpubserv,alothserv);
COAL # black and brown coal # read elements from file BASEDATA header "COAL"(blcoal,brcoal);
OILG # oil and gas commodities# read elements from file BASEDATA header "OILG"(oil,gas);
PETR # petroleum commodities# read elements from file BASEDATA header
"PETR"(autoptrl,keroptrl,lgasptrl,otherptrl);
ELEC # electricity commodities# read elements from file BASEDATA header "ELEC"(cmelecsup);
ELCG # electricity generating# read elements from file BASEDATA header
"ELCG"(elcblcoal,elcbrcoal,elcoil,elcgas,elcenew);
GNCOM # non-electricity general commodities # =GCOM-ELCG;
subset
GCOM is subset of COM;
COAL is subset of COM;
OILG is subset of COM;
PETR is subset of COM;
ELEC is subset of COM;
ELCG is subset of GCOM;
OCCD is subset of OCC;
```

Coefficients and Variables

Excerpt 5.2, 5.3 and 5.4 present coefficients and variables explaining basic flows, commodity taxes and factor payments and other flows. Other types of coefficients and variables defined in the model are presented under relevant subsections. As a general rule, coefficients appear in upper-case characters and variables appear in lower-case characters.

Excerpt 5.2 Data coefficients and variables relating to basis commodity flows

```
Coefficient  ! Basic flows of commodities (excluding margin demands)!
 (all,c,COM)(all,s,SRC)(all,i,IND)  V1BAS(c,s,i)  # Intermediate basic flows #;
 (all,c,COM)(all,s,SRC)(all,i,IND)  V2BAS(c,s,i)  # Investment basic flows #;
 (all,c,COM)(all,s,SRC)             V3BAS(c,s)    # Household basic flows #;
 (all,c,COM)(all,s,SRC)(all, h, HOU)V3BAH(c,s,h)  # Household basic flows#;
 (all,c,COM)                        V4BAS(c)      # Export basic flows #;
 (all,c,COM)(all,s,SRC)             V5BAS(c,s)    # Government basic flows #;
 (all,c,COM)(all,s,SRC)             V6BAS(c,s)    # Inventories basic flows #;
Read
```

```
 V1BAS from file BASEDATA header "1BAS";
 V2BAS from file BASEDATA header "2BAS";
 V3BAH from file BASEDATA header "3BAH";
 V4BAS from file BASEDATA header "4BAS";
 V5BAS from file BASEDATA header "5BAS";
 V6BAS from file BASEDATA header "6BAS";
Variable
 (all,c,COM)(all,s,SRC)(all,i,IND)  x1(c,s,i)  # Intermediate basic demands #;
 (all,c,COM)(all,s,SRC)(all,i,IND)  x2(c,s,i)  # Investment basic demands #;
 (all,c,COM)(all,s,SRC)             x3(c,s)    # Household basic demands #;
 (all,c,COM)(all,s,SRC)(all, h,HOU) x3h(c,s,h) # Household basic flows#;
 (all,c,COM)(all,s,SRC)(all, h,HOU) a3h(c,s,h) # Household taste by group#;
 (all,c,COM)                        x4(c)      # Export basic demands #;
 (all,c,COM)(all,s,SRC)             x5(c,s)    # Government basic demands #;
 (change) (all,c,COM)(all,s,SRC)    delx6(c,s) # Inventories demands #;
 (all,c,COM)(all,s,SRC)             p0(c,s)    # Basic prices for local users #;
 (all,c,COM)                        pe(c)      # Basic price of exportables #;
 (change)(all,c,COM)(all,s,SRC)  delV6(c,s)    # Value of inventories #;
Update
 (all,c,COM)(all,s,SRC)(all,i,IND)  V1BAS(c,s,i)  = p0(c,s)*x1(c,s,i);
 (all,c,COM)(all,s,SRC)(all,i,IND)  V2BAS(c,s,i)  = p0(c,s)*x2(c,s,i);
 (all,c,COM)(all,s,SRC)(all, h,HOU) V3BAH(c,s,h)  = p0(c,s)*x3h(c,s,h);
 (all,c,COM)                        V4BAS(c)      = pe(c)*x4(c);
 (all,c,COM)(all,s,SRC)             V5BAS(c,s)    = p0(c,s)*x5(c,s);
 (change)(all,c,COM)(all,s,SRC)     V6BAS(c,s)    = delV6(c,s);
Formula
 (all,c,COM)(all,s,SRC)V3BAS(c,s)=sum(h,HOU,V3BAH(c,s,h));
```

Excerpt 5.3 Data coefficients and variables relating to commodity taxes

```
Coefficient  ! Taxes on Basic Flows!
 (all,c,COM)(all,s,SRC)(all,i,IND)  V1TAX(c,s,i) # Taxes on intermediate #;
 (all,c,COM)(all,s,SRC)(all,i,IND)  V2TAX(c,s,i) # Taxes on investment #;
 (all,c,COM)(all,s,SRC)             V3TAX(c,s)   # Taxes on households #;
 (all,c,COM)(all,s,SRC)(all,h,HOU)  V3TAH(c,s,h) #  households tax #;
 (all,c,COM)                        V4TAX(c)     # Taxes on export #;
 (all,c,COM)(all,s,SRC)             V5TAX(c,s)   # Taxes on government #;
Read
 V1TAX from file BASEDATA header "1TAX";
 V2TAX from file BASEDATA header "2TAX";
 V3TAH from file BASEDATA header "3TAH";
 V4TAX from file BASEDATA header "4TAX";
 V5TAX from file BASEDATA header "5TAX";
formula
 (all,c,COM)(all,s,SRC)V3TAX(c,s)=sum(h,HOU,V3TAH(c,s,h));
Variable
 (change)(all,c,COM)(all,s,SRC)(all,i,IND) delV1TAX(c,s,i) # Interm tax rev #;
 (change)(all,c,COM)(all,s,SRC)(all,i,IND) delV2TAX(c,s,i) # Invest tax rev #;
 (change)(all,c,COM)(all,s,SRC)(all,h,HOU) delV3TAH(c,s,h)   # H'hold tax rev #;
 (change)(all,c,COM)                       delV4TAX(c)     # Export tax rev #;
 (change)(all,c,COM)(all,s,SRC)            delV5TAX(c,s)   # Govmnt tax rev #;
Update
 (change)(all,c,COM)(all,s,SRC)(all,i,IND)  V1TAX(c,s,i) = delV1TAX(c,s,i);
 (change)(all,c,COM)(all,s,SRC)(all,i,IND)  V2TAX(c,s,i) = delV2TAX(c,s,i);
 (change)(all,c,COM)(all,s,SRC)(all,h,HOU)  V3TAH(c,s,h) = delV3TAH(c,s,h);
 (change)(all,c,COM)                        V4TAX(c)     = delV4TAX(c);
 (change)(all,c,COM)(all,s,SRC)             V5TAX(c,s)   = delV5TAX(c,s);
```

Excerpt 5.4 Data coefficients and variables relating to primary factors and tariffes

```
Coefficient
 (all,i,IND)(all,o,OCC)  V1LAB(i,o)  # Wage bill matrix #;
 (all,i,IND)             V1CAP(i)    # Capital rentals #;
 (all,i,IND)             V1LND(i)    # Land rentals #;
 (all,i,IND)             V1PTX(i)    # Production tax #;
 Read
 V1LAB from file BASEDATA header "1LAB";
 V1CAP from file BASEDATA header "1CAP";
 V1LND from file BASEDATA header "1LND";
 V1PTX from file BASEDATA header "1PTX";
 Variable
 (all,i,IND)(all,o,OCC)   x1lab(i,o)  # Employment by industry and occupation #;
```

```
 (all,i,IND)(all,o,OCC)   p1lab(i,o)  # Wages by industry and occupation #;
 (all,i,IND)  x1cap(i)        # Current capital stock #;
 (all,i,IND)  p1cap(i)        # Rental price of capital #;
 (all,i,IND)  x1lnd(i)        # Use of land #;
 (all,i,IND)  p1lnd(i)        # Rental price of land #;
 (change)(all,i,IND) delV1PTX(i) # Ordinary change in production tax revenue #;
 (all,i,IND)  x1oct(i)        # Demand for "other cost" tickets #;
Update
 (all,i,IND)(all,o,OCC)  V1LAB(i,o)  = p1lab(i,o)*x1lab(i,o);
 (all,i,IND)             V1CAP(i)    = p1cap(i)*x1cap(i);
 (all,i,IND)             V1LND(i)    = p1lnd(i)*x1lnd(i);
(change)(all,i,IND)      V1PTX(i)    = delV1PTX(i);
 ! Data coefficients relating to import duties !
Coefficient (all,c,COM) V0TAR(c)  # Tariff revenue #;
Read V0TAR from file BASEDATA header "0TAR";
Variable (all,c,COM) (change) delV0TAR(c) # Ordinary change in tariff revenue #;
Update (change)  (all,c,COM) V0TAR(c) = delV0TAR(c);
```

Excerpt 5.5 Import/domestic composition of intermediate demands

```
Variable
 (all,c,COM)(all,s,SRC)(all,i,IND) a1(c,s,i) # Intermediate basic tech change #;
 (all,c,COM)(all,i,IND) x1_s(c,i)    # Intermediate use of imp/dom composite #;
 (all,c,COM)(all,i,IND) p1_s(c,i)    # Price, intermediate imp/dom composite #;
 (all,i,IND)            p1mat(i)     # Intermediate cost price index #;
 (all,i,IND)            p1var(i)     # Short-run variable cost price index #;
Coefficient
 (parameter)(all,c,COM) SIGMA1(c)    # Armington elasticities: intermediate #;
 (all,c,COM)(all,i,IND) V1PUR_S(c,i) # Dom+imp intermediate purch. value #;
 (all,c,COM)(all,s,SRC)(all,i,IND) S1(c,s,i) # Intermediate source shares #;
 (all,i,IND)            V1MAT(i)     # Total intermediate cost for industry i #;
 (all,i,IND)            V1VAR(i)     # Short-run variable cost for industry i #;
Read SIGMA1 from file BASEDATA header "1ARM";
Zerodivide default 0.5;
Formula
 (all,c,COM)(all,i,IND)            V1PUR_S(c,i) = sum{s,SRC, V1PUR(c,s,i)};
 (all,c,COM)(all,s,SRC)(all,i,IND) S1(c,s,i)    = V1PUR(c,s,i) / V1PUR_S(c,i);
 (all,i,IND)                       V1MAT(i)     = sum{c,GCOM, V1PUR_S(c,i)};
 (all,i,IND)                       V1VAR(i)     = V1MAT(i) + V1LAB_O(i);
Zerodivide off;
Equation E_x1  # Source-specific commodity demands #
 (all,c,COM)(all,s,SRC)(all,i,IND)
  x1(c,s,i)-a1(c,s,i) = x1_s(c,i) -SIGMA1(c)*[p1(c,s,i) +a1(c,s,i) -p1_s(c,i)];
Equation E_p1_s  # Effective price of commodity composite #
 (all,c,COM)(all,i,IND)
  p1_s(c,i) = sum{s,SRC, S1(c,s,i)*[p1(c,s,i) + a1(c,s,i)]};
Equation E_p1mat  # Intermediate cost price index #
 (all,i,IND)
  p1mat(i) = sum{c,COM, sum{s,SRC, (V1PUR(c,s,i)/ID01[V1MAT(i)])*p1(c,s,i)}};
Equation E_p1var  # Short-run variable cost price index #
 (all,i,IND)
  p1var(i) = [1/V1VAR(i)]*[V1MAT(i)*p1mat(i) + V1LAB_O(i)*p1lab_o(i)];
```

Excerpt 5.6 Industry demand for electricity generating

```
Coefficient
(parameter)(all,i,IND) SIGMA1elcg(i) #CES substitution, electricity generating#;
Read SIGMA1elcg from file BASEDATA header "SELC";
Coefficient (all,i,IND) V1ELCG(i) #Total electr-generation input to industry i#;
Formula     (all,i,IND) V1ELCG(i) = sum{c,ELCG, V1PUR_S(c,i)};
Variable
 (all,i,IND)  p1elcg(i)        # electricity generating price #;
 (all,i,IND)  x1elcg(i)        # electricity generating quantity #;
 (all,i,IND)  a1elcg(i)        # electricity generating tech-efficiency#;
 (all,c,COM)(all,i,IND) a1_s(c,i) # Tech change, int'mdiate imp/dom composite #;
equation
E_x1_sE (all,c,ELCG)(all,i,IND)
x1_s(c,i)=x1elcg(i)-SIGMA1elcg(i)*[p1_s(c,i)+a1_s(c,i)-p1elcg(i)];
E_p1elcg
(all,i,IND)[TINY+V1ELCG(i)]*p1elcg(i)=sum{c,ELCG, V1PUR_S(c,i)*p1_s(c,i)};
```

Excerpt 5.7 Industry demand for coal energy inputs

```
Coefficient
 (parameter)(all,i,IND) SIGMA1COL(i) # CES substitu between black and brown #;
 (all,i,IND) V1COL(i)   # Total coal usage in industry i #;
Read SIGMA1COL from file BASEDATA header "SCOL";
Formula
 (all,i,IND) V1COL(i) = sum{c,COAL, V1PUR_S(c,i)};
Variable
 (all,c,COAL)(all,i,IND) x1_col(c,i)  # Intermediate use of imp/dom composite #;
 (all,i,IND) p1col(i) # Price of coal composite in each industry #;
 (all,i,IND) x1col(i) # coal composite inputs in each industry  #;
Equation
  E_x1_sA   # Demand for composite commodity - coal group #
  (all,c,COAL)(all,i,IND) x1_s(c,i) = x1_col(c,i);
  E_x1_col   # Demand for black and brown coal #
  (all,c,COAL)(all,i,IND)
   x1_col(c,i) = x1col(i) - SIGMA1COL(i)*[p1_s(c,i) - p1col(i)];
 E_p1col # Price of coal composite #
  (all,i,IND) [TINY+V1COL(i)]*p1col(i) = sum{c,COAL, V1PUR_S(c,i)*p1_s(c,i)};
```

Excerpt 5.8 Industry demand for oil and gas energy inputs

```
Coefficient
 (parameter)(all,i,IND) SIGMA1OIG(i) # CES substitu between oil and gas #;
 (all,i,IND) V1OIG(i)   # Total oil-gas usage in industry i #;
Read SIGMA1OIG from file BASEDATA header "SOIG";
Formula
 (all,i,IND) V1OIG(i) = sum{c,OILG, V1PUR_S(c,i)};
Variable
 (all,c,OILG)(all,i,IND) x1_oig(c,i)  # Intermediate use of imp/dom composite #;
 (all,i,IND) p1oig(i) # Price of oil-gas composite in each industry #;
 (all,i,IND) x1oig(i) # oil-gas composite inputs in each industry  #;
Equation
  E_x1_sB   # Demand for composite commodity - oil-gas group #
  (all,c,OILG)(all,i,IND) x1_s(c,i) = x1_oig(c,i);
  E_x1_oig   # Demand for oil and gas #
  (all,c,OILG)(all,i,IND)
   x1_oig(c,i) = x1oig(i) - SIGMA1OIG(i)*[p1_s(c,i) - p1oig(i)];
 E_p1oig # Price of oil-gas composite #
  (all,i,IND) [TINY+V1OIG(i)]*p1oig(i) = sum{c,OILG, V1PUR_S(c,i)*p1_s(c,i)};
```

Excerpt 5.9 Industry demand for petroleum energy inputs

```
Coefficient
 (parameter)(all,i,IND) SIGMA1PTR(i) # CES substitu between petroes #;
 (all,i,IND) V1PTR(i)   # Total petro usage in industry i #;
Read SIGMA1PTR from file BASEDATA header "SPTR";
Formula
 (all,i,IND) V1PTR(i) = sum{c,PETR, V1PUR_S(c,i)};
Variable
 (all,c,PETR)(all,i,IND) x1_ptr(c,i)  # Intermediate use of imp/dom composite #;
 (all,i,IND) p1ptr(i) # Price of petro composite in each industry #;
 (all,i,IND) x1ptr(i) # petro composite inputs in each industry  #;
Equation
  E_x1_sC   # Demand for composite commodity - petrol group #
  (all,c,PETR)(all,i,IND) x1_s(c,i) = x1_ptr(c,i);
  E_x1_ptr   # Demand for petroes #
  (all,c,PETR)(all,i,IND)
   x1_ptr(c,i) = x1ptr(i) - SIGMA1PTR(i)*[p1_s(c,i) - p1ptr(i)];
 E_p1ptr # Price of petro composite #
  (all,i,IND) [TINY+V1PTR(i)]*p1ptr(i) = sum{c,PETR, V1PUR_S(c,i)*p1_s(c,i)};
```

Excerpt 5.10 Industry demand for composite energy

```
Coefficient
(parameter)(all,i,IND) SIGMA1ENG(i) # CES substitution, composite energy #;
Read SIGMA1ENG from file BASEDATA header "SENG";
Coefficient
 (all,i,IND) V1ELE(i) # Total electricity input to industry i#;
```

```
 (all,i,IND) V1ENG(i) # Total energy input to industry i#;
Formula
 (all,i,IND) V1ELE(i) = sum{c,ELEC, V1PUR_S(c,i)};
 (all,i,IND) V1ENG(i) = V1COL(i)+ V1OIG(i) + V1PTR(i) + V1ELE(i);
Variable
 (all,i,IND) p1eng(i)  # Effective price of energy composite #;
 (all,i,IND) x1eng(i)  # Energy composite #;
 (all,i,IND) p1ele(i)  # Price of commercial electricity #;
 (all,i,IND) x1ele(i)  # commercial electricity usage by industry #;
 (all,c,ELEC)(all,i,IND) x1_ele(c,i)  # Intermediate use of imp/dom composite #;
 (all,i,IND) a1col(i) # Coal-augmenting technical change #;
 (all,i,IND) a1oig(i)   # Oil-gas-augmenting technical change #;
 (all,i,IND) a1ptr(i)   # Petrol-augmenting technical change #;
 (all,i,IND) a1ele(i)   # Electricity-augmenting technical change #;
Equation
 E_x1_sD   # Demand for composite commodity - electricity group #
  (all,c,ELEC)(all,i,IND) x1_s(c,i) = x1_ele(c,i);
E_x1_ele   # Demand for electricity #
  (all,c,ELEC)(all,i,IND)
   x1_ele(c,i) = x1ele(i) - 0.5*[p1_s(c,i) - p1ele(i)];
E_p1ele # Price of elect composite #
  (all,i,IND) [TINY+V1ELE(i)]*p1ele(i) = sum{c,ELEC, V1PUR_S(c,i)*p1_s(c,i)};
E_x1col  # Industry demands for coal composite #
  (all,i,IND)  x1col(i) - a1col(i) =
   x1eng(i) - SIGMA1eng(i)*[p1col(i) + a1col(i) - p1eng(i)];
E_x1oig  # Industry demands for oil-gas #
  (all,i,IND)  x1oig(i) - a1oig(i) =
   x1eng(i) - SIGMA1eng(i)*[p1oig(i) + a1oig(i) - p1eng(i)];
E_x1ptr  # Industry demands for petroleum #
  (all,i,IND)  x1ptr(i) - a1ptr(i) =
   x1eng(i) - SIGMA1eng(i)*[p1ptr(i) + a1ptr(i) - p1eng(i)];
E_x1ele  # Industry demands for commercial electricity #
  (all,i,IND)  x1ele(i) - a1ele(i) =
   x1eng(i) - SIGMA1eng(i)*[p1ele(i) + a1ele(i) - p1eng(i)];
E_p1eng  # Effective price for energy #
  (all,i,IND)  V1ENG(i)*p1eng(i) =
   V1COL(i)*[p1col(i) + a1col(i)] + V1OIG(i)*[p1oig(i) + a1oig(i)]
   + V1PTR(i)*[p1ptr(i) + a1ptr(i)] + V1ELE(i)*[p1ele(i) + a1ele(i)];
```

Excerpt 5.11 Industry demand for composite capital-energy

```
Coefficient
(parameter)(all,i,IND) SIGMA1ENC(i) # CES substitution: capital-energy #;
Read SIGMA1ENC from file BASEDATA header "SENC";
Coefficient (all,i,IND) V1ENC(i) # Total cap-energy input to industry i#;
Formula     (all,i,IND) V1ENC(i) = V1ENG(i)+ V1CAP(i);
Variable
 (all,i,IND) p1enc(i)  # Effective price of capital-energy composite #;
 (all,i,IND) x1enc(i)  # capital-energy composite #;
 (all,i,IND) a1eng(i) # energy-augmenting technical change #;
 (all,i,IND) a1cap(i)   # Capital-augmenting technical change #;
Equation
 E_x1eng  # Industry demands for effective energy #
  (all,i,IND)  x1eng(i) - a1eng(i) =
   x1enc(i) - SIGMA1enc(i)*[p1eng(i) + a1eng(i) - p1enc(i)];
E_p1cap  # Industry demands for capital #
  (all,i,IND)  x1cap(i) - a1cap(i) =
   x1enc(i) - SIGMA1enc(i)*[p1cap(i) + a1cap(i) - p1enc(i)];
E_p1enc  # Effective price of cap-energy #
  (all,i,IND)  V1ENC(i)*p1enc(i) = V1ENG(i)*[p1eng(i) + a1eng(i)]
    + V1CAP(i)*[p1cap(i) + a1cap(i)];
```

Excerpt 5.12 Occupational composition of labour demand

```
Coefficient
 (parameter)(all,i,IND) SIGMA1LAB(i) # CES substitution between skill types #;
 (all,i,IND) V1LAB_O(i)   # Total labour bill in industry i #;
             TINY    # Small number to prevent zero divides or singular matrix #;
Read SIGMA1LAB from file BASEDATA header "SLAB";
Formula
 (all,i,IND) V1LAB_O(i) = sum{o,OCC, V1LAB(i,o)};
             TINY       = 0.000000000001;
```

```
Variable
 (all,i,IND) p1lab_o(i) # Price to each industry of labour composite #;
 (all,i,IND) x1lab_o(i) # Effective labour input #;
Equation
 E_x1lab   # Demand for labour by industry and skill group #
  (all,i,IND)(all,o,OCC)
   x1lab(i,o) = x1lab_o(i) - SIGMA1LAB(i)*[p1lab(i,o) - p1lab_o(i)];
 E_p1lab_o # Price to each industry of labour composite #
  (all,i,IND) [TINY+V1LAB_O(i)]*p1lab_o(i) = sum{o,OCC, V1LAB(i,o)*p1lab(i,o)};
```

Excerpt 5.13 Industry demand for primary factors

```
Coefficient
(parameter)(all,i,IND) SIGMA1PRIM(i) # CES substitution, primary factors #;
Read SIGMA1PRIM from file BASEDATA header "P028";
Coefficient (all,i,IND) V1PRIM(i) # Total factor input to industry i#;
Formula     (all,i,IND) V1PRIM(i) = V1LAB_O(i)+ V1ENC(i) + V1LND(i);
Variable
 (all,i,IND) p1prim(i)  # Effective price of primary factor composite #;
 (all,i,IND) x1prim(i)  # Primary factor composite #;
 (all,i,IND) a1lab_o(i) # Labor-augmenting technical change #;
 (all,i,IND) a1enc(i)   # Capital-energy-augmenting technical change #;
 (all,i,IND) a1lnd(i)   # Land-augmenting technical change #;
(change)(all,i,IND) delV1PRIM(i)# Ordinary change in cost of primary factors #;
Equation
 E_x1lab_o  # Industry demands for effective labour #
  (all,i,IND)  x1lab_o(i) - a1lab_o(i) =
   x1prim(i) - SIGMA1PRIM(i)*[p1lab_o(i) + a1lab_o(i) - p1prim(i)];
E_x1enc  # Industry demands for capital-energy composite #
  (all,i,IND)  x1enc(i) - a1enc(i) =
   x1prim(i) - SIGMA1PRIM(i)*[p1enc(i) + a1enc(i) - p1prim(i)];
E_p1lnd  # Industry demands for land #
  (all,i,IND)  x1lnd(i) - a1lnd(i) =
   x1prim(i) - SIGMA1PRIM(i)*[p1lnd(i) + a1lnd(i) - p1prim(i)];
E_p1prim  # Effective price term for factor demand equations #
  (all,i,IND)  V1PRIM(i)*p1prim(i) = V1LAB_O(i)*[p1lab_o(i) + a1lab_o(i)]
    + V1ENC(i)*[p1enc(i) + a1enc(i)] + V1LND(i)*[p1lnd(i) + a1lnd(i)];
E_delV1PRIM  # Ordinary change in total cost of primary factors #
  (all,i,IND) 100*delV1PRIM(i) = V1ENC(i)  * [p1enc(i) + x1enc(i)] + V1LND(i)*[p1lnd(i) + x1lnd(i)]+
sum{o,OCC, V1LAB(i,o)* [p1lab(i,o) + x1lab(i,o)]};
```

Excerpt 5.14 Top nest of industry input demands

```
Variable
 (all,i,IND)  x1tot(i)        # Activity level or value-added #;
 (all,i,IND)  a1prim(i)       # All factor augmenting technical change #;
 (all,i,IND)  a1tot(i)        # All input augmenting technical change #;
 (all,i,IND)  p1tot(i)        # Average input/output price #;
 Equation E_x1_sF  # Demands for commodity composites #
(all,c,GNCOM)(all,i,IND)  x1_s(c,i) - [a1_s(c,i) + a1tot(i)] = x1tot(i);
Equation E_x1elcg  # Demands for composite electricity generating #
 (all,i,IND)  x1elcg(i) - [a1elcg(i) + a1tot(i)] = x1tot(i);
Equation E_x1prim  # Demands for primary factor composite #
 (all,i,IND)  x1prim(i) - [a1prim(i) + a1tot(i)] = x1tot(i);
```

Excerpt 4.15 Output cost inclusive of production tax

```
Coefficient
 (all,i,IND)  V1CST(i)    # Total cost of industry i #;
 (all,i,IND)  V1TOT(i)    # Total industry cost plus tax #;
 (all,i,IND) PTXRATE(i)   # Rate of production tax #;
 (all,i,IND) V1PTC (i)   #  carbon production tax #;
 (all,i,IND) PTCRATE(i)   # Rate of carbon production tax #;
Formula
 (all,i,IND)  V1CST(i)    = V1PRIM(i) + V1OCT(i) + V1MAT(i);
 (all,i,IND)  V1TOT(i)    = V1CST(i) + V1PTX(i)+sum{c,com,TX1CO(c,i)};
 (all,i,IND)  PTXRATE(i)  = V1PTX(i)/V1CST(i);
 (all,i,IND)  V1PTC(i)  = sum{c,com,TX1CO(c,i)};
 (all,i,IND)  PTCRATE(i)  = V1PTC(i)/V1CST(i);
Write PTXRATE to file SUMMARY header "PTXR";
Write PTCRATE to file SUMMARY header "PTCR";
```

```
Variable
 (change)(all,i,IND) delV1CST(i)   # Change in ex-tax cost of production #;
 (change)(all,i,IND) delV1TOT(i)   # Change in tax-inc cost of production #;
 (change)(all,i,IND) delPTXRATE(i) # Change in rate of production tax #;
 (change)(all,i,IND) delPTCRATE(i) # Change in rate of carbon production tax #;
Equation
 E_delV1CST  (all,i,IND) delV1CST(i) = delV1PRIM(i) + sum{c,COM,sum{s,SRC,
0.01*V1PUR(c,s,i)*[p1(c,s,i) + x1(c,s,i)]}} +  0.01*V1OCT(i) *[p1oct(i)  + x1oct(i)];
 E_delV1TOT  (all,i,IND) delV1TOT(i) = delV1CST(i) + delV1PTX(i)+sum{c,com,delTX1CO(c,i)};
 E_p1tot     (all,i,IND) V1TOT(i)*[p1tot(i) + x1tot(i)] = 100*delV1TOT(i);
Variable (all,i,IND) p1cst(i) # Index of production costs (for AnalyseGE) #;
Equation E_p1cst  (all,i,IND) p1cst(i) =  [1/V1CST(i)]*[sum{c,COM,sum{s,SRC,  V1PUR(c,s,i)*p1(c,s,i)}}
+  V1OCT(i)    *p1oct(i) + V1CAP(i) *p1cap(i) + V1LND(i)  *p1lnd(i) + sum{o,OCC, V1LAB(i,o)
*p1lab(i,o)}];
```

Excerpt 5.16 Output mix of commodities

```
Coefficient (all,c,COM)(all,i,IND) MAKE(c,i) # Multiproduction matrix #;
Variable
 (all,c,COM)(all,i,IND)  q1(c,i)   # Output by commodity and industry #;
 (all,c,COM)(all,i,IND)  pq1(c,i)  # Price of com c produced by ind i #;
 (all,c,COM)  p0com(c)   # General output price of locally-produced commodity #;
Read MAKE from file BASEDATA header "MAKE";
Update (all,c,COM)(all,i,IND) MAKE(c,i)= pq1(c,i)*q1(c,i);
Variable
 (all,c,COM)  x0com(c) # Output of commodities #;
Coefficient
 (parameter)(all,i,IND) SIGMA1OUT(i) # CET transformation elasticities #;
Read SIGMA1OUT from file BASEDATA header "SCET";
Equation E_q1  # Supplies of commodities by industries #
 (all,c,COM)(all,i,IND)
  q1(c,i) = x1tot(i) + SIGMA1OUT(i)*[p0com(c) - p1tot(i)];
Coefficient
 (all,i,IND) MAKE_C(i) # All production by industry i #;
 (all,c,COM) MAKE_I(c) # Total production of commodities #;
Formula
 (all,i,IND) MAKE_C(i) = sum{c,COM, MAKE(c,i)};
 (all,c,COM) MAKE_I(c) = sum{i,IND, MAKE(c,i)};
Equation E_x1tot # Average price received by industries #
 (all,i,IND) p1tot(i) = sum{c,COM, [MAKE(c,i)/MAKE_C(i)]*pq1(c,i)};
Equation
 E_pq1  # Each industry gets the same price for a given commodity #
 (all,c,COM)(all,i,IND) pq1(c,i) = p0com(c);
 E_x0com # Total output of commodities (as simple addition) #
 (all,c,COM) x0com(c) = sum{i,IND, [MAKE(c,i)/MAKE_I(c)]*q1(c,i)};
```

Excerpt 5.17 Outputs for local and export markets

```
Variable
 (all,c,COM)  x0dom(c)  # Output of commodities for local market #;
Coefficient
 (all, c,COM) EXPSHR(c) # Share going to exports #;
 (all, c,COM) TAU(c)    # 1/Elast. of transformation, exportable/locally used #;
Zerodivide default 0.5;
Formula
 (all,c,COM) EXPSHR(c) = V4BAS(c)/MAKE_I(c);
 (all,c,COM) TAU(c) = 0.0;
Zerodivide off;
Equation E_x0dom  # Supply of commodities to export market #
 (all,c,COM) TAU(c)*[x0dom(c) - x4(c)] = p0dom(c) - pe(c);
Equation E_pe     # Supply of commodities to domestic market #
 (all,c,COM) x0com(c) = [1.0-EXPSHR(c)]*x0dom(c) + EXPSHR(c)*x4(c);
Equation E_p0com  # Zero pure profits in transformation #
 (all,c,COM) p0com(c) = [1.0-EXPSHR(c)]*p0dom(c) + EXPSHR(c)*pe(c);
```

Excerpt 5.17 Investment demands

```
Variable
 (all,c,COM)(all,i,IND)  x2_s(c,i)  # Investment use of imp/dom composite #;
 (all,c,COM)(all,i,IND)  p2_s(c,i)  # Price, investment imp/dom composite #;
 (all,c,COM)(all,s,SRC)(all,i,IND)  a2(c,s,i) # Investment basic tech change #;
```

```
Coefficient
 (parameter) (all,c,COM)  SIGMA2(c) # Armington elasticities: investment #;
Read SIGMA2 from file BASEDATA header "2ARM";
Coefficient
 (all,c,COM)(all,i,IND)     V2PUR_S(c,i) # Dom+imp investment purch. value #;
 (all,c,COM)(all,s,SRC)(all,i,IND)  S2(c,s,i) # Investment source shares #;
Zerodivide default 0.5;
Formula
  (all,c,COM)(all,i,IND)     V2PUR_S(c,i)  = sum{s,SRC, V2PUR(c,s,i)};
  (all,c,COM)(all,s,SRC)(all,i,IND)  S2(c,s,i) = V2PUR(c,s,i) / V2PUR_S(c,i);
Zerodivide off;
Equation E_x2  # Source-specific commodity demands #
(all,c,COM)(all,s,SRC)(all,i,IND)
x2(c,s,i)-a2(c,s,i) - x2_s(c,i) = - SIGMA2(c)*[p2(c,s,i)+a2(c,s,i) - p2_s(c,i)];
Equation E_p2_s  # Effective price of commodity composite #
(all,c,COM)(all,i,IND)
p2_s(c,i) = sum{s,SRC, S2(c,s,i)*[p2(c,s,i)+a2(c,s,i)]};
Variable
 (all,i,IND)  a2tot(i)        # Neutral technical change - investment #;
 (all,i,IND)  p2tot(i)        # Cost of unit of capital #;
 (all,i,IND)  x2tot(i)        # Investment by using industry #;
 (all,c,COM)(all,i,IND) a2_s(c,i) # Tech change, investment imp/dom composite #;
Coefficient (all,i,IND) V2TOT(i)  # Total capital created for industry i #;
Formula     (all,i,IND) V2TOT(i)  = sum{c,COM, V2PUR_S(c,i)};
Equation
 E_x2_s  (all,c,COM)(all,i,IND)  x2_s(c,i) - [a2_s(c,i) + a2tot(i)] = x2tot(i);
 E_p2tot (all,i,IND) p2tot(i) = sum{c,COM, (V2PUR_S(c,i)/ID01[V2TOT(i)])*[p2_s(c,i) +a2_s(c,i)
+a2tot(i)]};
```

Excerpt 5.19 Household demands

```
! Import/domestic composition of household demands !
Variable
(all,c,COM)(all,s,SRC)  a3(c,s)   # Household basic taste change #;
(all,c,COM)             x3_s(c)   # Household use of imp/dom composite #;
(all,c,COM)             p3_s(c)   # Price, household imp/dom composite #;
Coefficient
 (parameter)(all,c,COM) SIGMA3(c) # Armington elasticities: households #;
Read SIGMA3 from file BASEDATA header "3ARM";
Coefficient
 (all,c,COM)           V3PUR_S(c) # Dom+imp households purch. value #;
 (all,c,COM)(all,s,SRC)   S3(c,s) # Household source shares #;
Zerodivide default 0.5;
Formula
 (all,c,COM)           V3PUR_S(c) = sum{s,SRC, V3PUR(c,s)};
 (all,c,COM)(all,s,SRC)   S3(c,s) = V3PUR(c,s)   / V3PUR_S(c);
Zerodivide off;
Equation
E_x3  # Source-specific commodity demands #
(all,c,COM)(all,s,SRC)
x3(c,s)-a3(c,s) = x3_s(c) - SIGMA3(c)*[ p3(c,s)+a3(c,s) - p3_s(c) ];
E_x3h
(all,c,COM)(all,s,SRC)(all, h, HOU)
x3h(c,s,h)-a3h(c,s,h) = x3(c,s);

Equation E_p3_s  # Effective price of commodity composite #
(all,c,COM) p3_s(c) = sum{s,SRC, S3(c,s)*[p3(c,s)+a3(c,s)]};

! Household demands for composite commodities !
Variable
 (all,h,HOU)             p3toth(h) # Consumer price index #;
 (all,h,HOU)             x3toth(h) # Real household consumption #;
 (all,h,HOU)             w3toth(h) # Nominal total household consumption #;
 (all,h,HOU)             w3luxh(h) # Nominal luxury consumption #;
 (all,h,HOU)                 qh(h) # Number of households #;
 (all,h,HOU)           utilityh(h) # Utility per household #;
 (all,c,COM)(all,h,HOU) x3lux(c,h) # Household - supernumerary demands #;
 (all,c,COM)(all,h,HOU) x3sub(c,h) # Household - subsistence demands #;
 (all,c,COM)(all,h,HOU) a3lux(c,h) # Taste change, supernumerary demands #;
 (all,c,COM)(all,h,HOU) a3sub(c,h) # Taste change, subsistence demands #;
 (all,c,COM)(all,h,HOU)  a3_s(c,h) # Taste change, hhold imp/dom composite #;
 (all,c,COM)(all,h,HOU)  x3_sh(c,h) # Consumption, hhold imp/dom composite #;
Coefficient
 (all,h,HOU)    V3TOTh(h) # Total purchases by households #;
```

```
                   V3TOT # Total purchases by households #;
 (all,h,HOU)    FRISCH(h) # Frisch LES 'parameter'= - (total/luxury) #;
 (all,c,COM)(all,h,HOU)   EPS(c,h) # Household expenditure elasticities #;
 (all,c,COM)(all,h,HOU)  S3_S(c,h) # Household average budget shares #;
 (all,c,COM)(all,h,HOU) B3LUX(c,h) # Ratio, (supernumerary /total expenditure)#;
 (all,c,COM)(all,h,HOU) S3LUX(c,h) # Marginal household budget shares #;
Read   FRISCH from file BASEDATA header "P21h";
          EPS from file BASEDATA header "XPLh";
Update (change)(all,h,HOU) FRISCH(h) = FRISCH(h)*[w3toth(h) - w3luxh(h)]/100.0;
       (change)(all,c,COM)(all,h,HOU) EPS(c,h) = EPS(c,h)*
           [x3lux(c,h)-x3_sh(c,h)+w3toth(h) - w3luxh(h)]/100.0;
Formula
       (all,h,HOU)       V3TOTh(h) = sum{c,COM, V3PUR_SH(c,h)};
                             V3TOT = sum{h,HOU, V3TOTh(h)};
 (all,c,COM)(all,h,HOU)  S3_S(c,h) = V3PUR_SH(c,h)/V3TOTh(h);
 (all,c,COM)(all,h,HOU) B3LUX(c,h) = EPS(c,h)/ABS[FRISCH(h)];
 (all,c,COM)(all,h,HOU) S3LUX(c,h) = EPS(c,h)*S3_S(c,h);
Write  S3LUX   to file SUMMARY header "LSHR";
       S3_S    to file SUMMARY header "CSHR";
Equation
 E_x3sub # Subsistence demand for composite commodities #
  (all,c,COM)(all,h,HOU) x3sub(c,h) = qh(h) + a3sub(c,h);
 E_x3lux # Luxury demand for composite commodities #
  (all,c,COM)(all,h,HOU) x3lux(c,h) + p3_s(c) = w3luxh(h) + a3lux(c,h);
 E_x3_sh  # Total household demand for composite commodities #
  (all,c,COM)(all,h,HOU)
x3_sh(c,h) = B3LUX(c,h)*x3lux(c,h) + [1-B3LUX(c,h)]*x3sub(c,h);
 E_utilityh # Change in utility disregarding taste change terms #
 (all,h,HOU) utilityh(h) + qh(h) = sum{c,COM, S3LUX(c,h)*x3lux(c,h)};
 E_a3lux # Default setting for luxury taste shifter #
  (all,c,COM)(all,h,HOU)
a3lux(c,h) = a3sub(c,h) - sum{k,COM, S3LUX(k,h)*a3sub(k,h)};
 E_a3sub # Default setting for subsistence taste shifter #
  (all,c,COM)(all,h,HOU) a3sub(c,h) = a3_s(c,h)-sum{k,COM,S3_S(k,h)*a3_s(k,h)};
 E_x3toth # Real consumption #
 (all,h,HOU) x3toth(h) = sum{c,COM, S3_S(c,h)*x3_sh(c,h)};
 E_p3toth # Consumer price index #
 (all,h,HOU) p3toth(h) = sum{c,COM, S3_S(c,h)*p3_s(c)};

 E_w3toth # Household budget constraint: determines w3lux #
   (all,h,HOU) w3toth(h) = x3toth(h) + p3toth(h);
Variable
p3tot # Consumer price index #;
x3tot # Real household consumption #;
w3tot # Nominal total household consumption #;
Equation
 E_x3tot # Real consumption #
  0 = sum{h,HOU, V3TOTh(h)*[x3toth(h)-x3tot]};
 E_p3tot # Consumer price index #
  0 = sum{h,HOU, V3TOTh(h)*[p3toth(h)-p3tot]};
 E_w3tot # Household budget constraint: determines w3lux #
   w3tot = x3tot + p3tot;
 E_x3_s  # Total household demand for composite commodities #
  (all,c,COM) sum{h,HOU, ID01[V3PUR_SH(c,h)]*[x3_sh(c,h)- x3_s(c)]} = 0;
Coefficient (all,h,HOU) EPSTOTH(h) # Average Engel elasticity: should = 1 #;
Formula     (all,h,HOU) EPSTOTH(h) = sum{c,COM, S3_S(c,h)*EPS(c,h)};
Assertion (initial) # Check ave EPS =1 # (all,h,HOU) ABS[1-EPSTOTH(h)]<0.01;
Assertion # Hou check #
(all,c,COM)(all,h,HOU)
ABS[sum{s,SRC,V3BAH(c,s,h)+V3TAH(c,s,h)+sum{m,MAR,V3MAH(c,s,h,m)}}
           +TX3CC(c,h)-V3PUR_SH(c,h)]<0.1;
```

Excerpt 5.20 Export and government demands

```
! Export demands !
Coefficient
 (parameter)(all,c,COM) IsIndivExp(c) # >0.5 For individual export commodities#;
Read IsIndivExp from file BASEDATA header "ITEX";
Set TRADEXP # Individual export commodities # = (all,c,COM: IsIndivExp(c)>0.5);
Write (Set) TRADEXP  to file SUMMARY header "TEXP";
Variable
              phi     # Exchange rate, local currency/$world #;
 (all,c,COM)  f4p(c)  # Price (upward) shift in export demand schedule #;
 (all,c,COM)  f4q(c)  # Quantity (right) shift in export demands #;
```

```
Coefficient (parameter)(all,c,COM) EXP_ELAST(c)
  # Export demand elasticities: typical value -5.0 #;
Read EXP_ELAST from file BASEDATA header "P018";
Equation E_x4A  # Individual export demand functions #
(all,c,TRADEXP) x4(c) - f4q(c) = -ABS[EXP_ELAST(c)]*[p4(c) - phi - f4p(c)];
Set NTRADEXP # Collective Export Commodities # = COM - TRADEXP;
Write (Set) NTRADEXP  to file SUMMARY header "NTXP";
Variable
 x4_ntrad     # Quantity, collective export aggregate #;
 f4p_ntrad    # Upward demand shift, collective export aggregate #;
 f4q_ntrad    # Right demand shift, collective export aggregate #;
 p4_ntrad     # Price, collective export aggregate #;
Coefficient V4NTRADEXP # Total collective export earnings #;
Formula     V4NTRADEXP = sum{c,NTRADEXP, V4PUR(c)};
Equation E_X4B  # Collective export demand functions #
 (all,c,NTRADEXP) x4(c) - f4q(c) = x4_ntrad;
Equation E_p4_ntrad  # Average price of collective exports #
     [TINY+V4NTRADEXP]*p4_ntrad = sum{c,NTRADEXP, V4PUR(c)*p4(c)};
Coefficient (parameter) EXP_ELAST_NT # Collective export demand elasticity #;
Read EXP_ELAST_NT from file BASEDATA header "EXNT";
Equation E_x4_ntrad # Demand for collective export aggregate #
        x4_ntrad - f4q_ntrad = -ABS[EXP_ELAST_NT]*[p4_ntrad - phi - f4p_ntrad];

! Government and inventory demands !
Variable
 f5tot  # Overall shift term for government demands #;
 f5tot2 # Ratio between f5tot and x3tot #;
 (all,c,COM)(all,s,SRC) f5(c,s) # Government demand shift #;
 (change) (all,c,COM)(all,s,SRC)  fx6(c,s)    # Shifter on rule for stocks #;
Equation
 E_x5 # Government demands # (all,c,COM)(all,s,SRC) x5(c,s) = f5(c,s) + f5tot;
 E_f5tot # Overall government demands shift # f5tot = x3tot + f5tot2;
Coefficient (all,c,COM)(all,s,SRC) LEVP0(c,s) # Levels basic prices #;
Formula (initial) (all,c,COM)(all,s,SRC) LEVP0(c,s) = 1;
Update   (all,c,COM)(all,s,SRC) LEVP0(c,s) = p0(c,s);
Equation
 E_delx6 # Stocks follow domestic output # (all,c,COM)(all,s,SRC)
  100*LEVP0(c,s)*delx6(c,s) = V6BAS(c,s)*x0com(c) + fx6(c,s);
 E_delV6 # Update formula for stocks #     (all,c,COM)(all,s,SRC)
  delV6(c,s) = 0.01*V6BAS(c,s)*p0(c,s) + LEVP0(c,s)*delx6(c,s);
```

Excerpt 5.21 Carbon emissions intensity and determining carbon price

```
! carbon emission intensity!
Coefficient
(all, c, COM) (all, i, IND) EMI1(c, i) #industry input emission#;
(all, c, COM) (all, i, IND) EMO1(c, i) #industry output emission#;
(all, c, COM) (all, h, HOU) EMC3(c, h) #houshold consumption emission#;
(parameter)(all, c, COM) (all, i, IND) ETI1(c, i) #input emission intensity#;
(parameter)(all, c, COM) (all, i, IND) ETO1(c, i) #output emission intensity#;
(parameter)(all, c, COM) (all, h, HOU) ETC3(c, h) #houshold emission intensity#;
READ
EMI1 from file BASEDATA header "EMI1";
EMO1 from file BASEDATA header "EMO1";
EMC3 from file BASEDATA header "EMC3";
ETI1 from file BASEDATA header "ETI1";
ETO1 from file BASEDATA header "ETO1";
ETC3 from file BASEDATA header "ETC3";
Update
(change)(all, c, COM) (all, i, IND)
EMI1(c, i)=0.01*ETI1(c,i)*V1BAS(c,"dom",i)*x1(c,"dom",i);
(change)(all, c, COM) (all, i, IND)
EMO1(c, i)=0.01*ETO1(c,i)*MAKE(c,i)*q1(c,i);
(change)(all, c, COM) (all, h, HOU)
EMC3(c, h)=0.01*ETC3(c,h)*V3BAH(c,"dom",h)*x3h(c,"dom",h);
!carbon emission aggregation!
Variable
(change)(all, c, COM) (all, i, IND) x1ci(c,i) #input carbon emission#;
(change)(all, c, COM) (all, i, IND) x1co(c,i) #output carbon emission#;
(change)(all, c, COM) (all, h, HOU) x3cc(c,h) #consumption carbon emission#;
Equation
E_x1ci #input carbon emission by source and by industy#
(all, c, COM) (all, i, IND) x1ci(c,i) = 0.01*ETI1(c,i)*V1BAS(c,"dom",i)*x1(c,"dom",i);
E_x1co #output carbon emission by source and by industy#
```

```
(all, c, COM) (all, i, IND) x1co(c,i) = 0.01*ETO1(c,i)*MAKE(c,i)*q1(c,i);
E_x3cc #consumption carbon emission by source and by household group#
(all, c, COM) (all, h, HOU) x3cc(c,h) = 0.01*ETC3(c,h)*V3BAH(c,"dom",h)*x3h(c,"dom",h);
Equation
E_delTX1CI #input carbon tax by source and by industy#
(all, c, COM)(all, i, IND)1000*delTX1CI(c,i)= EMI1(c,i)*delP1CI(c,i) + P1CI(c,i)*x1ci(c,i);
E_delTX1CO # output carbon tax by source and by industy#
(all, c, COM)(all, i, IND)1000*delTX1CO(c,i)= EMO1(c,i)*delP1CO(c,i) + P1CO(c,i)*x1co(c,i);
E_delTX3CC# consumption carbon tax by source and by industy#
(all, c, COM)(all, h, HOU)1000*delTX3CC(c,h)= EMC3(c,h)*delP3CC(c,h) + P3CC(c,h)*x3cc(c,h);
Equation
E_et1
(all, c, COM)(all, i, IND) TX1CI(c,i)*[p0(c,"dom")+x1(c,"dom",i)]+
[TX1CI(c,i)+V1BAS(c,"dom",i)+tiny]*et1(c,i)=100*delTX1CI(c,i);
E_et3
(all, c, COM)(all, h, HOU) TX3CC(c,h)*[p0(c,"dom")+x3h(c,"dom",h)]+
[TX3CC(c,h)+V3BAH(c,"dom",h)+tiny]*et3(c,h)=100*delTX3CC(c,h);
E_et3_h
(all, c, COM) sum{h,HOU,TX3CC(c,h)*[p0(c,"dom")+x3h(c,"dom",h)]}+
sum{h,HOU,[TX3CC(c,h)+V3BAH(c,"dom",h)+tiny]}*et3_h(c)=100*delTX3CC_H(c);
```

Excerpt 5.22 Coefficients and variables for purchaser's prices (basic +taxes)

```
Variable
(change)(all, c, COM)(all, i, IND) delP1CI(c,i) #change in input carbon price by industry#;
(change)(all, c, COM)(all, i, IND) delP1CO(c,i) #change in output carbon price by industry#;
(change)(all, c, COM)(all, h, HOU) delP3CC(c,h) #change in carbon price by household group#;
(change)(all, c, COM)(all, i, IND) delTX1CI(c,i) #change in input carbon tax revenue#;
(change)(all, c, COM)(all, i, IND) delTX1CO(c,i) #change in output carbon tax revenue#;
(change)(all, c, COM)(all, h, HOU) delTX3CC(c,h) #change in consumption carbon tax revenue#;
Coefficient
(all, c, COM)(all, i, IND) P1CI(c,i) #price on input carbon by industry#;
(all, c, COM)(all, i, IND) P1CO(c,i) #price on output carbon by industry#;
(all, c, COM)(all, h, HOU) P3CC(c,h) #price on consumption carbon by household group#;
(all, c, COM)(all, i, IND) TX1CO(c,i) #output carbon tax revenue by industry#;
(all, c, COM)(all, i, IND) TX1CI(c,i) #input carbon tax revenue by industry#;
(all, c, COM)(all, h, HOU) TX3CC(c,h) #consumption carbon tax revenue by household group#;
Read
P1CI from file BASEDATA header "P1CI";
P1CO from file BASEDATA header "P1CO";
P3CC from file BASEDATA header "P3CC";
TX1CI from file BASEDATA header "TXCI";
TX1CO from file BASEDATA header "TXCO";
TX3CC from file BASEDATA header "TXCC";
Update
(change)(all, c, COM)(all, i, IND) P1CI(c,i)=delP1CI(c,i) ;
(change)(all, c, COM)(all, i, IND) P1CO(c,i)=delP1CO(c,i) ;
(change)(all, c, COM)(all, h, HOU) P3CC(c,h)=delP3CC(c,h) ;
(change)(all, c, COM)(all, i, IND) TX1CI(c,i)=delTX1CI(c,i) ;
(change)(all, c, COM)(all, i, IND) TX1CO(c,i)=delTX1CO(c,i) ;
(change)(all, c, COM)(all, h, HOU) TX3CC(c,h)=delTX3CC(c,h) ;
Coefficient !
 (all,c,COM)(all,s,SRC)(all,i,IND)  V1PUR(c,s,i)  # Intermediate purch. value #;
 (all,c,COM)(all,s,SRC)(all,i,IND)  V2PUR(c,s,i)  # Investment purch. value #;
 (all,c,COM)(all,s,SRC)             V3PUR(c,s)    # Households purch. value #;
 (all,c,COM)(all,s,SRC)(all,h,HOU)  V3PUH(c,s,h)  # Households purch. value #;
 (all,c,COM)(all,h,HOU)             V3PUR_SH(c,h)  # Households purch. value #;
 (all,c,COM)                        V4PUR(c)      # Export purch. value #;
 (all,c,COM)(all,s,SRC)             V5PUR(c,s)    # Government purch. value #;
Formula
!since we do not have seperate emission matrix for imports, we assume no
emission from imports!
(all,c,COM)(all,i,IND) V1PUR(c,"imp",i) = V1BAS(c,"imp",i) + V1TAX(c,"imp",i);
(all,c,COM)(all,i,IND) V1PUR(c,"dom",i) = V1BAS(c,"dom",i) + V1TAX(c,"dom",i) + TX1CI(c,i);
(all,c,COM)(all,s,SRC)(all,i,IND) V2PUR(c,s,i) = V2BAS(c,s,i) + V2TAX(c,s,i);
(all,c,COM)(all,h,HOU) V3PUH(c,"imp",h) = V3BAH(c,"imp",h) + V3TAH(c,"imp",h);
(all,c,COM)(all,h,HOU) V3PUH(c,"dom",h) = V3BAH(c,"dom",h) + V3TAH(c,"dom",h) + TX3CC(c,h);
(all,c,COM)(all,s,SRC)V3PUR(c,s)=sum(h,HOU,V3PUH(c,s,h));
(all,c,COM)(all,h,HOU)V3PUR_SH(c,h)=sum(s,SRC,V3PUH(c,s,h));
(all,c,COM) V4PUR(c)= V4BAS(c) + V4TAX(c);
(all,c,COM)(all,s,SRC) V5PUR(c,s) = V5BAS(c,s) + V5TAX(c,s);

Variable
```

```
 (all,c,COM)(all,s,SRC)(all,i,IND) p1(c,s,i)# Purchaser's price, intermediate #;
 (all,c,COM)(all,s,SRC)(all,i,IND) p2(c,s,i)# Purchaser's price, investment #;
 (all,c,COM)(all,s,SRC)           p3(c,s)  # Purchaser's price, household #;
 (all,c,COM)                      p4(c)    # Purchaser's price, exports,loc$ #;
 (all,c,COM)(all,s,SRC)           p5(c,s)  # Purchaser's price, government #;
Variable
 (all,c,COM)(all,s,SRC)(all,i,IND) t1(c,s,i) # Power of tax on intermediate #;
 (all,c,COM)(all,s,SRC)(all,i,IND) t2(c,s,i) # Power of tax on investment #;
 (all,c,COM)(all,s,SRC)           t3(c,s)   # Power of tax on household #;
 (all,c,COM)                      t4(c)     # Power of tax on export #;
 (all,c,COM)(all,s,SRC)           t5(c,s)   # Power of tax on government #;
Variable
(all, c, COM)(all, i, IND) et1(c,i) #Power of equivalent tax on intermediate#;
(all, c, COM)(all, h, HOU) et3(c,h) #Power of equivalent tax on consumption#;
(all, c, COM) et3_h(c) #Power of equivalent tax on consumption by commodity#;
Equation E_p1_A # Purchasers prices - producers #
 (all,c,COM)(all,i,IND) [V1PUR(c,"imp",i)+TINY]*p1(c,"imp",i) = [V1BAS(c,"imp",i)+
V1TAX(c,"imp",i)]*[p0(c,"imp")+ t1(c,"imp",i)];
Equation E_p1_B # Purchasers prices - producers #
 (all,c,COM)(all,i,IND) [V1PUR(c,"dom",i)+TINY]*p1(c,"dom",i)= [V1BAS(c,"dom",i)+
V1TAX(c,"dom",i)+TX1CI(c,i)]*[p0(c,"dom")+ t1(c,"dom",i)+et1(c,i)];
Equation E_p2 # Purchasers prices - capital creators #
 (all,c,COM)(all,s,SRC)(all,i,IND)[V2PUR(c,s,i)+TINY]*p2(c,s,i) =
[V2BAS(c,s,i)+V2TAX(c,s,i)]*[p0(c,s)+ t2(c,s,i)];
Equation E_p3_A # Purchasers prices - households #
 (all,c,COM)[V3PUR(c,"imp")+TINY]*p3(c,"imp") = [V3BAS(c,"imp")+V3TAX(c,"imp")]*[p0(c,"imp")+
t3(c,"imp")];
Equation E_p3_B # Purchasers prices - households #
 (all,c,COM)[V3PUR(c,"dom")+TINY]*p3(c,"dom") =[V3BAS(c,"dom")+V3TAX(c,"dom")+
sum{h,HOU,TX3CC(c,h)}]*[p0(c,"dom")+ t3(c,"dom")+et3_h(c)];
Equation E_p4 # Zero pure profits in exporting #
 (all,c,COM)[V4PUR(c)+TINY]*p4(c) =[V4BAS(c)+V4TAX(c)]*[pe(c)+ t4(c)];
Equation E_p5 # Zero pure profits in distribution to government #
 (all,c,COM)(all,s,SRC)[V5PUR(c,s)+TINY]*p5(c,s) =[V5BAS(c,s)+V5TAX(c,s)]*[p0(c,s)+ t5(c,s)];
```

Excerpt 5.23 Market clearing conditions

```
Set DEST # Sale Categories #
(Interm, Invest, HouseH, Export, GovGE, Stocks, Margins);
Coefficient (all,c,COM)(all,s,SRC)(all,d,DEST) SALE(c,s,d) # Sales aggregates #;
Formula
 (all,c,COM)(all,s,SRC) SALE(c,s,"Interm")      = sum{i,IND, V1BAS(c,s,i)};
 (all,c,COM)(all,s,SRC) SALE(c,s,"Invest")      = sum{i,IND, V2BAS(c,s,i)};
 (all,c,COM)(all,s,SRC) SALE(c,s,"HouseH")      = V3BAS(c,s);
 (all,c,COM)            SALE(c,"dom","Export")  = V4BAS(c);
 (all,c,COM)            SALE(c,"imp","Export")  = 0;
 (all,c,COM)(all,s,SRC) SALE(c,s,"GovGE")       = V5BAS(c,s);
 (all,c,COM)(all,s,SRC) SALE(c,s,"Stocks")      = V6BAS(c,s);
 Write SALE to file SUMMARY header "SALE";
Coefficient (all,c,COM) V0IMP(c) # Total basic-value imports of good c #;
Formula     (all,c,COM) V0IMP(c) = sum{d,DEST, SALE(c,"imp",d)};
Coefficient (all,c,COM) SALES(c) # Total sales of domestic commodities #;
Formula     (all,c,COM) SALES(c) = sum{d,DEST, SALE(c,"dom",d)};
Coefficient (all,c,COM) DOMSALES(c) # Total sales to local market #;
Formula     (all,c,COM) DOMSALES(c) = SALES(c) - V4BAS(c);
Variable (change)
 (all,c,COM)(all,s,SRC)(all,d,DEST) delSale(c,s,d) # Sales aggregates #;
Equation
E_delSaleA (all,c,COM)(all,s,SRC) delSale(c,s,"Interm") =
                 0.01*sum{i,IND,V1BAS(c,s,i)*x1(c,s,i)};
E_delSaleB (all,c,COM)(all,s,SRC) delSale(c,s,"Invest") =
                 0.01*sum{i,IND,V2BAS(c,s,i)*x2(c,s,i)};
E_delSaleC (all,c,COM)(all,s,SRC) delSale(c,s,"HouseH")=0.01*V3BAS(c,s)*x3(c,s);
E_delSaleD (all,c,COM)            delSale(c,"dom","Export")=0.01*V4BAS(c)*x4(c);
E_delSaleE (all,c,COM)            delSale(c,"imp","Export")=   0;
E_delSaleF (all,c,COM)(all,s,SRC) delSale(c,s,"GovGE") =0.01*V5BAS(c,s)*x5(c,s);
E_delSaleG (all,c,COM)(all,s,SRC) delSale(c,s,"Stocks") = LEVP0(c,s)*delx6(c,s);
Set LOCUSER # Non-export users #(Interm, Invest, HouseH, GovGE, Stocks,Margins);
Subset LOCUSER is subset of DEST;
Equation E_p0A # Supply = Demand for domestic commodities #
(all,c,COM) 0.01*[TINY+DOMSALES(c)]*x0dom(c) =sum{u,LOCUSER,delSale(c,"dom",u)};
Variable (all,c,COM)  x0imp(c)       # Total supplies of imported goods #;
Equation E_x0imp # Import volumes #
 (all,c,COM) 0.01*[TINY+V0IMP(c)]*x0imp(c) = sum{u,LOCUSER,delSale(c,"imp",u)};
```

Excerpt 5.24 SAM extension

```
!labour balance!
Coefficient
(all, h, HOU)(all,o,OCCD)HHL(h,o) #household labour supply#;
(all,o,OCCD)HHL_H(o) #household labour supply#;
LTRW  #labour payment to foreign#;
RWTL #foreign labour in foreign firm#;
read
HHL from file BASEDATA header "HHL";
LTRW from file BASEDATA header "LTRW";
RWTL from file BASEDATA header "RWTL";
formula
(all,o,OCCD)HHL_H(o)=sum(h,HOU,HHL(h,o));
variable
(all, h, HOU)(all,o,OCCD)xHHL(h,o) #household labour supply#;
(all,o,OCCD)xHHL_H(o) #household labour supply#;
xLTRW  #labour payment to foreign#;
xRWTL #foreign labour in foreign firm#;
update
(all, h, HOU)(all,o,OCCD)HHL(h,o)=p1lab_i(o)*xHHL(h,o);
LTRW=p1lab_io*xLTRW;
RWTL=p1lab_io*xRWTL;
Equation
E_xHHL_H
(all,o,OCCD)HHL_H(o)*xHHL_H(o)=sum(i,IND,V1lab(i,o)*x1lab(i,o));
E_xHHL
(all, h, HOU)(all,o,OCCD)xHHL(h,o)=xHHL_H(o);
E_xLTRW
LTRW*xLTRW= RWTL*xRWTL+sum(i,IND,V1lab(i,"foreign")*x1lab(i,"foreign"));
!capital balance!
Coefficient
(all, h, HOU) HHK (h) #household capital contribution#;
HHK_H #household capital contribution#;
NFK #non-financial capital contribution#;
FFK #financial capital contribution#;
GGK #government capital contribution#;
read
HHK from file BASEDATA header "HHK";
NFK from file BASEDATA header "NFK";
FFK from file BASEDATA header "FFK";
GGK from file BASEDATA header "GGK";
formula
HHK_H=sum(h,HOU,HHK(h));
variable
(all, h, HOU) xHHK (h) #household capital contribution#;
xHHK_H #household capital contribution#;
xNFK #non-financial capital contribution#;
xFFK #financial capital contribution#;
xGGK #government capital contribution#;
fHHK_H #household capital contribution#;
fNFK #non-financial capital shifter#;
fFFK #financial capital shifter#;
fGGK #government capital shifter#;
update
(all, h, HOU)HHK(h)=p1cap_i*xHHK(h);
NFK=p1cap_i*xNFK;
FFK=p1cap_i*xFFK;
GGK=p1cap_i*xGGK;
Equation
E_xHHK_H
HHK_H*xHHK_H=sum(i,IND,V1cap(i)*x1cap(i));
E_xHHK
(all, h, HOU)xHHK(h)=xHHK_H;
E_xGGK
sum(h,HOU,HHK(h)*xHHK(h))+NFK*xNFK+FFK*xFFK+GGK*xGGK=
sum(i,IND,V1cap(i)*x1cap(i))+fHHK_H+fNFK+fFFK+fGGK;

!household account!
set LHOU # low income households#
(Decile1,Decile2,Decile3,Decile4,Decile5,Decile6);
subset LHOU is subset of HOU;
set HHOU # high income groups # = HOU-LHOU;
```

```
Coefficient
(all, h, HOU) HHLD (h) #household land income#;
HHLD_H  #household land income#;
(all, n, HOU)(all, h, HOU) HTH (n,h) #household n pay to household h#;
(all, h, HOU) NFTH (h) #non-financial transfer to household#;
(all, h, HOU) FTH (h) #financial transfer to household#;
(all, h, HOU) GTH (h) #government transfer to household#;
(all, h, HOU) RWTH (h) #foreign transfer to household#;
(all, h, HOU) HTNF (h) #household transfer to non-financial#;
(all, h, HOU) HTF (h) #household transfer to financial#;
(all, h, HOU) HTG (h) #household transfer to government#;
(all, h, HOU) HTRW (h) #household transfer to foreign#;
(all, h, HOU) HINC (h) #household saving#;
(all, h, HOU) HEXP (h) #household saving#;
(all, h, HOU) HHSV (h) #household saving#;
SUMGTH  #total government transfer to household#;
(all, h, HOU) S_GTH (h) #household social benift share#;
read
HHLD from file BASEDATA header "HHLD";
HTH from file BASEDATA header "HTH";
NFTH from file BASEDATA header "NFTH";
FTH from file BASEDATA header "FTH";
GTH from file BASEDATA header "GTH";
RWTH from file BASEDATA header "RWTH";
HTNF from file BASEDATA header "HTNF";
HTF from file BASEDATA header "HTF";
HTG from file BASEDATA header "HTG";
HTRW from file BASEDATA header "HTRW";
formula
HHLD_H=sum(h,HOU,HHLD(h));
(all, h, HOU) HINC (h)=sum(o,OCCD,HHL(h,o))+HHK(h)+HHLD(h)+sum(n,HOU,HTH(h,n))+
NFTH(h)+FTH(h)+GTH(h)+RWTH(h);
(all, h, HOU) HEXP (h)=V3TOTH(h)+sum(n,HOU,HTH(n,h))+HTNF(h)+HTF(h)+HTG(h)+HTRW(h);
(all, h, HOU) HHSV (h)=HINC(h)-HEXP(h);
SUMGTH=sum{h,HOU,GTH(h)};
(all, h, HOU) S_GTH(h)=GTH(h)/SUMGTH;
write HEXP to file SUMMARY header "HEXP";
write HINC to file SUMMARY header "HINC";
variable
(all, h, HOU) xHHLD (h) #household land income#;
xHHLD_H  #household land income#;
(all, n, HOU)(all, h, HOU) xHTH (n,h) #household n pay to household h#;
(all, h, HOU) xNFTH (h) #non-financial transfer to household#;
(all, h, HOU) xFTH (h) #financial transfer to household#;
(all, h, HOU) xGTH (h) #government transfer to household#;
(all, h, HOU) xRWTH (h) #foreign transfer to household#;
(all, h, HOU) xHTNF (h) #household transfer to non-financial#;
(all, h, HOU) xHTF (h) #household transfer to financial#;
(all, h, HOU) xHTG (h) #household transfer to government#;
(all, h, HOU) xHTRW (h) #household transfer to foreign#;
(all, h, HOU) xHINC (h) #household income#;
(all, h, HOU) xHEXP (h) #household expenditure#;
(change)(all, h, HOU) delHINC (h) #household income#;
(change)(all, h, HOU) delHEXP (h) #household expenditure#;
(all, h, HOU) xHHSV (h) #household savings#;
(all, h, HOU) f3lux(h)  #household consumption propensity shift#;
(all, h, HOU) delGTH(h) #nominal change of government transfer to households#;
(all, h, HOU) f1delGTH(h) #switch for carbontax revenue transfer to households#;
(all, h, HOU) f2delGTH(h) #switch for carbontax revenue transfer to households#;
(all, h, HOU) f3delGTH(h) #switch for carbontax revenue transfer to households#;
(all, h, LHOU) f4delGTH(h)#switch for carbontax revenue transfer to households#;
(change)f5delGST3 #switch for revenue transfer to reduce GST on households#;
update
(all, h, HOU)HHLD(h)=p1lnd_i*xHHLD(h);
(all, n, HOU)(all, h, HOU) HTH (n,h)=p3tot*xHTH(n,h);
(all, h, HOU)NFTH(h)=p3toth(h)*xNFTH(h);
(all, h, HOU)FTH(h)=p3toth(h)*xFTH(h);
(all, h, HOU)GTH(h)=p3toth(h)*xGTH(h);
(all, h, HOU)RWTH(h)=p3toth(h)*xRWTH(h);
(all, h, HOU)HTNF(h)=p3toth(h)*xHTNF(h);
(all, h, HOU)HTF(h)=p3toth(h)*xHTF(h);
(all, h, HOU)HTG(h)=p3toth(h)*xHTG(h);
(all, h, HOU)HTRW(h)=p3toth(h)*xHTRW(h);
Equation
E_w3luxh (all,h,HOU)w3luxh(h)=xHINC(h)-xHTG(h)+xGTH(h)+p3toth(h)+f3lux(h);
E_delHINC (all,h,HOU)delHINC(h)=0.01*HINC(h)*xHINC(h);
```

```
E_delHEXP (all,h,HOU)delHEXP(h)=0.01*HEXP(h)*xHEXP(h);
E_xHHLD_H HHLD_H*xHHLD_H=sum(i,IND,V1lnd(i)*x1lnd(i));
E_xHHLD (all,h,HOU) xHHLD(h)=xHHLD_H;
E_xHINC (all, h, HOU) HINC(h)*xHINC(h)=sum(o,OCCD,HHL(h,o)*xHHL(h,o))+HHK(h)*xHHK(h)+
HHLD(h)*xHHLD(h)+sum(n,HOU,HTH(h,n)*xHTH(h,n))+NFTH(h)*xNFTH(h)+FTH(h)*xFTH(h)+GTH(h)*
xGTH(h)+RWTH(h)*xRWTH(h);
E_xHEXP (all, h, HOU) HEXP(h)*xHEXP(h)=V3TOTH(h)*x3toth(h)+sum(n,HOU,HTH(n,h)*xHTH(n,h))
+HTNF(h)*xHTNF(h)+HTF(h)*xHTF(h)+HTG(h)*xHTG(H)+HTRW(h)*xHTRW(H);
E_xHHSV (all, h, HOU) HHSV(h)*xHHSV(h)=HINC(h)*xHINC(h)-HEXP(h)*xHEXP(h);
E_XGTH (all, h, HOU) delGTH(h)=0.01*GTH(h)*xGTH(h);

!non-financial coporation account!
Coefficient
NFTN  #non-financial transfer to non-financial#;
FTNF  #financial transfer to non-financial#;
GTNF  #government transfer to non-financial#;
RWTN  #foreign transfer to non-financial#;
NFTF  #non-financial transfer to financial#;
NFTG  #non-financial transfer to government#;
NTRW  #non-financial transfer to foreign#;
NINC  #non-financial coporrate income#;
NEXP  #non-financial coporrate expenditure#;
NFSV  #non-financial coporrate saving#;
read
NFTN from file BASEDATA header "NFTN";
FTNF from file BASEDATA header "FTNF";
GTNF from file BASEDATA header "GTNF";
RWTN from file BASEDATA header "RWTN";
NFTF from file BASEDATA header "NFTF";
NFTG from file BASEDATA header "NFTG";
NTRW from file BASEDATA header "NTRW";
formula
NINC =NFK+sum(h,HOU,HTNF(h))+NFTN+FTNF+GTNF+RWTN;
NEXP =sum(h,HOU,NFTH(h))+NFTN+NFTF+NFTG+NTRW;
NFSV =NINC-NEXP;
variable
xNFTN  #non-financial transfer to non-financial#;
xFTNF  #financial transfer to non-financial#;
xGTNF  #government transfer to non-financial#;
xRWTN  #foreign transfer to non-financial#;
xNFTF  #non-financial transfer to financial#;
xNFTG  #non-financial transfer to government#;
xNTRW  #non-financial transfer to foreign#;
xNINC  #non-financial coporrate income#;
xNEXP  #non-financial coporrate expenditure#;
xNFSV  #non-financial coporrate saving#;
update
NFTN=p3tot*xNFTN;
FTNF=p3tot*xFTNF;
GTNF=p3tot*xGTNF;
RWTN=p3tot*xRWTN;
NFTF=p3tot*xNFTF;
NFTG=p3tot*xNFTG;
NTRW=p3tot*xNTRW;
Equation
E_xNINC
NINC*xNINC=NFK*xNFK+sum(h,HOU,HTNF(h)*xHTNF(h))+ NFTN*xNFTN+FTNF*xFTNF+GTNF*xGTNF+
RWTN*xRWTN;
E_xNEXP
NEXP*xNEXP =sum(h,HOU,NFTH(h)*xNFTH(h))+ NFTN*xNFTN+NFTF*xNFTF+NFTG*xNFTG+
NTRW*xNTRW;
E_xNFSV
NFSV*xNFSV =NINC*xNINC-NEXP*xNEXP;
!financial coporation account!
Coefficient
FTF  #financial transfer to financial#;
GTF  #financial transfer to financial#;
RWTF  #foreign transfer to financial#;
FTG  #financial transfer to government#;
FTRW  #financial transfer to foreign#;
FINC  #financial coporrate income#;
FEXP  #financial coporrate expenditure#;
FFSV  #financial coporrate saving#;
read
FTF from file BASEDATA header "FTF";
GTF from file BASEDATA header "GTF";
```

```
RWTF from file BASEDATA header "RWTF";
FTG from file BASEDATA header "FTG";
FTRW from file BASEDATA header "FTRW";
formula
FINC =FFK+sum(h,HOU,HTF(h))+NFTF+FTF+GTF+RWTF;
FEXP =sum(h,HOU,FTH(h))+FTNF+FTF+FTG+FTRW;
FFSV =FINC-FEXP;
variable
xFTF  #financial transfer to financial#;
xGTF  #financial transfer to financial#;
xRWTF  #foreign transfer to financial#;
xFTG  #financial transfer to government#;
xFTRW  #financial transfer to foreign#;
xFINC  #financial coporrate income#;
xFEXP  #financial coporrate expenditure#;
xFFSV  #financial coporrate saving#;
update
FTF=p3tot*xFTF;
GTF=p3tot*xGTF;
RWTF=p3tot*xRWTF;
FTG=p3tot*xFTG;
FTRW=p3tot*xFTRW;
Equation
E_xFINC
FINC*xFINC=FFK*xFFK+sum(h,HOU,HTF(h)*xHTF(h))+ NFTF*xNFTF+FTF*xFTF+GTF*xGTF+RWTF*xRWTF;
E_xFEXP
FEXP*xFEXP =sum(h,HOU,FTH(h)*xFTH(h))+FTNF*xFTNF+FTF*xFTF+FTG*xFTG+FTRW*xFTRW;
E_xFFSV
FFSV*xFFSV =FINC*xFINC-FEXP*xFEXP;
!government account!
Coefficient
GTG  #governmetn transfer to government#;
RWTG  #foreign transfer to government#;
GTRW  #government transfer to foreign#;
GINC  #government  income#;
GEXP  #government  expenditure#;
GGSV  #government  saving#;
SUBG # governement production subsidy#;
read
GTG from file BASEDATA header "GTG";
RWTG from file BASEDATA header "RWTG";
GTRW from file BASEDATA header "GTRW";
SUBG from file BASEDATA header "SUBG";
formula
GINC =sum(i,IND,sum(c,COM,sum(s,SRC,V1TAX(c,s,i)+V2TAX(c,s,i))+TX1CI(c,i)+
TX1CO(c,i))+V1PTX(i))+sum(c,COM,sum(h,HOU,sum(s,SRC,V3TAH(c,s,h))+TX3CC(c,h))+
V4TAX(c)+sum(s,SRC,V5TAX(c,s)))+V0TAR_C+GGK+sum(h,HOU,HTG(h))+NFTG+FTG+GTG+RWTG;
GEXP =V5TOT+sum(h,HOU,GTH(h))+GTNF+GTF+GTG+GTRW+SUBG;
GGSV =GINC-GEXP;
variable
xGTG  #governmetn transfer to government#;
xRWTG  #foreign transfer to government#;
xGTRW  #government transfer to foreign#;
xGINC  #government  income#;
xGEXP  #government  expenditure#;
xGGSV  #government  saving#;
xSUBG # government subsidy #;
update
GTG=p3tot*xGTG;
RWTG=p3tot*xRWTG;
GTRW=p3tot*xGTRW;
SUBG=p3tot*xSUBG;
Equation
E_xGINC
GINC*xGINC=sum{i,IND,sum{c,COM,sum{s,SRC,delV1TAX(c,s,i)+delV2TAX(c,s,i)}+delTX1CI(c,i)+
delTX1CO(c,i)}+delV1PTX(i)}+delV0TAR_C+sum(c,COM,sum(h,HOU,sum(s,SRC,delV3TAH(c,s,h))+
delTX3CC(c,h)))+{GGK*xGGK+sum(h,HOU,HTG(h)*xHTG(h))+NFTG*xNFTG+FTG*xFTG+GTG*xGTG+
RWTG*xRWTG};
E_xGEXP
GEXP*xGEXP =V5TOT*x5TOT+sum(h,HOU,GTH(h)*xGTH(h))+ GTNF*xGTNF+GTF*xGTF+
GTG*xGTG+GTRW*xGTRW+SUBG*xSUBG;
E_xGGSV
GGSV*xGGSV =GINC*xGINC-GEXP*xGEXP;
!external account!
Coefficient
RWRW  #foreign transfer to goreign#;
```

```
RINC  #ROW  income#;
REXP  #ROW  expenditure#;
RWSV  #ROW  saving#;
read
RWRW from file BASEDATA header "RWRW";
formula
RINC =sum(c,COM,sum(i,IND,V1BAS(c,"imp",i)+V2BAS(c,"imp",i))+
      sum(h,HOU,V3BAH(c,"imp",h))+V5BAS(c,"imp")+V6BAS(c,"imp"))+
      LTRW+sum(h,HOU,HTRW(h))+NTRW+FTRW+GTRW+RWRW;
REXP =V4TOT+RWTL+sum(h,HOU,RWTH(h))+RWTN+RWTF+RWTG+RWRW;
RWSV =RINC-REXP;
variable
xRWRW  #foreign transfer to foreign#;
xRINC  #ROW  income#;
xREXP  #ROW  expenditure#;
xRWSV  #ROW  saving#;
update
RWRW=p3tot*xRWRW;
Equation
E_xRINC
RINC*xRINC=sum(c,COM,sum(i,IND,V1BAS(c,"imp",i)*x1(c,"imp",i)+
     V2BAS(c,"imp",i)*x2(c,"imp",i))+sum(h,HOU,V3BAH(c,"imp",h)*x3h(c,"imp",h))+
     V5BAS(c,"imp")*x5(c,"imp")+delx6(c,"imp"))+LTRW*xLTRW+
     sum(h,HOU,HTRW(h)*xHTRW(h))+NTRW*xNTRW+FTRW*xFTRW+GTRW*xGTRW+RWRW*xRWRW;
E_xREXP
REXP*xREXP =V4TOT*x4TOT+RWTL*xRWTL+sum(h,HOU,RWTH(h)*xRWTH(h))+ RWTN*xRWTN+RWTF*xRWTF+
RWTG*xRWTG+RWRW*xRWRW;
E_xRWSV
RWSV*xRWSV =RINC*xRINC-REXP*xREXP;
```