CHAPTER 9

Computable General Equilibrium Modeling of Environmental Issues in Australia: Economic Impacts of an Emissions Trading Scheme

Philip D. Adams*, Brian R. Parmenter,†**

*Centre of Policy Studies, Monash University
**Queensland Competition Authority

Abstract

A key distinguishing characteristic of computable general equilibrium (CGE) modeling in Australia is its orientation to providing inputs to the policy-formation process. Policy makers require detail. They want to be able to identify convincingly which industries, which occupations, which regions and which households would benefit or lose from policy changes, and when the benefits or losses might be expected to flow. In this chapter, we explain how the necessary level of detail can be provided, using as an example analysis that was undertaken by Centre of Policy Studies (CoPS) and Frontier Economics of the potential economic impacts of a carbon price on the Australian economy. The Australian carbon price framework is assumed to be part of a global emissions trading scheme (ETS). Over time, the global ETS becomes the dominant greenhouse abatement policy for all countries including Australia. It sets the price for carbon permits and allocates the number of permits available to each country. A number of key findings emerge from the CGE simulations of the effects of the ETS policy. (i) Domestic abatement falls well short of targeted abatement, requiring significant amounts of permits to be imported. (ii) Despite the requirement for deep cuts in emissions, the ETS reduces Australia's GDP by only about 1.1% relative to the base case in 2030. The negative impact on real household consumption (the preferred measure of national welfare) is somewhat greater, reflecting the need to import permits. (iii) The national macroeconomic impacts of the ETS might be described as modest in the context of the policy task. However, this does not carry through to the industry and state/territory levels where some industries and regions prove particularly vulnerable in terms of potential lost employment. The need for detail is highlighted throughout the analysis. For example, a suitably detailed treatment of electricity supply is provided by linking CoPS' CGE model with Frontier's detailed bottom-up model of the stationary energy sector. Similarly, necessary detail on the effects of the global ETS on Australia's international trading conditions is provided by linking with a multicountry model.

Keywords

Emissions trading, Australia, CGE modeling

JEL classification codes

C68, Q52, Q58

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9.1 INTRODUCTION

The key distinguishing characteristic of computable general equilibrium (CGE) modeling in Australia is its orientation to providing inputs to the policy-formation process. This reflects the history of the funding of CGE research. Australia's best-known CGE modeling group — the team now located in the Centre of Policy Studies (CoPS) at Monash University — was originally established in 1975 by the Australian Government under an interagency arrangement — the IMPACT Project — administered by the (then) Industry Commission (now the Productivity Commission). Since then, Australian government departments, principally the Productivity Commission and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), have continued to support CGE research and have maintained substantial in-house modeling capabilities. Universities, principally Monash University, have played an important role in the development of CGE models in Australia, but the focus of the work has always been as much on practical application of the models as on contributing to the academic literature.

Policy makers require detail. They want to be able to identify convincingly which industries, which occupations, which regions and which households would benefit or lose from policy changes, and when the benefits or losses might be expected to flow. Economic theory alone, or stylized general equilibrium analysis, is not well suited to meeting information demands at this level of detail. However, combining the theory in a CGE framework with disaggregated input-output data, labor force survey statistics, data on the sector composition of the regional economies, and household income and expenditure data provides the tool that policy makers require.

Starting in the early 1990s, greenhouse gas emissions, global warming and climate change emerged as prime policy concerns in Australia, culminating in 2007 with the Australian government's decision to ratify the Kyoto Protocol and to attempt to introduce a greenhouse gas emissions trading scheme (ETS). CGE modeling has played a prominent role in informing Australia's emissions policy debate.[1]

As in earlier policy debates (e.g. about trade liberalization), detail has been a key issue for economic modelers engaged in the emissions debate. In this context, modelers face a number of questions relating to model, data and simulation design.

- Stationary energy accounts for more than 50% of Australia's greenhouse gas emissions. At what level of detail must the stationary energy sector be modeled for the effects of policy on its emissions to be captured adequately? And is the required level of detail better provided by augmenting the representation of the sector inside the CGE model or by linking the CGE model with a detailed bottom-up model of the stationary energy sector?

[1] Academic contributions started with Dixon *et al*. (1990) and Dixon and Johnson (1990), followed by McDougall and Dixon (1996), and McKibbin and Pearce (1996).

- Investment in electricity generation (and many other branches of heavy industry, including energy-intensive minerals processing) is typically lumpy, not smooth. Is it necessary to include this lumpiness explicitly in CGE computations of the effects of climate change policy? To what aspects of the results does lumpiness matter?
- Concern about greenhouse gas emissions centers on a global externality problem. Does this mean that the consequences of emissions policy can only be investigated using a global model? In any case, the domestic effects of a particular country's policy will depend on what other countries do. If a single-country model is used to analyze the domestic policy effects, how can the effects of foreign countries' policies be included?
- Emissions policy is policy for the long term, with the underlying global externality and many abatement options involving complex dynamics. It is now common for CGE models to have dynamic or quasidynamic structures, but what dynamic mechanisms are required to make a meaningful input to decisions about emissions policy? For example, do we need agents with full intertemporal optimization or will recursive dynamics do?
- The possibility of international emissions leakage is a problem that proponents of unilateral emissions policy must face. What representation of a country's emissions-intensive trade-exposed industries (EITEIs) is required to handle this?
- The energy consumption of end users (including households) is conditioned by their investment decisions about energy-using equipment (appliances, vehicles, etc.) – another aspect of the dynamics of emissions policy. National-accounts-based models do not handle this well as far as households are concerned. How should energy usage be treated in the household consumption specification of a model to be used for the analysis of emissions policy?
- Emissions-intensive industries, especially in the energy sector, tend to be geographically concentrated, due mainly to the availability of primary energy sources – fossil or renewable. Hence, emissions policy could have significant regional effects. How can policy models inform policy makers about such effects?
- Carbon taxes and most ETSs would raise large amounts of government revenue and increase consumer prices. What effect will the recycling of this revenue have on the efficiency costs of the policy and on income distribution? To deal adequately with these issues, a policy model will need a detailed representation of the country's fiscal system and the ability to identify the income-distribution consequences of policy options.

In this chapter, how these issues have been handled by Australian CGE modelers is explained. This is done using an example: the analysis of the potential impacts on the Australian economy of a carbon price policy outlined in the Government's *Carbon Pollution Reduction Scheme Green Paper* (Department of Climate Change, 2008;

Department of Treasury, 2008) and the Garnaut Climate Change Review (Garnaut, 2008). The policy is assumed to apply as part of a global ETS. Over time, the global ETS becomes the dominant emissions abatement policy for all countries, including Australia. It sets the price for carbon permits and allocates the number of permits available to each country.

The analysis relies on a series of applications of three CGE models developed in Australia: the Global Trade and Environment Model (GTEM) (Pant, 2007), the G-Cubed model (McKibbin and Wilcoxen, 1998) and the Monash Multi-Regional Forecasting model (MMRF) (Adams *et al.*, 2011).[2] GTEM and G-Cubed are multi-country models. MMRF is a single-country multiregional model of Australia and its six states and two territories.

Much of the modeling of the global aspects of the ETS was undertaken using the GTEM model. Information from GTEM was then used to inform simulations of MMRF.[3] The role of MMRF was to supply estimates of the effects of the scheme on the Australian economy at the level of detail required by the policy makers. A key dimension was detail about the electricity system. To cover this, MMRF was linked to a specialized bottom-up model of the Australian electricity system. In the original work commissioned by the Treasury and the Garnaut Review, the electricity modeling was conducted by the consulting firm McLennan, Magasanik and Associates (MMA), using their probabilistic simulation model of the electricity market.[4] Subsequent studies were undertaken with the consulting firm Frontier Economics, using Frontier's *WHIRLYGIG* model of electricity supply (Frontier Economics, 2009). The latter studies also contained updated base-case assumptions and updated views about growth of Australia's trading partners with and without a global ETS. The results discussed in this Chapter are from these latter simulations.

The rest of the chapter is organized as follows. A brief general description of MMRF is given in Section 9.2. In Section 9.3 the enhancements of the general form of the model that were necessary for the ETS modeling are described. Specific items discussed are:

- linking with GTEM and with the detailed electricity model;
- modeling the free allocation of permits to shield emissions-intensive, trade-exposed industries during the period of transition to a full global ETS;
- modeling abatement of non-combustion emissions in response to an emissions price;
- land—land substitution in agriculture and forestry.

2 MMRF and GTEM are solved using GEMPACK software (Harrison and Pearson, 1996). An overview of the current version of GEMPACK is given in Harrison and Pearson (2002).

3 G-Cubed was broadly calibrated to the GTEM base-case scenario and provided comparative global cost estimates for the policy scenarios based on different rate-of-adjustment assumptions for global capital markets.

4 An overview of MMA's suite of models covering the National Electricity Market (NEM), South West Interconnected System (SWIS) and the Darwin Katherine Interconnected System (DKIS) is given in MMA (2008).

Aspects of simulation design are given in Section 9.4 (the base case) and Section 9.5 (the policy simulation), including the exogenous shocks that drive the policy simulations. The effects of the shocks are given in Section 9.6 as deviations between the values of variables in the policy simulation and their values in the base case. The discussion of results in Section 9.6 focuses on explaining outcomes in a sequential way. National outcomes are dealt with first, then results for states and territories, and finally results for substate regions. The rationalization of macro results draws on a stylized model containing MMRF's principal macro mechanisms. An Appendix contains a description of the stylized model. Concluding remarks are in Section 9.7.

9.2 MMRF

9.2.1 Overview

MMRF is a dynamic, multisector, multiregion model of Australia. The current version of the model distinguishes 58 industries (Table 9.1), 63 products produced by the 58 industries, eight states/territories and 56 substate regions. At the state/territory level, it is

Table 9.1 Industries in MMRF[a]

Name	Description of major activity
1. Sheep and beef cattle	Sheep and cattle production
2. Dairy cattle	Raw milk and dairy cattle
3. Other livestock	Activities associated with other animals
4. Grains	Grains production
5. Other agriculture	Other primary agricultural production
6. Agricultural services, fishing, hunting	Agricultural services, fishing, hunting
7. Forestry	Logging and forestry services
8. Coal mining	Mining of coal
9. Oil mining	Mining of oil
10. Gas mining	Production of natural gas at well
11. Iron ore mining	Mining of iron ore
12. Non-ferrous ore mining	Mining of ore other than iron
13. Other mining	Other mining activity
14. Meat and meat products	Processed food related to animal
15. Other food, beverages and tobacco	Other food and drink products
16. Textiles, clothing and footwear	Textiles, clothing and footwear
17. Wood products	Manufacture of wood products
18. Paper products	Manufacture of paper products
19. Printing and publishing	Printing and publishing
20. Petroleum products	Manufacture of petroleum (refinery) products
21. Basic chemicals	Manufacture of basic chemicals and paints
22. Rubber and plastic products	Manufacture of plastic and rubber products

(*Continued*)

Table 9.1 Industries in MMRF[a]—cont'd

Name	Description of major activity
23. Non-metal construction products	Non-metallic building products excl. cement
24. Cement	Manufacture of cement
25. Iron and steel	Manufacture of primary iron and steel
26. Alumina	Manufacture of alumina
27. Aluminum	Manufacture of aluminum
28. Other non-ferrous metals	Manufacture of other non-ferrous metals
29. Metal products	Manufacture of metal products
30. Motor vehicles and parts	Manufacture of motor vehicles and parts
31. Other manufacturing	Manufacturing non elsewhere classified
32. Electricity generation-coal	Electricity generation from coal
33. Electricity generation-gas	Electricity generation from natural gas
34. Electricity generation-oil products	Electricity generation from oil products
35. Electricity generation-nuclear	Electricity generation from nuclear
36. Electricity generation-hydro	Electricity generation from hydro
37. Electricity generation-other	Electricity generation from other renewable
38. Electricity supply	Distribution of electricity; generator to user
39. Gas supply	Urban distribution of natural gas
40. Water supply	Provision of water and sewerage services
41. Construction services	Residential and other construction services
42. Trade services	Provision of wholesale and retail trade services
43. Accommodation, hotels and cafes	Accommodation, meal and drink services
44. Road passenger transport	Provision of road transport services – passenger
45. Road freight transport	Provision of road transport services – freight
46. Rail passenger transport	Provision of rail transport services – passenger
47. Rail freight transport	Provision of rail transport services – freight
48. Water, pipeline and transport services	Provision of water transport services
49. Air transport	Provision of air transport services
50. Communication services	Provision of communication services
51. Financial services	Provision of financial services
52. Business services	Provision of business services
53. Dwelling services	Provision of dwelling services
54. Public services	Government and community services
55. Other services	Provision of services not elsewhere classified
56. Private transport services	Provision of services to households from the stock of motor vehicles
57. Private electricity equipment services	Provision of services to households from the stock of electrical equipment
58. Private heating services	Provision of services to households from the stock of heating equipment

[a]For most of the industries identified in this table there is an obvious correspondence to one or more standard categories in the Australian and New Zealand Standard Industrial Classification (ANZSIC), 2006 version. The exceptions are: industries 32–38, which together comprise ANZSIC 26 *Electricity Supply*; industry 53, which is equivalent to the *Ownership of dwellings* industry in the industrial classification of the official Input/output statistics; and industries 56–58, which relate to the provision of services from the private stocks of motor vehicles, electrical equipment (not heating) and heating equipment.

a fully specified bottom-up system of interacting regional economies. A top-down approach is used to estimate the effects of the policy at the substate level.

Of the 58 industries, three produce primary fuels (coal, oil and gas), one produces refined fuel (petroleum products), six generate electricity and one supplies electricity to final customers. The six generation industries are defined according to primary source of fuel: *Electricity-coal* includes all coal-fired generation technologies; *Electricity-gas* includes all plants using turbines, cogeneration and combined cycle technologies driven by burning gas; *Electricity-oil products* covers all liquid-fuel generators; *Electricity-hydro* covers hydro generation; and *Electricity-other* covers the remaining forms of renewable generation from biomass, biogas, wind, etc. Nuclear power generation is not currently used in Australia, but *Electricity-nuclear* is included and could be triggered, if desired, at a specified emissions price.

Apart from *Grains* (industry 4) and *Petroleum products* (industry 20), industries produce single products. *Grains* produces grains for animal and human consumption and biofuel used as feedstock by *Petroleum products*. *Petroleum products* produces gasoline, (including gasoline-based biofuel blends), diesel (including diesel-based biofuel blends), LPG, aviation fuel and other refinery products (mainly heating oil).

9.2.2 General equilibrium core

9.2.2.1 Nature of markets

MMRF determines regional supplies and demands of commodities through optimizing behavior of agents in competitive markets. Optimizing behavior also determines industry demands for labor and capital. Labor supply at the national level is determined by demographic factors, while national capital supply responds to rates of return. Labor and capital can cross regional borders in response to relative regional employment opportunities and relative rates of return.

The assumption of competitive markets implies equality between the basic price (i.e. the price received by the producer) and marginal cost in each regional sector. Demand is assumed to equal supply in all markets other than the labor market (where excess-supply conditions can hold). The government intervenes in markets by imposing *ad valorem* sales taxes on commodities. This places wedges between the prices paid by purchasers and the basic prices received by producers. The model recognizes margin commodities (e.g. retail trade and road transport) that are required for the movement of a commodities from producers to the purchasers. The costs of the margins are included in purchasers' prices of goods and services.

9.2.2.2 Demands for inputs to be used in the production of commodities

MMRF recognizes two broad categories of inputs: intermediate inputs and primary factors. Firms in each regional sector are assumed to choose the mix of inputs that minimizes the costs of production for their levels of output. They are constrained in their choices by a three-level nested production technology. At the first level, intermediate-input bundles and a primary-factor bundle are used in fixed proportions to output.[5] These bundles are formed at the second level. Following Armington (1969), intermediate-input bundles are combinations of domestic goods and goods imported from overseas. The primary-factor bundle is a combination of labor, capital and land. At the third level, inputs of domestic goods are formed as combinations of goods sourced from each of the eight domestic regions and the input of labor is formed as a combination of inputs from nine occupational categories.

9.2.2.3 Domestic final demand: household, investment and government

In each region, the household buys bundles of goods to maximize a utility function subject to an expenditure constraint. The bundles are combinations of imported and domestic goods, with domestic goods being combinations of goods from each domestic region. A Keynesian consumption function is usually used to determine aggregate household expenditure as a function of household disposable income (HDI).

Capital creators for each regional sector combine inputs to form units of capital. In choosing these inputs, they minimize costs subject to a technology similar to that used for current production, with the main difference being that they do not use primary factors directly.

State/territory governments and the Federal government demand commodities from each region. In MMRF, there are several ways of handling these government demands, including:

- by a rule such as moving government expenditures with aggregate household expenditure, domestic absorption or GDP;
- as an instrument to accommodate an exogenously determined target such as a required level of government budget deficit;
- exogenous determination.

9.2.2.4 Foreign demand (international exports)

MMRF adopts the ORANI[6] specification of foreign demand. Each export-oriented sector in each state or territory faces its own downward-sloping foreign demand curve. Thus, a shock that reduces the unit costs of an export sector will increase the quantity exported, but reduce the foreign currency price. By assuming that the foreign demand schedules are specific to product and region of production, the

5 A miscellaneous input category, *Other costs*, is also included and required in fixed proportion to output. The price of O*ther costs* is indexed to the price of private consumption. It is assumed that the income from *Other costs* accrues to the government.

6 MMRF and MONASH (Dixon and Rimmer, 2002) have evolved from the Australian ORANI model (Dixon *et al*., 1977, 1982).

model allows for differential movements in foreign currency prices across domestic regions.

9.2.2.5 Regional labor markets

The response of regional labor markets to policy shocks depends on the treatment of three key variables – regional labor supplies, regional unemployment rates and regional wage differentials. The main alternative treatments are:

- to set regional labor supplies and unemployment rates exogenously and determine regional wage differentials endogenously;
- to set regional wage differentials and regional unemployment rates exogenously and determine regional labor supplies endogenously (via interstate migration or changes in regional participation rates);
- to set regional labor supplies and wage differentials exogenously and determine regional unemployment rates endogenously.

The second treatment is the one adopted for the ETS simulations reported in this chapter, with regional participation rates exogenous. Under this treatment, workers move freely (and instantaneously) across state borders in response to changes in relative regional unemployment rates. With regional wage rates indexed to the national wage rate, regional employment is demand determined.

9.2.2.6 Physical capital accumulation

Investment undertaken in year t is assumed to become operational at the start of year $t+1$. Under this assumption, capital in industry i in region q accumulates according to:

$$K_{i,q}(t+1) = (1 - DEP_{i,q}) \times K_{i,q}(t) + Y_{i,q}(t), \tag{9.1}$$

where $K_{i,q}(t)$ is the quantity of capital available in industry i in region q at the start of year t, $Y_{i,q}(t)$ is the quantity of new capital created in industry i in region q during year t and $DEP_{i,q}$ is the rate of depreciation for industry i in region q. Given a starting value for capital in $t=0$, and with a mechanism for explaining investment, equation (9.1) traces out the time paths of industries' capital stocks.

Following the approach taken in the MONASH model (Dixon and Rimmer, 2002, section 16), investment in year t is explained via a mechanism of the form:

$$\frac{K_{i,q}(t+1)}{K_{i,q}(t)} = F_{i,q}\left[\frac{EROR_{i,q}(t)}{RROR_{i,q}(t)}\right], \tag{9.2}$$

where $EROR_{i,q}(t)$ is the expected rate of return in year t, $RROR_{i,q}(t)$ is the required rate of return on investment in year t and $F_{i,q}$ is an increasing function of the ratio of expected to required rate of return. In standard closures of the model, *RROR* is an exogenous variable which can be moved to achieve a given growth rate in capital

In the current version of MMRF, it is assumed that investors take account only of current rentals and asset prices when forming expectations about rates of return (static expectations). An alternative treatment available in the MONASH model, but not currently for MMRF, allows investors to form expectations about rates of return that are consistent with model-determined present values of the rentals earned from investing $A1 in year t (rational expectations).[7]

9.2.2.7 Lagged adjustment process in the national labor market

The ETS simulations are year-to-year recursive-dynamic simulations, in which it is assumed that the national real wage rate deviates from its base-case level in inverse proportion to deviations in the national unemployment rate. That is, in response to a shock-induced increase (decrease) in the unemployment rate, the real wage rate declines (increases), stimulating (reducing) employment growth. The coefficient of adjustment is chosen so that effects of a shock on the unemployment rate are largely eliminated after about ten years. This is consistent with macroeconomic modeling in which the NAIRU (non-accelerating inflation rate of unemployment) is exogenous.

Given the treatment of regional labor markets outlined in Section 9.2.2.5, if the national real wage rate rises (falls) in response to a fall (rise) in the national unemployment rate, then wage rates in all regions rise (fall) by the same percentage amount, and regional employment adjusts immediately, with regional labor supplies adjusting to stabilize relative regional unemployment rates.

9.2.3 Environmental enhancements

In this subsection, the key environmental enhancements of MMRF to facilitate the ETS study are described. These are:

- an accounting module for energy and greenhouse gas emissions that covers each emitting agent, fuel and region recognized in the model;
- quantity-specific carbon taxes or prices;
- equations for interfuel substitution in transport and stationary energy;
- a representation of Australia's National Electricity Market (NEM);
- an improved treatment of energy-using equipment in private household demand.

9.2.3.1 Energy and emissions accounting

MMRF tracks emissions of greenhouse gases according to: emitting agent (58 industries and the household sector), emitting state or territory (8) and emitting

[7] The treatment of rational expectations in the MONASH model is discussed in Dixon *et al.* (2005).

activity (9). Most of the emitting activities are the burning of fuels (coal, natural gas and five types of petroleum products). A residual category, named *Activity*, covers non-combustion emissions such as emissions from mines and agricultural emissions not arising from fuel burning. *Activity* emissions are assumed to be proportional to the level of activity in the relevant industries (animal-related agriculture, gas mining, cement manufacture, etc.).

The resulting $59 \times 8 \times 9$ array of emissions is designed to include all emissions except those arising from land clearing. Emissions are measured in terms of carbon dioxide equivalents (CO_2-e). Table 9.2 summarizes MMRF's emission data for the starting year of the simulations − the financial year 2006. Note that MMRF accounts for domestic emissions only; emissions from combustion of Australian coal

Table 9.2 Summary of MMRF emissions data for Australia, 2005−2006 (kt of CO_2-e)

	Source of emissions (fuel and non-fuel)				
Fuel user	**Coal**	**Gas**	**Refinery**	**Non-fuel**	**Total**
1. Sheep and beef cattle	0.0	1.3	1179.6	70179.0	71360.0
2. Dairy cattle	0.0	0.4	483.8	9297.0	9781.3
3. Other livestock	0.0	0.7	192.4	2983.0	3176.1
4. Grains	0.0	0.8	1650.1	2399.0	4050.0
5. Other agriculture	0.0	0.7	1248.3	3085.0	4333.9
6. Ag services, fishing, hunting	0.0	1.2	1231.2	13.0	1245.5
7. Forestry	0.0	0.0	473.6	−19610.0	−19136.4
8. Coal mining	0.0	0.0	2761.5	21610.0	24371.5
9. Oil mining	0.0	0.0	136.4	818.0	954.3
10. Gas mining	0.0	8991.0	263.2	6360.0	15614.1
11. Iron ore mining	37.1	312.0	321.8	0.0	670.9
12. Non-ferrous ore mining	699.9	660.0	3699.9	1634.0	6693.7
13. Other mining	0.0	0.0	926.4	0.0	926.4
14. Meat and meat products	78.7	83.2	21.1	0.0	182.9
15. Other food and drink	718.4	1529.8	124.8	0.0	2373.0
16. Textiles, clothing, footwear	2.8	350.3	12.8	0.0	365.9
17. Wood products	371.1	96.1	14.1	0.0	481.4
18. Paper products	606.7	682.3	17.2	704.0	2010.3
19. Printing and publishing	13.0	174.0	32.6	0.0	219.6
20. Petroleum products	0.0	1255.1	4740.4	490.0	6485.5
21. Basic chemicals	507.0	1332.2	2073.0	2513.0	6425.2
22. Rubber, plastic products	27.0	982.9	398.0	0.0	1407.9
23. Other construction products	404.2	1814.1	156.4	1499.0	3873.7
24. Cement	2004.8	1011.9	406.5	4738.0	8161.2
25. Iron and steel	3532.0	1295.0	170.4	8961.0	13958.5
26. Alumina	3488.7	3023.6	1958.9	0.0	8471.2

(*Continued*)

Table 9.2 Summary of MMRF emissions data for Australia, 2005—2006 (kt of CO_2-e)—cont'd

	Source of emissions (fuel and non-fuel)				
Fuel user	**Coal**	**Gas**	**Refinery**	**Non-fuel**	**Total**
27. Aluminum	0.0	0.0	291.6	4642.0	4933.6
28. Other non-ferrous metals	1778.1	3380.8	481.0	0.0	5640.0
29. Metal products	0.0	76.6	25.6	0.0	102.2
30. Motor vehicles and parts	0.0	62.1	20.5	0.0	82.5
31. Other manufacturing	97.1	228.0	73.3	674.0	1072.4
32. Electricity-coal	179163.0	0.0	0.0	0.0	179163.0
33. Electricity-gas	0.0	14573.0	0.0	0.0	14573.0
34. Electricity-oil products	0.0	0.0	1042.3	0.0	1042.3
35. Electricity-nuclear	0.0	0.0	0.0	0.0	0.0
36. Electricity-hydro	0.0	0.0	0.0	0.0	0.0
37. Electricity-other	0.0	0.0	0.0	0.0	0.0
38. Electricity supply	0.0	0.0	662.6	0.0	662.6
39. Gas supply	0.0	0.0	15.5	2132.0	2147.5
40. Water supply	0.0	0.0	307.4	0.0	307.4
41. Construction services	0.0	159.3	1696.7	0.0	1856.0
42. Trade services	0.0	1490.4	5299.0	361.0	7150.4
43. Accommodation, etc.	0.0	232.9	705.3	302.0	1240.2
44. Road passenger transport	0.0	5.6	2371.0	728.0	3104.7
45. Road freight transport	0.0	71.5	22468.7	0.0	22540.3
46. Rail passenger transport	0.0	0.0	341.3	0.0	341.3
47. Rail freight transport	0.0	0.0	1793.6	0.0	1793.6
48. Water transport	0.0	4.1	2657.8	0.0	2661.8
49. Air transport	0.0	0.0	5136.3	0.0	5136.3
50. Communication services	0.0	98.2	1574.1	0.0	1672.3
51. Financial services	0.0	2.3	3.2	0.0	5.6
52. Business services	0.0	262.3	1635.9	0.0	1898.2
53. Dwelling services	0.0	5.4	18.5	0.0	23.9
54. Public services	0.0	187.4	1867.9	0.0	2055.4
55. Other services	0.0	44.1	1634.0	17037.0	18715.1
56. Private transport services	0.0	0.0	36905.0	1613.0	38518.0
57. Private electricity equipment services	0.0	0.0	0.0	835.0	835.0
58. Private heating services	0.0	6983.6	0.0	0.0	6983.6
Residential	16.8	0.0	277.9	0.0	294.7
Total	193546.4	51466.3	114000.6	145997.0	505010.4

exports, say, are not included, but fugitive emissions from the mining of the coal are included.

According to Table 9.2, the burning of coal, gas and refinery products account for around 38%, 10% and 23% of Australia's total greenhouse emissions. The residual, about 29%, comes from non-combustion sources. The largest emitting industry is electricity generation, which contributes around 39% of total emissions. The next largest is animal-agriculture, which contributes 14%; agriculture in total contributes nearly 20%. Other large emitters are: transport (including private transport services) with about 10% of total emissions, coal mining with around 5% and other services (including waste dumps) with nearly 4%.

9.2.3.2 Carbon taxes and prices

MMRF treats the ETS price on emissions as a specific tax on emissions of CO_2-e. On emissions from fuel combustion, the tax is imposed as a sales tax on the use of fuel. On *Activity* emissions, it is imposed as a tax on production of the relevant industries.

In MMRF, sales taxes are generally assumed to be *ad valorem*, levied on the basic value of the underlying flow. Carbon taxes, however, are specific, levied on the quantity (CO_2-e) emitted by the associated flow. Hence, equations are required to translate a carbon tax, expressed per unit of CO_2-e, into *ad valorem* taxes, expressed as percentages of basic values. The CO_2-e taxes are specific but coupled to a single price index (typically the national price of consumption) to preserve the nominal homogeneity of the system. Suppressing indices, an item of CO_2-e tax revenue can be written as:

$$TAX = S \times E \times I, \tag{9.3}$$

where S is the specific rate ($A per tonne of CO_2-e), E is the emission quantity (tonne of CO_2-e) and I is a price index (base year = 1) used to preserve nominal homogeneity.

Ad valorem taxes in MMRF raise revenue:

$$TAX = \frac{V \times P \times Q}{100}, \tag{9.4}$$

where V is the percentage *ad valorem* rate, P is the basic price of the underlying taxed flow and Q is the quantity of the underlying taxed flow.

To translate from specific to *ad valorem* the right-hand sides of equations (9.3) and (9.4) are set equal to each other, yielding:

$$V = \frac{S \times E \times I \times 100}{P \times Q}. \tag{9.5}$$

As can be seen from equation (9.5), to convert specific CO_2-e taxes to *ad valorem* taxes frequent use is made of the ratio of the indexed-value of emissions ($E \times I$) to the value of the *ad valorem* tax base ($P \times Q$). Indeed, values for the ratio across all fuels and users and the matrix of specific tax rates are the primary additional data items added to MMRF for carbon tax/ETS modeling.

Production taxes in MMRF are also assumed to be *ad valorem*, and levied on the basic value of production. Accordingly, the linking equation for a CO_2-e tax on *Activity* emissions is:

$$V = \frac{S \times E \times I \times 100}{P \times Z}, \tag{9.6}$$

where Z is the volume of production for which P is the basic price.

9.2.3.3 Interfuel substitution

In the standard specification of MMRF, there is no price-responsive substitution between composite units of commodities or between composite commodities and the composite of primary factors.[8] With fuel–fuel and fuel–factor substitution ruled out, CO_2-e taxes could induce abatement only through activity effects.

We correct this in two ways:

(i) by introducing interfuel substitution in electricity generation using the 'technology bundle' approach;[9]

(ii) by introducing a weak form of input substitution in sectors other than electricity generation to mimic 'KLEM substitution'.[10]

Electricity-generating industries are distinguished based on the type of fuel used (Section 9.2.1 and Table 9.1). There is also an end-use supplier (*Electricity supply*) in each state and territory and a single dummy industry (*NEM*) covering the six regions that are included in Australia's NEM [New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA), the Australian Capital Territory (ACT) and Tasmania (TAS)]. Electricity flows to the local end-use supplier either directly from generators in the case of Western Australia (WA) and the Northern Territory (NT) or via *NEM* in the remaining regions. Further details of the operation of *NEM* are given in Section 9.2.3.4.

Purchasers of electricity from the generation industries (*NEM* in NEM regions or the *Electricity supply* industries in the non-NEM regions) can substitute between the different generation technologies in response to changes in generation costs. Such substitution is price-induced, with the elasticity of substitution between the technologies typically set at around 5.

[8] Composite commodities are constant elasticity of substitution (CES) aggregations of domestic and imported products with the same name. The composite of primary factors is a CES aggregation of labor, capital and land inputs – see Section 9.2.2.2.

[9] The technology bundle approach has its origins in the work done at the CoPS, Monash University in the early 1990s (McDougall, 1993) and at ABARES for the MEGABARE model (Hinchy and Hanslow, 1996).

[10] KLEM substitution allows for substitution between capital (K), labor (L), energy (E) and materials (M) for each sector: see Hudson and Jorgenson (1974), and Berndt and Wood (1975). Other substitution schemes used in Australian models are described in chapter 4 of Pezzy and Lambie (2001). A more general current overview is in Stern (2012).

For other energy-intensive commodities used by industries, MMRF allows for a weak form of input substitution. If the price of cement (say) rises by 10% relative to the average price of other inputs to construction, the construction industry will use 1% less cement, and a little more labor, capital and other materials. In most cases, as in the cement example, a substitution elasticity of 0.1 is imposed. For important energy goods (petroleum products, electricity supply and gas) the substitution elasticity in industrial use is 0.25. Being driven by price changes, this input substitution is especially important in an ETS scenario, where outputs of emitting industries are made more expensive.

9.2.3.4 NEM

The NEM is a wholesale market covering nearly all of the supply of electricity to retailers and large end-users in NEM regions. MMRF's represents the NEM as follows.

Final demand for electricity in each NEM region (Section 9.2.3.3) is determined within the CGE core of the model in the same manner as demand for all other goods and services. All end users of electricity in NEM regions purchase their supplies from their own-state *Electricity supply* industry. Each of the *Electricity supply* industries in the NEM regions sources its electricity from a dummy industry called *NEM*, which does not have a regional dimension; in effect *NEM* is a single industry that sells a single product (electricity) to the *Electricity supply* industry in each NEM region. *NEM* sources its electricity from generation industries in each NEM region. Its demand for electricity is price-sensitive. For example, if the price of hydro generation from TAS rises relative to the price of gas generation from NSW, then *NEM* demand will shift towards NSW gas generation and away from TAS hydro generation.

The explicit modeling of the NEM enables substitution between generation types in different NEM regions. It also allows for interstate trade in electricity, without having to trace explicitly the bilateral flows. Note that WA and NT are not part of the NEM, and electricity supply and generation in these regions is determined on a state-of-location basis.[11]

This modeling of the NEM is adequate for many MMRF simulations, but for the ETS simulations reported in this chapter much of it was overwritten by results from Frontier's detailed bottom-up model of the electricity system (Section 9.3.2). The MMRF electricity system structure described above provides a suitable basis for interfacing MMRF with the bottom-up model.

9.2.3.5 Services of energy-using equipment in private household demand

The final three industries shown in Table 9.1 are dummy industries that provide services of energy-using equipment to private households. These dummy industries enable

[11] Note that transmission costs are handled as margins associated with the delivery of electricity to *NEM* or to the *Electricity supply* industries of WA and the NT. Distribution costs in NEM regions are handled as margins on the sale of electricity from *NEM* to the relevant *Electricity supply* industries.

households to treat energy and energy-using equipment as complementary, which is not possible in MMRF's standard budget-allocation specification based on the linear expenditure system (LES).

Industry 56 provides private transport services to the household sector, using inputs of capital (private motor vehicles), automotive fuel and other inputs required for the day-to-day servicing and running of vehicles. Industry 57 provides the services of electrical equipment (including air conditioners) to households, using inputs of capital (electrical equipment) and electricity. Industry 58 provides the services of appliances used for heating and cooking, using inputs of capital (heating and cooking appliances), gas and electricity. Energy used by these three dummy industries accounts for all of the energy consumption of the residential sector.

Including these dummy industries improves the model's treatment of price-induced energy substitution and its treatment of the relationship between energy and energy equipment in household demand. For example, in the LES-based specification of household demand, if the price of electricity fell relative to the price of other goods and services, electricity would be substituted for other commodities, including electrical and heating appliances. However, under the dummy-industry specification, a change in the price of electricity induces substitution only through its effect on the prices of electrical equipment services and private heating services. If the change in the electricity price reduces the price of electrical equipment services relative to the price of other products, then electrical equipment services (including its inputs of appliances and energy) will be substituted for other items in the household budget.

9.3 ADDITIONAL ENHANCEMENT FOR ETS MODELING

In this section, enhancements to our modeling that are necessary for simulating the effects of a real-world ETS are explained. This involves:

- linking MMRF to GTEM, to enhance MMRF's handling of global aspects of the ETS and of changes to Australia's trading conditions;
- linking MMRF to Frontier's *WHIRLYGIG* electricity model, to enhance MMRF's electricity-supply detail;
- modeling transitional arrangements for EITEIs;
- modeling abatement of non-combustion emissions;
- modeling carbon sequestration in forest industries.

9.3.1 Linking with GTEM

Linking economic models with different economic structures is not straightforward. For example, MMRF and GTEM have similar production structures, but their industrial classifications are not the same (compare Table 9.1 with Table 9.3, which gives the

Table 9.3 Industries and regions in the GTEM modeling

Regions	Industries
Australia	Coal mining
US	Oil mining
EU	Gas mining
Japan	Petroleum and coal products
China	Electricity with 12 technologies: coal, oil, gas, nuclear, hydro, etc.)
India	Iron and steel with two technologies: electric arc and blast furnace
Indonesia	Non-ferrous metals
Other South and East Asia	Chemical, rubber and plastic products
Russia and CIS	Other mining
OPEC	Non-metallic minerals
Canada	Other manufacturing
South Africa	Air transport
Rest of World	Water transport
	Other transport with five technologies: rail, internal combustion road, advanced internal combustion road, hybrid road and non-fossil fuel vehicles
	Crops
	Livestock
	Fishing and forestry
	Food products
	Services

industrial and regional classifications in the version of GTEM used for the ETS simulations). Also, the elasticities of supply and demand associated with comparable industries are not necessarily consistent across the two models.

In general, the degree of linking required will vary depending on the number and nature of variables that are common between the two models. For example, if the only common variables are exogenous in the primary model (MMRF), then a relatively simple top-down linking from the secondary model (GTEM) is sufficient. On the other hand, if there are many common variables with some endogenous to both systems, a more complex linking with two-way transmission of results may be necessary.

As discussed in Section 9.1, the simulations reported in this chapter relate to a global ETS, with a global cap, a global price and allocations of permits to participating countries. GTEM was used to model the global scheme. Projections were obtained from GTEM for the global permit price and the allocation of permits across regions for each global emissions target. The projections for the global permit price and Australia's emissions allocation were fed directly into MMRF. In MMRF, the global permit price and Australia's emissions allocation are naturally exogenous variables. Hence, a simple one-way link from GTEM to MMRF is sufficient.

GTEM also simulates changes in world trading conditions faced by Australia, with and without the global ETS. These are as represented in MMRF as changes in the positions of foreign export-demand and import-supply schedules. In MMRF, import supply is assumed to be perfectly elastic and foreign-currency import prices are naturally exogenous, once again allowing for one-way transmission from GTEM to MMRF.

For exports, however, foreign demand schedules are assumed to be downward sloping. In this case, one-way transmission is problematic because export prices and quantities are endogenous in both models. Despite the potential for feedback, the linking between GTEM and MMRF for export variables was done via one-way transmission from GTEM to MMRF. The main challenge was to deduce the changes in position of export-demand schedules in MMRF implied by the projected changes in export volumes and prices in GTEM.

In the remainder of this subsection we give a short overview of the GTEM model and then explain how changes in export demand schedules were transmitted to MMRF.

9.3.1.1 GTEM Overview

GTEM (Pant, 2007) and MMRF are based on a common theoretical framework – the ORANI model.[12] GTEM can be likened to a series of ORANI models, one for each national region, linked by a matrix of bilateral international trade flows. Similarly, MMRF can be likened to a series of ORANI models, one for each state and territory, linked by a matrix of interstate trade flows. However, unlike the static ORANI model, MMRF and GTEM are recursively dynamic models, developed to address long-term global policy issues, such as climate change mitigation costs.

GTEM models inter-regional linkages arising from the flows of tradable goods and services and of capital. In doing so it ensures that each region's total exports equal total imports of these goods by other regions.

Industry demands in each region in GTEM are derived from solutions to a cost-minimization problem involving a three-level production function like that used in MMRF. The only difference is that in GTEM regional substitution is between different national regions rather than different Australian states and territories. In GTEM, aggregate household expenditure in each region is determined as a constant share of total regional income.

The cost-minimizing capital creator in each region in GTEM combines inputs to assemble units of capital, subject to a nested production technology similar to that facing each sector for current production. Investment in each region is financed from a global pool of savings. Each region contributes a fixed proportion of its income to the

[12] GTEM was derived from MEGABARE and the static GTAP model (Hertel, 1997). Aspects of MEGABARE are described in Hinchy and Hanslow (1996), Kennedy *et al*. (1998), and Tulpule *et al*. (1999).

savings pool. In standard GTEM, there are two alternative ways of allocating this pool to investment in each region. The first makes investment in each region a fixed proportion of the overall size of the pool – if the pool increases by 10%, investment in each region increases by 10%. The second relates investment allocation to relative rates of return. Regions that experience increases in their rate of return relative to the global average will receive increased shares of the investment pool, whereas regions experiencing reductions in their rate of return relative to the global average will receive reduced shares.

9.3.1.2 Environmental enhancements in GTEM

GTEM contains a number of enhancements relative to the MEGABARE and GTAP systems to improve its capability for environmental analysis.

- It has a global emissions database that includes all major sources of greenhouse gases, except land-use change. This database is built primarily from data compiled for the GTAP-E model.[13]
- As in MMRF, in GTEM it is assumed that combustion emissions of CO_2-e are proportional to the quantity of fuel combusted, while *Activity* emissions are proportional to the level of production in the industry generating them.
- Emission response functions are defined for *Activity* emissions. These specify abatement as increasing functions of the rate of carbon tax and reflect the assumption that the marginal cost of abatement rises with the level of abatement.
- GTEM uses the 'technology-bundle' approach to model electricity generation, transport and steel manufacture. Under this approach, multiple technologies are specified for the production of the relevant output. The shares of the technologies in aggregate output depend on their relative profitabilities but there is no input substitution within technologies.
- Other industries can substitute between four energy commodities in determining their aggregate use of energy. Energy can then be combined with a primary factor composite. Finally, the energy/factor composite can be combined with other intermediate inputs in fixed proportions to produce a single good.
- For emerging electricity generation technologies, such as solar and geothermal, learning-by-doing mechanisms are added. These lower primary-factor input requirements per unit of output over time.
- In some mining industries, factor productivity is assumed to decline with increases in the cumulative level of resource extraction, reflecting increasing extraction costs as the resource base diminishes.

[13] GTAP-E is a version of the GTAP (Global Trade Analysis Project) model designed at the GTAP Center specifically for global greenhouse analysis. Its structure and database are outlined in Truong (1999), Burniaux and Truong (2002), and (latest database) McDougall and Golub (2009).

9.3.1.3 Linking export variables

As outlined earlier, GTEM projections for the international permit price, Australia's emissions' allocation and foreign-currency import prices can easily be taken in to MMRF via a simple one-way link.[14] However, for exports, GTEM must provide MMRF with changes in the positions of the individual (downward-sloping) export-demand schedules, not changes in quantities or foreign-currency prices.

Figure 9.1 shows the method by which changes in export prices and quantities projected in GTEM (Figure 9.1a) are translated into movements in export-demand schedules in MMRF (Figure 9.1b). In Figure 9.1(a), the initial export price-quantity point is A — at the intersection of the initial demand and supply schedules. In modeling the effects of a global ETS, demand moves from D to D′ and supply from S to S′, with the price-quantity point changing from A to B. The quantity exported changes by *q* and export price by *p*. Note that the changes in demand and supply schedules are not directly observed — only the changes *p* and *q*.

Figure 9.1(b) shows how the information from GTEM (Figure 9.1a) is used to deduce the shift in the export-demand schedule required for the MMRF simulation.

First note that the elasticity of the demand curve in MMRF is shown as being the same as in GTEM. This is not necessary for the top-down procedure to work, but it does help avoid unduly large differences in *ex post* outcomes for export quantities and prices. GTEM's import-substitution elasticities were adjusted to ensure consistency between its implied export-demand elasticities and the explicit elasticities in MMRF.

The values for *p* and *q* from the GTEM simulation are used to shift the export-demand schedule in MMRF in two directions. The schedule shifts horizontally by *q* and vertically by *p*. If in MMRF the supply schedule had the same shape as in GTEM, and if it were to shift in the same way, then in MMRF the *ex post* outcomes for export price and volume would be the same as in GTEM. Typically though, this was not the case — for several commodities MMRF's supply response was quite different from the supply response in GTEM. Thus, even though the shifts in export demand were the same, the observed changes in export price and quantity were quite different.

9.3.2 Linking with *WHIRLYGIG*

The idea that environmental issues could be tackled effectively by linking a CGE model with a detailed bottom-up energy model has a long history with Australian modelers. The first attempts were in a joint CoPS/ABARES project using ORANI and MENSA, which is an Australian version of the International Energy Agency's generic MARKAL framework.

[14] The only complication is that GTEM has a more aggregated commodity classification than does MMRF, so the GTEM information must first be mapped to MMRF commodities.

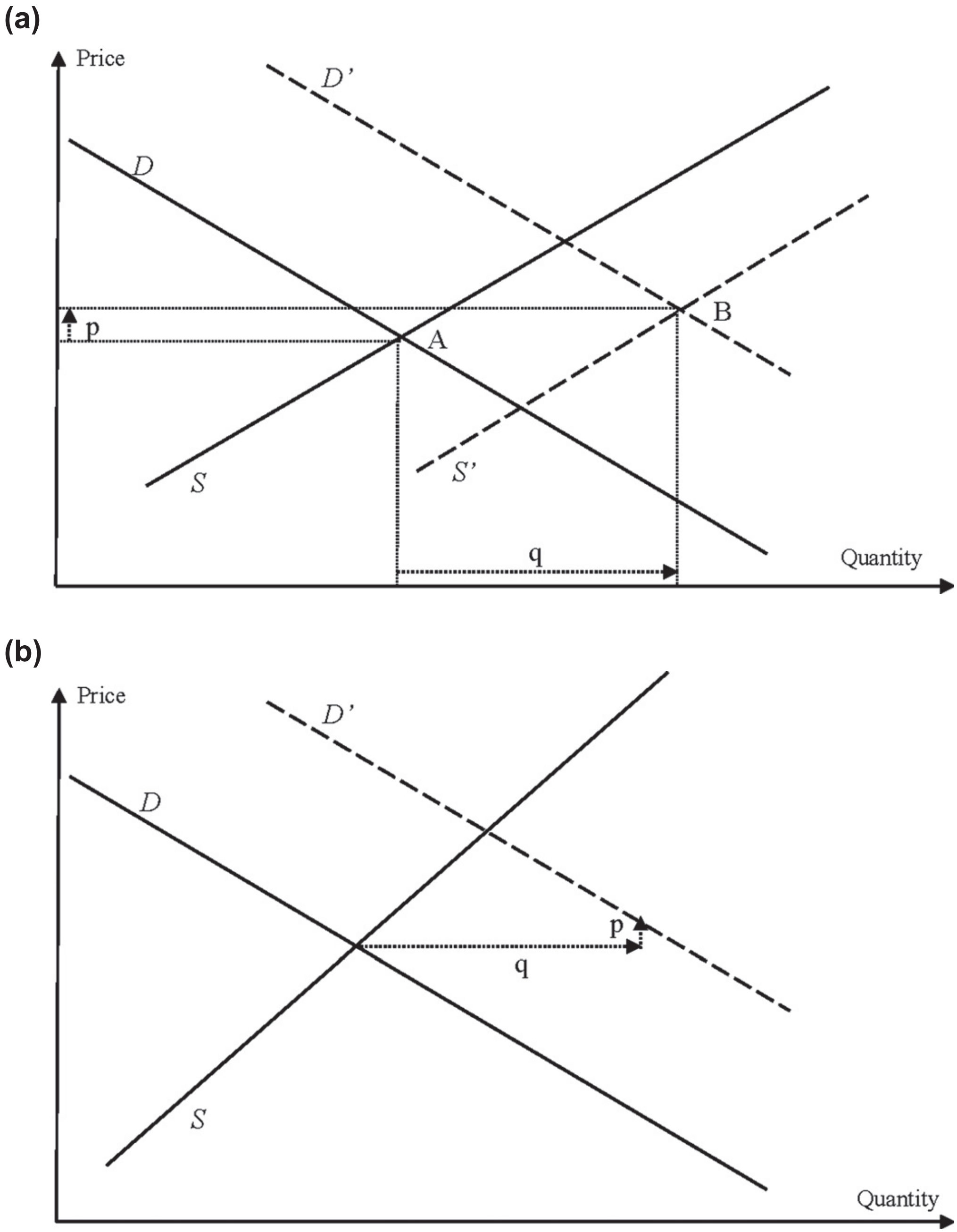

Figure 9.1 (a) Export response in GTEM. (b) Shift in export demand in MMRF.

MENSA/MARKAL is an optimization model of the Australian energy system. Adams *et al.* (1992) provide an exposition in a form that makes it accessible to CGE modelers. Powell (1993) discusses methodological issues arising in attempts to link such a model with a CGE model and presents an ambitious agenda for complete two-way integration – an agenda that is still not met in current practice.

Frontier's *WHIRLYGIG* model simulates the least-cost expansion and operation of generation and transmission capacity in the Australian electricity system (Section 9.3.2.1). In linking MMRF to *WHIRLYGIG*, the electricity sector in MMRF (Sections 9.2.1, 9.2.3.3 and 9.2.3.5) is effectively replaced with *WHIRLYGIG*'s specification. MMRF provides information on fuel prices and other electricity-sector costs, and on electricity demand from industrial, commercial and residential users. This is fed into *WHIRLYGIG*, which generates a detailed description of supply, covering generation by generation type, capacity by generation type, fuel use, emissions, and wholesale and retail electricity prices. Retail electricity prices are a key endogenous variable in both systems. Information is passed back and forth between the two models in a series of iterations that stop when the average retail price in the electricity model has stabilized. Experience suggests that up to three iterations for each year are necessary to achieve convergence.

There are a number of reasons to prefer linking to a detailed electricity model over the use of MMRF's standard treatment of electricity.

- *Technological detail.* MMRF recognizes six generation technologies (Table 9.1). *WHIRLYGIG* recognizes many hundreds, some of which are not fully proved and/or are not in operation. For example, MMRF recognizes one form of coal generation. *WHIRLYGIG* recognizes many forms, including cleaner gasification technologies and generation in combination with carbon capture and storage (CCS). Having all known technologies available for production now or in the future allows for greater realism in simulating the technological changes available in electricity generation in response to a price on emissions. *WHIRLYGIG* also captures details of the inter-relationships between generation types. A good example is the reliance by hydro generation on base-load power in off-peak periods to pump water utilized during peak periods back to the reservoir.
- *Changes in capacity.* MMRF treats investment in generation like all other forms of investment (Section 9.2.2.6). Capital supply is assumed to be a smooth increasing function of expected rates of return, which are set equal to current rates of return. Changes in generation capacity, however, are generally lumpy, not smooth, and investment decisions are forward looking, given long asset lives. *WHIRLYGIG* allows for lumpy investments and for realistic lead times between investment and capacity change. It also allows for forward-looking expectations, which aligns more with real-world experience than does MMRF's standard

static assumption. The demand for electricity is exogenous in *WHIRLYGIG* but when demand is endogenized by running *WHIRLYGIG* linked to MMRF, investment in the electricity sector is essentially driven by model-consistent expectations.

- *Policy detail*. Currently, in Australia there are around 100 policies at the state, territory and commonwealth levels affecting electricity generation and supply. These include: market-based instruments to encourage increased use of renewable generation, regulations affecting the prices paid by final residential customers and regional policies that offer subsidies to attract certain generator types. Some of these policies interact with an ETS. For example, the market-based Renewable Energy Target (RET), which is designed to ensure that 20% of Australia's electricity supply will come from renewable sources by 2020, operates by requiring electricity retailers to acquire and surrender Renewable Energy Certificates (RECs). These RECs have a market price that will be sensitive to an ETS. Associated interactions and policy details are handled well in *WHIRLYGIG*, but are generally outside the scope of stand-alone modeling in MMRF.
- *Sector detail*. In MMRF, electricity production is undertaken by symbolic industries – *Electricity-coal Victoria*, *Electricity-gas NSW*, etc. In *WHIRLYGIG*, actual generation units are recognized – unit x in power station y located in region z. Thus, results from the detailed electricity model can be reported at a much finer level and in a way which industry experts fully understand. This adds to credibility in result reporting.

In the remainder of this section we describe further the Frontier electricity model and how it is used to inform MMRF.

9.3.2.1 WHIRLYGIG *overview*

Formally, *WHIRLYGIG* is a mixed integer linear programming model of Australia's electricity system. The objective function is the total cost (including fixed and variable costs) of the system. The model solves for optimal investment and generation to minimize total cost subject to constraints that include:

- system supply must meet system demand at all times;[15]
- minimum reserve requirements;
- generators cannot run more than allowed for by their physical capacity factors;
- certain generators must run for certain periods;
- some generators cannot run for specified periods;
- policy-related constraints, like that imposed by a price on emissions.

15 *WHIRLYGIG* recognizes the (very high) price cap that is imposed in the NEM. This prevents prices rising to clear the market at extreme market conditions. To handle this, the objective function in *WHIRLYGIG* includes a valuation of the unmet demand (*lost load*) at the NEM price cap.

Inputs to *WHIRLYGIG* cover:

- general system data for electricity demand by region and the reserve capacity requirements for each region;
- data for the capacity of each inter-regional interconnector and for transmission losses;
- data on fixed and variable costs of production for each generation plant (existing and new), and on capacities and plant-commissioning timeframes;
- data on greenhouse gas emissions for each generation option.

Outputs are categorized as *decision* variables and *calculated* variables. The main decision variables are investment (or changes in capacity) for the various generation options, and production (or dispatch) from each available generation type. The key calculated variables are total costs of each plant, total system cost, wholesale and retail electricity prices, and greenhouse emissions and total greenhouse emission abatement.

WHIRLYGIG's modeling of capacity changes takes account of establishment of new units and retirement of existing units. Its modeling of wholesale electricity prices is based on the long-run marginal cost of generation. Retail prices comprise the wholesale price (multiplied by the marginal loss factor in transmission) *plus* network fees *plus* gross retail margins, market fees and the cost of administering various government schemes to encourage the purchase of renewable generation.

9.3.2.2 Linking

The linking of *WHIRLYGIG* to MMRF proceeds as follows. For either a base-case or a policy simulation, an initial MMRF simulation is conducted, with the electricity system unconstrained. From this simulation come annual projections for:

1. electricity demand by industry and region in petajoules (PJ);
2. prices for labor, energy carriers such as coal and other relevant material inputs.

   These projections are supplied to *WHIRLYGIG*. The Frontier modelers take the annual demand projections, generate within-year load profiles, and update their estimates for the variable costs of generation for each option. The electricity model is then run (with appropriate constraints relating to CO_2-e emissions if necessary) to provide annual projections by region for:
3. sent-out generation (GWh) by type, aggregated to MMRF's level of detail;[16]
4. fuel usage by generation type (PJ), aggregated appropriately;
5. emissions by generation type (tonnes of CO_2-e), aggregated appropriately;
6. capacity by generation type (GW), aggregated appropriately;
7. wholesale electricity prices ($A/GWh);
8. retail electricity prices ($A/GWh).

[16] Three stages of electricity production are identified in *WHIRLYGIG* and MMRF. Generation sent out is raw generation net of electricity used in the generation process. Final-use electricity is electricity sent out less transmission and distribution losses. Any generation option in the detailed electricity model associated with the use of coal is aggregated into a single number for the MMRF industry *Electricity-coal*, etc.

Table 9.4 Transfer of information from *WHIRLYGIG* to MMRF

WHIRLYGIG variable	MMRF target	MMRF Instrument
3. Sent-out generation by type and region	Sent-out generation by type and region	Cost-neutral shifts in input technologies of the electricity supply industry in each state
4. Fuel usage by generation type and region	Fuel usage by generation type and region	Cost-neutral shifts in input technologies of the fossil fuel generation industries
5. Emissions by generation type and region	Emissions per unit of fuel used by fossil fuel generation industries	Naturally exogenous
6. Capacity by generation type and region	Capital stock in use by generation type and region	Shifts in the required rate of return on capital by generation type and region, which allows capital supply to be exogenous and set equal to achieve the targeted change in capacity (equation 9.2)
7. Wholesale electricity prices by region	Average basic price of the output of generator industries in each region	Equiproportionate shifts in the price of 'other costs' of each generator in a region to mimic changes in unit pure profit
8. Retail electricity prices by region	Basic price of the electricity supply industry in each region	Shifts in the price of 'other costs' of the electricity supply industry in each region

Items 3–8 are then input to MMRF, enabled by closure changes that in effect turn off MMRF's treatment of electricity supply and investment. Details of the closure changes are given in Table 9.4. The first column shows the *WHIRLYGIG* variable being transferred. The second column shows the MMRF variable targeted. Most of these variables are naturally endogenous but must be made exogenous. The final column gives the MMRF variable – typically a naturally exogenous variable – endogenized to allow the targeted variable to be exogenized.

The changes in generation mix imposed on MMRF are initially cost-neutral and so have no effect on the average price of the *Electricity supply* industry. *WHIRLYGIG* estimates of changes in average wholesale price and in the retail prices of electricity in each region are introduced into MMRF via changes in *Other costs*[17] in MMRF's generation and electricity supply industries.

17 See Section 9.2.2.2, especially footnote 5.

Imposing these *WHIRLYGIG* values in MMRF and rerunning completes the first iteration. Revised values for items 1 and 2 are passed to *WHIRLYGIG* which then recalculates values for variables 3–8. Iterations continue until between successive iterations the retail prices of electricity in each region stabilize.

9.3.3 Transitional arrangements

In the policy framework outlined in the Australian government's ETS design paper, certain EITEIs were to be shielded from some of the cost effects of the permit price during the initial years when a global ETS is being established. Shielding reduces the adverse effects of the carbon price on the EITEIs and limits the carbon leakage that imposing a carbon tax in Australia in advance of its adoption by major international trade competitors would otherwise induce.

In the ETS modeling reported in this chapter, shielding is implemented as a general production subsidy to offset the combined direct and indirect effects of the emissions price on an industry's average cost. The direct effects arise from the imposition of the emission price on the industry's combustion emissions or on the emissions directly associated with its activity (e.g. industrial and fugitive emissions); the indirect effects arise from the increased cost of electricity.

To offset the direct impacts of a carbon price, the proposed ETS specified shielding proportional to the emission price and the shielded industry's output level. The coefficient of proportionality reflects the coverage of the shielding scheme[18] and the industry's initial (2005–2006) emissions intensity, i.e.:

$$SHIELDING_{\mathrm{DIR}} = -COVER \times T \times \left[\frac{QGAS}{OUTPUT}\right]_{\mathrm{INIT}} \times OUTPUT, \qquad (9.7)$$

where $SHIELDING_{\mathrm{DIR}}$ (a negative number) is the required offset to average cost, *COVER* is the rate of coverage (a number between 0 and 1.0), *T* is the effective carbon tax rate (\$A per tonne of CO_2-e), *QGAS* is the number of tonnes of CO_2-e emissions, *OUTPUT* is the output of the industry and $[\ ]_{\mathrm{INIT}}$ indicates the initial, 2005–2006, ratio of emissions to output.

For shielding to offset the increased cost of electricity:

$$\begin{aligned} SHIELDING_{\mathrm{IND}} = {} & -COVER \times \left[PETS - PREF\right] \times \left[\frac{ELEC}{OUTPUT}\right]_{\mathrm{INIT}} \\ & \times OUTPUT, \end{aligned} \qquad (9.8)$$

[18] Under the Government's proposal two industry classes were considered for shielding – one deemed most exposed to the ETS and the other deemed less adversely affected, but still requiring shielding. The rates of shielding for the two categories start at 0.9 and 0.6, respectively, and then decline over time.

where $SHIELDING_{IND}$ (a negative number) is the required offset to average cost, *PETS* is the price of a unit of electricity with the ETS in place *PREF* is the price of electricity in the absence of the ETS, *ELEC* is the number of units of electricity used and $[\ ]_{INIT}$ indicates the initial, 2005–2006, ratio of electricity to output.

Equation (9.8) is similar in structure to equation (9.7), with the emissions-price-induced increase in the electricity price in (9.8) replacing the permit price in (9.7).

Having determined the necessary offsets for the direct and indirect costs associated with emissions pricing, the model then applies the offset to each shielded industry via a production subsidy. The subsidy is paid for initially by the Federal government. However, since government budget balances are held fixed at base-case case levels in the ETS simulations via endogenous lump-sum payments to households, the shielding subsidy is ultimately paid by Australian households.

Shielding has a macro/welfare impact due to its role in recycling the revenue raised from the sale of emissions permits (or from the imposition of a carbon tax). Shielding payments reduce the lump-sum payments to households that are the default revenue-recycling method in the ETS simulation. By definition, lump-sum payments to households are non-distorting in the conventional public finance sense. Since the carbon tax is distorting and ignoring any environmental benefits that it might have, the policy of imposing the tax and recycling its revenue through lump-sum payments reduces GDP and conventionally measured economic welfare. Shielding represents a reduction in the effective energy tax impost associated with the ETS and a corresponding reduction in the lump-sum payments that are required to recycle the ETS revenue. This reduces the adverse effects on GDP and conventionally measured welfare. Proponents of the ETS or a carbon tax often argue that these adverse effects could be reduced further, or even eliminated, by using the revenue to reduce other distorting taxes – the so-called double-dividend argument.

9.3.4 Abatement of non-combustion emissions

Non-combustion (or *Activity*) emissions include: agricultural emissions (largely from animals), emissions from land-clearing or forestry, fugitive emissions (e.g. gas flaring); emissions from industrial processes (e.g. cement manufacture) and emissions from land-fill rubbish dumps. In modeling with MMRF, it is assumed that in the absence of an emissions price, non-combustion emissions move with industry output, so that non-combustion emissions intensity (emissions per unit of output) is fixed.

MMRF's theory of abatement of non-combustion emissions in the presence of an emissions price is similar to that developed for GTEM. It assumes that as the price of CO_2-e rises, *targeted* non-combustion emissions intensity (emissions per unit of output) falls (abatement per unit increases) through the planned introduction of less emission-intensive technologies. More specifically, for *Activity* emitter i in region q it is assumed that abatement per unit of output can be achieved at an increasing marginal cost according to a curve such as that shown in Figure 9.2(a). In Figure 9.2(a), units are chosen so that complete elimination of non-combustion emissions corresponds to an abatement level of 1. However, complete elimination is not possible. So, as shown in Figure 9.2(a), the marginal cost of abatement goes to infinity as the abatement level per unit of output reaches a maximum level, $1 - MIN$, where MIN is the proportion of non-combustion emissions that cannot be

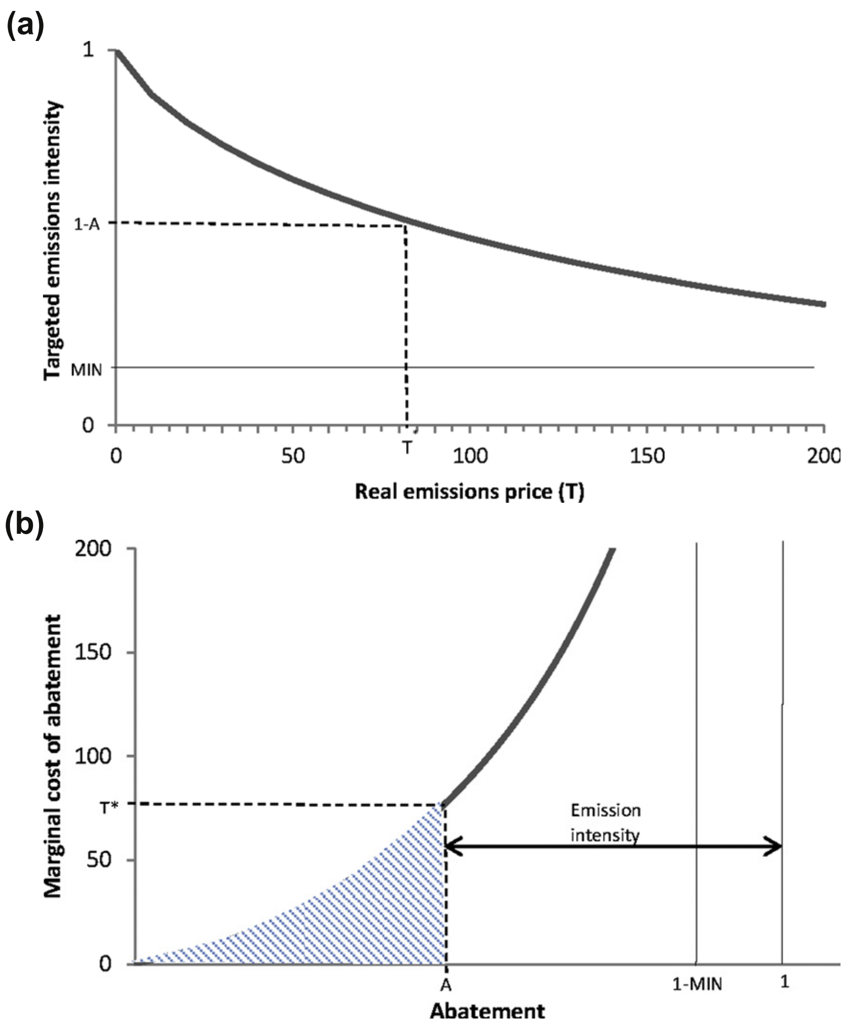

Figure 9.2 (a) Emissions intensity as a function of the real carbon price. (b) Marginal abatement curve for the hypothetical industry.

removed. From Figure 9.2(a), an intensity function for emissions can be derived of the form:

$$Intensity_{i,q} = MAX_{i,q}\{MIN_{i,q},\ F_{i,q}(T)\}, \tag{9.9}$$

where $Intensity_{i,q}$ is the target level of non-combustion emissions intensity, $MIN_{i,q}$ is the minimum possible level of emissions intensity and $F_{i,q}$ is a non-linear monotonic decreasing function of the real level of the emissions price, T (\$A per tonne of CO_2-e in constant 2010 prices).

This is illustrated in Figure 9.2(b), which shows for a typical *Activity* abater the relationship between targeted emissions intensity and emissions price, with intensity indexed to 1 for $T = 0$.

To ensure that emissions intensities do not respond too vigorously to changes in the emissions price, especially at the start of a simulation in which the price of CO_2-e rises immediately from zero, a lagged adjustment mechanism is also put in place, allowing actual emissions intensity to adjust slowly towards targeted emissions intensity specified by (9.9).

In MMRF the abatement cost per unit of output (the shaded area in Figure 9.2a) is imposed as an all-input using technological deterioration in the production function of the abating industry.[19]

9.3.5 Land use in forestry

In MMRF, land is an input to production for the agricultural industries and forestry. Prior to the ETS project, the standard treatment had land industry specific and in fixed supply. Hence when a land-using industry expanded, the scarcity value of its land increased, leading to an increase in its rental price.

For the ETS simulations, land is considered region-specific, but not industry-specific, and there are regional supply constraints. This means that within a region, an industry can increase its land usage but that increase has to be met by reduced usage by other industries within the region. Land is assumed to be allocated between users to maximize the total return to land subject to a constant elasticity of transformation (CET) constraint defining production possibilities across the various land-using sectors. This is the same treatment as adopted in GTAP and GTEM. With this mechanism in place, if demand for biosequestration pushes up demand for land in the forestry sector, then forestry's use of land will increase, increasing the regionwide price of land and causing non-forestry industries to reduce their land usage and overall production.

[19] Here, the MMRF treatment differs from the treatment in GTEM where it is assumed that the change in technology necessary to achieve the reduction in emission intensity is costless.

9.4 BASE CASE

The base case is the control projection against which the policy scenario (with an ETS in place) is compared. For the ETS work, much importance was placed on establishing a detailed base case with a credible projection for emissions across regions and sectors. There were two reasons for this. (i) The cost of implementing the ETS in each year depends critically on the underlying level of base-case emissions (Weyant and Hill, 1999). (ii) Acceptance of the modeling outcomes, including the level of shielding necessary for emission-intensive industries, is reliant on the credibility of the base case.

In Section 9.4.1 we describe the key assumptions underlying the base case. Sections 9.4.2—9.4.5 contain base-case projections for macroeconomic variables, industry outputs, greenhouse gas emissions and electricity generation.

9.4.1 Key assumptions

The base case for the ETS simulation reported in this chapter incorporates a large amount of information from specialist forecasting agencies. MMRF traces out the implications of the specialists' forecasts at a fine level of industrial and regional detail. Information imposed on the model included:

- state/territory macroeconomic forecasts to 2014 based on information provided by Frontier Economics;
- national-level assumptions for changes in industry production technologies and in household preferences developed from MONASH and MMRF historical-decomposition modeling;[20]
- forecasts through to 2014 for the quantities of agricultural and mineral exports from a range of industry sources;
- estimates of changes in generation mix, generation capacity, fuel use, emissions and wholesale prices from Frontier Economics' electricity modeling;
- forecasts for state/territory populations and participation rates drawing, in part, on projections in the Treasury's *Intergenerational Report* (Department of Treasury, 2007);
- forecasts for land-use change and for forestry sequestration from experts at ABARES;
- forecasts for changes in Australia's aggregate terms of trade and for the foreign export and import prices for Australia's key traded goods in agriculture, mining and manufacturing drawn from simulations of GTEM undertaken for the Treasury.

To impose this information in MMRF, numerous naturally endogenous variables are made exogenous. To allow the naturally endogenous variables to be exogenous, an

[20] Historical decomposition modeling is discussed in Dixon and Rimmer (2002, chapter 5) and in Dixon *et al.* in Chapter 2 of this Handbook.

equal number of naturally exogenous variables are made endogenous. For example, to accommodate the exogenous setting of the aggregate terms of trade, an all-commodity and all-region shift variable, naturally exogenous in MMRF but endogenous in the base-case simulation, imparts an equi-proportionate change in the positions of foreign demand curves. Another example relates to private consumption. In the base case, real private consumption by state (a naturally endogenous variable) is set exogenously by allowing the average propensity to consume (APC) in each state to adjust endogenously.

9.4.2 Base-case projections for selected macroeconomic variables

Figure 9.3(a—c) shows base-case projections for selected national macroeconomic variables. The following are some key features.

- Real GDP (Figure 9.3a) grows at an average annual rate of 3.1% between 2010 and 2020, slowing to an average rate of 2.6% between 2020 and 2030. Average annual growth over the full projection period (2.9%) is consistent with the historical norm for Australia. Note that in the first 4 years after 2010, growth exceeds 3%, supported by strong growth in exports as the world recovers from the global financial crisis. Thereafter, GDP growth is projected to stabilize, eventually declining slowly in line with demographic projections from the *Intergenerational Report*.
- Although not shown in Figure 9.3(a), but in line with recent history, the export-oriented states — QLD and WA — are projected to be the fastest growing state economies, followed by NSW and VIC. SA and TAS are the slowest growing, although the gap between the slowest and fastest growing states and territories is a little less than in recent times.
- Real national private consumption (Figure 9.3a) grows at an average annual rate of 3.0% in the first half of the period and 2.9% in the second half. This time profile is similar to that for real GDP: initially strong, then stabilizing and eventually declining slowly.
- The regional pattern of growth for consumption is also similar to that for GDP: fastest growth occurs in QLD and WA, and slowest growth in TAS and SA.
- Over the 15 years leading up to 2010, the volumes of international exports and imports grew rapidly relative to real GDP. This reflects several factors — declining transport costs, improvements in communications, reductions in protection in Australia and overseas, and technological changes favoring the use of import-intensive goods such as computers and communication equipment.[21] All these factors

[21] The effects of changes in technology and preferences in explaining the rapid growth in trade are discussed in Dixon *et al.* (2000).

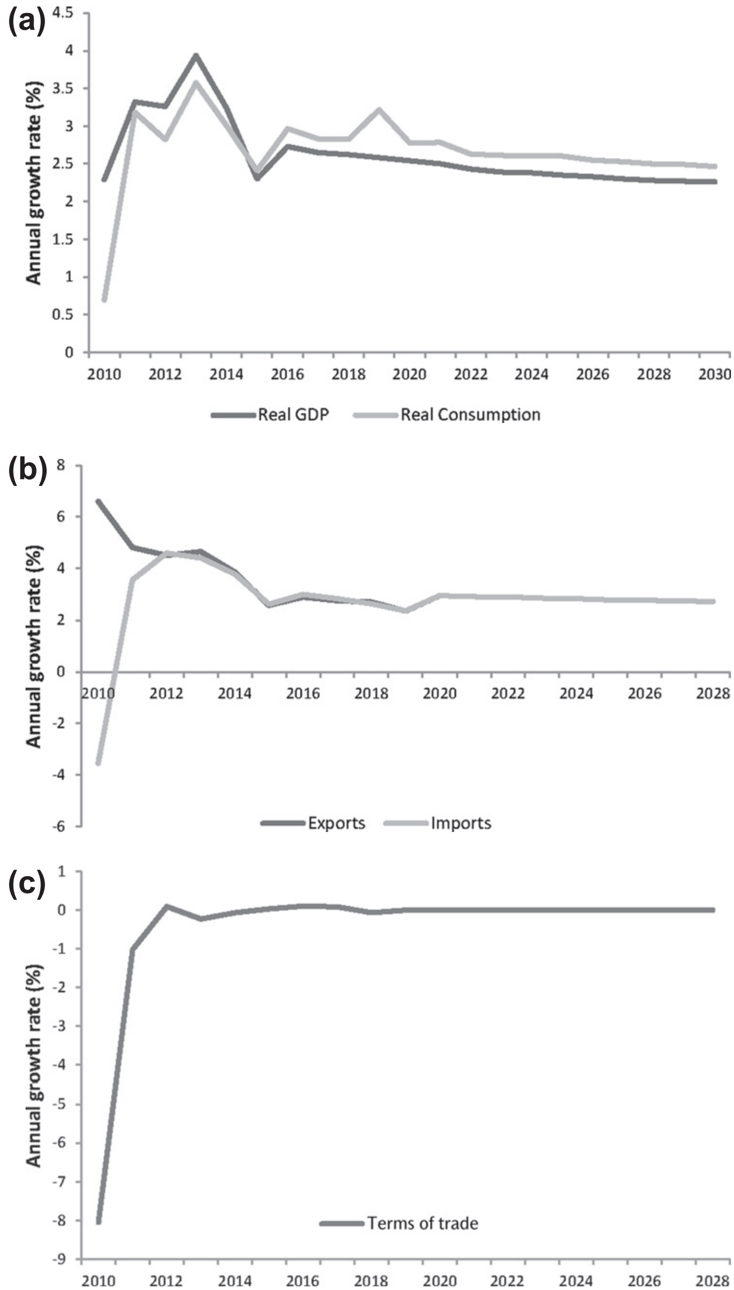

Figure 9.3 (a) Real GDP and national private consumption in the base case. (b) Export and import volumes in the base case. (c) Terms of trade in the base case.

are extrapolated into the early years of the base case, but their influence is assumed to weaken over time (Figure 9.3b). On average, trade volumes grow relative to GDP by about 1.5% per year. Unlike in recent history, import growth is projected to be in line with export growth, implying little improvement in the current imbalance between export and import volumes.

- Australia's terms of trade are assumed to decline sharply in the first few years of the base case (Figure 9.3c), returning to a historically normal level by 2020 from their initial 50-year high.

9.4.3 Base-case projections for national industry production

Table 9.5 and Figures 9.4(a–i) show base-case projections for industry output at the national level.

Table 9.5 Projections for national industry output: base case (average annual percentage changes, ranked)

Rank	Industry	2010–2030
1	37. Electricity generation-other	7.3
2	7. Forestry	7.0
3	49. Air transport	5.2
4	50. Communication services	4.6
5	52. Business services	4.6
6	10. Gas mining	4.2
7	8. Coal mining	4.0
8	33. Electricity generation-gas	4.0
9	47. Rail freight transport	3.7
10	51. Financial services	3.6
11	46. Rail passenger transport	3.6
12	13. Other mining	3.5
13	54. Public services	3.4
14	44. Road passenger transport	3.4
15	55. Other services	3.1
16	12. Non-ferrous ore mining	3.1
17	45. Road freight transport	3.0
18	41. Construction services	3.0
19	57. Private electricity equipment services	3.0
20	48. Water, pipeline and transport services	2.9
21	43. Accommodation, hotels and cafes	2.9
22	53. Dwelling services	2.8
23	11. Iron ore mining	2.8
24	4. Grains	2.7
25	39. Gas supply	2.6
26	26. Alumina	2.6

(*Continued*)

Table 9.5 Projections for national industry output: base case (average annual percentage changes, ranked)—cont'd

Rank	Industry	2010–2030
27	42. Trade services	2.5
28	19. Printing and publishing	2.3
29	24. Cement	2.2
30	5. Other agriculture	2.1
31	28. Other non-ferrous metals	1.9
32	40. Water supply	1.8
33	27. Aluminum	1.8
34	56. Private transport services	1.7
35	6. Agricultural services, fishing and hunting	1.7
36	58. Private heating services	1.7
37	38. Electricity supply	1.7
38	1. Sheep and beef cattle	1.6
39	20. Petroleum products	1.5
40	23. Non-metal construction products	1.5
41	3. Other livestock	1.3
42	22. Rubber and plastic products	1.3
43	17. Wood products	1.3
44	29. Metal products	1.2
45	15. Other food, beverages and tobacco	1.1
46	14. Meat and meat products	1.1
47	25. Iron and steel	1.1
48	2. Dairy cattle	0.9
49	18. Paper products	0.9
50	9. Oil mining	0.6
51	21. Basic chemicals	0.5
52	32. Electricity generation-coal	0.4
53	30. Motor vehicles and parts	0.1
54	36. Electricity generation-hydro	0.0
55	34. Electricity generation-oil products	0.0
56	35. Electricity generation-nuclear	0.0
57	31. Other manufacturing	−0.1
58	16. Textiles, clothing and footwear	−0.8

- *Electricity generation-other renewable* (industry 37) has the strongest growth prospects, with average annual growth of 7.3%, of which most occurs in the first half of the period. This industry generates electricity from renewable sources other than hydro. Its prospects are greatly enhanced by the Australian government's mandated target for the share of renewable energy in total electricity generation that is integrated into the modeling. Other forms of electricity generation have mixed prospects. Generation from gas (industry 33, rank 8) is projected to grow at a relatively strong average annual rate of 4.0%, supported by environmental policies at both the federal and state level.

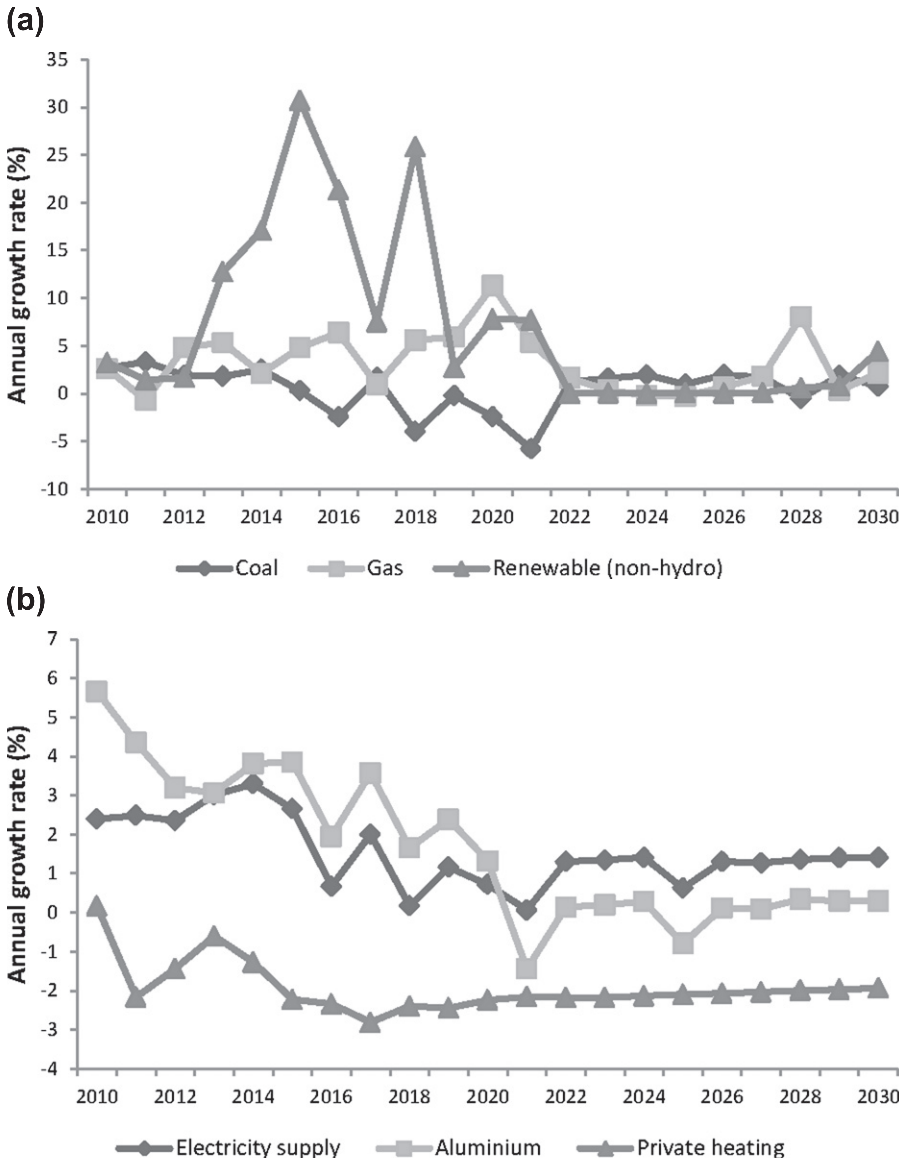

Figure 9.4 (a) Electricity generation in the base case. (b) Electricity use and major customers in the base case. (c) Forestry and wood products in the base case. (d) Selected transport industries in the base case. (e) Communication, financial and business services in the base case. (f) Mining in the base case. (g) Agriculture in the base case. (h) Selected manufacturing industries in the base case. (i) Selected service industries in the base case.

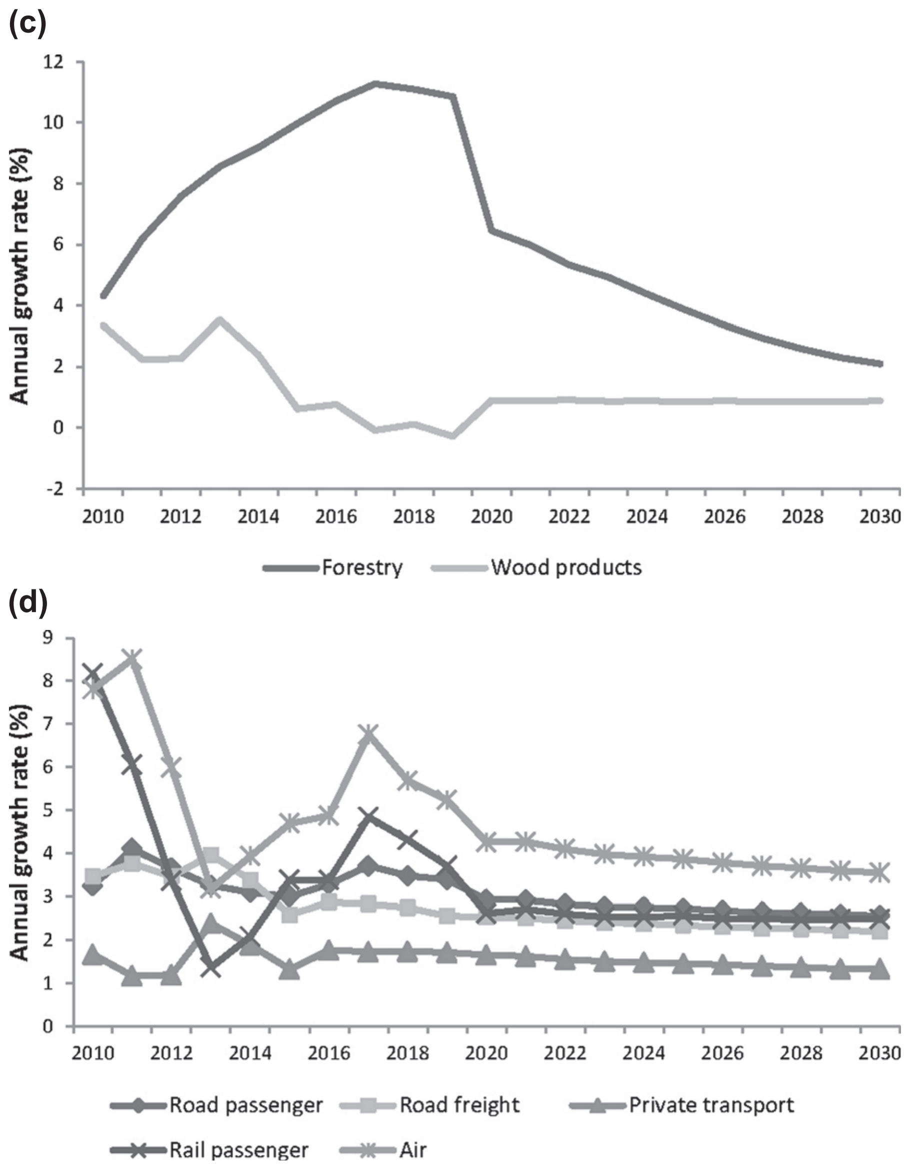

Figure 9.4 (***continued***).

The same policies restrict the average annual growth rate of emission-intensive coal generation (industry 32, rank 52) to 0.4%. It is assumed that generation from oil products (industry 34, rank 55) and hydro (industry 36, rank 54) will not change over the projection period. Production of hydroelectricity is constrained by environmental factors, while the detailed electricity sector modeling indicates little scope for oil-based generation to change.

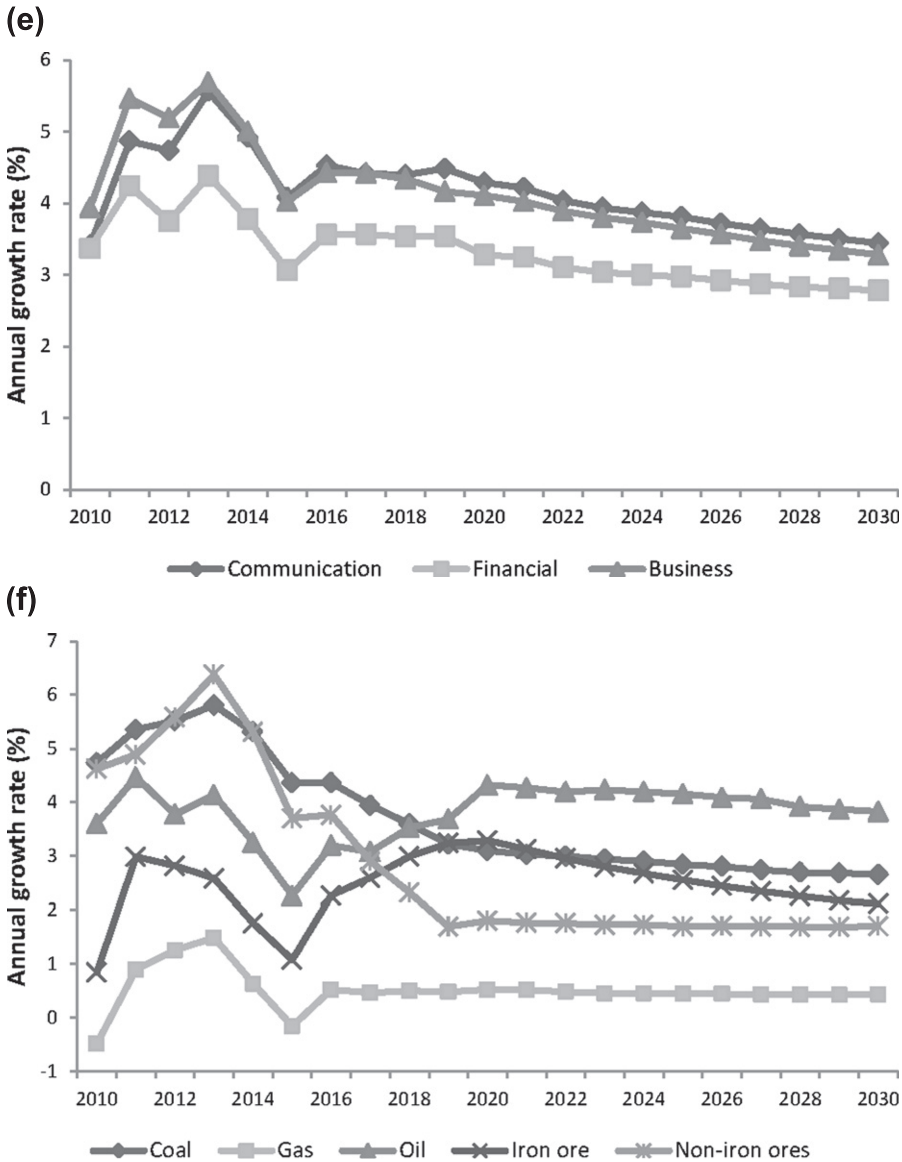

Figure 9.4 (*continued*).

- Figure 9.4(a) shows that the production of the key electricity generation sectors does not evolve smoothly over time. For example, annual growth for other renewable generation in the 4 years from 2014 to 2017 is 16.5%, 31.0%, 19.8% and 7.1%. These numbers come directly from the detailed electricity modeling which allows for large and discrete increases in renewal generation capacity. Similarly, there can be discrete changes in utilization of existing capacity.

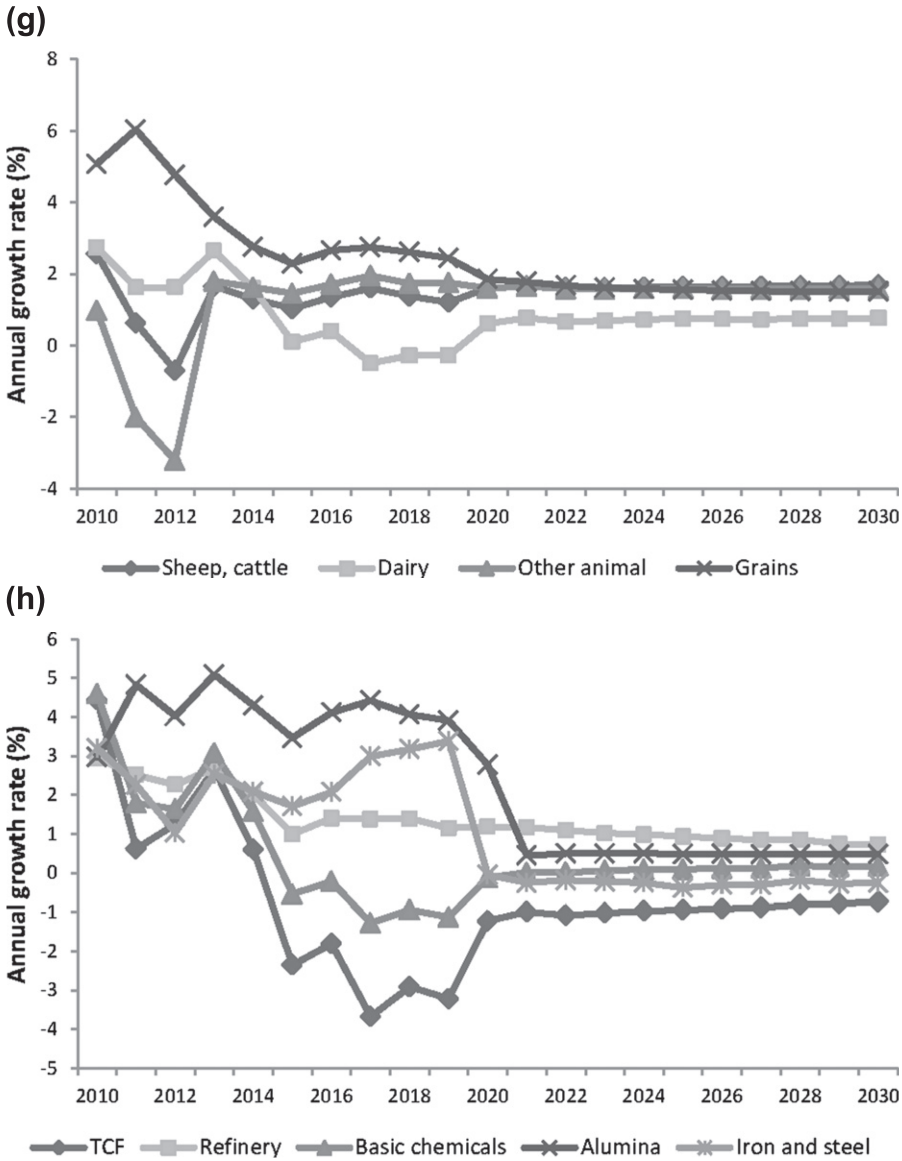

Figure 9.4 (***continued***).

- Projected growth in overall *Electricity supply* (industry 38, rank 37) is relatively slow at 1.7% per annum (Figure 9.4b). In line with recent history, the base case includes an autonomous annual 0.5% rate of electricity-saving technological change in all forms of end-use demand. This, coupled with relatively slow average annual growth in two of the main electricity-using industries – *Aluminum* (1.8%) and *Private heating services* (1.7%) – explains the relatively slow growth projected for *Electricity supply*.

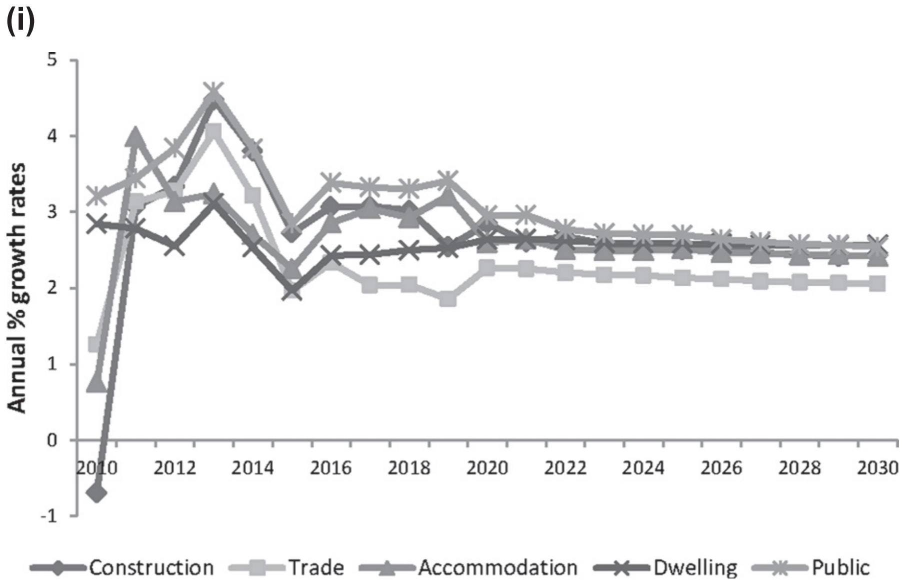

Figure 9.4 (*continued*).

- The fastest growing industry outside of the electricity sector is *Forestry* (industry 7), with a projected average annual growth rate of 7.0 per cent. This industry benefits from strong growth of softwood plantations on land previously used in marginal broad-acre agriculture The ABARES GTEM model projects significant growth in world demand for *Forestry* which absorbs much of the additional forestry supply with relatively little change in basic price. The expansion in exports explains how *Forestry* can expand strongly while its main domestic customer, *Wood products* (industry 17, rank 43), has a relatively low growth ranking (Figure 9.4c).
- *Air transport* is the third ranked industry, with a projected average annual growth rate of 5.2%. Prospects for this industry are good because of expected strong growth in inbound tourism, and the assumed continuation of a taste shift in household spending towards air and away from road as the preferred mode for long-distance travel.
- *Rail freight transport* (industry 47, rank 9) and *Rail passenger transport* (industry 46, rank 11) are each ranked in the top 15 industries by growth prospect. *Rail freight* is used mainly to transport bulk commodities (coal, iron ore and grains) to port for export. It grows strongly in the base case because of strong growth in coal exports. *Rail passenger transport* is dominated by urban rail services. It is assumed that road congestion in urban areas will intensify through the projection period, inducing commuters to substitute rail for road travel.
- Rapid growth in *Communication services*, *Business services* and *Financial services* (industries 50, 52 and 51, ranks 4, 5 and 10) reflects the assumption that changes in technology through the projection period will favor intermediate usage of these

services strongly and that comparatively rapid productivity growth will reduce their prices relative to consumer prices in general (see Figure 9.4e).

- *Gas mining* and *Coal mining* (industries 10 and 8, ranks 6 and 7) have good growth prospects (see Figure 9.4d), reflecting an assumption of very strong growth in exports of liquefied natural gas (LNG) and coal. Note that the main domestic users of gas and coal – *Gas supply* (industry 39, rank 25) and coal-fired electricity generation – have relatively low growth prospects. The former supplies town gas in the Eastern states, and is closely connected to *Private heating services*, which has projected average annual growth of just 1.7%. As noted above, base-case growth in coal-fired electricity generation is very weak.
- Prospects for the non-energy mining industries are governed by projections for world demand taken from GTEM. Production of *Oil* is expected to increase at an average annual rate of just 0.6%, reflecting estimates of supply availability from current reserves.
- Forecasts for the agricultural sector are, in the main, determined by the prospects of downstream food and beverage industries. These have below-average growth prospects, reflecting fairly weak growth in exports and expected increases in import penetration on local markets. *Grains* (industry 4, rank 24) has the best growth prospects of the agricultural industries, due mainly to relatively strong export-demand growth forecast by GTEM. *Agricultural services, fishing and hunting* (industry 6, rank 35) is projected to grow relatively slowly due to resource constraints on fishing stocks.
- Most manufacturing industries have weak growth prospects, due mainly to increases in import competition and weak growth in exports (see Figure 9.4e). The effects of increasing import competition are seen most clearly in the prospects for *Other manufacturing* (industry 31, rank 57) and *Textiles, clothing and footwear* (industry 16, rank 58), which are the only industries expected to contract over the projection period. Despite projected strong growth in exports, growth in output for the *Iron and steel* industry (25, rank 47) is projected to be weak due to slow growth in domestic demand. *Alumina* and *Aluminum* (26 and 27, ranks 26 and 33) have better growth prospects than *Iron and steel* because they have much larger export propensities and world demand for these products is expected to be stronger.
- Nearly all of the remaining industries have close to average growth prospects. The prospects for *Construction services* (industry 41, rank 18) reflect the model's projection for growth in real national investment. *Trade services* (industry 42, rank 27) sells widely throughout the economy. Its growth rate, though, is below that of real GDP because of adverse taste and technology shifts. *Public services* (industry 54, rank 13) and *Other services* (industry 55, rank 15) are oriented

towards public consumption which moves in line with private consumption. *Dwelling services* (industry 53, rank 22) is projected to grow slightly slower than aggregate private consumption in the base case. Its expenditure elasticity is around 1.2 but this is offset by the prospect of the price of dwellings rising relative to the CPI.

9.4.4 Base-case projections: emissions by source

Figure 9.5 gives a year-to-year picture of the level of emissions at the national level. In line with Kyoto accounting principles, it covers all emissions except for emissions from land clearing. Table 9.6 gives region-specific details on the sources of emissions in the base case.

- In aggregate, emissions are projected to grow at an average annual rate of 1.8% between 2010 and 2020, 1.2% between 2020 and 2030, and 1.5% across the full projection period. By 2020, emissions are projected to be 19.6% higher than in 2010. Emission levels at 2030 are projected to be 34.5% above 2010 levels.
- The largest source of emissions is electricity generation, especially generation from coal combustion. In 2010, electricity contributed almost 36% to total emissions. However, the detailed electricity modeling indicates that average annual growth in emissions from electricity will be only 0.2% through the projection period. This is a little below the assumed growth rate in output (generation) of 0.4%, reflecting improved fuel efficiency.

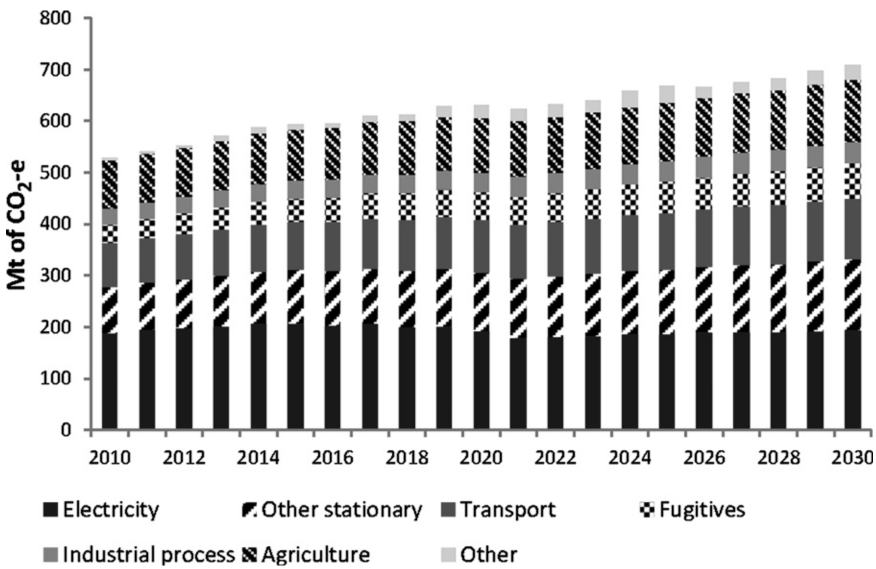

Figure 9.5 Emissions by major source in the base case.

Table 9.6 CO_2-e emissions by major source category: base case

	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUS
Average annual growth rates (%), 2010–2030									
Energy sector, total	1.0	−0.1	1.8	−2.0	3.6	0.9	2.2	1.5	1.3
Fuel combustion	0.7	−0.1	1.6	−1.8	3.0	0.9	2.2	1.5	1.1
Stationary	0.5	−0.4	1.5	−3.5	3.2	1.1	2.2	1.3	0.9
Electricity	0.3	−0.9	1.1	−8.8	1.2	1.2	2.2	0.0	0.2
Other	0.9	0.7	2.2	−0.6	4.3	1.1	2.3	1.3	2.2
Transport	1.3	1.2	2.2	0.8	2.2	0.6	2.1	1.6	1.6
Fugitive emissions	2.4	0.5	3.3	−3.6	7.4	0.5	3.1	2.1	3.3
Industrial processes	1.0	1.4	2.3	1.1	1.5	1.2	2.8	2.0	1.4
Agriculture	1.2	1.2	1.5	1.0	1.1	0.5	1.6	0.8	1.3
Waste	0.9	1.0	1.7	0.5	1.5	0.3	1.4	0.9	1.1
Forestry	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total	1.1	0.4	1.8	−0.5	3.6	2.0	2.0	1.7	1.5
Shares in Australia-wide total (%) 2010									
Energy sector, total	20.4	20.0	19.2	3.7	10.3	0.7	1.1	0.3	75.7
Fuel combustion	17.4	19.7	17.1	3.2	9.4	0.7	1.1	0.3	68.8
Stationary	12.9	15.9	13.4	2.2	7.1	0.3	0.8	0.1	52.8
Electricity	9.3	12.2	9.7	1.2	3.0	0.1	0.3	0.0	35.7
Other	3.6	3.7	3.8	1.0	4.2	0.3	0.5	0.1	17.0
Transport	4.5	3.8	3.7	1.0	2.3	0.4	0.3	0.2	16.0
Fugitive emissions	3.0	0.3	2.1	0.5	0.9	0.0	0.0	0.0	6.9
Industrial processes	2.5	0.7	0.9	0.5	1.0	0.2	0.1	0.0	5.9
Agriculture	3.6	3.5	5.4	1.1	2.3	0.5	1.3	0.0	17.7
Waste	1.2	0.8	0.7	0.2	0.4	0.1	0.0	0.0	3.5
Forestry	−0.2	−0.8	0.0	−0.3	−1.2	−0.3	0.0	0.0	−2.8
Total	27.5	24.3	26.3	5.1	12.9	1.2	2.4	0.4	100.0
2030									
Energy sector, total	18.5	14.6	20.5	1.9	15.4	0.6	1.3	0.3	73.1
Fuel combustion	14.9	14.4	17.6	1.7	12.6	0.6	1.2	0.3	63.3
Stationary	10.5	10.8	13.3	0.8	10.0	0.3	0.9	0.1	46.8
Electricity	7.4	7.7	9.0	0.1	2.8	0.1	0.3	0.0	27.4
Other	3.2	3.1	4.3	0.7	7.2	0.2	0.6	0.1	19.4
Transport	4.4	3.5	4.3	0.9	2.6	0.3	0.3	0.2	16.5
Fugitive emissions	3.6	0.3	2.9	0.2	2.8	0.0	0.1	0.0	9.8
Industrial processes	2.3	0.7	1.1	0.4	1.0	0.2	0.1	0.0	5.8
Agriculture	3.4	3.3	5.4	1.0	2.1	0.4	1.3	0.0	16.9
Waste	1.1	0.8	0.8	0.1	0.4	0.1	0.0	0.0	3.3
Forestry	0.0	0.2	0.0	0.1	0.5	0.1	0.0	0.0	0.9
Total	25.3	19.6	27.8	3.5	19.5	1.3	2.7	0.4	100.0
Total emissions (Mt of CO_2-e)									
2010	144.9	128.1	138.6	27.2	68.0	6.3	12.8	1.9	527.8
2030	179.3	138.8	197.6	24.8	138.3	9.4	18.9	2.7	709.8

- The second largest source of emissions is agriculture, with a 2010-share of 17.7%. In the Kyoto-accounting framework, most of Australia's agricultural emissions come from methane emitted by cattle and sheep. Base-case growth prospects for these livestock industries are well below GDP growth: *Sheep and beef cattle* (1.6% per annum), *Dairy cattle* (0.9%) and *Other livestock* (1.3%). Average annual growth in emissions from agriculture is 1.3%.
- Other stationary energy sources contribute 17.0% to total emissions in 2010. These include residential, industrial and commercial space heating. Emissions from other stationary sources are projected to grow at an average annual rate of 2.2%. This is below the growth rate of real GDP, reflecting the relatively slow growth of *Private heating services* (1.7% per annum) and *Other manufacturing* (−0.1%).
- Transport contributes 16.0% to total emissions in 2010 and has projected emissions growth of 1.6% per annum. Around 60% of transport emissions are due to *Private transport services*, which is projected to grow at an average annual rate of 1.7%. Much of the remaining transport emissions come from *Road freight transport*, which grows at an average annual rate of 3.0%. Emissions grow by less than output in these two key industries because it is assumed that use of bioproducts will increase.
- Of the remaining sources, growth in fugitive emissions is highest, reflecting rapid growth in the mining of gas and coal. Industrial process emissions are projected to grow at an average annual rate of 1.4%, reflecting growth in output from *Cement* and the metals manufacturing industries. Emissions of methane from landfill waste dumps are assumed to grow in line with recent history.
- The final category is *Forestry*. The modeling ignores all emissions from land-use change except for sequestration from forestation and reforestation in areas where the preceding vegetation or land use was not forest. For the base case, data on forestry sequestration were supplied by ABARES. The ABARES projections take account of the life cycle of individual forests established since 1990, accounting for carbon sequestered when the forest is planted and growing, and for carbon released when the forest is harvested. Note that this makes a negative contribution to emissions in 2010 but positive contributions in 2020 and 2030.

Aggregate emissions per $A of real GDP (national emissions intensity) is projected to fall, on average, by 1.4% per year. Much of this has been explained in our discussion of growth rates in emissions by source. In addition, there is a structural effect. The service industries, *Communication services*, *Financial and business services*, *Dwelling ownership*, *Public services* and *Other services*, together contribute around 40% of GDP, but emit relatively little (directly and indirectly via their use of electricity) per unit of real value added. In the base case, they contribute significantly to growth in real

GDP, but have little impact on growth in emissions, generating a fall in emissions per unit of GDP.

Table 9.6 shows that total emissions are projected to grow fastest in the states/territories with the highest projected growth rates – NT, WA and QLD. Total emissions are highest in NSW and VIC up until 2015. Beyond 2015, QLD surpasses VIC. Emissions in WA increase by more than other states reflecting the high economic growth rates and the increase in mining, natural gas and mineral processing activities in that state.

9.4.5 Base-case projections: electricity generation sent out

Figure 9.6(a) shows base-case projections for the shares of generating technologies (other than oil) in aggregate generation (PJ). Figure 9.6(b) shows projections for shares in capacity (GW). Both figures are based on information provided by detailed electricity modeling in *WHIRLYGIG* and summarize the final information fed to MMRF (Section 9.3.2). Further detail is given in Table 9.7.

Total generation sent out is forecast to increase at an average annual rate of 1.5% over the forecast period, which is 1.3 percentage points higher than the growth rate in emissions from generation (Section 9.4.4).[22] The difference is due, in the main, to the federal and state policies included in the detailed electricity modeling that encourage non-coal generation and improved fuel efficiencies within the coal generation sector.

The national share of gas generation (Figure 9.6a) is projected to increase from 14.0% in 2010 to 17.7% in 2020 and to 19.7% in 2030. The total renewable share increases from 13.8% in 2010 to 18.9% in 2020 and increases slightly thereafter. Over the 20-year period, coal's share falls from 73.8% to 61.1%.

Figure 9.6(b) is broadly consistent with Figure 9.6(a). However, the pattern of capacity installation is lumpy, not smooth as the CGE model would have it were it not for the imposition of data from the bottom-up electricity model. Recall that changes in electricity capacity are accommodated in MMRF by shifts in required rates of return (see equation 2 and Table 9.4).

The share of coal in generation capacity declines, as does its share in aggregate sent-out generation. The capacity shares of gas and non-hydro renewables increase as do their generation shares. Note that the share of coal in total capacity (Figure 9.6b) is always less than its share in total generation (Figure 9.6a), reflecting the high rates of capacity utilization of base-load technologies. After 2022, coal's capacity share is fairly

[22] Growth in total generation sent out (Table 9.7) does not necessarily equal growth in the output of the *Electricity supply* industry. *Electricity supply* produces transmission, distribution and retail services. Growth in the volume of these services may differ from growth in generation sent out if, for example, there are improvements in the efficiency of distribution, which means more generation can be delivered with the same amount of distribution services.

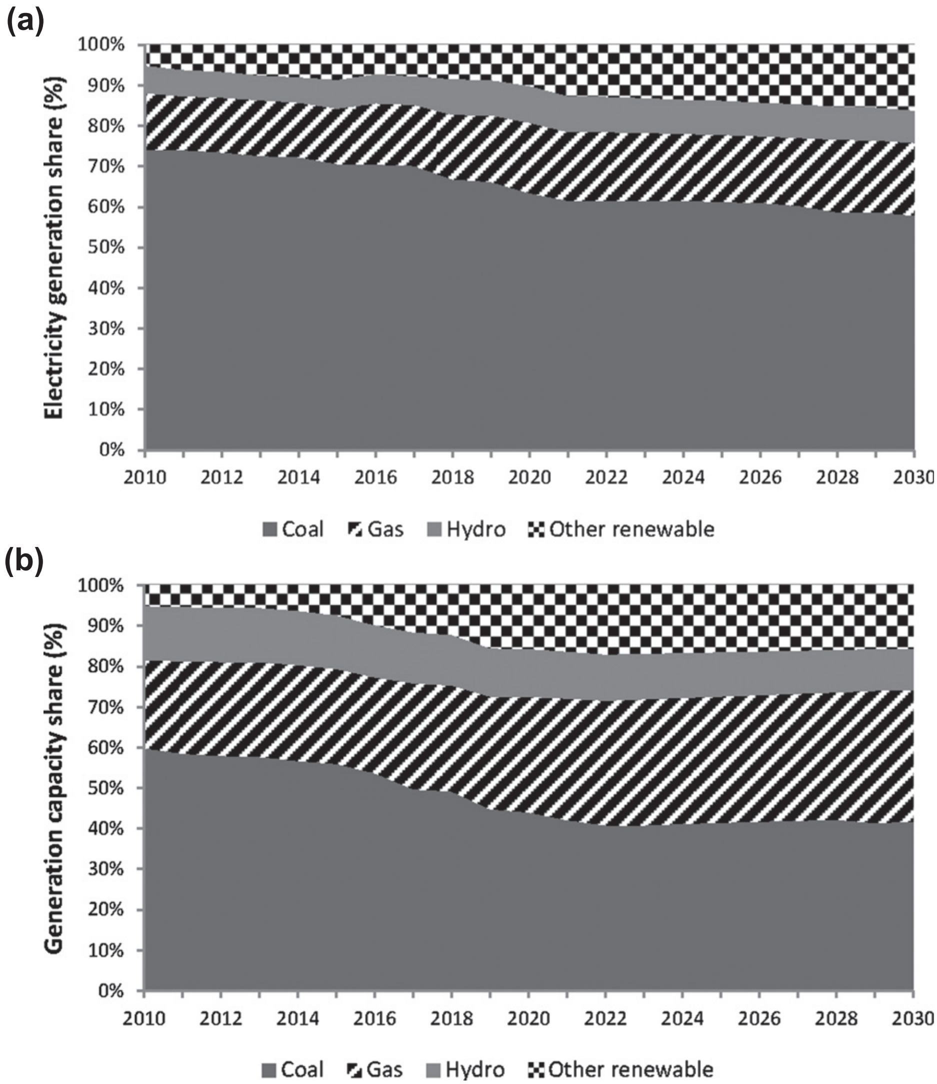

Figure 9.6 (a) Generation sent out by type (shares) in the base case. (b) Generation capacity by type (shares) in the base case.

constant at around 45%, but its generation share continues to fall. In the detailed electricity modeling, there are no net additions to coal capacity after 2022, but the rate of utilization of older plants not being replaced declines. Capacity for gas generation increases by more than is suggested by the change in its generation share. This reflects, in part, forward-looking expectations in the detailed electricity model, which allow for new capacity to come on line even if initially it has a low utilization rate.

Table 9.7 Generation sent out by generator type for Australia: base case

	Average annual percentage growth rates 2010 to 2030
Electricity generation-coal	0.5
Electricity generation-gas	3.2
Electricity generation-oil products	0.0
Electricity generation-hydro	0.0
Electricity generation-other	6.7
Total	1.5

	Levels (PJ)								
	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUS
2010									
Electricity generation-coal	205.5	186.6	200.6	19.1	42.9	0.0	0.0	0.0	654.7
Electricity generation-gas	14.1	12.1	41.9	4.2	37.9	1.8	12.3	0.0	124.4
Electricity generation-oil products	1.2	0.0	1.2	0.1	1.3	0.0	0.0	0.0	3.8
Electricity generation-hydro	10.7	11.4	3.5	0.0	0.0	34.5	0.0	0.0	60.1
Electricity generation-other	6.9	5.6	4.3	9.0	14.3	4.6	0.0	0.0	44.7
Total	238.4	215.8	251.5	32.4	96.5	40.9	12.3	0.0	887.7
2030									
Electricity generation-coal	243.7	174.2	285.3	0.2	20.9	0.0	0.0	0.0	724.2
Electricity generation-gas	25.8	16.4	41.9	10.0	117.0	2.5	20.0	0.0	233.6
Electricity generation-oil products	1.2	0.0	1.2	0.1	1.3	0.0	0.0	0.0	3.8
Electricity generation-hydro	10.7	11.4	3.5	0.0	0.0	34.5	0.0	0.0	60.1
Electricity generation-other	24.5	47.8	21.8	49.4	15.9	4.8	0.0	0.0	164.1
Total	305.9	249.8	353.6	59.6	155.1	41.8	20.0	0.0	1185.9

9.5 ETS SIMULATION DESIGN

9.5.1 Introduction

In Section 9.6, we report MMRF simulations of a global ETS with a global allocation of permits sufficient to reduce global emissions in 2050 to 5% below their level in the year 2000.[23] The simulations examine the effects of this scheme out to 2030. The effects are reported as deviations from the values of variables in the base-case projection described in Section 9.4.

The main inputs to the MMRF policy simulation are projected effects of the scheme on:

- various aspects of electricity supply, as modeled by Frontier Economics;
- vehicle use by vehicle type, as modeled by the Australian Bureau of Infrastructure, Transport and Regional Economics (BITRE) and by the Commonwealth Scientific and Industrial Research Organization (CSIRO);
- forestry sequestration and plantation use of land from land-use experts at ABARES;
- foreign currency import prices and the positions of foreign export-demand schedules from the GTEM model;
- the global emissions price and Australia's allocation of global permits as specified by the Australian Treasury.

In the remainder of this section, we first outline the key features of the scheme (Section 9.5.2), including the permit price and Australia's allocation of emission permits. In Section 9.5.3 we discuss the other key inputs listed above. Key assumptions regarding the behavior of the macroeconomy in the MMRF simulations are discussed in Section 9.5.4.

9.5.2 Scheme design

Table 9.8 summaries design features of the modeled ETS scheme.

9.5.2.1 Permit price

The GTEM projection of the international permit price, converted to real Australian dollars in MMRF, is given in Figure 9.7. The starting price is \$A24.3 per tonne by the year 2012. Thereafter, it increases at an annual rate of around 4%, reaching \$A33.3 per tonne in 2020 and \$A49.3 per tonne in 2030.

In MMRF, the permit price is modeled as a tax imposed per unit of CO_2-e (Section 9.2.3.2). In keeping with the design of the scheme, initially the tax is imposed on all sources of emissions other than agriculture and transport. From 2012 onwards it is extended to transport, and from 2015 to agriculture. Thus, all emissions are priced at the same rate after 2015.

[23] This is the scheme identified by the Australian Treasury as the CPRS (Carbon Pollution Reduction Scheme)-5.

Table 9.8 Features of the ETS scheme as modeled

Assumption	Details
Timing and relationship to global action	Scheme starts in 2011 as a domestic scheme with a specified emissions price. From 2012 to 2020 it continues to operate as a domestic scheme, but with permits allowed to be purchased from overseas such as credits generated through projects under the Kyoto Protocol's Clean Development Mechanism (CDM). From 2020 onwards, Australia's scheme is fully integrated into a single comprehensive global scheme. Scheme price is specified for each year. The allocation of permits in Australia is specified from 2012 onwards. Emission price and permit allocation come from GTEM and are given in Sections 9.5.2.1 and 9.5.2.2.
Coverage	Phased coverage of sectors: • All emissions other than from agriculture and transport from 2011 onwards. • Transport emissions from 2012. • Agricultural emissions from 2015. All sectors covered by the scheme face the same emissions price.
Free permit allocation to generators	Limited free allocation of permits to electricity generators to 2020. Emission permits are allocated to offset net loss in profits.
Compensation for trade exposed, energy intensive industries	Energy-intensive trade exposed industries are compensated through to 2020 according to the shielding formulae (7) and (8). Category 1 industries are: Sheep and beef cattle (industry 1), Dairy cattle (2), Grains (4), Cement (24), Iron and steel (25) and Aluminum (27). Category 2 industries are: Other livestock (industry 3), Gas mining (10), Paper products (18), Basic chemicals (21), Non-metal construction products (23), Alumina (26) and Other non-ferrous metals (28). From 2020 onwards the shielding rates decline in a linear way to zero in 2025.
Recycling of surplus revenue	Remaining permits, beyond those used to compensate generators and trade-exposed energy sectors, were assumed to be auctioned, with surplus revenue recycled as a lump sum to households.
Other Australian mitigation policies	The MRET continues to operate through to 2020. Most other mitigation policies included in the base case cease with the exception of a QLD scheme designed to increase gas generation in that state to 15% of total generation.
Banking	Unconstrained banking is allowed, but no borrowing. The impact of banking is reflected in the Frontier modeling for the electricity generation sector and thus influences the permit price adopted in the MMRF modeling. Banking allows arbitrage between higher permit prices later in the ETS period and lower permit prices earlier. This has the effect of increasing the amount of (cheaper) abatement undertaken early, and reducing the amount of (more expensive) abatement later.

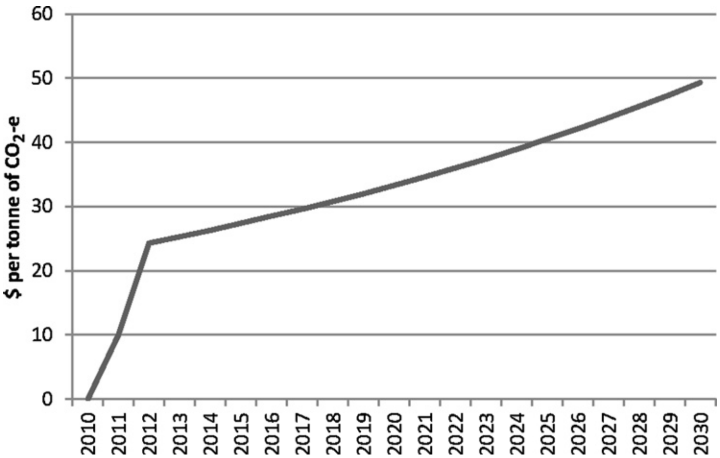

Figure 9.7 Price of permits in real Australian dollars.

9.5.2.2 Australia's allocation of permits

Figure 9.8 shows Australia's allocation of permits under the global ETS. It also shows Australia's projected path for emissions in the base case where no ETS is in place. In the base case, emissions rise from 528 Mt of CO_2-e in 2010 to 710 Mt in 2030. Australia's permit allocation in 2030 is for emissions of 365 Mt of CO_2-e.

The gap between base-case emissions and permit allocation represents the international abatement obligation faced by Australia under the global ETS. As shown in Figure 9.8 the gap steadily widens over time, so that by 2030 the abatement obligation is

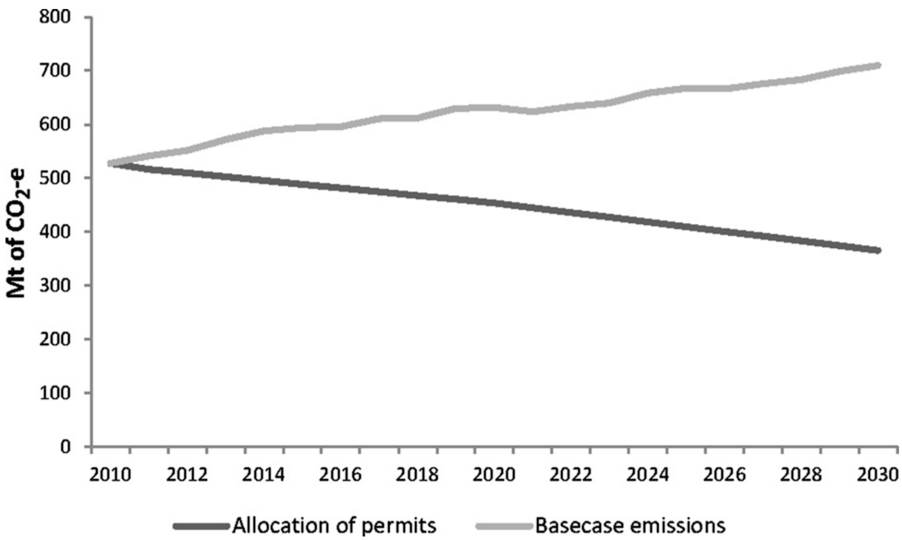

Figure 9.8 Permit allocation and base case path of emissions.

345 ($= 710 - 365$) Mt of CO_2-e. Australia can meet this in two ways: by domestic abatement in response to the emission price and by purchasing permits from overseas. As will be seen, based on the price profile in Figure 9.7, Australia ends up importing a large number of permits.

9.5.2.3 Electricity inputs from Frontier WHIRLYGIG

Following the iterative process described in Section 9.3.2.2, the Frontier electricity model provides projections (deviations from base-case values) for electricity generation, energy use, generation capacity, emissions and electricity prices. These projections are accommodated in the MMRF modeling via the closure changes given in Table 9.4.

In the Frontier modeling, the electricity sector responds to the permit price by switching technologies, changing the utilization of existing capacity, and replacing old plants with new more-efficient plants. The modeling also includes the reduction in electricity usage projected in MMRF's modeling of demand. These factors underlie the deviations from base plotted in Figure 9.9(a) (generation) and Figure 9.9(b) (capacity). Further detail on generation is given in Table 9.9.

Compared to the base case, the overall level of generation in 2030 is down by 6.9% and the mix of generation has changed appreciably away from coal and towards gas and non-hydro renewables. By assumption, there is no change in generation from oil products (not shown in Figure 9.9a) and hydro.

In the base case, the detailed electricity modeling tells a fairly straightforward story for the relationship between generation and capacity for each generation technology (Figure 9.6a and b). However, in the ETS-induced deviations from base case the relationships are more complicated. For coal, capacity declines at the same rate as it does in the base case through to 2020, yet generation falls significantly relative to base-case levels, reflecting reduced capacity utilization. From 2020 onwards, the emission price depresses expectations of long-run profit to such a degree that conventional coal capacity starts to decline – replacement investments in coal-fired capacity that occur in the base case are discouraged by the emissions price. In 2030, coal capacity is 28% below its base-case level, while coal generation is down by about 20%.

Capacity for gas generation, which expands in the base case, is below base-case levels from 2014 onwards. Units of gas generation are generally smaller than units of coal generation. Hence, in the detailed electricity modeling, gas generation capacity can be adjusted relatively quickly. Note that rate of capacity utilization for gas plant is above the base-case rate throughout the projection period. This is especially marked after 2019, due to the ETS bringing forward a large upgrade of an existing plant, reducing its unit operating costs.

Capacity for other-renewable generation initially falls relative to its base-case levels, before exceeding base-case levels from 2013 onwards. This postpones the rate at which

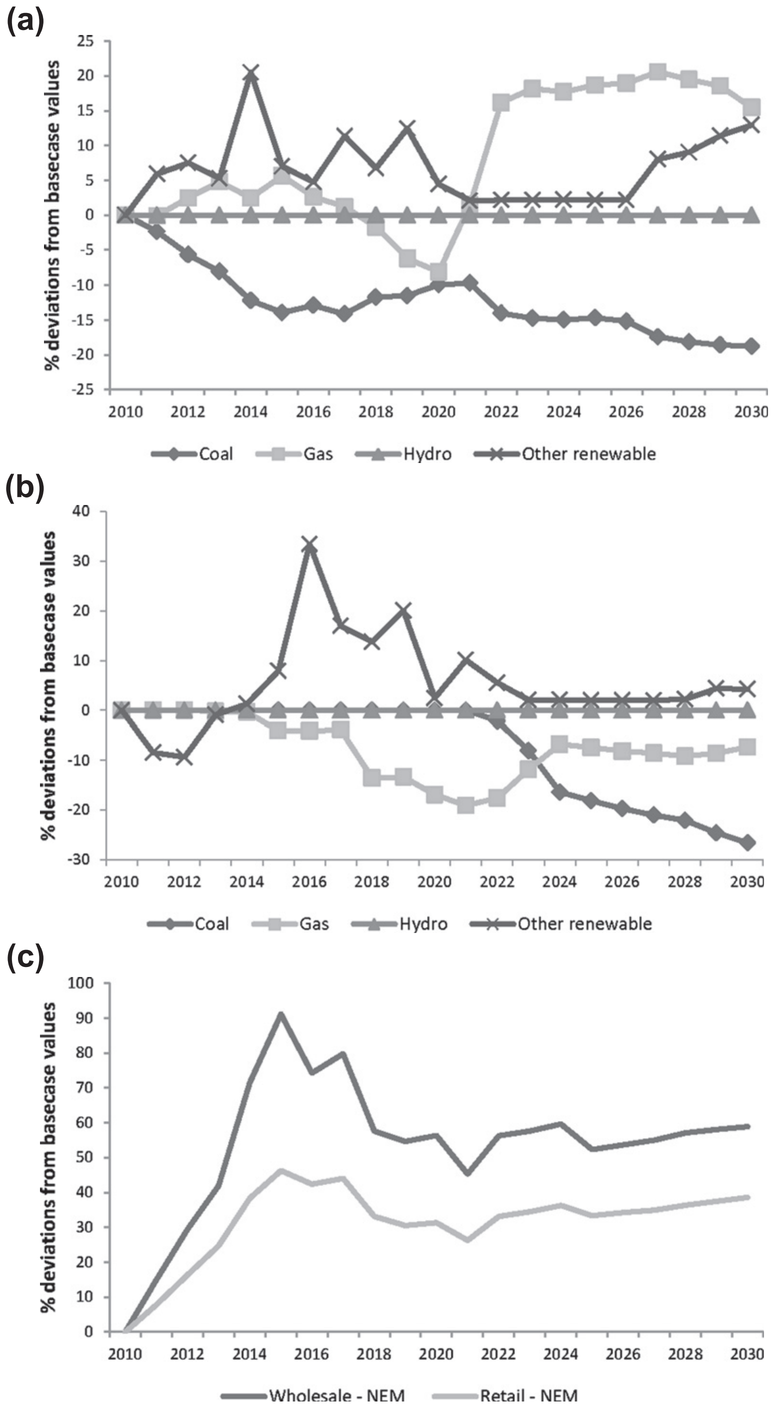

Figure 9.9 (a) Electricity generation by type. (b) Electricity capacity by type. (c) NEM electricity prices.

Table 9.9 Generation sent out by generator type for Australia: policy

Percentage deviations from base-case values	2015	2020	2030
Electricity generation-coal	−13.0	−9.8	−18.0
Electricity generation-gas	6.6	−5.7	11.5
Electricity generation-oil products	0.0	0.0	0.0
Electricity generation-hydro	0.0	0.0	0.0
Electricity generation-other	4.7	5.0	13.3
Total	−8.0	−6.5	−6.9

	Changes in levels (PJ)								
	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUS
2015									
Electricity generation-coal	−38.0	−39.4	−10.4	−1.3	−6.3	0.0	0.0	0.0	−95.3
Electricity generation-gas	−1.4	−1.2	0.7	9.1	3.2	−0.2	−0.5	0.0	9.6
Electricity generation-oil products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity generation-hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity generation-other	−0.1	20.8	−10.2	−7.8	0.9	−0.1	0.0	0.0	3.7
Total	−39.4	−19.8	−19.9	0.1	−2.1	−0.3	−0.5	0.0	−81.9
2030									
Electricity generation-coal	−25.0	−42.5	−47.4	−0.6	−15.1	0.0	0.0	0.0	−130.6
Electricity generation-gas	17.6	−0.4	1.7	−5.3	14.5	−0.2	−1.1	0.0	26.8
Electricity generation-oil products	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity generation-hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electricity generation-other	0.0	8.1	10.7	3.0	0.0	0.0	0.0	0.0	21.8
Total	−7.5	−34.9	−34.8	−2.8	−0.6	−0.2	−1.1	0.0	−82.1

new renewable plant is installed relative to base-case assumptions. Note, however, that renewable generation is still replacing coal-fired generation in these early years. This is due to a rise in capacity utilization for renewable and a fall for coal. After 2013, capacity in the non-hydro renewable sector increases but unevenly, reflecting the detailed electricity model's handling of lumpy investments.

In the Frontier modeling, cleaner technologies for generating electricity from coal are adopted when the price on emissions makes it economical to do so. The uptake of such technologies is the reason that, as a percentage of base-case values, emissions from coal generation fall by more than generation levels. Relative to base case, coal generation falls by 13.0% (2015), 9.8% (2020) and 18.0% (2030), while emissions are down 14.5% (2015), 10.6% (2020) and 23.9% (2030).

In addition to generation and capacity, electricity prices are key variables imported into MMRF from *WHIRLYGIG*. Figure 9.9(c) gives deviations from base-case values for average wholesale and retail prices in the NEM.

With base-case emission intensities and the base-case composition of generation, the carbon price (Figure 9.7) would increase the average cost of generation in the NEM to about 80% above its base-case level in 2030. With wholesale electricity accounting for around 40% of the retail cost, we would then expect the retail price in 2030 to be about 30% above its base-case value. As shown in Figure 9.9(c), however, in the detailed electricity modeling the wholesale price jumps quickly to be about 90% above its base-case level, then declines in a jumpy way to about 60% above base in 2030. The retail price follows a similar pattern, ending up about 40% higher than its base-case level.

The initial increase in the wholesale price occurs because the carbon price increases the relative cost of Victorian brown-coal generation so that it becomes the marginal supply that sets the price in the early years, instead of being base-load plant. As the brown-coal generators set the price in the NEM and because they have high emission intensities (of greater than 1 t/MWh), electricity prices increase by the full amount of the increase in their short-run marginal cost. After 2015, the conventional brown-coal generators are phased out (though not immediately scrapped, as can be seen from Figure 9.9b) and the marginal generator changes to gas and renewable generation units with lower marginal costs. These changes continue until by 2030 with a carbon price of almost $A50 per tonne, the wholesale price has reached a level about 60% above its base-case value.

The increase in retail price is higher than would be expected given the increase in wholesale price. Higher network charges associated with the significant changes in type and location of generation account for this.

9.5.2.4 Road transport inputs from the BITRE and CSIRO

The BITRE and CSIRO provide data for changes away from base-case values in fuel use and emissions for private transport by region. The assumptions suggest that to 2030 the emissions price will have little impact on fuel choice and emissions in private transport.[24]

Projections for the use of gasoline, diesel and LPG in road transport are accommodated in MMRF by endogenous shifts in fuel-usage coefficients in industries' production functions. The BITRE/CSIRO emissions projections are accommodated by endogenous shifts in emissions per unit of fuel used.

9.5.2.5 Forestry land and biosequestration inputs from ABARES

According to the ABARES inputs, the global ETS would have a significant impact on forestry production and forest biosequestration, as shown in Figure 9.10. By 2030, forestry production has risen 80% above its base-case level and sequestration has risen by 30 Mt.

Corresponding changes in land under forestry are also imposed. With total land availability by region, fixed, land available for agriculture falls.

The ABARES estimates of the response of forestry sequestration to the emissions price is accommodated in MMRF by endogenous shifts in emissions per unit of forestry output.

9.5.2.6 Trade variables based on information from GTEM

Projections of changes in foreign-currency import prices and in the positions of foreign export-demand schedules for Australia in response to a global emissions price are sourced from GTEM modeling.[25] The GTEM projections are summarized by changes in the aggregate terms of trade shown in Figure 9.11.

The long-term effect of the ETS on Australia's terms of trade is negative. This is driven mainly by a reduction in the world price of coal as users switch to less emission-intensive fuels. However, when China joins the international coalition in 2015[26] there is a temporary jump in global coal prices as Chinese demand is diverted from local to foreign supplied product. This effect dissipates in 2020 when India and the rest of the world join the scheme and world coal demand falls.

9.5.2.7 Assumptions about gas reserves and gas prices from various industry sources

In the base-case and policy simulations, gas reserves in the eastern Australia gradually close down and are replaced by supplies from WA and the NT. WA and NT gas is produced for export as well as for local use and its price is set by the global gas price. Gas from eastern sources is produced for local demand and its price is determined, in the

24 Note that the post-2030 ETS modeling reported by the Treasury has electric-powered cars taking significant market share away from vehicles relying on internal combustion technologies.

25 The methodology used to introduce the GTEM results into MMRF is described in Section 9.3.1.

26 The Treasury's CPRS assumed a multistage approach to international emissions trading. Developed countries act first, then developing countries join over time.

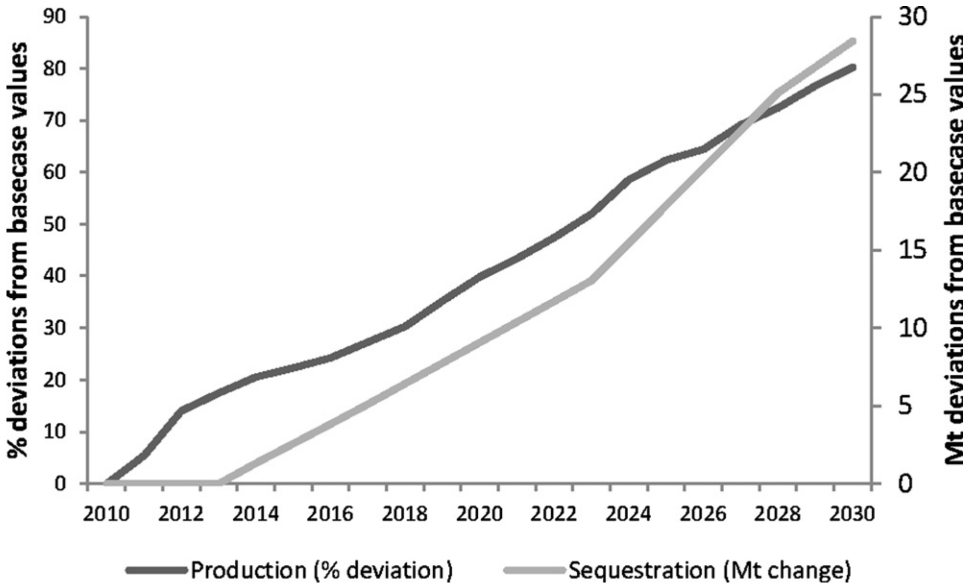

Figure 9.10 Forestry production and sequestration.

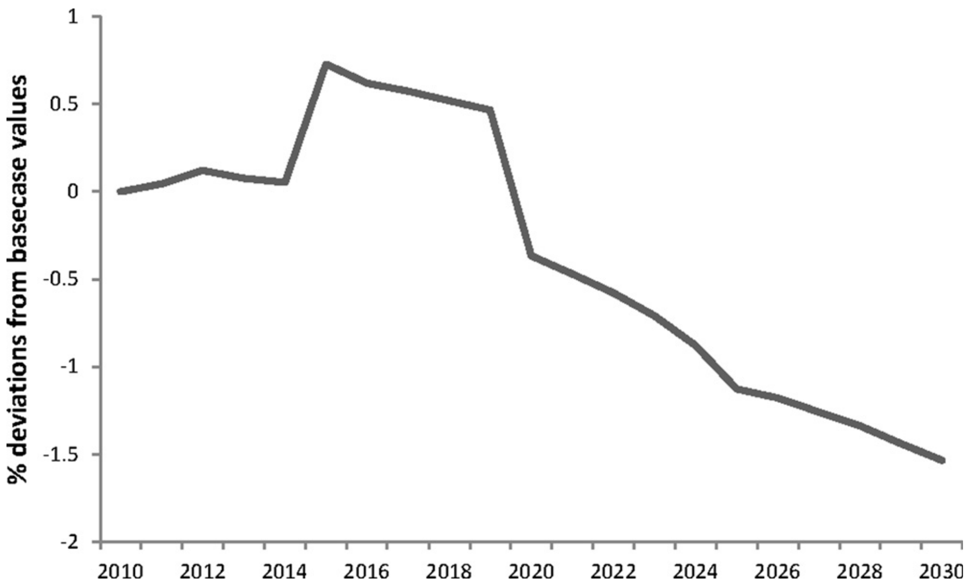

Figure 9.11 Australia's terms of trade.

main, by domestic factors. As eastern fields are replaced by WA and NT gas, so the prices paid by customers in the eastern states move to international parity. In the base-case and policy simulations, it is assumed that eastern gas prices rise gradually to reach full international parity by 2030.

9.5.3 Assumptions for the macroeconomy in the policy scenarios

The following assumptions are made for key aspects of the macro economy in the policy (with-ETS) simulation.

9.5.3.1 Labor markets

At the national level, lagged adjustment of the real-wage rate to changes in employment is assumed. Adoption of the ETS can cause employment to deviate from its base-case value initially, but thereafter, real wage adjustment steadily eliminates the short-run employment consequences of the emissions price. In the long run, the costs of emissions pricing are realized almost entirely as a fall in the national real wage rate, rather than as a fall in national employment. This labor-market assumption reflects the idea that in the long run national employment is determined by demographic factors, which are unaffected by the adoption of an emissions price.

At the regional level, labor is assumed to be mobile between state economies (Section 9.2.2.5). Labor is assumed to move between regions so as to maintain interstate unemployment-rate differentials at their base-case levels. Accordingly, regions that are relatively favorably affected by emissions pricing will experience increases in their labor forces as well as in employment, at the expense of regions that are relatively less favorably affected.

9.5.3.2 Private consumption and investment

Private consumption expenditure is determined via a Keynesian consumption function that links nominal consumption to HDI. HDI includes the lump-sum return of permit income which is part of the ETS design. In the ETS simulations, the APC is an endogenous variable that moves to ensure that the balance on current account in the balance of payments remains at its base-case level. Thus, any change in aggregate investment brought about by the ETS is accommodated by a change in domestic saving, leaving Australia's call on foreign savings unchanged.

This treatment of domestic and foreign savings is sufficient, but more extreme than is necessary, to ensure that the long-run deviation in real private consumption from its base-case level is a valid measure of the impacts of the ETS on the welfare of Australians. A less extreme treatment would be to impose a foreign-debt constraint directly and allow the year-to-year pattern of aggregate consumption and the current account to reflect year-to-year changes in disposable income.

Investment in all but a few industries is allowed to deviate from its base-case value in line with deviations in expected rates of return on the industries' capital stocks. In the policy scenarios, MMRF allows for short-run divergences in rates of return from their base-case levels. These cause divergences in investment and hence capital stocks that gradually erode the initial divergences in rates of return. Provided there are no further shocks, rates of return revert to their base-case levels in the long run. An exception to this rule is the electricity generating industries, for which changes in capacity are taken from the detailed electricity model. The changes are accommodated by allowing the required rates of return on investment to shift endogenously.

9.5.3.3 Government consumption and fiscal balances

MMRF contains no theory to explain changes in real public consumption. In these simulations, public consumption is simply indexed to nominal GDP. The fiscal balances of each jurisdiction (federal, state and territory) as a share of nominal GDP are fixed at their values in the base case. Budget balance constraints are accommodated by endogenous movements in lump-sum payments to households.

9.5.3.4 Production technologies and household tastes

MMRF contains many variables to allow for shifts in technology and household preferences. In the policy scenarios, most of these variables are exogenous and have the same values as in the base-case projection. The exceptions are technology variables that are made endogenous to allow for:

- changes in the fuel intensity of electricity generation, based on data from the detailed electricity modeling;
- the new production technology required to achieve the reductions in emissions intensity implied by equation (9.9) (Section 9.3.4);
- the replacement of gasoline and diesel with cleaner (but more expensive) biofuels and electricity in the provision of private transport services. This is based on information from the detailed road-transport modeling (Section 9.5.2.4).

9.6 ECONOMIC EFFECTS OF THE ETS

9.6.1 Introduction

Figure 9.12 illustrates the interpretation of MMRF results for the effects of an ETS on a particular variable, e.g. real GDP. MMRF generates a base case, which is a projection through time for the variable without an ETS (Section 9.4). The base case is depicted as the path between points A and B. The model is also used to produce an alternative projection in which endogenous variables shift away from base-case trends to accommodate the exogenous shocks associated with the ETS (Section 9.5). A typical alternative projection for the variable considered in Figure 9.12 is shown as the path between points A and C.

Figure 9.12 has been drawn with the base-case path and the ETS path both smooth and with the deviation of the ETS path from the base-case path also growing smoothly. In this case, it is apparent that there are a number of options for reporting the effects of the ETS, all of which will tell a similar story.

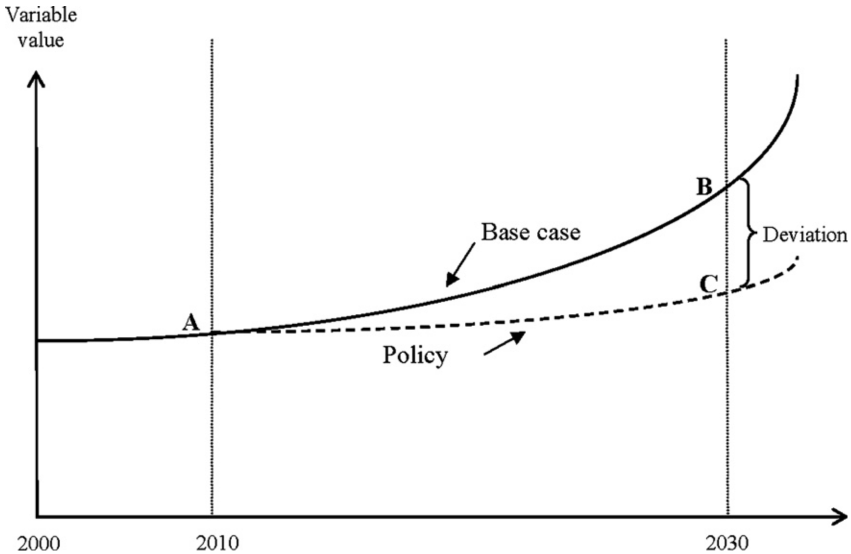

Figure 9.12 Interpretation of results.

One option is to compare average annual growth in the base case with average annual growth in the ETS simulation. In terms of average annual rates between 2010 and 2030, we would be comparing:

$$100 \times \left\{ \left(\frac{B}{A} \right)^{1/20} - 1 \right\} \text{ with } 100 \times \left\{ \left(\frac{C}{A} \right)^{1/20} - 1 \right\}. \tag{9.10}$$

Note that in the smooth case shown in Figure 9.12, comparing average annual growth rates over shorter periods will not be seriously misleading relative to the whole-period comparison.

Alternatively, deviations can be reported by comparing the value of variables in a specific year in the ETS simulation with values in the base case. Deviations could be expressed as percentage changes from base-case values in the final year of the simulation period:

$$100 \times \left\{ \left(\frac{C}{B} \right) - 1 \right\}, \tag{9.11}$$

or as absolute ($A million or Mt, etc.) changes from base-case values:

$$(C - B). \tag{9.12}$$

Again, in the smooth case intermediate-year comparisons will not be seriously misleading relative to the final-period comparison.

Users of model-based projections of the effects the ETS policy have often been tempted to select their preferred reporting option according to how it is likely to be interpreted by non-specialists. Proponents of the ETS opt for measures that appear superficially to suggest that its cost will be small while opponents opt for measures that appear to suggest large costs.

To illustrate this, in Table 9.10 we report the effects of the ETS on Australian real GDP in 2020 and 2030 according to measures (9.10)−(9.12) and according to a fourth measure (9.13) that emphasizes that negative deviations from base-case values are compatible with continuing strong growth in an economy that would have been enjoying strong growth in the absence of the ETS. This fourth measure expresses the deviation as the number of months of base-case growth that are lost as a consequence of the ETS:

$$-12 \times \frac{\left\{\left(\frac{C}{B}\right) - 1\right\}}{\left\{\left(\frac{B}{A}\right)^{1/20} - 1\right\}}. \tag{9.13}$$

Unsurprisingly, proponents of the ETS usually opt for the first or fourth measure, while opponents tend to concentrate on the second or especially the third measure.

More fundamental than this cosmetic point is the question of how to report results in cases in which, unlike Figure 9.12, the base-case path or the ETS path or the deviation between the paths does not develop smoothly. As shown in Figures 9.9(a−c) and 9.11, when we incorporate results from a bottom-up model of the electricity system like *WHIRLYGIG* or a world-trade model like GTEM, the paths and deviations for electricity variables and the terms of trade may not develop smoothly. One option is to report a time profile of the deviations of base-case values from ETS values. Another is to use an aggregate measure that includes all the year-specific deviations. The present value of the deviations is an obvious choice.

9.6.2 Results

The rest of this section contains a discussion of deviations from base-case values in the ETS simulations (Tables 9.11−9.14). National impacts are dealt with first, followed by

Table 9.10 Alternative interpretation of ETS impacts

Equation	Description of measure	2020	2030
10	Average annual growth rates (%)	2.91 (base)/ 2.87 (ETS)	2.63 (base)/ 2.56 (ETS)
11	Deviations from base case (%)	−0.5	−1.1
12	Absolute deviations from base case ($Am)	−7268.7	−20138.4
13	Months of growth lost due to the ETS	2.0	4.9

state and substate outcomes. Projected deviations for 2030 are given in Tables 9.11 (macro variables), 9.13 (national industry output) and 9.14 (emissions of CO_2-e). A series of charts provide time profiles of the deviations for key variables. In the discussion below, which focuses mainly on the final year (2030), subheadings headings outline the main features of the results.

Our explanations of the national-level macroeconomic results are informed by a stylized back-of-the-envelope (BOTE) macro model that we constructed to demonstrate the macroeconomic mechanisms underlying the MMRF results. Details of the stylized model are in the Appendix.

9.6.2.1 National variables

In the short run, the ETS reduces employment relative to its base-case level; over time, the employment deviation remains fairly constant as the national real wage rate adjusts downwards

The explanation of macro effects begins with the impacts on the national labor market. Figure 9.13 shows percentage deviations in national employment, the national real wage rate and the national real cost of labor. The real wage is defined as the ratio of the nominal wage rate to the price of consumption. The real cost of labor is defined as the ratio of the nominal wage rate to the national price of output (measured by the factor-cost GDP deflator). Assuming competitive markets, the equilibrium nominal wage will be equal to the value of the marginal product of labor.

According to the labor market specification in MMRF (Section 9.5.3.1), the real wage rate is sticky in the short run (i.e. the nominal wage moves with the price of consumption), but adjusts with a lag downwards (upwards) in response to a fall (rise) in employment. When the ETS starts up, the emissions price increases the price of spending (e.g. household consumption) relative to the price of output and hence moves the nominal wage above the value of the marginal product of labor in the short run. In

Table 9.11 Macroeconomic variables (% changes from base-case values, 2030)

	Real GDP/ GSP	Real consumption	Real international exports	Real international imports	Employment
NSW	−1.2	−1.9	1.2	−2.4	−0.5
VIC	−0.9	−2.0	6.9	−1.6	0.1
QLD	−1.8	−1.1	−2.0	−2.8	−0.9
SA	−0.7	−2.5	7.2	−1.6	0.0
WA	−0.8	0.8	−1.5	−1.4	1.0
TAS	3.3	−1.8	21.4	1.6	3.1
NT	1.5	2.2	3.3	1.0	2.2
ACT	−1.2	−3.0	3.0	−2.8	−0.9
National	−1.1	−1.5	1.2	−2.0	−0.1

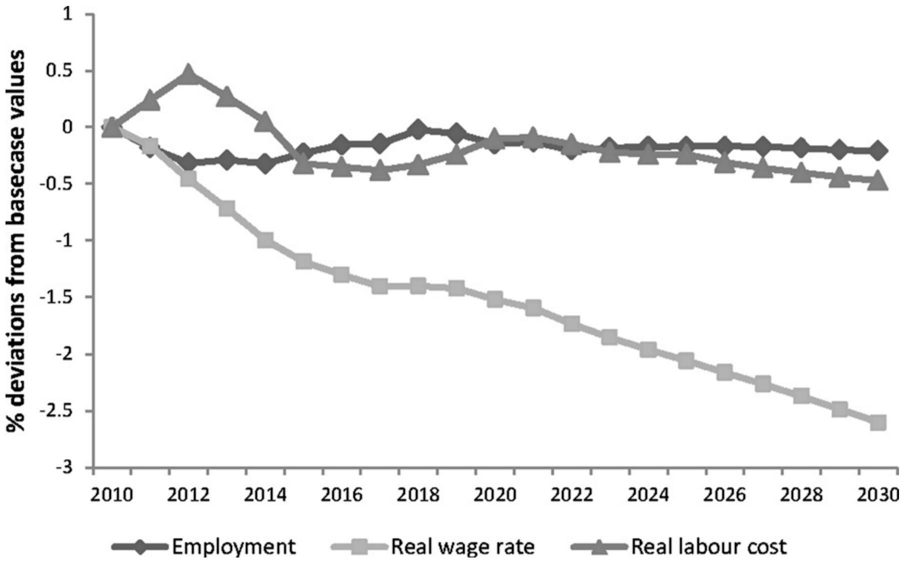

Figure 9.13 Deviations in employment and real wage rates.

Figure 9.13 this shows as an increase in the real cost of labor relative to its base-case value and a fall in employment relative to base case.

If there were no further shocks, over time the real wage rate would progressively fall relative to base-case levels, reducing the real cost of labor and forcing employment back to its base-case level. In the ETS simulations, however, shocks continue with the permit price increasing under a progressively tighter regime of tradable permits. Hence, as shown in Figure 9.13, the employment deviation is never fully eliminated and the real wage rate declines steadily relative to its base-case value. In 2030, the employment deviation is −0.2%, while the real wage rate is down 2.6%.

Note that the deviations in employment and the real wage rate are not smooth, especially in the early years, despite the smoothness of the permit-price trajectory (Figure 9.7). This reflects a number of factors:

- the changing coverage of the ETS scheme, with transport industries entering in 2012 and agricultural industries entering in 2015 (Table 9.8);
- large changes in electricity generation and capacity by technology type projected by the detailed electricity modeling (Figure 9.9a and b);
- swings in the national terms of trade projected by GTEM (Figure 9.11).

The swings in the terms of trade have a significant impact on the labor market in the short run. An increase in the terms of trade causes the price of final domestic demand (which *includes* import prices but *excludes* export prices) to fall relative to the price of GDP (which *excludes* import prices but *includes* export prices), leading to downward pressure on the real cost of labor. Hence, relative to base, changes in the terms of trade

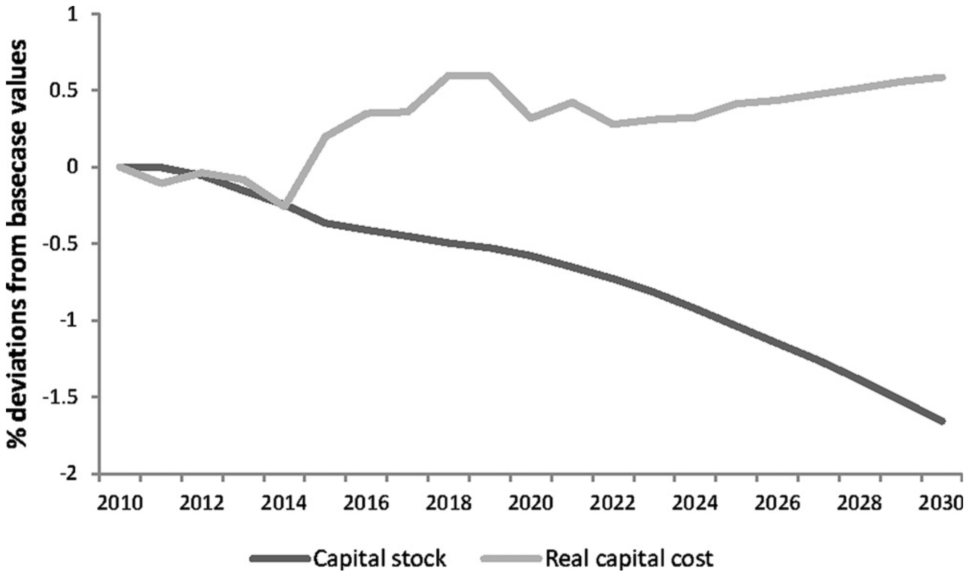

Figure 9.14 Deviations in capital stock and the real cost of capital.

contribute positively to employment in the first few years of the projection when the terms of trade rise.

A final point to note is that even though the fall in national employment is fairly small, this does not mean that employment at the individual industry or regional level remains close to base-case values. In most industries and regions, there are significant permanent employment responses to the ETS, compounding or defusing existing (base-case) pressures for structural change.

The ETS depresses the economy-wide labor/capital ratio

Figure 9.14 shows percentage deviations from base-case values for the national capital stock and the real cost of capital. The latter is defined as the ratio of the nominal rental cost of capital to the national price of output (measured by the factor-cost GDP deflator). In 2030, the capital stock deviation is −1.7%, implying an increase in the ratio of labor to capital of around 1.6%. In the same year, the real cost of capital is up 0.6% relative to its base case level.[27]

The reduction in capital is due, in part, to changes in relative factor prices. As the real cost of labor falls relative to the real cost of capital (compare Figure 9.13 with Figure 9.14), producers substitute labor for capital across the economy. In 2030, with the real cost of capital relative to the real cost of labor rising by around 1.1%, the shift in

[27] In general terms, as the real cost of labor falls, so the real cost of the other key factor of production (capital) will rise.

relative factor prices could be expected to contribute about $0.5 \times 3.0 = 1.5$ percentage points to the eventual 1.6% increase in the labor/capital ratio.[28] In addition, there is a compositional effect due to the fact that the energy-related mining and coal-fired electricity sectors that are suppressed by the ETS are capital-intensive.

With little change in employment and technology, the reduction in capital leads to a fall in real GDP at factor cost

The percentage change in real GDP at factor cost is a share-weighted average of the percentage changes in quantities of factor inputs (labor, capital and agricultural land), with allowance for technological change. Figure 9.15(a) shows, in stacked annual columns, the contribution of each component other than land to the overall percentage deviation in real factor-cost GDP. Although land can be re-allocated between uses, its availability overall is fixed.

Real GDP at factor cost falls relative to its base-case level in all years of the simulation. In the final year it is down 0.9%. The possibility of achieving large cuts in emissions at a relatively mild macro-cost is a common theme in all of the analyses of carbon taxes and emission trading schemes undertaken at CoPS.

As Figure 9.15(a) shows, nearly all of the fall in factor-cost GDP is due to the reduction in capital. Labor's contribution in the final year is a little more than −0.1 percentage point.

The ETS does induce some technological change (Section 9.5.3.4), but its contribution to the deviation in real GDP is small. In the MMRF simulation, the carbon price leads to technological deterioration primarily through the adoption of more expensive, but less emission-intensive, production technologies (Section 9.3.4). This is evident in Figure 9.15(a) for the early years of the simulation period. In the later years it is offset and eventually dominated by a compositional factor. In dynamic policy simulations, deviations in real GDP are affected by induced changes in the composition of GDP (Dixon and Rimmer, 2002; Section 9.7.2). If the policy shock increases the shares in GDP of industries with rapid technological progress and reduces the shares of industries with less rapid technological progress, then real GDP growth will be elevated in the policy simulation relative to the base case.[29] In our base-case simulation, service industries are assumed to have stronger labor-saving technological progress than mining and manufacturing industries. As the carbon price shifts the composition of the economy towards services, this allows technological change to make a positive contribution to the deviation in real GDP from 2019 onwards.

28 The capital to labor substitution elasticity is 0.5.

29 Similar phenomena affect the measurement of other macro indices. For example, the path of real consumption in a policy simulation can deviate from its base-case path not only because of deviations in quantities consumed of each commodity, but also because of deviations in budget shares.

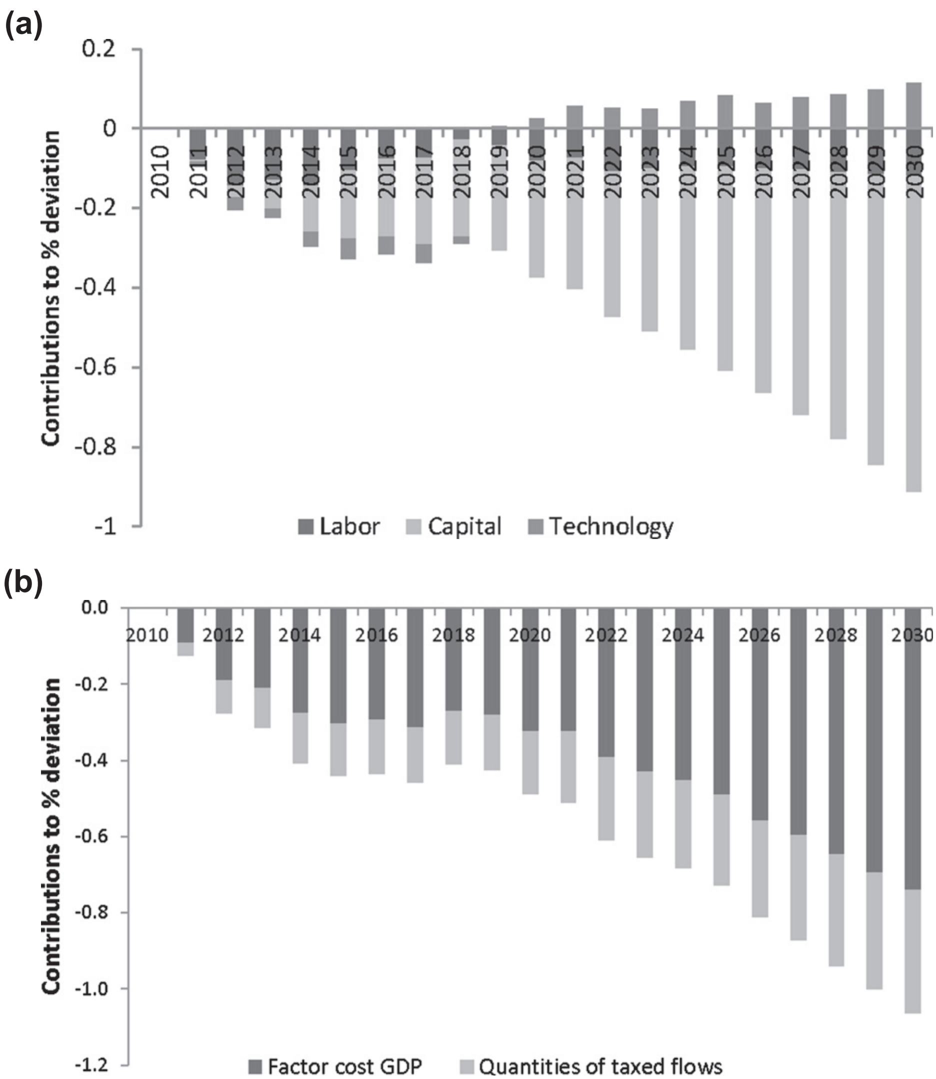

Figure 9.15 (a) Contributions to percent deviation in real GDP at factor cost. (b) Contributions to percent deviation in real GDP at market prices.

Real GDP at market prices falls by more than real GDP at factor cost, due to a contraction in real indirect-tax bases

The percentage change in real GDP at market prices is a share-weighted average of the percentage change in real GDP at factor cost and real net-indirect-tax bases. As shown in Figure 9.15b, in line with the fall in factor-cost GDP, market-price GDP falls through the projection period to be 1.1% below its base-case value in 2030. Box 9.1 provides a plausibility check on this result.

BOX 9.1 Check on reality via BOTE calculations

As noted above, by 2030 with an emissions price of close to $A50, real GDP at market prices is projected to be 1.1% lower than it otherwise would have been and emissions are projected around 25% lower.

Is this result plausible? To answer this question, CoPS modelers typically make use of BOTE calculations. This can be done in a formal way using a stylized model as demonstrated in the Appendix. Or it can be done less formally. For example, we know that the main CO_2-e emitting activities are the fossil fuel-based provision of electricity and transport services. According to the MMRF database, in 2011 these activities represent about 2.5% of market-price GDP and about 55% of total emissions. Based on the Frontier Economics electricity model and expert transport sector input, Australia can cut its emissions from these sectors by about 45% with roughly a 55% increase in the costs of electricity and motor fuels. As a BOTE calculation, this suggests that Australia could make a 25% cut in emissions at a cost of around 1.4% (= 55% of 2.5) of GDP. The projected outcome for real GDP is a little milder than this, suggesting that cheaper abatement opportunities exist than might be available from electricity and transport alone.

The contribution made by changes in real indirect-tax bases in 2030 is −0.3 percentage points. CO_2-e emissions, petroleum products and consumption are the principal bases on which indirect taxes are levied. All of these contract relative to their base-case values. More specifically, in 2030:

- Emissions are down 25.6%, contributing −0.1 percentage points to the gap of −0.3 percentage points between the deviation in market-price real GDP and factor-cost real GDP.
- Petroleum usage is down 3.8%, contributing −0.03 percentage points.
- Real consumption is down 1.5%, contributing −0.04 percentage points.

The residual of just over 0.1 percentage points is due to changes in the miscellaneous *Other-costs* category, which is treated as an indirect tax on production for GDP accounting purposes. *Other-costs* rates in the electricity generation and supply industries are endogenous variables in the policy simulation, adjusting to accommodate changes in wholesale and retail electricity prices taken from the detailed electricity modeling (Table 9.4, see also Figure 9.9c). To accommodate these changes, MMRF requires little change in the *Other-costs* rate for generation, but relatively large increases for electricity supply. MMRF does not fully capture the resource costs associated with using more expensive renewable forms of generation. Neither does it capture the impact on electricity network costs. Inputs from the detailed electricity modeling correct for this and in doing so force retail electricity prices in the MMRF simulation to increase by more than they would otherwise do in response to a carbon price. As demand for electricity falls, so does the production of the now heavily taxed electricity supply industries. This fall in the real *Other-costs* base contributes 0.1 percentage points to the overall fall in real market-price GDP.

By 2030 Australia must import a significant quantity of permits to meet its global ETS obligation

Figure 9.16 repeats the plots of Australia's permit allocation and base-case emissions from Figure 9.8 and adds a plot of emissions permit imports from the ETS simulation. Permit imports fill the gap between the permit allocation and actual emissions under the ETS.

The permit price effectively stabilizes total emissions near to their 2010 levels. Hence, with Australia's allocation of permits progressively falling, there is an increasing need to purchase permits from overseas. In 2030, around 160 Mt of permits are required. At a price of nearly $A50 per tonne, this translates into an annual financing cost of close to $A8 billion.

This financing cost represents a reduction in domestic welfare in the form of a transfer to foreigners. An alternative way in which Australia might meet its emissions target would be to impose a domestic emissions tax on top of the international permit price. This would involve a transfer of tax revenue from the domestic private sector to the Australian government and a deadweight loss. The latter represents a reduction in domestic welfare and is additional to the loss represented by the purchase of permits from the international market under the scheme that we have simulated. Hence, relying on imported permits minimizes the global cost of abatement and the loss of domestic welfare.

The ETS reduces HDI and real private consumption, but the fall in consumption is attenuated by an increase in the APC

Figure 9.17 shows percentage deviations from base-case values for real private consumption, consumer-price-deflated HDI and the national average APC. In 2030,

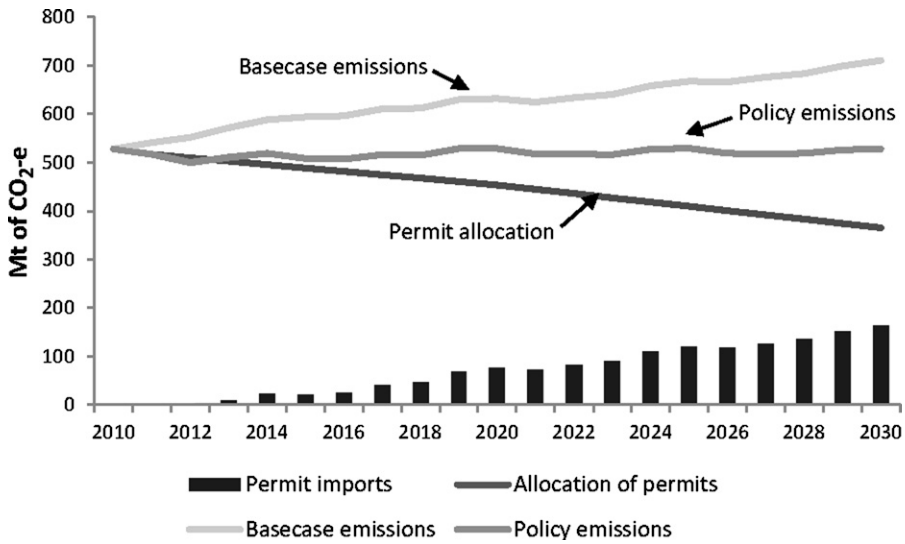

Figure 9.16 Emissions, permit allocation and permit imports.

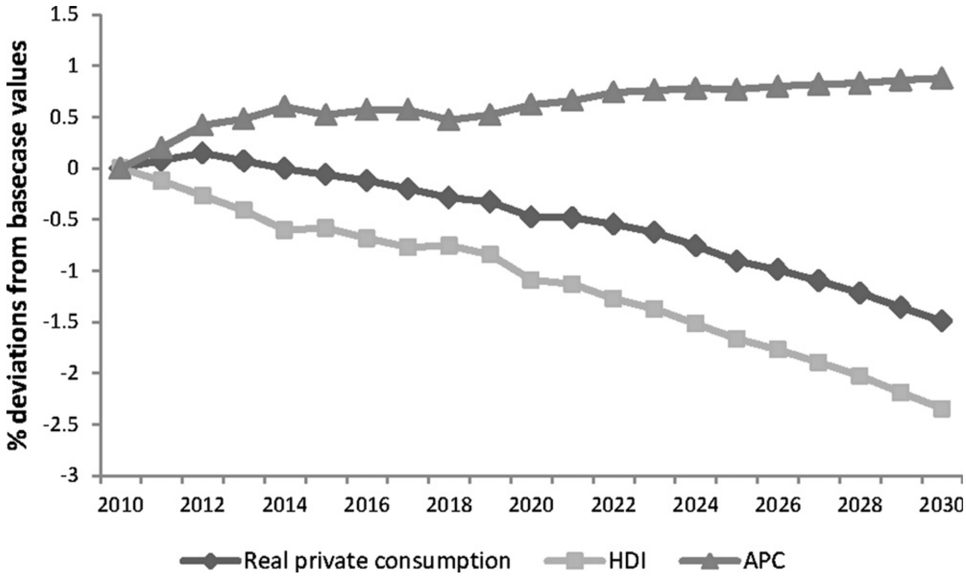

Figure 9.17 Real private consumption, HDI and the propensity to consume.

HDI is down 2.3% relative to its base-case level, and real private consumption is down 1.5%. The difference is due to an increase in the APC of 0.9%.

The carbon charge reduces HDI by reducing the factor incomes (wages and profits, after income tax) that domestic residents receive from domestic enterprises. However, the charge does not reduce HDI by the entire amount of the gross revenue that it raises. Some of that revenue is required to purchase emissions permits from overseas, but some is returned to domestic households, either indirectly via shielding payments that are made to domestic EITEIs or directly via lump-sum recycling payments. In a partial equilibrium world, the lump-sum payments would be equal to the difference between the gross ETS revenue and the costs of shielding and international permit purchases. However, our general equilibrium calculations take account of the indirect effects that the ETS might have on the government budget balance. Lump-sum payments to households are then whatever is necessary to insulate the government budget balance (as a share of GDP) from the total effects of the ETS. The first part of Table 9.12 decomposes the change in HDI in 2030 into its components. Note that the excess of gross ETS revenue over the international permit cost is $A18.1 billion, but only $A14.5 billion of this is returned to household via lump-sum payments. The reason is that the indirect effects of the ETS on the government budget are negative — the ETS reduces income tax revenue, for example.

Recall from Section 9.5.3.2 that the APC is an endogenous variable, moving to ensure that the national balance on current account remains at its base-case level. To maintain an unchanged balance on current account, domestic savings (private *plus* public)

Table 9.12 Household income, consumption, savings and investment (changes from base-case values, 2030)

	Deviation ($A billion)
Household disposable income	
Household income from labor and capital after income tax	−33.4
Permit price times emissions (gross permit tax)	26.0
Minus value of permits purchased from overseas	−7.9
Minus value of shielding	0.0[a]
Government handout to maintain budget balances (ex permit income)	−14.5
Total HDI	−29.8
Private consumption expenditure	−14.8
Public consumption expenditure	−6.3
Private saving (ΔHDI − Δprivate consumption)	−15.1
Public saving (Δgovernment income − Δpublic consumption)	−3.4
Investment	−18.1

[a]Shielding rates decline to zero after 2020.

must change to accommodate changes in aggregate investment. As shown in Table 9.12, the ETS generates an $A18.1 billion (or 3.4%) reduction in aggregate investment relative to base case. Public saving falls by $A3.4 billion. Hence, private saving must fall by around $A15 billion. Given a fall in total HDI of $A29.8 billion and a base-case value for the APC of 0.78, the APC must rise to achieve the necessary change in saving.

Real gross national expenditure falls relative to real GDP leading to an improvement in the net volume of trade

Figure 9.18 shows percentage deviations from base-case values for real private consumption (C), real public consumption (G), real investment (I), real exports (X) and real imports (M). Deviations in C have already been discussed. Deviations in nominal G reflect deviations in nominal GDP (Section 9.5.3.3). Real government consumption rises relative to real GDP because the price of government spending (heavily influenced by the price of labor) relative to the price of GDP moves in line with the real wage rate. Deviations in I, which as noted above are particularly sharp, reflect the declines in gross investment necessary to accommodate the falls in capital shown in Figure 9.14.

On balance, real gross national expenditure (= C + I + G) falls by more than real GDP, implying an improvement in the net volume of trade (X − M). This sterilizes the impacts on the current account balance of deterioration in the terms of trade and the cost of purchasing global emissions permits.

To achieve the necessary improvement in net trade volumes, mild depreciation of the real exchange rate is necessary. This improves the competitiveness of export industries on foreign markets and the competitiveness of import-competing industries on local markets. In 2030, the real exchange rate is 2.5% below its base-case value.

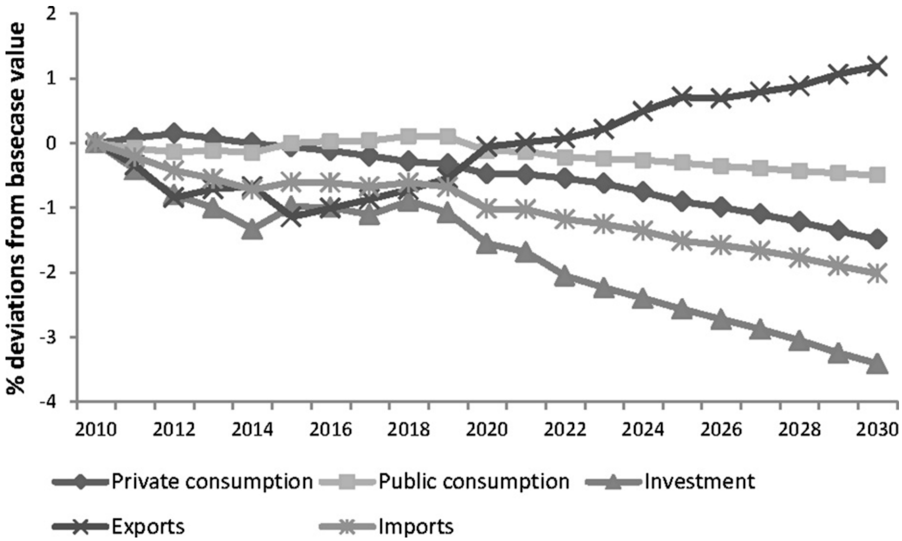

Figure 9.18 Deviations in main expenditure components of real GDP.

Production in some industries increases relative to base case, while production in other industries falls

Table 9.13 gives percentage deviations from base-case production levels for industries nationally in 2030. There are a number of industries for which the ETS raises output significantly. The most favorably affected industry is *Forestry* (industry 7), for which the carbon charge is effectively a production subsidy on biosequestration. Two other industries very favorably affected are *Electricity generation-other renewable* (industry 37, rank 3) and *Electricity generation-gas* (industry 33, rank 2). The carbon price causes substitution in favor of these industries at the expense of high-emissions *Electricity generation-coal* (industry 32, rank 58). Another negative factor for coal generation is the reduction in overall electricity demand due to the increased price of electricity to final customers. In Table 9.13, this shows up as a decline in production in the *Electricity supply* industry (industry 38, rank 55).

Table 9.13 shows significant increases in production for *Iron and steel* (industry 25, rank 4) and *Alumina* (industry 26, rank 6). Both are energy-intensive and trade-exposed, and under a unilateral ETS would contract, unless shielded. However, GTEM analysis of the multilateral aspects of the ETS projects trade diversion towards these Australian industries due to the availability of cheap energy abatement options in Australia that are not matched by competing suppliers. Another positive factor for these industries, and for all other traded-goods sectors, is the projected depreciation in the real exchange rate. A lower real exchange rate means that exports of industries such as the metal producers are more competitive on world markets.

Table 9.13 National industry output (% changes from base-case values, 2030, ranked)

Rank	Industry	2030
1	7. Forestry	80.2
2	33. Electricity generation-gas	15.5
3	37. Electricity generation-other	12.9
4	25. Iron and steel	9.1
5	28. Other non-ferrous metals	9.1
6	26. Alumina	6.5
7	21. Basic chemicals	3.8
8	3. Other livestock	1.9
9	46. Rail passenger transport	1.8
10	16. Textiles, clothing and footwear	1.7
11	23. Non-metal construction products	1.6
12	30. Motor vehicles and parts	1.5
13	18. Paper products	1.4
14	17. Wood products	1.2
15	22. Rubber and plastic products	1.0
16	2. Dairy cattle	0.8
17	45. Road freight transport	0.8
18	15. Other food, beverages and tobacco	0.7
19	6. Agricultural services, fishing, hunting	0.3
20	19. Printing and publishing	0.2
21	34. Electricity generation-oil products	0.0
22	36. Electricity generation-hydro	0.0
23	35. Electricity generation-nuclear	0.0
24	9. Oil mining	0.0
25	1. Sheep and cattle	−0.1
26	31. Other manufacturing	−0.1
27	29. Metal products	−0.2
28	4. Grains	−0.2
29	53. Dwelling services	−0.2
30	54. Public services	−0.2
31	51. Financial services	−0.2
32	48. Water, pipeline and transport services	−0.2
33	42. Trade services	−0.3
34	52. Business services	−0.3
35	11. Iron ore mining	−0.4
36	12. Non-ferrous ore mining	−0.5
37	5. Other agriculture	−0.6
38	50. Communication services	−0.7
39	40. Water supply	−0.8
40	14. Meat and meat products	−0.8
41	39. Gas supply	−1.0
42	55. Other services	−1.2
43	43. Accommodation, hotels and cafes	−1.6

(*Continued*)

Table 9.13 National industry output (% changes from base-case values, 2030, ranked)—cont'd

Rank	Industry	2030
44	13. Other mining	−1.7
45	24. Cement	−1.7
46	47. Rail freight transport	−2.1
47	49. Air transport	−2.1
48	27. Aluminum	−2.4
49	56. Private transport services	−2.4
50	44. Road passenger transport	−2.4
51	41. Construction services	−3.1
52	58. Private heating services	−4.6
53	10. Gas mining	−5.8
54	20. Petroleum products	−5.9
55	38. Electricity supply	−6.8
56	57. Private electricity equipment services	−7.7
57	8. Coal mining	−12.8
58	32. Electricity generation-coal	−18.8

Coal (industry 8, rank 57) production is projected to fall by 12.8% compared to its base-case level. The imposition of the ETS adversely affects coal demand for electricity generation and steel production in Australia and overseas. Domestic demand for coal falls by 14.6%. Foreign demand, which contributes around 85% to overall demand, is down 12.5%. These projections are remarkably sanguine when compared to the dire predictions from coal industry representatives. In terms of average annual growth, the projections imply a reduction from 4.0% in the base case to 3.3% with the ETS in place. The key factor underlying this mild outcome is rapid uptake of clean-coal technologies for electricity generation. In Australia, the new technologies are mainly based on CCS. In the rest of the world, as modeled by GTEM, the new technologies include CCS and other less radical innovations that have already started to be used in Australia.

Contraction in export demand accounts for the 5.8% reduction in production of *Gas mining* (industry 10, rank 53).

Other adversely affected industries are *Private transport services* (industry 56, rank 49), *Private electricity equipment services* (industry 57, rank 56) and *Private heating services* (industry 58, rank 53). All three are affected by increases in the price of energy: automotive fuels for transport services, electricity for electrical equipment services and gas for heating services. Increased energy costs shift their supply schedules up, leading to adverse substitution in residential demand.

Most of the remaining industries suffer mild contractions in output relative to base-case levels, in line with the general shrinkage of the economy. General economic conditions are particularly influential for the service industries.

For most sectors, the effects of the ETS build smoothly over the projection period but there are exceptions. These generally reflect the influence of inputs taken in from the models to which MMRF was linked for the ETS simulations. Figure 9.19(a and b) gives some examples.

Figure 9.19(a) shows deviations from base-case production for the main electricity generation sectors. It is moreorless a repeat of Figure 9.9(a), which is based on PJ data

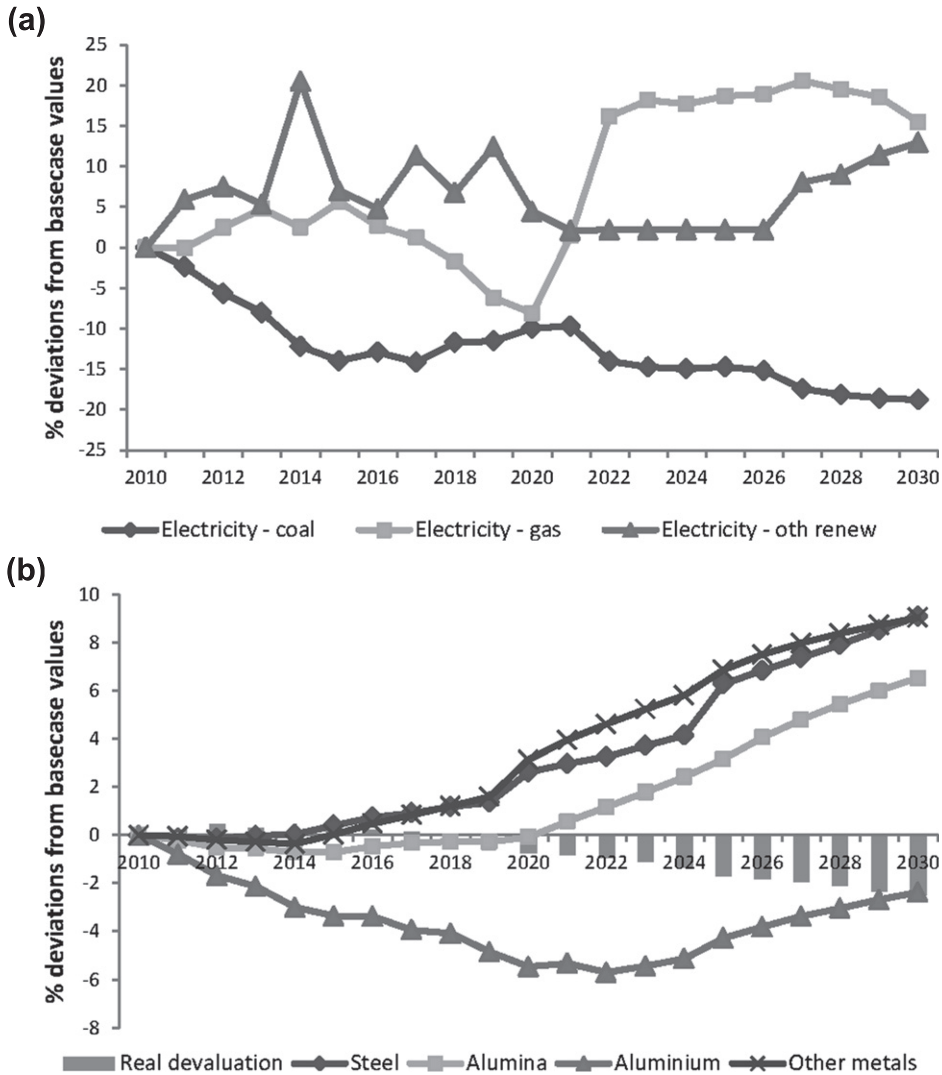

Figure 9.19 (a) Deviations in production of electricity generation industries. (b) Deviations in production of metal manufacturing industries.

taken from the detailed electricity modeling and reflects particular sequences of the introduction of new types of capacity that are included in the detailed electricity model.

Figure 9.19(b) shows deviations in the production of the metal-manufacturing sectors, together with deviations in the real exchange rate ($local/$foreign). The metal-processing sectors are all highly trade-exposed. Nevertheless, after 2020 when shielding is removed and the terms of trade start to decline (Figure 9.11), their production responds positively to the carbon price due to the changes in the real exchange rate, also shown in Figure 9.19(b). As the need to import global permits intensifies, so the volume of net trade must improve. This requires increasing depreciation of the real exchange rate, which more than offsets the contraction in export demand imposed from GTEM, allowing export volumes for a number industries, such as the metals producers, to expand.

Emissions from most sources fall

Table 9.14 shows deviations (in percentages and Mt of CO_2-e) from domestic base-case emissions. In 2030, total domestic emissions are down by 25.6%, or 181.8 Mt of CO_2-e. In addition, permits for 160 Mt of CO_2-e are imported, making Australia's total contribution to global emissions reduction about 342 Mt of CO_2-e.

Domestic emissions from stationary energy and fugitive sources deliver the bulk of the overall abatement. Emissions from stationary energy are down 47.5 Mt relative to their base-case levels, with emissions from electricity generation down by 37.4 Mt, and emissions from other forms of direct combustion down by 10.1 Mt. Fugitive emissions fall by 41.4% (28.6 Mt). Significant abatement also occurs in other areas, and in terms of percentage deviations are larger than abatement from stationary energy and fugitive sources. From waste, emissions are down by 75.9% (or 10.9 Mt of CO_2-e) relative to base-case levels, while emissions from industrial processes fall by 56.1%, (or 23.1 Mt of CO_2-e).

All of the emission reductions outside of electricity and transport occur via reductions in the output of the relevant emitting industry or reductions in emissions intensity brought about by the price-responsive mechanisms outlined in Section 9.3.4. The abatement from stationary energy and transport is achieved via industry activity effects, fuel switching and technology changes. The last-mentioned is most important for electricity where, according to the detailed electricity modeling, extensive abatement is achieved from the uptake of clean coal technologies, especially in the later part of the projection period.

9.6.2.2 State variables

Real gross state product falls relative to base case in all states/territories, except TAS and NT

Figure 9.20 shows projected percentage deviations from base-case levels of real gross state product (GSP). Percentage deviations in 2030 are given in Table 9.11.

Table 9.14 CO_2-e emissions by major source category for Australia (changes from base-case values)

	Percentage deviations from base-case values 2030
Energy sector, total	−17.3
Fuel combustion	−13.6
Stationary	−14.3
Electricity generation	−19.2
Other	−7.3
Transport	−11.7
Fugitive emissions from fuels	−41.1
Industrial processes	−56.1
Agriculture	−17.6
Waste	−75.9
LUCF	NA
Total	−25.6

	NSW	VIC	QLD	SA	WA	TAS	NT	ACT	AUS
Change from base-case value (Mt of CO_2-e)									
2015									
Energy sector, total	−10.6	−18.1	−9.6	−0.6	−4.2	−0.2	−0.4	−0.1	−43.9
Fuel combustion	−5.0	−17.8	−6.0	−0.1	−2.9	−0.2	−0.3	−0.1	−32.4
Stationary	−3.2	−16.3	−4.4	0.3	−1.9	−0.1	−0.2	0.0	−25.8
Electricity generation	−2.2	−15.5	−2.5	0.4	−1.0	0.0	−0.1	0.0	−20.8
Other	−0.9	−0.8	−1.9	−0.2	−1.0	−0.1	−0.1	0.0	−5.0
Transport	−1.8	−1.5	−1.6	−0.4	−1.0	−0.1	−0.1	−0.1	−6.6
Fugitive emissions from fuels	−5.6	−0.4	−3.6	−0.5	−1.3	0.0	−0.1	0.0	−11.4
Industrial processes	−6.1	−1.7	−2.4	−1.2	−2.3	−0.4	−0.1	−0.1	−14.2
Agriculture	−2.5	−2.5	−4.0	−0.8	−1.7	−0.4	−1.1	0.0	−13.0
Waste	−3.7	−2.6	−2.4	−0.5	−1.4	−0.2	−0.1	−0.1	−10.9

LUCF	−0.4	−1.0	−0.1	−0.4	−1.4	−0.3	−0.2	0.0	−3.8
Total	−23.2	−25.9	−18.6	−3.4	−11.0	−1.6	−1.8	−0.3	−85.8
Change from base-case value (Mt of CO_2-e)									
2020									
Energy sector, total	−12.2	−10.5	−13.5	−2.4	−7.0	−0.2	−0.5	−0.1	−46.5
Fuel combustion	−4.7	−10.1	−8.6	−1.9	−4.7	−0.2	−0.4	−0.1	−30.8
Stationary	−2.3	−8.2	−6.4	−1.4	−3.5	−0.1	−0.3	0.0	−22.2
Electricity generation	−1.3	−7.5	−4.0	−1.2	−2.0	0.0	−0.1	0.0	−16.1
Other	−1.1	−0.8	−2.4	−0.2	−1.4	−0.1	−0.2	0.0	−6.1
Transport	−2.3	−1.9	−2.1	−0.5	−1.3	−0.2	−0.1	−0.1	−8.5
Fugitive emissions from fuels	−7.5	−0.4	−4.9	−0.5	−2.3	0.0	−0.1	0.0	−15.7
Industrial processes	−7.5	−2.1	−3.1	−1.5	−2.6	−0.5	−0.1	−0.1	−17.5
Agriculture	−3.0	−2.9	−4.8	−0.9	−1.9	−0.4	−1.4	0.0	−15.3
Waste	−4.3	−3.0	−2.9	−0.6	−1.7	−0.3	−0.1	−0.2	−13.0
LUCF	−0.8	−2.5	−0.2	−0.9	−5.0	−0.8	−0.2	0.0	−10.4
Total	−27.7	−21.1	−24.5	−6.3	−18.3	−2.2	−2.3	−0.4	−102.7
2030									
Energy sector, total	−29.5	−16.4	−26.1	−2.0	−14.8	−0.1	−0.5	−0.2	−89.7
Fuel combustion	−17.0	−15.8	−17.6	−1.7	−8.3	−0.1	−0.4	−0.2	−61.2
Stationary	−13.4	−13.0	−13.8	−1.0	−6.1	0.0	−0.2	0.0	−47.5
Electricity generation	−11.9	−12.0	−10.4	−0.8	−2.2	0.0	−0.1	0.0	−37.4
Other	−1.5	−1.0	−3.4	−0.2	−4.0	0.1	−0.1	0.0	−10.1
Transport	−3.6	−2.8	−3.7	−0.7	−2.1	−0.2	−0.2	−0.2	−13.6
Fugitive emissions from fuels	−12.5	−0.5	−8.6	−0.3	−6.5	0.0	−0.1	0.0	−28.6
Industrial processes	−9.5	−2.9	−4.4	−1.8	−3.6	−0.6	−0.2	−0.1	−23.1
Agriculture	−4.1	−3.9	−6.7	−1.2	−2.6	−0.4	−2.4	0.0	−21.2
Waste	−5.8	−4.1	−4.1	−0.8	−2.3	−0.3	−0.1	−0.2	−17.7
LUCF	−2.6	−7.5	−0.7	−2.6	−12.9	−2.6	−1.0	−0.1	−30.1
Total	−51.4	−34.7	−42.0	−8.4	−36.3	−4.0	−4.2	−0.6	−181.8

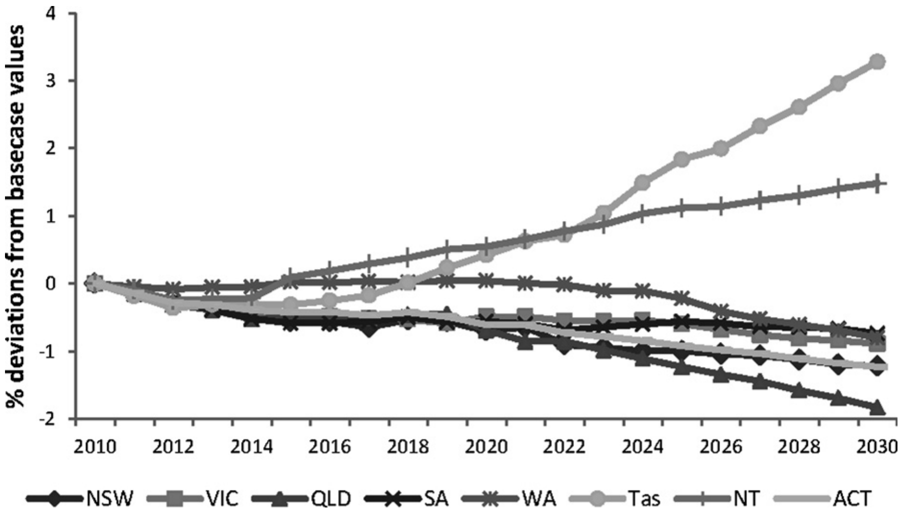

Figure 9.20 Deviations in real GSP.

The pattern of impacts on real GSP in 2030 reflects the industry effects of the ETS (Table 9.13). Just as some industries experience output gains relative to the base case and some industries experience output loss, so some regions experience output gain and others output loss, with differences between regions explained by the differences in the industrial compositions of the regions.

QLD and to a lesser extent NSW have over-representations of *Coal mining* and *Coal-fired electricity generation*, which is the main reason why the ETS is expected to reduce their shares in the national economy. The ACT is the capital territory of Australia. Its economy is almost entirely service oriented, with an over-representation of energy-intensive providers of private transport, private electricity equipment and private heating services. This is the main reason why the territory is relatively adversely affected by the ETS.

WA is favored by an industrial composition with an over-representation of gas-fired generation, natural gas and trade-exposed industries that benefit from trade diversion under the global ETS (*Iron ore*, *Alumina* and *Other non-ferrous metals*).

As discussed earlier SA's coal-fired generation industry is phased out by 2015 in the base case and its gas industry ceases production by 2025. The absence of these two significantly adversely affected industries and an over-representation of agricultural industries, which do relatively well under the ETS, is enough to elevate SA's GDP share.

TAS does not have coal-fired generation or gas and coal mining. *Forestry* and agriculture are over represented. Hence, it gains share in the national economy. The NT has an over-representation of animal-agriculture and *Alumina* production. Thus, even though it has no *Forestry*, it too gains share in the national economy.

9.6.2.3 Substate results

MMRF includes a top-down facility for generating base-case prospects and the effects of ETS policies on gross regional product (GRP) and regional employment for 57 substate regions: the ABS statistical divisions.[30]

Under the top-down procedure, the model's 58 industry sectors are split into two groups: the group whose outputs are readily traded between regions and the group producing outputs (mainly services) that are not readily traded between regions. For an industry in the first group, our assumption is that the ETS policy has the same percentage effect on output and employment in a substate region as it has on output and employment overall in the industry in the state to which the substate region belongs. If this assumption were applied to all industries, then differences between substate regions in the estimated effects of the ETS would depend simply on differences between regions in industries' shares in output or employment. However, in addition to this, we recognize that for industries in the second (non-traded) group demand in a substate region will be met by output in that region. This means that changes in activity in a substate region arising from changes in activity in industries in the first group have local multiplier effects.

The key data input to our top-down method for generating output and employment results for the substate regions is a database showing gross value added and employment by industry and region. From this the shares of each region's GRP and employment accounted for by each industry can be calculated. These shares allow the implications for a region's gross product or employment of a change in an industry's activity level within the region to be inferred. In this section, we concentrate on employment.

An extract of the data is given in Figure 9.21. The extract refers to five industries that are particularly vulnerable to ETS policies and to 12 regions in which the six industries in total account for relatively large shares of gross product or employment. As a benchmark, we show in the last bar of the figure the industries' shares in aggregate national employment. For Australia as a whole, the five vulnerable industries account for less than 2% of aggregate employment. However, some substate regions are much more heavily dependent on the vulnerable industries. Hence, we should expect that these regions will be much more vulnerable to ETS policies than is the Australian economy overall.

One issue that arises in presenting substate regional employment results is the issue of scale. Scale is ignored if the results are presented as percentage deviations between the level of employment attained with the ETS policy in place and the base-case level of employment. For example, we might identify a region for which the ETS policy has a large adverse *percentage* effect, but which is very small so that the effect of the policy is small in terms of numbers employed. In such a case, although the ETS has a large effect

30 A review of top-down regional models, and regional CGE models more generally, is given in Giesecke and Madden in Chapter 7 of this Handbook.

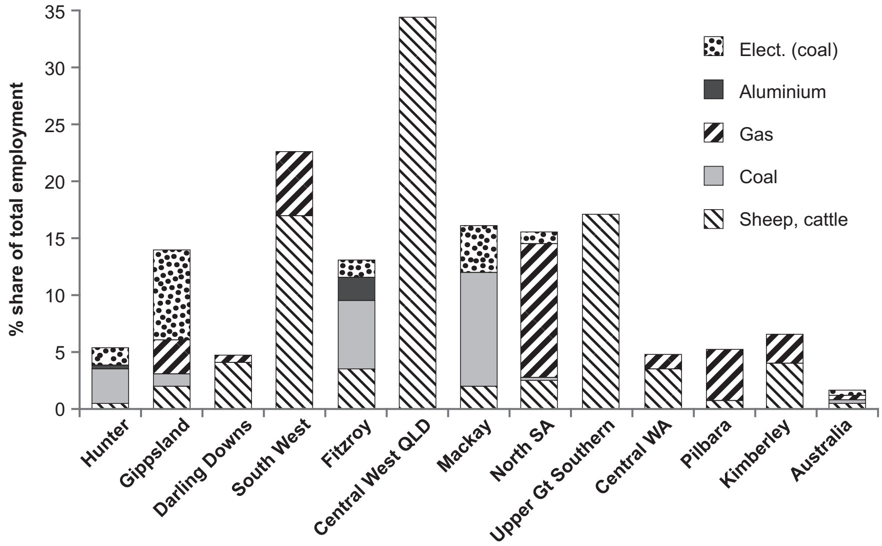

Figure 9.21 Employment by region and industry, 2010.

from the point of view of the particular region, the significance of the effect from a wider (e.g. national or state) point of view would be small. An implication would be that any adjustment policy necessary to assist the region to cope with the effects of the policy might be manageable.

The scale issue is dealt with by reporting the regional employment effects of the ETS policy in two ways: as percentage deviations from base-case values and as numbers employed. Figures 9.22 and 9.23 provide examples. Figure 9.22 shows the eight regions most adversely affected by the ETS policy as measured by its percentage-point effect on total growth of employment over the period 2010–2030. Figure 9.23 shows the eight most favorably affected regions. In Figures 9.22 and 9.23 we deal with the scale issue by making the areas of the dots representing the regions proportional to the numbers of jobs lost on account of the ETS in 2030.

It is clear from Figure 9.22 that *Hunter NSW* is of particular significance: it has a large employment loss from the ETS in percentage terms and the largest loss in terms of numbers of jobs. As shown in Figure 9.21, *Coal mining* and *Coal-fired electricity generation* are both important industries in the *Hunter* region. The two central-coast QLD regions (*Fitzroy* and *Mackay*), are also face significant employment losses from the ETS.

The industries that contribute most strongly to the policy-induced expansions in the regions' employment growth shown in Figure 9.23 are mainly the industries (*Forestry* and *Electricity generation-other renewable*) that are identified in Table 9.13 as sectors that are favorably affected by the ETS policy.

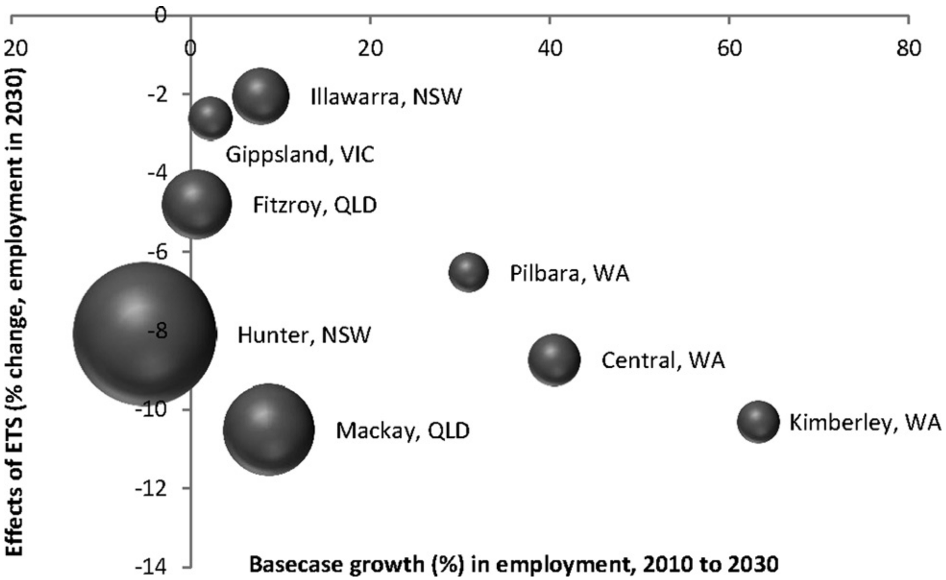

Figure 9.22 Regions most adversely affected by the ETS: employment.

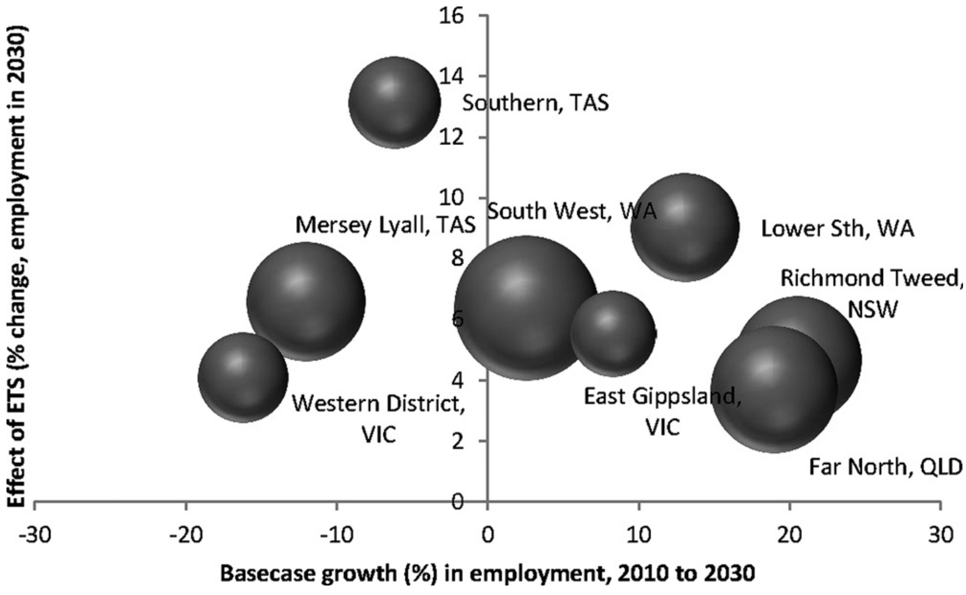

Figure 9.23 Regions most favorably affected by the ETS: employment.

In Figures 9.22 and 9.23, we show regions' base-case growth prospects as well as the regional effects of the ETS. The reason is that the main policy interest in the regional results relates to structural adjustment. Structural adjustment problems are likely to be most severe for regions that are affected adversely by the ETS and already

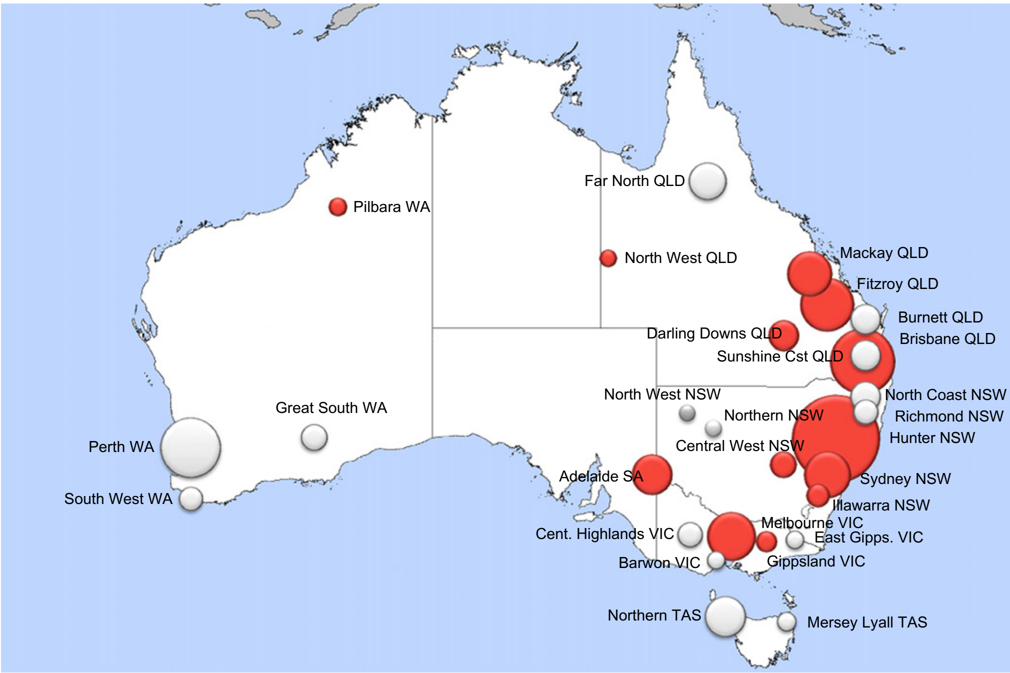

Figure 9.24 Geographic dispersion of the employment effects of the ETS.

face poor or negative base-case growth prospects. A good example is the *Hunter* region.

Figure 9.24 provides a final perspective on the geographic aspect of the structural change that adoption of the ETS would require. The map is coded to show regions in which employment growth is reduced by the ETS (indicated by dark bubbles) and regions in which employment growth is stimulated by the ETS (indicated by light bubbles). As in Figures 9.22 and 9.23, the areas of the dots in Figure 9.24 are proportional to the numbers of jobs created or lost on account of the adoption of the ETS.

It is clear from Figure 9.24 that, in many cases, the stimulated regions are far from contiguous with the adversely affected regions. This suggests that there might be geographical adjustment problems to the extent that structural adjustment requires relocation of workers between adversely affected and stimulated regions.

9.7 CONCLUSION

In this chapter, we focus on issues that arise in using a CGE model of the Australian economy to provide advice to policy makers and other stakeholders about the effects of complex real-world policy proposals. To illustrate the issues, we use a study of the effects of the Australian government's 2008 emissions trading policy proposal (Table 9.8). The proposal integrates Australia into a global trading scheme by 2015 and requires Australia to progressively reduce emissions to around 40% below their base-case level by 2030. This reduction can be achieved by a mix of domestic abatement and purchases of emissions permits from the global market. The global price of permits rises from around $A25 per tonne in 2015 to around $A50 per tonne in 2030.

9.7.1 Main results

A number of key findings emerge from our simulations of the effects of the ETS policy.

(i) Domestic abatement falls well short of targeted abatement, requiring significant amounts of permits to be imported. As can be seen in Figure 9.16, in 2030 only about half of the required reduction in emissions is met from domestic abatement, leaving half to be met from foreign permit purchases.

(ii) Despite the requirement for deep cuts in emissions, the ETS reduces Australia's GDP by only just over 1.1% in 2030 relative to the base case (Figure 9.15b). In Section 9.6.1 (see especially Table 9.10) we discuss alternative ways in which this result can be presented.

(iii) The negative impact on real household consumption, which is the preferred measure of national welfare, is somewhat greater reflecting the need to import permits. The cost of imported permits reduces household income. Relative to its base-case level real household consumption is down by over 2.0% in 2030 (Figure 9.17).

(iv) While the national macroeconomic impacts of the ETS are modest in the context of the policy task, this does not carry through to the industry (Table 9.13) and regional (Figures 9.20—9.23) levels.

(v) Relative to base case, there are a number of industries for which the ETS significantly raises output in percentage terms. The most favorably affected industry is *Forestry*, for which the carbon charge effectively is a production subsidy. Within the electricity sector, non-hydro renewables and gas-fired generation gain at the expense of coal-fired generation. Somewhat surprisingly, production of *Iron and steel* and *Alumina* also increase due in part to overcompensation during the transition period, and in part to GTEM projection of trade diversion in favor of the Australian industries at the expense of other suppliers. Other adversely affected industries are *Private transport services*, *Private electricity equipment services* and *Private heating services.* All three are affected by increases in the price of energy: automotive fuels for transport services, electricity for electrical equipment services and gas for heating services.

(vi) The pattern of impacts on Australian regions in 2030 reflects the industry effects of the ETS. At the state/territory level, QLD is the most adversely affected region, due to its over representation of coal and coal-fired generation, and TAS is the most favorably affected, due to the importance of forestry.

Twelve (substate) regions are identified as particularly vulnerable in terms of potential loss of employment. These include coal-dependent regions such as Hunter in NSW, Fitzroy in QLD and Gippsland in VIC. On the other hand, eight regions are identified as potentially gaining employment. These regions generally have an over-representation of the sectors that expand due to the ETS, especially forestry and renewable electricity generation.

9.7.2 Including detail

In the introduction to this chapter, eight questions were posed regarding the level of detail required by policy makers and other stakeholders when considering CGE-based analyses of an ETS. Our experience from the Australian study suggests the following answers.

- *At what level of detail must the stationary-energy sector be modeled for the effects of policy on its emissions to be captured adequately?* For the credibility of results, we think that very fine detail is required, especially for the electricity sector. Even the BOTE explanation of GDP outcomes given in Box 9.1 relies on detailed understanding of the costs and abatement opportunities available in the future from the electricity sector. Our experience is that the required level of detail is best provided by linking with a detailed bottom-up model of the stationary energy sector. The alternative is to elaborate the representation of the sector inside the CGE model. While attractive from a pure theoretical point of view, this is much more difficult than our preferred option because of computational and data constraints.
- *Is it necessary to include the lumpiness of generation investment explicitly in CGE computations of the effects of climate change policy?* The issue here is really about the timing of results. If the stakeholder is interested only in broad-based analysis of outcomes for some far-off future year, or a net present value (NPV) calculation of effects across many years, then the answer is probably no, assuming that the existing treatment of investment is realistic for the projected long-run change in capital. On the other hand, if the focus is on year-to-year changes for investment and other variables, then incorporating lumpiness does matter, as illustrated in Figure 9.9(a and b) and the associated commentary.
- *Concern about greenhouse gas emissions centers on a global externality problem. Does this mean that the consequences of emissions policy can only be investigated using a global model?* Certainly for Australia, and probably for most other countries, changes in trading conditions brought about by global action on climate change will be significant and therefore should be incorporated into modeling the effects of reducing greenhouse emissions. In this chapter, we showed how this can be done via linking of a detailed

country model with a multicountry system (GTEM). GTEM provides MMRF with a carbon price and projections of changes in Australia's trading environment for the base case and the ETS-inclusive projections.

- *In modeling the effects of an emissions policy, do we need agents with full intertemporal optimization or will recursive dynamics do?* An ETS is normally designed to ensure a measure of certainty – there will be a non-zero carbon price after a specified date, that price will probably increase given a scheme of increasing tightness of emission allocation, during the early transition period to a multinational arrangement certain EITEIs will be shielded, etc. Under such arrangements, investment in industries such as electricity generation, where asset lives are very long, would be expected to change in line with anticipated future changes in permit price, rather than in response to announcements. Thus, a degree of forward-looking expectations is important, especially in the early years of any arrangement. The modeling reported in this chapter generally assumes recursive dynamics (Sections 9.2.2.8 and 9.2.2.9). However, it does incorporate forward-looking expectations in electricity and transport via linking with the specialized bottom-up models that assume full intertemporal optimization. This improves the analysis considerably, particularly for the early years.
- *What representation of a country's EITEIs is required when early action against climate change is unilateral?* Unilateral action has the potential to disadvantage a country's EITEIs. Accordingly, nearly all unilateral schemes specify some form of assistance or shielding during the period of transition to a fully global ETS. Modeling such assistance is necessary if realistic projections of industry output and employment are required. In the modeling reported in this chapter, a detailed representation is put in place (Section 9.3.3). The influence of the associated shielding can be seen, for example, in Figure 9.16(b) where, for the early transition years to 2020 some of Australia's key ETIEIs suffer little if any production loss despite the significant direct increase in unit cost due to a domestic carbon price.
- *How should energy usage be treated in the household consumption specification of a model to be used for the analysis of emissions policy?* As explained in Section 9.2.3.5, we think that a traditional budget allocation model of household demand across standard budget categories, which identify energy and energy equipment as separate products leads to unrealistic projections of final demand for energy and equipment. Our preferred treatment allows for dummy industries that provide services of energy-using equipment to private households.
- *Can CGE modeling inform policy makers about the regional effects of emissions policy?* The answer to this question is yes, as evidenced in this chapter by our discussion of the regional implications of the ETS in Sections 9.6.2.2 and 9.6.2.3. Another related question is to what extent policy makers require projections of regional effects. Our experience of modeling the effects of an ETS in Australia, and our

experience more generally across many countries, is that national and regional policy makers are very concerned with the regional dimension. Much of the current discussion in Australia regarding the impacts of the proposed ETS is based about the regional implications of the ETS where the impacts, as discussed in this chapter, could be highly significant. This has had a significant impact on public opinion regarding the policy.

- *What effect will the recycling of revenue from a carbon tax or sale of permits under an ETS have on the efficiency costs of the policy and on income distribution?* Revenue can be recycled in a number of ways, such as increasing government spending or transfer payments, or reducing other existing taxes. As noted in Section 9.3.3, the net welfare effects of the ETS depend on the extent to which recycling of the ETS revenue adds to or offsets the distortionary effects of the ETS charge. The double-dividend literature suggest that it is possible to recycle in such a way as achieve conventional resource allocation gains by using the revenue to reduce existing tax distortions. Another view is that the revenue churn associated with the ETS is likely to introduce inefficiencies.
- The issues here are complex, but are crucial to an understanding of the welfare implications of an emissions policy. To deal adequately with these issues, a policy model needs to have a detailed representation of the country's fiscal system and the ability to identify the income-distribution consequences of policy options. MMRF has this facility, though little use has made of it for the study reported in this chapter. Here, it is simply assumed that any revenue from the ETS in excess of that used for buying foreign emission permits or shielding domestic EITEIs is returned to households as a lump-sum payment.

9.7.3 Interpretation of results

To meet the needs of stakeholders engaging in real-world policy debates, the analysis requires, in addition to substantially more detail than is included in most CGE models, a detailed intuitive explanation of key results.

Users of economic models are often faced with skeptical audiences of policy advisors who may have some economic training, but have little knowledge of economic modeling. In this context, a key to modeling success is interpretation of results.

On the one hand, interpretation is about telling a story true to the modeling outcomes without referring to the technicalities of the modeling. This is difficult, but is essential for the general acceptance of the results. Section 9.6 contains an example of detailed explanation that aims to demonstrate the relatively simple economic mechanisms underlying the apparently complex results.

On the other hand, interpretation is about explaining results in quantitative detail. This aids credibility and acceptance of the modeling, but it is also a check on whether the modeling has been done correctly. To this end, CoPS modelers make extensive use of BOTE calculations, often supported by formal stylized models of the type described in the Appendix. There are three roles for such models (Dixon *et al.*, 1977, pp. 194—195). (i) With a model as large as MMRF, 'the onus is on the model builders to provide convincing evidence that the computations have been performed correctly, i.e. that the results do in fact follow from the theoretical structure and database'. (ii) Calculations with stylized models are the only way '... to understand the [full] model; to isolate those assumptions which cause particular results; and to assess the plausibility of particular results by seeing which real-world phenomena have been considered and which have been ignored'. (iii) By extending the stylized calculations, '... the reader will be able to obtain a reasonably accurate idea of how some of the projections would respond to various changes in the underlying assumptions and data'.

An example of the use of BOTE calculations is given in Box 9.1, which focuses on the plausibility of the headline finding — *big emission cuts at relatively mild macro-cost*. There it is shown that such a finding can be rationalized by considering the abatement opportunities available in only the key areas of electricity and transport.

9.7.4 Future work – integrated assessment modeling

The approach to environmental modeling described in this chapter — based on linking models of the electricity system (*WHIRLYGIG*) and world trade in emissions permits (GTEM) along with other models to a multiregion, multisector model of the Australian economy — has an obvious parallel with integrated assessment models (IAMs).[31] The latter also depend on linking models of different types, but unlike the system we have described, IAMs aim to deal with the benefit side of emissions control as well as its costs. An Australian example of this is work by ABARES to develop its global integrated assessment model (GIAM) model in collaboration with CSIRO (Gunasekera *et al.*, 2008). In the GIAM project, ABARES supplies economic modeling and CSIRO supplies physical climate modeling.

Figure 9.25 outlines the basic structure of GIAM. The ovals represent submodels and the rectangles represent the variables that connect the models. To project a base case with GIAM, an iterative procedure is used. It starts with a preliminary economic scenario for the period of interest, generated in the *Economy* submodel. This submodel includes a facility for projecting the path of greenhouse gas emissions associated with

[31] Early overviews of IAMs are given in Schneider (1997) and Goodess, *et al.* (2003). An up-to-date explanation is provided by Nordhaus in Chapter 16 of this Handbook. To our knowledge, most other IAMs used around the world use aggregated economic accounts. These include DICE, MERGE, WIAGEM and MiniCAM (see Mastrandrea, 2010).

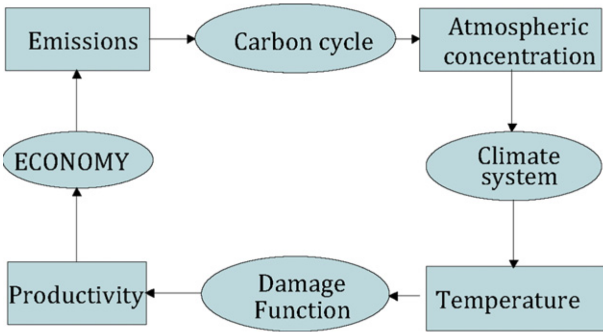

Figure 9.25 Structure of GIAM.

economic activity: principally the use of fossil fuels in the generation of stationary energy and in transport. The emissions path from the preliminary economic scenario is fed into two climate submodules: a *Carbon-cycle* submodel that projects the accumulation of greenhouse gasses in the atmosphere and a *Climate-system* submodel that projects the development of the global climate on the basis of these atmospheric concentrations. Finally, a system of *Damage Functions* translates the projected climate change into changes in variables that are relevant to economic development (e.g. agricultural productivity).

As indicated in Figure 9.25, the output of the *Damage Functions* is fed back into the *Economy* submodel and the sequence is repeated until satisfactory convergence is achieved. The *Economy* submodel allows agents to adapt to the economic effects of climate change (e.g. to react to changes in relative prices induced by the damage effects), but in generating the base case no policy reactions are assumed.

GIAM provides an example of how an Australia-focused IAM can be constructed using readily available components, in particular drawing on computable general economic modeling techniques that have a long history in policy analysis in Australia. The GIAM results that have been published to date are preliminary and just illustrative of the capability of the model. In particular, the range of climate change effects included is not yet wide enough to provide a base case for assessment of the benefits and costs of greenhouse policy.

For the simulations discussed in this chapter, no effort is made to include the possible effects of climate change in the base-case projection. Not including climate change means that we do not account for any of the possible direct economic benefits arising from the abatement achieved by an ETS. Including the potential benefits, and hence being able to show a net economic gain from an ETS, is an important item for further research with MMRF. The way forward is likely to be through linking MMRF with a climate model, such as that developed at the CSIRO.

APPENDIX: STYLIZED MODEL

A.1 Introduction

The explanation of the deviations in macro variables given in Section 9.6 relied, but not explicitly, on a stylized macroeconomic model.[32] In this Appendix the model and its calibration in the context of the ETS simulations is described. The predictive power of the model is then demonstrated by comparing results computed using MMRF with those computed using the stylized system. The comparison also offers additional insight into the MMRF projections.

A.2 Model

Equations of the stylized model are given in Table A1. The first part of the table shows the levels equations. The second part shows the equations linearized in the changes (percentage or otherwise) of the variables.

A.2.1 Non-linear form in levels of variables

Equations (A)−(J) deal with real GDP (factor cost and market prices) and the main components of real expenditure. Equation (A) defines real GDP at market prices (Y_{MP}) as the sum of real consumption (C), real investment (I), real government consumption (G) and the net volume of trade (X − M). Ignoring changes in stocks, this is the standard expenditure-side definition for real GDP.

Equation (B) is the economy's production function, based on a constant returns to scale functional form (as assumed in MMRF). It relates real GDP at factor cost (Y_{FC}) to inputs of labor (L) and capital (K), with an allowance for technological change summarized by the variable A: an increase in A means technological regress; a decrease means technological progress. There are many forms of technological change incorporated into the MMRF system, but in this stylized system we only allow for one − the overall technological regress (or cost) associated with the factors identified in Section 9.5.3.4. Note that in writing (B), and elsewhere in the stylized model, the existence of a third primary factor of production, agricultural land, is ignored.

Total emissions (Q_{CO_2}) is related positively to the size of the economy and negatively to the emissions price (T). This is shown in equation (C), which is a fairly crude

[32] The stylized model described here is similar to the model in Adams (2005) that was developed to explain results from a GTAP simulation. The idea of using stylized models as an aid to interpretation is discussed in detail in Dixon *et al.* (1984). The stylized model is based on the microeconomic theory underlying a conventional CGE model, like MMRF. It is comparative static, not dynamic. The model is designed to be as simple and transparent as possible. Adding dynamics would increase the complexity of the model, without enhancing significantly its explanatory power. As the stylized model is comparative static, we do not use it to analyze deviations through time. Instead, it is used to analyze deviations at specific points, typically in the first year of the simulation (short run) and after a long period of time (long run). Here, we assume that short run is 2011 and long run is 2030 (even though the economy is still adjusting to exogenous shocks).

Table A1 Stylized macro model
Levels equations

$$Y_{\mathrm{MP}} = C + I + G + (X - M) \tag{A}$$

$$Y_{\mathrm{FC}} \times A = F_Y(L, K) \tag{B}$$

$$Q_{\mathrm{CO_2}} = F_{Q_{\mathrm{CO_2}}}\left(Y_{\mathrm{FC}}, \frac{1}{T}\right) \tag{C}$$

$$A = F_A(T) \tag{D}$$

$$P_{\mathrm{GDP}}^{\mathrm{MP}} \times Y_{\mathrm{MP}} = P_{\mathrm{GDP}}^{\mathrm{FC}} \times Y_{\mathrm{FC}} + Q_{\mathrm{CO_2}} \times T \tag{E}$$

$$P_C \times C = \left\{P_{\mathrm{GDP}}^{\mathrm{MP}} \times Y_{\mathrm{MP}}\right\} \times \Omega \tag{F}$$

$$P_C \times RW \times G = P_{\mathrm{GDP}}^{\mathrm{MP}} \times Y_{\mathrm{MP}} \times \Gamma \tag{G}$$

$$M = Y_{\mathrm{MP}} \times F_M(RER) \tag{H}$$

$$X = F_X\left(\frac{1}{RER}\right) \times Y_{\mathrm{WORLD}} \tag{I}$$

$$\frac{I}{K} = F_{\frac{I}{K}}\left(\frac{ROR}{ROR_{\mathrm{REQ}}}\right) \tag{J}$$

$$RER = \frac{P_{\mathrm{GDP}}^{\mathrm{MP}}}{\Phi \times P_{\mathrm{WORLD}}} \tag{K}$$

Table A1 Stylized macro model—cont'd

Levels equations

$$P_{\mathrm{GDP}}^{\mathrm{MP}} = F_{P_{\mathrm{GDP}}^{\mathrm{FC}}}\left(P_{\mathrm{GDP}}^{\mathrm{FC}}, T\right) \quad \text{(L)}$$

$$TOT = \frac{F_{\mathrm{TOT}}\left(\frac{1}{X}\right)}{P_{\mathrm{WORLD}}} \quad \text{(M)}$$

$$\frac{P_C}{P_{\mathrm{GDP}}^{\mathrm{MP}}} = F_{P_{\mathrm{GDP}}}^{P_C}\left(\frac{1}{TOT}, T\right) \quad \text{(N)}$$

$$\frac{K}{L} = F_{KL}\left(\frac{RP_{\mathrm{L}}}{RP_{\mathrm{K}}}\right) \quad \text{(O)}$$

$$(A \times RP_{\mathrm{L}})^{S_{\mathrm{L}}} = (A \times RP_{\mathrm{K}})^{-S_{\mathrm{K}}} \quad \text{(P)}$$

$$RP_{\mathrm{L}} = F_{RP_{\mathrm{L}}}\left(RW, \frac{1}{TOT}, T\right) \quad \text{(Q)}$$

$$RP_{\mathrm{K}} = F_{RP_{\mathrm{K}}}\left(ROR, \frac{1}{TOT}, T\right) \quad \text{(R)}$$

Linearized equations in the percentage changes of variables

$$y_{\mathrm{mp}} = S_C c + S_{\mathrm{I}} i + S_G g + \left(S_X x - S_M m\right) \quad \text{(a)}$$

$$y_{\mathrm{fc}} = S_{\mathrm{L}} l + S_{\mathrm{K}} k - a \quad \text{(b)}$$

$$q_{\mathrm{co_2}} = y_{\mathrm{mp}} + \sigma_T \times d\_T \quad \text{(c)}$$

(*Continued*)

Table A1 Stylized macro model—cont'd
Levels equations

$$a = \sigma_A \times d\_T \tag{d}$$

$$y_{\mathrm{mp}} = S_{\mathrm{GDP}}^{\mathrm{FC}} y_{\mathrm{fc}} + S_T q_{\mathrm{co_2}} \tag{e}$$

$$c = p_{\mathrm{gdp}}^{\mathrm{mp}} + y_{\mathrm{mp}} + \omega - p_c \tag{f}$$

$$g = p_{\mathrm{gdp}}^{\mathrm{mp}} + y_{\mathrm{mp}} + \gamma - \left(rw + p_{\mathrm{c}}\right) \tag{g}$$

$$m = y_{\mathrm{mp}} + \sigma_M rer \tag{h}$$

$$x = y_{\mathrm{world}} + \sigma_X rer \tag{i}$$

$$i - k = \sigma_{\mathrm{I}}\left(ror - ror_{req}\right) \tag{j}$$

$$rer = p_{\mathrm{gdp}}^{\mathrm{mp}} - \left(\varphi + p_{\mathrm{world}}\right) \tag{k}$$

$$S_{\mathrm{GDP}}^{\mathrm{FC}} p_{\mathrm{gdp}}^{\mathrm{fc}} = p_{\mathrm{gdp}}^{\mathrm{mp}} - CO_2 ratio \times d\_T \tag{l}$$

$$tot = \frac{x}{\sigma_X} - p_{\mathrm{world}} \tag{m}$$

$$p_{\mathrm{gdp}}^{\mathrm{mp}} = p_c + S_X tot \tag{n}$$

$$k - l = \sigma_{KL}\left\{rp_l - rp_k\right\} \tag{o}$$

Table A1 Stylized macro model—cont'd

Levels equations

$$rp_l = -\frac{S_K}{S_L} rp_k - \frac{1}{S_L} a \tag{p}$$

$$rp_l = rw - S_X tot + CO_2 ratio \times d\_T \tag{q}$$

$$rp_k = ror - S_X tot + CO_2 ratio \times d\_T \tag{r}$$

summary of the many abatement possibilities available in the full model. Equation (D) relates the technological change variable in equation (B) to the permit price to capture deadweight loss effects associated with an ETS.

The relationship between the value of GDP at market prices and the value of GDP at factor cost is explained in equation (E). $P_{\mathrm{GDP}}^{\mathrm{MP}}$ is the price of GDP at market prices. $P_{\mathrm{GDP}}^{\mathrm{FC}}$ is the price of GDP at factor cost. The emission price is the only form of indirect tax allowed for in the stylized system. The value of the emissions tax is the quantity of emissions (tonnes) times the emission price ($A per tonne).

Equation (F) is the economy's private consumption function, relating the value of consumption ($P_C C$) to the value of income via the Average Propensity to Consume (APC) (Ω). In the stylized system, household income is proxied by GDP at market prices. Market-price GDP includes the total return to factors plus income from indirect taxes (the gross value of the emissions tax). Accordingly it does not account for factor income accruing to foreigners, neither does it account for income used to purchase permits from overseas.

The value of government consumption is explained in equation (G). Γ is the ratio of public consumption expenditure to market-price GDP. Public consumption is labor intensive. Thus in (G) the price of public consumption is indexed to the wage rate, here defined as the product of the real wage rate (RW) and the price of consumption.

Equation (H) relates the volume of imports to the general level of real activity (Y_{MP}) and to the real exchange rate (RER). In the stylized system the real exchange rate is both an indicator of international competitiveness (+ means less competitive, − means more competitive) and a proxy for the ratio of the average price of domestic goods to the average price of foreign imported substitutes. Thus, equation (H) is consistent with the Armington specification of demand in the full model. As shown in equation (H), imports are an increasing function of the real exchange rate. Equation (I) is the corresponding export function. Y_{WORLD} is an exogenous variable representing the general level of activity in the rest of the world. Exports are inversely related to the real exchange rate.

Equation (J) is the economy's investment function. This relates the ratio of investment to capital (or annual capital growth ignoring depreciation) to the rate of return on capital (ROR) relative to the rate of return required by investors (ROR_{REQ}). This approximates, in a comparative-static framework, the dynamic relationship between capital growth and the expected rate of return in MMRF (equation 9.2).

Equations (K)−(N) deal with relative prices. Equation (K) is MMRF's definition of the real exchange rate: the ratio of the price of GDP in the domestic economy (a proxy for local production costs) to the foreign currency price of GDP in the rest of the world (P_{WORLD}), converted to domestic currency by the nominal exchange rate (Φ). The nominal exchange rate is defined as units of domestic currency per unit of foreign currency. The relationship between the price of GDP at market prices and the price of GDP at factor cost is given by equation (L).

Equation (M) relates the terms of trade (TOT) (i.e. the price of exports relative to the price of imports) negatively to the volume of exports, making allowance for exogenous changes in import prices (P_{WORLD}). The function $F_{\mathrm{TOT}}\{\}$ is a decreasing function of X. Equation (M) is consistent with the assumption in MMRF that Australia is a small country with respect to imports, but faces downward-sloping demand curves for its exports.

Equation (N) explains the ratio of the price of consumption to the price of GDP at market prices as a decreasing function, $F^{PC}_{\mathrm{PGDP}}\{\}$, of the terms of trade. A terms-of-trade improvement reduces the price of total domestic final expenditure (which includes imports, but not exports) relative to the market price of output (which includes exports, but not imports).[33]

The final block of equations, equations (O)−(R) relate to the prices and quantities of capital and labor. Equation (O) is the macro-equivalent of the industry-level CES relationship between relative factor inputs and relative factor prices. RP_{L} is the real price of labor, defined as the nominal wage rate relative to the price of GDP at factor cost (i.e. to the price of output). RP_{K} is the real price of capital, defined as the nominal rental on capital relative to the price of GDP at factor cost. Under equation (O), an increase in the real price of labor relative to the real price of capital will cause an increase in the capital intensity of the economy. Notice that with perfect competition, the real price of labor is equivalent to the marginal product of labor and the real price of capital is equivalent to the marginal product of capital.

33 Note, though, that since imports of consumption goods are only part of total imports, not all terms-of-trade changes will lead to changes in the price of consumption goods relative to the GDP deflator. Moreover, consumption is only a part of total domestic final expenditure (GNE). Changes in other factors, such as the price of labor, may affect other GNE prices more than the price of consumption, leading to a change in the price of consumption relative to the GDP deflator which has nothing to do with the terms of trade.

Equation (P) is the relationship between marginal products and technological change at the industry level, carried over to the macro level in the stylized model. It is known as the factor-price frontier (Samuelson, 1962) and is consistent with the geometric average form:

$$P_{\mathrm{GDP}}^{\mathrm{FC}} = (A \times P_{\mathrm{L}})^{S_{\mathrm{L}}} \times (A \times P_{\mathrm{K}})^{S_{\mathrm{K}}}, \tag{9.14}$$

where S_{L} and S_{K} are the shares of labor and capital in the economy ($S_{\mathrm{L}} + S_{\mathrm{K}} = 1$), and P_{L} and P_{K} are the nominal wage rate and the nominal rental on capital. To obtain equation (P), divide both sides of (9.14) by the factor-cost price of GDP, redefine in terms of real prices and then rearrange.

Equation (Q) explains the real price of labor as a function of the real wage rate (RW) (i.e. the nominal wage rate deflated by the price of consumption), the inverse of the terms of trade, and the permit price. This is based on the following decomposition of the real cost of labor:

$$\frac{P_{\mathrm{L}}}{P_{\mathrm{GDP}}^{\mathrm{FC}}} = \frac{P_{\mathrm{L}}}{P_{C}} \times \frac{P_{C}}{P_{\mathrm{GDP}}^{\mathrm{MP}}} \times \frac{P_{\mathrm{GDP}}^{\mathrm{MP}}}{P_{\mathrm{GDP}}^{\mathrm{FC}}}. \tag{9.15}$$

On the right-hand side of (9.15), the first term is the real wage rate (RW), the second term is a function of the inverse of the terms of trade (equation N) and the third term is related to T (equation L).

In deriving equation (R), note that for the real cost of capital:

$$\frac{P_{\mathrm{K}}}{P_{\mathrm{GDP}}^{\mathrm{FC}}} = \frac{P_{\mathrm{K}}}{P_{\mathrm{I}}} \times \frac{P_{\mathrm{I}}}{P_{\mathrm{GDP}}^{\mathrm{MP}}} \times \frac{P_{\mathrm{GDP}}^{\mathrm{MP}}}{P_{\mathrm{GDP}}^{\mathrm{FC}}}, \tag{9.16}$$

where P_{I} is the price of investment. On the right hand side of (9.16), the first term can be interpreted as the economy's gross rate of return, ROR. The second term, like the corresponding term in (9.15), responds generally to changes in the inverse of the terms of trade.[34] The final term is an increasing function of T.

A.2.2 Linearized form in changes of variables

The linearized forms of equations (A)−(R) are given in the second part of Table A1 as equations (a)−(r). In writing the equations, lowercase letters are used to identify percentage changes in variables written in the corresponding uppercase letters. The prefix '*d_*' attached to a variable name indicates ordinary (not percentage) change. Only the permit price (or carbon tax) is expressed as an ordinary change variable because its value can pass through zero.

Variables in the linearized model are listed in Table A2, coefficients and parameters in Table A3. The derivations of the linear forms are generally straightforward. However, some explanation is necessary.

[34] The previous footnote, which relates to consumption goods, also applies to investment goods.

Table A2 Variables, percentage change and otherwise, in the stylized model

Symbol	Description	Naturally exogenous(X)/ endogenous (N)	Short run	Long run
y_{mp}	Real GDP at market prices	N		
C	Real private consumption	N		
I	Real investment	N		
G	Real public consumption	N		
X	Real exports	N		
M	Real imports	N		
y_{fc}	Real GDP at factor cost	N		
a	Technological change	N		
l	Employment		N	X
k	Capital stock		X	N
d_T	Emissions price	X		
q_{CO_2}	Quantity of emissions	N		
p_c	Price of consumption	X (numéraire)		
p_{gdp}^{fc}	GDP price (factor cost)	N		
p_{gdp}^{mp}	GDP price (market prices)	N		
ω	APC	X		
γ	Public consumption share	X		
rer	Real exchange rate	N		
p_{world}	World GDP price	N		
φ	Nominal exchange rate	N		
y_{world}	World GDP	X		
ror	Rate of return on capital		N	X
ror_{req}	Required rate of return	X		
tot	Terms of trade	X		
rp_l	Real price of labor	N		
rp_k	Real price of capital	N		
rw	Real wage rate		X	N

All variables in this table are expressed as percentage changes except for the change in permit price, which expressed in \$A per tonne of CO_2-e.

To obtain equation (c), the elasticity of emissions to the size of the economy is assumed to be one. The semielasticity with respect to the ordinary change in permit price (d_T) is given by the parameter σ_T. As a semielasticity, σ_T has units: % Δemissions per \$A. The value of σ_T summarizes the percentage abatement impact of the permit price through the effects of fuel switching, land-use change, introduction of less-emission-intensive production technologies, etc. For the purpose of this chapter, the elasticity will be calibrated using results from the main model. Similar calibration is necessary for the semielasticity σ_A in equation (d). σ_A is expressed as % Δtechnological cost per \$A.

Table A3 Coefficients and parameters in the stylized model

Symbol	Description	Indicative value[a]	
		2011	**2030**
S_C	Share of private consumption in GDP at market prices	0.52	0.53
S_I	Share of investment in GDP at market prices	0.29	0.28
S_G	Share of public consumption in GDP at market prices	0.19	0.19
S_X	Share of exports in GDP at market prices	0.22	0.23
S_M	Share of imports in GDP at market prices	0.23	0.23
S_L	Share of the cost of labor in GDP at factor cost	0.53	0.56
S_K	Share of the cost of capital in GDP at factor cost	0.47	0.44
S_{GDP}^{FC}	Share of factor cost in GDP at market prices	1.00	1.00
S_T	Share of indirect taxes in GDP at market prices	0.00	0.00
σ_T	Semi elasticity: % Δ emissions to \$A Δ in permit price	−0.45	−0.50
σ_A	Semi elasticity: % Δ technological cost to \$A Δ in permit price	0.0020	0.002
σ_{KL}	Capital/labor substitution elasticity (+ number)	0.5	0.5
σ_M	Average domestic/import substitution elasticity (+ number)	2.6	2.6
σ_X	Price elasticity of world demand for exports (− number)	−5.0	−5.0
σ_I	Elasticity of I/K to rate of return (+ number)	1.0	1.0
$CO_2 ratio$	100 times the ratio of emissions to GDP (Mt/\$A m)	0.0475	0.0386

[a]Data are from the model's base case for 2011 (short run) and 2030 (long run) with the exceptions of data for σ_T, σ_A and σ_I.Values for each of these elasticities are inferred *ex post* from the MMRF modeling results reported in Section 9.6.

In writing equation (e), the first share on the right-hand side is the share of factor cost in market-price GDP. The second share is the share of indirect taxes (the value of permits) in market-price GDP. It is assumed that changes in the underlying quantity (emissions) directly affect real GDP. Changes in the tax rate only directly affect the price of GDP (equation l).

In equation (h), σ_M, a positive parameter, is the value of the average domestic/import substitution elasticity evaluated using data from MMRF. In equation (i), σ_X, a negative parameter, represents the average price elasticity of world demand for Australian exports. Again, its value comes from MMRF.

Equation (j) relates the percentage change in capital growth in the comparative-static year, to the percentage change in rate of return net of the required rate of return. The elasticity σ_I is a positive parameter. As for σ_T and σ_A, the value for σ_I will be calibrated using results from the main model.

Equation (l) is generated by first noting that the percentage change in the price of GDP at market prices is a share weighted sum of the percentage changes in factor prices and in the price associated with indirect taxes (in this model, the permit price or carbon tax). In other words:

$$p_{\mathrm{gdp}}^{\mathrm{mp}} = S_{\mathrm{GDP}}^{\mathrm{FC}} p_{\mathrm{gdp}}^{\mathrm{fc}} + \frac{Q_{\mathrm{CO_2}} T}{P_{\mathrm{GDP}}^{\mathrm{MP}} \times Y_{\mathrm{MP}}} \times 100 \times \frac{d\_T}{T}. \tag{9.17}$$

Cancelling T gives equation (l), with the economy's emission intensity ($\times 100$) given by:

$$CO_2\ ratio = 100 \times \frac{Q_{\mathrm{CO_2}}}{P_{\mathrm{GDP}}^{\mathrm{MP}} \times Y_{\mathrm{MP}}}, \tag{9.18}$$

For equation (n), it is assumed that:

$$p_{\mathrm{gdp}}^{\mathrm{mp}} = S_C p_{\mathrm{c}} + S_G p_{\mathrm{g}} + S_{\mathrm{I}} p_{\mathrm{i}} + \left(S_X p_x - S_M p_m\right). \tag{9.19}$$

If the prices of private consumption, public consumption and investment move together, i.e.:

$$p_c = p_g = p_i, \tag{9.20}$$

and trade is initially balanced, i.e.:

$$S_X = S_M, \tag{9.21}$$

then:

$$p_{\mathrm{gdp}}^{\mathrm{mp}} - p_c = S_X\left(p_x - p_m\right) = S_X tot. \tag{9.22}$$

Equation (o) is an implication of the CES form for capital/labor substitution:

$$\frac{K}{L} = \left(\frac{P_{\mathrm{L}} \times P_{\mathrm{GDP}}^{\mathrm{FC}}}{P_{\mathrm{K}} \times P_{\mathrm{GDP}}^{\mathrm{FC}}}\right)^{\sigma_{KL}}. \tag{9.23}$$

where σ_{KL} is a positive parameter, representing the capital/labor substitution elasticity.

The starting point for equation (q) is equation (9.15). This implies that the percentage change in real price of labor is the sum of: (i) the percentage change in the real wage rate (*rw*), (ii) the percentage change in the ratio of the consumption price to the market-price GDP deflator and (iii) the percentage change in the ratio of the market-price GDP deflator to the factor-cost GDP deflator. Component (ii) is explained by equation (n). Component (iii) is explained by equation (l). The derivation of equation (r) from equation (9.16) is analogous to the derivation of (q) from (9.15).

The number of variables (9.27) exceeds the number of equations (9.18) by nine. Thus, nine variables must be declared exogenous. Table A2 shows the exogenous/endogenous status of each variable in the short-run and long-run closures of the model. Seven variables are shown as exogenous in both cases. The price of consumption is the numéraire. The terms of trade is also exogenous, reflecting its status in the MMRF simulations. It is exogenized by making endogenous the world GDP price (the proxy for import prices).

This leaves two more variables to be made exogenous. As indicated in the final two columns of Table A1, in short-run comparative-static simulations, the capital stock and real wage rate are exogenous, allowing the model to determine values for employment and the rate of return on capital. In long-run comparative-static simulations, employment and the rate of return are exogenous, allowing the model to determine values for capital and the real wage rate.

In the next section, simulation results from MMRF are compared to results deduced using the stylized model.

A.3 MMRF Projections compared with results from the stylized model

Table A4 compares Australia-wide results for the ETS as simulated by MMRF with those derived using the stylized model. In the column labeled 'Short (2011)', results from the first year (2011) of the MMRF simulation, expressed as deviations from base case, are compared with short-run comparative-static results from the stylized model. In the column labeled 'Long (2030)', results for the final simulation year (2030) of the MMRF simulation are compared with long-run comparative-static results from the stylized model. All simulations with the stylized model were run using the same multistep solution procedure as used for MMRF simulations.

First, the short-run results are compared. Generally, these are the easiest to understand in terms of known details about the underlying data, equations and closure. Then, the long-run results are examined. These are more easily understood once the short-run outcomes have been discussed.

A.3.1 Short-run impacts

The MMRF simulation of the effects of the ETS in 2011 is reproduced in the stylized model by shocking the exogenous variables d_T, *tot*, *rw* and ω, and setting all other exogenous variables to zero change (see the italic entries of Table 9.4). The values of the shocks are the deviations from base case imposed or simulated using the full model for 2011.

Table A4 Values for variables compared

		Short (2011)		Long (2030)	
Symbol	**Description**	**Stylized**	**MMRF**	**Stylized**	**MMRF**
y_{mp}	Real GDP at market prices	−0.1	−0.1	−0.8	−1.1
c	Real private consumption	0.1	0.1	−1.3	−1.5
i	Real investment	−0.6	−0.4	−2.3	−3.4
g	Real public consumption	−0.1	−0.1	−1.2	−0.5
x	Real exports	0.0	−0.3	1.6	1.2
m	Real imports	−0.1	−0.2	−1.6	−2.0
y_{fc}	Real GDP at factor cost	−0.1	−0.1	−0.4	−0.8
a	Technological change	0.0	0.0	0.0	−0.1
l	Employment	−0.2	−0.2	*−0.1*	−0.1
k	Capital stock	*0.0*	0.0	−0.5	−1.7
d_T	Emissions price ($A per tonne of CO_2-e)	*10.0*	10.0	*49.3*	49.3
q_{co_2}	Quantity of emissions	−4.5	−4.5	−24.4	−25.6
p_c	Price of consumption	*0.0*	0.0	*0.0*	0.0
p^{fc}_{gdp}	GDP price (factor cost)	−0.3	−0.4	−1.6	−2.1
p^{mp}_{gdp}	GDP price (market prices)	0.0	−0.1	−0.4	−0.8
ω	APC	*0.2*	0.2	*−0.1*	0.9
γ	Public consumption share	*0.0*	0.0	*0.0*	0.0
rer	Real exchange rate	0.0	−0.2	−0.3	−2.5
p_{world}	World GDP price	0.0	NA	1.3	NA
φ	Nominal exchange rate	0.0	−0.3	−1.3	1.0
y_{world}	World GDP	*0.0*	NA	*0.0*	NA
ror	Rate of return on capital	−0.6	−0.4	*−1.2*	−1.2
ror_{req}	Required rate of return	*0.0*	0.0	*0.0*	0.0
tot	Terms of trade	*0.0*	0.0	*−1.5*	−1.5
rp_l	Real price of labor	0.2	0.2	−0.5	−0.5
rp_k	Real price of capital	−0.2	−0.1	0.4	0.6
rw	Real wage rate	*−0.2*	−0.2	−2.1	−2.6

NA indicates that the variable is not present in the full model.

According to equation (q), the imposition of a carbon price of $A10 per tonne of CO_2-e, combined with no change in the terms of trade and a real wage cut of 0.2%, causes the real price of labor (RP_L) to increase by 0.2%. The increase in real price of labor implies a decrease in the real price of capital (RP_K) (equation p). The stylized model projects a fall of 0.2%. In the full model, the real price of labor increases relative to its base-case value by 0.2% and the real price of capital falls by 0.1%. The stylized model overestimates the impact on the real price of capital mainly because it ignores the other factor fixed in the short-run, agricultural land. In the full model, the imposition of the carbon price in the short run causes the real price of land to fall by 0.9%. Land is about

5% of GDP. A weighted average of the changes in land and capital prices is −0.2%, as predicted in the stylized model.

An increase in the real price of labor relative to the real price of capital causes producers to substitute capital for labor. According to the CES equation (o), the ratio of capital to labor should increase by 0.2%. With capital exogenous and set to zero change in the short-run, employment falls by 0.2%. In this case the prediction of the stylized model is the same as the projection of the full system.

Via equation (b), in the absence of technological change, the fall in employment leads to a 0.1% decline in real GDP at factor cost. Real GDP in market prices falls by the same percentage amount (equation e). These are the same results projected in the full model. Compositional effects, which are not captured in the stylized model, appear to have had a negligible impact on the short-run results for employment and real GDP.[35]

The stylized model predicts that the price of GDP at market prices will be affected by less than 0.1% (see equation n).[36] This implies, via equation (l), a 0.3% reduction in the price of GDP at factor cost. In the full model, the price of GDP at market prices falls relative to base by 0.1% and the price of GDP at factor cost falls by 0.4%.

We now turn to the expenditure-side aggregates of real GDP. In the stylized model, the change in real private consumption is explained by equation (f). If there were no change in the APC (Ω), then the stylized model would predict a 0.1% reduction in real consumption, in line with the fall in the value of GDP at market prices. However, the full model predicts a 0.2% increase in the APC to ensure that the balance on current account remains unchanged relative to its base case level. After taking this into account, the final predicated change in consumption is 0.1%, in line with the simulated deviation from the full model.

Equation (j) explains the percentage change in investment (with capital held fixed) as a function of the percentage change in the ratio of the actual to required rate of return. According to equation (r), based on the 0.2% fall in the real price of capital (already explained), the rate of return on capital will fall by 0.6%. Given a value of 1.0 for σ_{I}, the stylized model predicts a fall in investment of 0.6%, which is the same as the simulated deviation from base in the full model.

In the stylized model, the changes in real private consumption and investment, together with the assumption that public consumption moves with nominal GDP, imply a percentage change in real final domestic absorption (C + I + G) of:

$$S_C c + S_{\mathrm{I}} i + S_G g = 0.52 \times 0.1 + 0.29 \times -0.6 + 0.19 \times -0.1 = -0.1\%.$$

35 In a multisectoral model, the economy-wide ratio of capital to labor is affected not only by changes in the ratio of aggregate factor prices, but also by changes in the sectoral composition of GDP. For example, in the short-run the capital-to-labor ratio can fall because of changes in the composition of the economy away from capital-intensive industries. Conversely, it can rise with changes in composition towards capital-intensive industries.

36 Recall, that the price of consumption is the numéraire, which is fixed at zero change.

This matches the predicted percentage change in real GDP at market prices. With the initial trade balance assumed to be slightly in deficit (Table A3), equal percentage changes in real GDP and real GNE requires the percentage change in import volume to be a little below the percentage change in export volume. This is consistent with the full model.

To generate the necessary changes in trade volumes, equations (h) and (i) suggest that no change in the real exchange rate is necessary. This is in contrast to the full model, where a real devaluation of 0.2% is projected. Without the devaluation, the carbon price, which has relatively adverse effects on export-oriented mining and manufacturing sectors, would shift the trade balance towards deficit. These compositional effects are not captured by the stylized model. Note, that with no change in the real exchange rate and no change in the world GDP price, there is no scope for change in the nominal exchange rate (equation k).

Based on the calibrated values for σ_T and σ_A of −0.45 and 0.02, the emissions price of $A10 generates a changes in emissions and technological change consistent with the projections of the full model.

A.3.2 Long-run impacts

The MMRF simulation of the effects of the ETS in 2030 is reproduced in the stylized model by shocking the exogenous variables d_T, tot, ror, ω and l, and setting all other exogenous variables to zero change (see the entries of the last panel of numbers in Table A4). With one exception, the values of the shocks are the deviations from base case imposed or simulated using the full model for 2030. The exception is the shock to the APC (ω). MMRF projects an increase of 0.9%. For the stylized model, this is adjusted down by 1.0 percentage points to −0.1% to account for the loss of consumption associated with the need to purchase global emissions permits from overseas ($A7.9 billion in 2030). It is assumed in the full and stylized modeling that these purchases are ultimately paid for by private households.

According to equation (r), the imposition of the tax ($A49.3 per tonne of CO_2-e), combined with the terms-of-trade deterioration of 1.5% and a fall of 1.2% in capital's rate of return, causes the real price of capital to increase by 0.4%. This leads to a fall in the real price of labor of 0.5% (equation p). In the full model, the real price of capital increases by 0.6% relative to base and the real price of labor falls by 0.5%.

The predicted change in real factor prices causes the ratio of capital to labor to fall by 0.4% (equation o). With employment down by 0.1%, this implies a 0.5% decline in capital. In the full model, relative to the stylized model the change in real factor prices is similar. However, the outcome for the ratio of capital to labor is different, with the full model projecting a change of −1.6%, rather than −0.4%. The difference is due to the long-run compositional effect mentioned in Section 9.6.2.1. The effect operates primarily in the long-run and allows the national ratio of capital to labor to fall with relatively little change in relative factor prices when the economy's composition moves away from capital-intensive sectors.

The stylized model predicts a 0.4% fall in real GDP at factor cost (equation b), while the full model projects a 0.8% fall. This is in line with the respective outcomes for labor and capital, which suggest a larger fall in the main model for factor-cost GDP. The stylized model predicts little change in technology. The full model projects technological improvement (a negative value for *a*) of 0.1%.

According to equation (e), with real GDP at factor cost down by 0.4% and a reduction in emissions of roughly 25%, the percentage change in real GDP at market prices will be −0.8%: the reduction in highly taxed emissions reduces real GDP by 0.4 percentage points. In the full model real GDP at market prices falls by 1.1%, with changes in the underlying volumes of taxed flows contributing −0.3 percentage points. Changes in the volumes of taxed flows are strongly influenced by compositional factors, which account for the different contributions in the two sets of model results.

The stylized model predicts that the price of GDP at market prices will fall relative to the price of consumption by 0.4%, driven by the 1.5% cut in terms of trade (equation n). The full model projects a fall of 0.8%. There are a number of compositional factors causing the stylized model to underestimate the change in price of GDP. A key factor is that it fails to take account of the composition of changes in foreign currency import prices that are based on projections from GTEM. In the GTEM shocks, the price of imported consumption goods fall relative to the average price of imported products, leading to a larger fall in the market-price GDP deflator relative to the consumption deflator than predicted by the stylized model. The stylized model also underestimates the fall in the factor-cost deflator. This is due, in the main, to the underestimation of the change in the market-price deflator.

We now turn to the expenditure side aggregates of real GDP. Given a 0.1% decrease in APC, the stylized model predicts a fall in real consumption of 1.3% (equation f). Given the fall in capital of 0.5%, a reduction in the rate of return on capital of 1.2%, the stylized model predicts a fall in investment of 2.3% (equation j). In the full model, real private consumption falls by 1.5% and real investment falls 3.4%.

In the stylized model, the changes in real private consumption, real public consumption and investment imply a 0.7% reduction in real domestic absorption relative to real GDP at market prices. Thus, the volume of imports must fall relative to the volume of exports. In the stylized model, imports fall by 1.6% and exports rise by 1.6%. In the full model, imports fall by 2.0% and exports increase by 1.2%. In the stylized model, mild depreciation of the real exchange rate is necessary to achieve the required outcome for the net volume of trade. In the full model, stronger real depreciation is required, in part to offset compositional shifts against traded-goods industries.

A.4 Final remarks regarding the stylized model

The stylized model assists in identifying the principal theoretical mechanisms that underlie the projections from the full model. It also aids in highlighting the important elements of the database (Table A3). The extent of its predictive power is inversely proportional to the degree to which compositional changes, not allowed for in the stylized framework, influence the final simulation outcome. However, as shown in Sections A.3.1 and A.3.2 of this Appendix, even for the ETS simulations in which compositional effects are strong, the stylized model can aid interpretation by identifying the strength of specific compositional effects and in some cases the nature and location of those effects.

In addition to being interpretation aid, the stylized model can also be used to create summary reduced-form expressions for the short- and long-run impacts of an ETS on real GDP. These assist further with arguments about plausibility, etc. The reduced-form expressions are given below.

A.4.1 Short-run

From equations (o)−(q), the following reduced-form expression for $(k-l)$ is obtained:

$$k - l = \frac{\sigma_{KL}}{S_{\mathrm{K}}}\{rw - S_{\mathrm{X}} tot + CO_2 \ ratio \times d\_T + a\}. \qquad (9.24)$$

Substituting equation (24) into (b) yields an expression for the deviation in real GDP at factor cost:

$$y_{\mathrm{fc}} = -\frac{S_{\mathrm{L}}\sigma_{KL}}{S_{\mathrm{K}}}\{rw - S_{\mathrm{X}} tot + CO_2 \ ratio \times d\_T + a\} + k - a. \qquad (9.25)$$

From (e) the following expression for real GDP at market prices is derived:

$$y_{\mathrm{mp}} = S^{\mathrm{FC}}_{\mathrm{GDP}}\left[-\frac{S_{\mathrm{L}}\sigma_{KL}}{S_{\mathrm{K}}}\{rw - S_{\mathrm{X}} tot + CO_2 \ ratio \times d\_T + a\} + k - a\right] + S_T q_{\mathrm{CO}_2}. \qquad (9.26)$$

The contribution of changes in factor inputs to the percentage change in real market-price GDP is given by the first of the two right-hand terms. The contribution from the efficiency effects associated with changes in the quantity of taxed flows is given by the second of the two right-hand terms.

If in the short-run there is no impact on capital and the real wage rate, and if there is no technological change, then carbon price's short-run effect on real GDP at factor cost reduces to:

$$\left[-\frac{S_{\mathrm{L}}\sigma_{KL}}{S_{\mathrm{K}}}\{-S_{\mathrm{X}} tot + CO_2 \ ratio \times d\_T\}\right]. \qquad (9.27)$$

CO_2 $ratio \times d\_T$ is the ratio of the emissions tax to GDP. Thus, ignoring compositional changes and terms-of-trade effects, the percentage effect on real GDP of a carbon tax is inversely proportional to the size of the tax relative to GDP. Based on the data in Table A3, in 2011 the short-run impact on real GDP of a $A10 per tonne tax will be −0.3% (actual outcome −0.1%).

A.4.2 Long-run

The corresponding equations for the long run are:

$$k - l = \frac{\sigma_{KL}}{S_{\mathrm{L}}}\{ror - S_X tot + CO_2\ ratio \times d\_T + a\} \tag{9.28}$$

$$y_{\mathrm{fc}} = -\frac{S_{\mathrm{K}}\sigma_{KL}}{S_{\mathrm{L}}}\{ror - S_X tot + CO_2\ ratio \times d\_T + a\} + l - a \tag{9.29}$$

$$y_{\mathrm{mp}} = S_{\mathrm{GDP}}^{\mathrm{FC}}\left[-\frac{S_{\mathrm{K}}\sigma_{KL}}{S_{\mathrm{L}}}\{ror - S_X tot + CO_2\ ratio \times d\_T + a\} + l - a\right] + S_T q_{\mathrm{CO_2}}. \tag{9.30}$$

In the long run, assuming no change in rate of return and employment, and no technological change, then carbon price's short-run effect on real GDP at factor cost reduces to:

$$\left[-\frac{S_{\mathrm{K}}\sigma_{KL}}{S_{\mathrm{L}}}\{-S_X tot + CO_2\ ratio \times d\_T\}\right]. \tag{9.31}$$

Evaluated at coefficient values for 2030 given in Table A3, and ignoring terms-of-trade changes, equation (9.31) yields an estimate of −0.8% for the long-run impact of a $A49.3 carbon price on real factor-cost GDP (actual outcome −0.8%).

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