Appendix A: Modelling framework

1.1 Introduction

No one model adequately captures the global, national, sectoral and household dimensions or focuses on all relevant aspects of mitigation policy in Australia. Previous Australian studies of mitigation policy typically focus on one of these dimensions — a particular sector (for example, electricity generation) isolated from the broader national economy, or the national economy without a consistent global analysis.

In contrast, this analysis and previous Treasury modelling (Australian Government, 2008) use a suite of models that together span global, national, sectoral and household scales, to simultaneously explore these four dimensions.

The modelling includes two top-down, computable general equilibrium (CGE) models developed in Australia: the Global Trade and Environment Model (GTEM) and the Monash Multi-Regional Forecasting (MMRF) model. These CGE models are economy-wide models that capture the interactions between different sectors and among producers and consumers. GTEM models the global economy. MMRF models the Australian economy with state and territory level detail. A series of bottom-up sector-specific modelling for electricity generation, road transport, agriculture and forestry complement these CGE models.

This appendix provides a summary of Treasury's modelling framework.

1.2 Economy-wide modelling

1.2.1 GTEM global model

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) developed the recursively dynamic general equilibrium model, GTEM, to analyse policy issues with global dimensions, such as climate change mitigation costs. It is derived from the MEGABARE model and the static Global Trade Analysis Project (GTAP) model (Pant, 2007; Hertel, 1997; ABARE, 1996 and Australian Government, 2008). In this report, GTEM represents the global economy through 13 regions (including Australia, the United States, China and India) each with 19 industrial sectors and a representative household (for each whole regional society). Trade and investment link the regions and a range of taxes and subsidies capture government policies. The model assumes multiple production technologies for three energy-intensive sectors: the electricity, transport, and iron and steel sectors.

Table A1: Regions and sectors of GTEM

Regions			Industry sectors	
United States			**Coal mining**	
European Union (25)			**Oil mining**	
Austria	Belgium	Cyprus	**Gas mining**	
Czech Republic	Denmark	Estonia	**Petroleum and coal products**	
Finland	France	Germany	**Electricity**	
Greece	Hungary	Ireland	with 12 technologies:	
Italy	Latvia	Lithuania	Coal	Petroleum and coal products
Luxembourg	Malta	Netherlands	Gas	Nuclear
Poland	Portugal	Slovakia	Hydro	Wind
Slovenia	Spain	Sweden	Solar	Biomass
United Kingdom			Waste	Other renewables
Japan			Coal CCS	Gas CCS
China			**Iron and steel**	
India			with 2 technologies:	
Indonesia			Electric arc	Blast furnace
Other South and East Asia			**Non-ferrous metals**	
Brunei	Cambodia	Laos	**Chemical, rubber and plastic products**	
Malaysia	Maldives	Myanmar	**Other mining**	
Philippines	Korea	Singapore	**Non-metallic minerals**	
Thailand	Timor-Leste	Vietnam	**Manufacturing**	
Former Soviet Union			**Air transport**	
Armenia	Azerbaijan	Belarus	**Water transport**	
Georgia	Kazakhstan	Kyrgyzstan	**Other transport**	
Moldova	Russia	Tajikistan	with 5 technologies:	
Turkmenistan	Ukraine	Uzbekistan	Non-road (rail)	Internal combustion engine
OPEC (a)			Advanced internal combustion engine	
Bahrain	Iran	Iraq	Hybrids	Non-fossil fuel vehicles
Israel	Jordan	Kuwait	**Crops**	
Lebanon	Palestine	Oman	**Livestock**	
Qatar	Saudi Arabia	Syria	**Fishing and forestry**	
UAE	Venezuela	Yemen	**Food**	
Canada			**Services**	
Australia				
South Africa				
Lesotho	Namibia	South Africa		
Swaziland				
Rest of world				
Remaining countries in the GTAP database				

Note: (a) Includes some non-OPEC countries.
Source: GTEM.

Modifications to GTEM

Some modifications have been made to GTEM for this exercise. They include: the implementation of capacity constraints for some electricity technologies; introduction of inequality constraints to implement constrained permit trading and the renewable energy target; and implementation of a border tax adjustment.

This report exploits Cao (2010), which made solving inequality constraints more efficient in GEMPACK (the software platform on which GTEM is implemented). Cao's method is used to replace the existing implementation of capacity constraints and implement the renewable energy target and constrained permit trading. The renewable energy target requires energy generators produce renewable energy cumulatively each year to be at least the target for that year. In

addition, this method allows for the exploration of limits on the amount of abatement sourced from overseas.

An equation was introduced to calculate, if relevant, the import tariff which is equivalent to the import price increase that would occur if the carbon price of the destination country applied in the source country. This method only includes the direct carbon cost. Any indirect costs due to higher input costs, such as from electricity, are not measured in this calculation. For a given commodity, the calculation uses the direct emission intensity of producing the commodity in the source country and the carbon price in the destination country.

Similarly, an extra equation is introduced to calculate the export subsidy equivalent to the export price decrease, if the carbon price were not in place. As in the tariff calculation, this subsidy measurement only covers the direct carbon cost. For a given commodity, the calculation uses the direct emission intensity of production in the source country and the carbon price in the same country.

1.2.2 MMRF Australian model

The Centre of Policy Studies (CoPS) at Monash University developed MMRF as a detailed model of the Australian economy (Adams et al, 2011 and Australian Government, 2008). MMRF is rich in industry detail and provides results for all eight states and territories. It is also dynamic, employing recursive mechanisms to explain investment and sluggish adjustment in factor markets.

Table A2: Sectoral aggregation in MMRF

Category	Sectors
Agriculture, forestry and fishing	Sheep and beef cattle; dairy cattle; other animals; grains; agriculture services and fishing; forestry; and other
Mining	Coal, oil, gas, iron ore, non-ferrous ore and other
Manufacturing	Meat products; other food, beverages and tobacco; textiles, clothing and footwear; wood products; paper products; printing; refinery (including petroleum and coal products); chemicals; rubber and plastic products; non-metal construction products; cement; iron and steel; alumina; aluminium; other non-ferrous metals; metal products; motor vehicles and parts; and other
Utilities	Electricity generation (coal, gas, oil, hydro and other), electricity supply, gas supply and water supply
Services	Construction; trade; accommodation, hotels, cafes and restaurants; communication; finance and insurance; property and business; dwelling; public; and other
Transport	Road (passenger and freight), rail (passenger and freight), water and air
Households (a)	Household consumption (private electrical, private heating and private transport)

Note: (a) The sectors 'private electrical', 'private heating' and 'private transport' in the MMRF model relate to provision of services from the private stocks of electrical equipment (not heating), heating equipment and motor vehicles only.
Source: Adams et al (2011).

Sector specific modelling

A series of bottom-up sector-specific models for electricity generation, road transport, agriculture and forestry complement the CGE models. Detailed analysis of these emission-intensive sectors is useful in understanding the economy's likely response to carbon pricing, particularly over the short to medium term.

Electricity sector modelling

ROAM Consulting and SKM MMA part of the Sinclair Knight Merz group (SKM MMA) each provided detailed bottom-up modelling of the Australian electricity generation sector, providing projections which are averaged for the results presented. Using the average projections of two models provides a natural hedge against the inherent uncertainty of economic modelling. Projections are provided for levels of generation (on a sent out basis), total capacity (installed), emissions (of carbon dioxide equivalent), energy use (fuel use), wholesale and retail electricity prices and the profit streams of generators. The results are provided at the generator or unit level and provide insight into the transformation of the electricity generation sector.

Both sets of modelling are highly detailed and aim to represent actual market conditions as closely as possible. The models incorporate economic relationships between individual generating plants in the system and their technical and cost profiles. The models incorporate a range of fuel types, including brown coal, black coal, natural gas and renewables (including hydro, biomass, solar, wind and geothermal). The modelling also incorporates technologies such as carbon capture and storage, and differences between natural gas technologies (such as combined cycle gas turbines and open cycle gas turbines). The SKM MMA models use hourly data while ROAM uses half hourly data and aggregated electricity demand, capturing daily and seasonal fluctuations in energy use.

Reports covering the modelling of the electricity sector are available on the Treasury website (SKM MMA, 2011; and ROAM Consulting, 2011).

Road transport sector modelling

Australian road transport sector modelling was conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). CSIRO uses a partial equilibrium model, the Energy Sector Model (ESM) of the Australian energy sector, which includes detailed road transport sector representation (Graham and Reedman, 2011). The ESM was developed by CSIRO and ABARE in 2006. The model has an economic decision-making framework based around the cost of alternative fuels and technologies.

The model evaluates the uptake of different technologies based on cost competitiveness, practical constraints in transport markets, current excise and mandated fuel mix legislation, greenhouse gas emission limits, each state's existing plant and vehicle stock, lead times in the availability of new vehicles or plant and the degree of flexibility in the existing fleet. Graham and Reedman (2011) document the ESM.

Consumers (both individuals and firms) are assumed to minimise cost, through their choices of vehicles and fuels. It is assumed that vehicles last for ten years. The mix of vehicle sizes is exogenous in the model, and, in the current modelling, the average vehicle size is assumed to decrease over time as fuel costs increase. The availability of alternative technologies also depends, exogenously, on prices. The ESM supply-side exogenous assumptions are largely based on CSIRO's research in conjunction with other major stakeholders.

A report from CSIRO covering details of the road transportation sector modelling is available on the Treasury website (Graham and Reedman, 2011).

Agriculture, land use change and forestry modelling

The output of the Australian agricultural sector is driven by both international and domestic demand and productivity improvements. GTEM determines external demand for agricultural produce, while productivity growth is consistent with improvements used by the Department of Climate Change and Energy Efficiency (DCCEE) in their emissions projections.

The emissions of the agricultural sector to 2020, assuming there are no incentives for abatement, align with the DCCEE's detailed bottom-up projections (DCCEE, 2011d).[1] Both the global action and policy scenarios assume abatement from land use, land use change and the forestry sector are driven by the Carbon Farming Initiative (CFI).

DCCEE provided modelling of the abatement expected from the agriculture, land use change and legacy waste components of the CFI. Estimates of abatement in agriculture are updated to reflect the policy parameters of the CFI and recent developments in the availability and costs of abatement opportunities. The estimates are in line with previous bottom-up estimates by DCCEE.

DCCEE used a top-down approach to estimate proportional reductions in emissions in response to carbon prices under the CFI. The estimated price-emissions reduction relationship involves using a similar functional form to that used for the Marginal Abatement Cost (MAC) curves for non-energy emissions in previous Treasury modelling (Australian Government, 2008). The parameters of the MAC curves are calibrated to DCCEE's bottom-up preliminary estimates of CFI abatement in 2020. For each price scenario, the level of abatement is estimated by multiplying projected baseline emissions by the estimate of proportional emission reductions. A report from DCCEE about this modelling is available on the Treasury website (DCCEE, 2011b).

ABARES models the abatement expected from the reforestation component of the CFI. ABARES analysis is based on estimates of agricultural and forestry returns, the discount rate, costs, yields and sequestration rates across the regions using ABARES' spatially based land use models and MMRF. The framework used is spatially explicit, and involves analysing the opportunities for carbon sequestration provided by reforestation on cleared agricultural land. These opportunities are determined by comparing the net present value (NPV) of returns from reforestation investments with the corresponding expected agricultural value to estimate the potential area of clear agricultural land that is economically viable for reforestation within each spatial grid cell.

Reforestation options considered in ABARES's analysis included long rotation hardwood plantations and carbon plantations that may be eligible for CFI credits, as follows:

- a plantation of 'traditional species/rotation' that is planted with the intention of harvesting it for fibre (timber/chip) or biomass (energy) and selling these products and is planted in non-traditional, lower rainfall areas only because there will be revenue from the payment for both carbon sequestration and fibre and/or biomass sales;
- trees planted or direct seeded with no intention to harvest and planted solely for the revenue from the payment for carbon sequestration; and

1 Australia's emissions projections 2010 http://www.climatechange.gov.au/en/publications/projections/australias-emissions projections.aspx. Various assumptions are made about emission intensities beyond 2020.

- trees planted or direct seeded with no intention to harvest.

A report from ABARES about this modelling is available on the Treasury website (Burns et al, 2011).

Price Revenue Incidence Simulation Model (PRISMOD.IO)

Treasury's Price Revenue Incidence Simulation Model (PRISMOD.IO) examines the inter industry transmission of price changes (also called second round effects) in addition to direct effects. PRISMOD.IO, a large-scale, highly disaggregated model of the Australian economy, captures the flows of goods between industries and final consumers. The data in PRISMOD.IO comprise the transactions and consumption patterns of 109 industry categories and seven categories of final demand. The 2011 version of PRISMOD.IO is based on data from the 2005-06 Input-Output Tables (ABS, 2009). Other key characteristics of PRISMOD.IO are set out below.

- The focus is on the inter-industry transmission of price changes. For example, it tracks how a change in the price of electricity impacts on all industries that purchase electricity, and on all industries that purchase from those industries, and on all purchasers of those industries, and so forth.

- Quantities are held fixed: only price impacts are modelled. Price changes are calculated for the 'morning after' the policy change, before production techniques or volumes adjust. Businesses continue to operate with exactly the same inputs, and produce exactly the same outputs, before and after the change being simulated.

- All cost and price impacts are passed on fully to final purchasers (such as governments and households). That is, it is assumed that the imposed carbon price will be passed through fully to domestic consumers in the form of higher prices.

- The model does not provide information as to the timing of price changes. All price impacts calculated by the model are long term in nature. This means PRISMOD.IO estimates of short-term price impacts may be overstated, if the transmission of the carbon price is slower or not fully passed on.

Price Revenue Incidence Simulation Model — Distribution (PRISMOD.DIST)

The distributional implication for households of carbon pricing is analysed using Treasury's Price Revenue Incidence Simulation Model and Distribution Model (PRISMOD.DIST). This model is a static micro simulation model which can be used to examine the distributional effects of government policies on household income. The key characteristics of PRISMOD.DIST include:

- the 2011 version of the model is based on data from the 2003-04 Household Expenditure survey (HES) (ABS, 2006b);

- the HES data were updated to 2011 using actual state CPI item price movements.[2] The totals for a variety of expenditure baskets are then projected to 2013 using headline CPI forecasts and projections;
- the HES data were normalised to conform to the fifteenth series CPI weights to adjust for under-and over-reporting of certain expenditure items in the HES;
- Treasury's enhanced HES version of NATSEM's STINMOD model was used to re-weight the HES data for projected demographic changes;[3] and
- the income and household type variables also are taken from STINMOD.

The model projects household spending for 2012-13 based on projected growth in the CPI for expenditure classes, and projects incomes based on growth in wages and transfer payments and legislated tax rates and thresholds. Households purchase constant quantities of goods and services: only prices vary over time.

Household spending on stationary and transport energy includes direct spending on electricity, mains gas, bottled gas, heating oil, wood for fuel, bottled gas for barbecues, kerosene, paraffin, petrol, diesel fuel, LPG, other gas fuels, other domestic fuel and holiday petrol. Where stationary fuel use is reported separately, petrol, diesel fuel, LPG other gas fuels, other domestic fuel and holiday petrol are excluded.

Unless otherwise stated, households are only included in the analysis if they spend money on energy and have a positive disposable income. Excluding households with negative or nil disposable income results in slightly fewer households in the lowest quintile but it partially addresses ABS concerns that incomes in the lowest decile may not accurately reflect the level of their wellbeing. The analysis excludes around 0.8 per cent of households with positive disposable income that report no direct spending on energy and around 1.8 per cent of households with positive disposable income reporting no spending on stationary energy.

MAGICC overview

To examine whether the emission trajectories from the global action scenarios derived in GTEM meet specified concentration targets around 2100, the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) is used to estimate the atmospheric concentrations of the emission trajectories (Raper et al, 1996; Wigley and Raper, 1992; and Wigley and Raper, 2001). MAGICC is calibrated against more complex climate models and was used in the IPCC's Fourth Assessment Report (IPCC, 2007b). GTEM covers emissions of 7 gases, including both low and high global warming potential gases from various sources and sinks. As the global action scenarios project emission paths only to 2050 and the concentration targets are for around 2100, projections of emissions beyond 2050 for the estimation of concentrations by MAGICC are based on emission trends before 2051 and draw on post-2050 emissions information from the Garnaut scenarios in previous Treasury modelling (Australian Government, 2008).

2 All results in this publication are in Australian financial years, ending 30 June of the year quoted.
3 More information on NATSEM's version of STINMOD can be found at http://www.canberra.edu.au/centres/natsem/research-models/projects_and_models/stinmod.

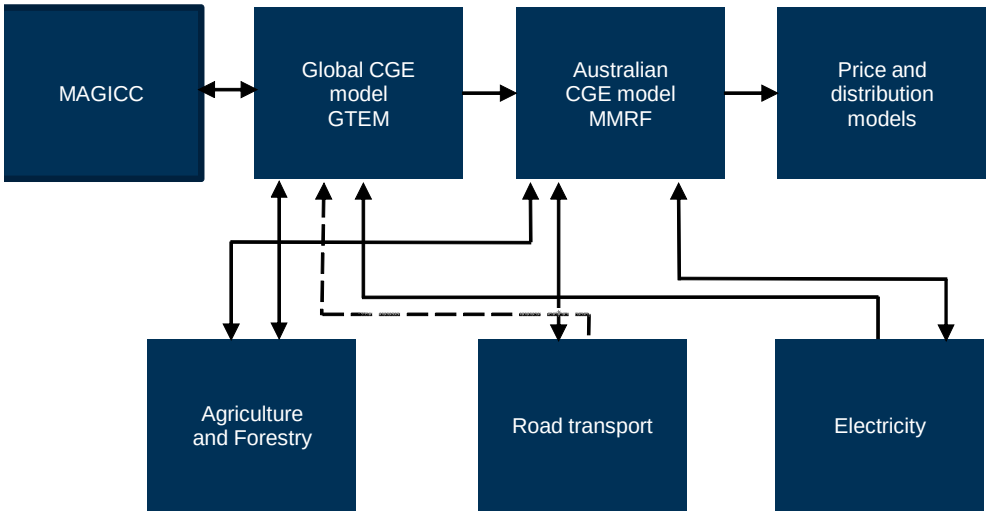
An integrated modelling framework

The results from each of these models are drawn together into an integrated set of projections that are consistent at the macroeconomic level and sufficiently detailed in key sectors to provide insights into the likely transformation of the Australian economy under carbon pricing.

Modelling of the global economy with GTEM provides the international economic and emissions context for modelling of the Australian economy within MMRF, which in turn is informed by the bottom-up modelling of key sectors. MAGICC is used to estimate the greenhouse gas atmospheric concentration levels, with the world carbon price paths being set so atmospheric concentration levels of the emissions paths from the model broadly match the environmental targets.

Linking economic models with different economic structures is not straightforward. Significant research was involved to ensure the suite of models were linked sensibly.

Chart A1: How the suite of models fit together



Note: Solid arrow indicates direct transfer of results as an input/output. Dashed arrow indicates use of results for calibration. GTEM does not take input from the agriculture model but does take input from the forestry model.
Source: Treasury.

While input assumptions are harmonised as much as possible across GTEM and MMRF, the projections in these models for Australia are not identical. The differences arise primarily from the different structures of the models, and these differences reflect the uncertainty surrounding modelling estimates.

The MMRF takes world market conditions as given. This means it does not determine endogenously the prices Australia faces in world markets, nor does it project the changes that may occur in demand for Australian exports. GTEM determines such prices and quantities, aggregated over all other regions. This requires care to ensure the world demand curve determined within GTEM is appropriately linked with MMRF.

GTEM also determines the global carbon price that achieves the desired environmental target. The global carbon price trajectory is used as input into the MMRF model for the period after the transition to flexible cap and trade scheme.

Table A3: Concordance of GTEM and MMRF

GTEM (sectors)	MMRF (commodities)
Livestock	Sheep and beef cattle, dairy cattle and other animals
Crops	Grains, biofuels, other agriculture
Fishing and forestry	Agriculture services and fishing; and forestry
Coal mining	Coal mining
Oil mining	Oil mining
Gas mining	Gas mining
Other mining	3 commodities: Iron ore mining, non-ferrous ore mining and other mining
Food	Meat and meat products Other food, beverages and tobacco
Manufacturing	Textiles, clothing, footwear and leather, wood products, paper products, printing, publishing and recorded media, metal products, motor vehicles and other manufacturing
Petroleum and coal products	Gasoline, diesel, LPG, air fuel, other fuel.
Chemical, rubber and plastic products	2 commodities: Chemicals and rubber and plastic products
Non-metalic minerals	Non-metal construction products and cement
Iron and steel	Iron and steel
Non-ferrous metals	3 commodities: Alumina, aluminium and other non-ferrous metals
Electricity	Electricity generation (coal; gas; oil; hydro; other)
Services	15 commodities: Electricity supply, gas supply and water supply (3 commodities), construction, trade, accommodation, hotels, cafes and restaurants, communication, finance and insurance, property and business, dwelling, public, other and household consumption (3 commodities: electricity; heating; transport)
Other transport	Road (passenger; freight) and rail (passenger; freight)
Air transport	Air transport
Water transport	Water, pipeline and transport services

Source: Treasury from GTEM and MMRF.

Electricity generation sector

MMRF is linked with the electricity bottom-up modelling from SKM MMA and ROAM through a series of iterations. The demand for electricity is modelled in MMRF, with the SKM MMA and ROAM modelling providing the supply-side detail. MMRF electricity demand was provided to SKM MMA and ROAM, together with the carbon price. SKM MMA and ROAM then each projected the response of the electricity sector to meet that demand. This was integrated into MMRF by calibrating the technology shares, fuel efficiency, emission intensity of fuel use, wholesale price and retail price by industry. MMRF was re-run to generate new demand levels (one based on ROAM data and the other on SKM MMA) which were then re-supplied to the consultants. The iteration process continued until demand and supply broadly converged.

Road transport sector

The road transport sector of MMRF is linked with the bottom-up modelling from CSIRO. The demand for road transport is determined in MMRF, taking into account population growth, the projected output of industries and changes in the cost structure of road transport. With demand for road transport activities from MMRF as an input, demand for individual fuels and vehicle

types is determined using the ESM model. The outputs from ESM are then used as an input back into MMRF. The iteration process continued until demand and supply broadly converge.

Table A4: Inputs and outputs of the Energy Sector Model (ESM)

Inputs	Outputs
Carbon price	ESM provides projections of distance travelled (billion km), fuel used (PJ), and greenhouse gas emissions (Mt CO_2-e).
Transport demand (from MMRF)	ESM results are presented by state across the following categories:
Private transport	**Engine technologies**
Road passenger	Internal combustion engine
Road freight	Hybrid
Fuel prices	Plug-in hybrid
Treasury's oil, coal and gas price assumptions	Full electric
Electricity prices (from SKM MMA and ROAM)	Hydrogen fuel cell
Other exogenous assumptions	**Transport modes**
Fuel efficiency assumptions	Private passenger vehicles
Technology cost assumptions	Buses
Emission factors	Light commercial vehicles
Fuel and other vehicle operating costs	Articulated trucks and rigid trucks
Government transport policy settings	**Fuel types**
	Petrol
	Diesel
	Liquefied petroleum gas
	Biofuels (including biodiesel and ethanol blends)
	Electricity
	Natural gas and hydrogen
	Synthetic fuels (coal-to-liquid, gas-to-liquid)

Agriculture and forestry sectors

The agriculture and forestry sectors of MMRF are linked with the bottom-up modelling from ABARES. Agricultural output prices and land prices were obtained from MMRF and provided to ABARES, which then provided estimates for establishment rates of forestry plantations and associated changes in forestry sequestration. These estimates are incorporated into MMRF as exogenous inputs. GTEM incorporates GCOMAP calculations of the net change in emission stocks associated with land use change and forestry (Sathaye et.al 2006, 2008).

DCCEE modelled the abatement from livestock, crops, savannah fire management, avoided deforestation and managed regrowth, and legacy waste under the Carbon Farming Initiative (CFI). This abatement from the CFI was incorporated into MMRF by adjusting the emission factors of the appropriate industries and accounting for permit income flows.