

ANNEX A: MODELLING FRAMEWORK

A.1 INTRODUCTION

No single existing 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 focus on one or other of these dimensions — a particular sector (for example, electricity generation) in isolation from the broader national economy, or on the national economy but without a consistent global analysis. In contrast, this analysis uses a suite of models that together span global, national, sectoral and household scales, to simultaneously explore these four dimensions.

Treasury's climate change mitigation policy modelling includes three top-down, computable general equilibrium (CGE) models developed in Australia: Global Trade and Environment Model (GTEM); G-Cubed model; and the Monash Multi-regional Forecasting (MMRF) model. These CGE models are whole-of-economy models that capture the interactions between different sectors of the economy. GTEM and G-Cubed are models of the global economy; whereas, MMRF models the Australian economy with state and territory-level detail. The CGE models are complemented by a series of bottom-up sector-specific models for electricity generation, transport, land-use change and forestry (LUCF), with additional analysis for other industrial sectors.

This annex sets out the details of Treasury's modelling framework, including an overview of the CGE models and details on the sector-specific models.

A.2 GLOBAL/ECONOMY-WIDE MODELLING

A.2.1 GTEM model overview

GTEM is a recursively dynamic general equilibrium model developed by ABARE to address policy issues with long-term global dimensions, such as climate change mitigation costs. It is derived from the MEGABARE model and the static GTAP model (Pant, 2007; Hertel, 1997; ABARE, 1996). The dimension of GTEM used in this report represents the global economy through 13 regions (including Australia, the United States, China and India) each with 19 industry sectors (Table A.1) and a representative household (for society). The regions are linked by trade and investment. Government policies are represented by a range of taxes and subsidies. The model also disaggregates three energy-intensive sectors into specific technologies: electricity generation, transport, and iron and steel. Some modifications have been made as part of the Treasury modelling program.

Key characteristics of GTEM

Regional households receive the region's gross national income and allocate it (in fixed proportion) to private and public consumption, and savings. Because of this feature and the learning and resource depletion effects, GTEM belongs to the class of Solow-Swan type growth models with endogenous sector-specific technical change. A limitation of the fixed savings rate assumption could be that the true cost of mitigation policy may be underestimated. For example, if an emission price reduces the rate of return on capital, this could reduce global savings and hence global investments, which in turn, could lower global GDP through reduced productive capacity. This limitation has been traded off against the need for simplicity in parameterisation and tractability of the model.

Household demand for private consumption goods responds to changes in income and relative prices. Household consumption behaviour is modelled by using a constant difference in elasticity of substitution function. This function has the property that the price and income elasticity of demand depend on the budget share and are, therefore variable, over time. Public consumption expenditure is allocated to commodities by maximizing a Cobb-Douglas utility function.

GTEM sectors produce output by employing four factors of production: land; labour; capital; and natural resources and material inputs. Labour and capital are perfectly mobile across sectors. Land is sluggishly mobile between agricultural and forestry sectors, in response to higher rental returns. Natural resources are used by the mining and forestry and fishing sectors. Capital accumulates by net investment and takes a year to install. Land supply is fixed. Supply of labour in the present application is exogenously given, and an unlimited supply of natural resources is available at a constant real price. These assumptions, together with the inter-factor substitutability, allow sectors to adjust instantaneously in response to changes in relative prices.

Three key energy-intensive sectors that employ multiple technologies to produce output are identified. These sectors are defined as technology bundle sectors, and include electricity generation, transport, and iron and steel. The sectors use the output of the respective technology bundle, and other commodities, in fixed proportions to distribute to the users. For example, various technologies generate electricity, which is used by the electricity sector with other inputs (proxy for transmission system), then it is distributed to end users. Technology bundles are modelled to make sure that only technically feasible combinations of inputs are used. As a default, input substitutions within a technology are not allowed — each technology uses its inputs in fixed proportions — while substitution between technologies is allowed. Outputs from each of the technologies are chosen to minimise the cost of producing a CRESH (constant ratio of elasticities of substitution, homothetic) aggregate of the outputs of all technologies.

GTEM models the demand and supply of electricity in Australia and the other GTEM regions, with a set of 12 established and emerging technologies (Table A.1). GTEM does not distinguish between peak and base-load electricity demand.

For non-technology bundle industries, several layers of substitution are possible. These industries can substitute between four energy commodities to produce an energy composite. This energy composite is then combined with a primary factor composite. At the final level, this energy-factor composite is combined with other intermediate inputs in fixed proportions to produce a single good. The inter-fuel and inter-factor substitutions and substitution between fuels and primary factors occur via a nested CES (constant elasticity of substitution) approach.

Mining sectors are subject to increasing costs, via an endogenous fall in labour and capital efficiency, as the cumulative level of extraction rises. This captures, in a stylised way, the resource depletion effect and causes prices of mining products, in particular fossil fuels, to rise over time.

A sophisticated handling of transport and electricity technologies, with endogenous productivity growth via learning by doing, a detailed technology portfolio including a suite of zero or near zero-emission technologies, and substitution across technologies, allows electricity generation and the transport sector to be gradually emission free, if market incentives are right. Parameters for the learning-by-doing functions are in Annex B.

Industries in GTEM alter their use of energy and other emission sources in response to relative price changes. Hence, the energy use by households and industries could be emissions free if they switch fully to electricity (and hydrogen) generated by zero-emission technologies.

Substitution between non-energy intermediate inputs in response to relative prices is not possible. GTEM, however, has a mechanism to model sector and input biased productivity changes that are consistent with a single region-wide input and sector-neutral productivity growth. GTEM uses this process to stylise the possible dematerialisation process that may take place, but it is not sensitive to policy changes. GTEM also allows improvements in energy efficiency via the biased allocation of the region-specific exogenous productivity growth over all inputs and sectors.

Fugitive emission response functions are incorporated into the model to enable mitigation of non-combustion emissions. Emission reductions from this source are assumed to be available to industry using the same production inputs. These functions proxy the reorganisation of existing production processes, or introduction of new technology, at the same cost as existing production. In that sense, there is no additional cost for these technologies. This feature of the model is explored in the sensitivity analysis.

Net emissions from land-use change and forestry are exogenously linked to GTEM. The implied assumption, therefore, is that forestry sequestration is possible without a call on factor inputs. This assumption results in an underestimation of mitigation cost, but the effect is expected to be modest as conservative assumptions have been used for land availability. The impact would be greatest in Indonesia, Other Asia and the Rest of World. The implications of having no forestry sinks are explored in the sensitivity analysis.

GTEM, like many other CGE models, maintains that all markets everywhere clear each year. As investment is not equal to capital depreciation and investments are not necessarily equal to savings in each region, capital accumulation and debt accumulation may continue year after year. Hence, the maintained equilibrium is not necessarily a steady-state equilibrium. Because of these features the model may display a dynamic momentum, provided the initial database is not in steady state. It is a suitable approach to analyse medium to long-term responses to an exogenous shock.

Most parameter values and the social accounting matrix (SAM) of GTEM currently are based on GTAP's version 6 database, with a base year of 2001 (Dimarannan, 2006). The emission database was developed at ABARE and contains estimates of six anthropogenic greenhouse gases — combustion and non-combustion carbon dioxide, methane, nitrous oxide, HFCs, PFCs and SF₆; all Kyoto gasses. Calibrations of additional GTEM specific parameters are described in Annex B.

Table A.1: Regions and sectors of GTEM

Regions	Industry sectors
Australia	Coal mining
United States	Oil mining
European Union	Gas mining
Japan	Petroleum and coal products
China	Electricity (with 12 technologies: coal, petroleum and coal products, gas, nuclear, hydro, wind, solar, biomass, waste, other renewables, coal CCS and gas CCS)
India	
Indonesia	Iron and steel (2 technologies, electric arc and blast furnace)
Other South and East Asia	Non-ferrous metals
Russia + CIS (a)	Chemical, rubber and plastic products
OPEC	Other mining
Canada	Non-metallic minerals
South Africa	Manufacturing
Rest of world	Air transport
	Water transport
	Other transport (5 technologies: non-road (rail), internal combustion engine, advanced internal combustion engine, hybrids and non-fossil fuel vehicles)
	Crops
	Livestock
	Fishing and forestry
	Food
	Services

(a) Commonwealth of independent states.
Source: GTEM.

The relatively high-level industry (commodity) aggregation could limit the degree of substitutions between commodities. This implies GTEM could not represent a decline in emission intensity in a sector (or commodity) due to compositional changes (with the exception of the three technology bundle industries). To the extent that this happens, emission projections from GTEM with such aggregations will be biased upwards. However, the calibration of the fugitive emission response functions takes some account of this factor. Such aggregation biases are unavoidable, given the computing and database limitations. The chosen aggregation reflects these tradeoffs.

All markets, including foreign exchange markets, are assumed to be in equilibrium in 2001. To the extent this assumption does not hold (financial turmoil was considerable in 2001), some exchange rates, such as Australia and the former Soviet Union (FSU), may be undervalued relative to the US dollar. This tends to result in higher emission intensity per dollar value of output when values are expressed in US dollars. This may overestimate these countries' loss of competitiveness following an emission price change. This effect moderates over time, as the Australian dollar appreciates against the US dollar. The implication of this assumption is greater for distribution costs across countries rather than aggregate mitigation costs.

Changes to the GTEM model

GTEM has been modified in three different levels — the structural level, the parametric level and the database level, to represent and simulate the policy scenarios presented in this report (Pant, 2007).

Structural changes

Modifications of GTEM at the structural level involve changes made in the investment demand function, the introduction of instruments to shield the emission-intensive and trade-exposed sectors (EITES) for a defined period at defined rates, and introduction of technology-bundle approach to modelling the other transport sector (land transport).

The investment demand function has been made sensitive to regional exposure to foreign debt. As regional debt rises, the risk premium rises, leading to a reduction in foreign investment. This in turn decreases the difference between investment and savings, so the rate of debt accumulation falls over the long term, relative to the case in which investments do not respond to changes in a regions debt exposure. This modification prevents uncontrolled escalation of foreign debt and better represents real-world risk adjustments in globalised investment markets over long timeframes.

An equation has been added in GTEM to represent the shielding framework for EITES, as outlined in the *Carbon Pollution Reduction Scheme Green Paper* (DCC, 2008). All of these sectors are shielded from the emission price on direct emissions, and from electricity price rises relative to the reference case from 2011-2025, except for the agriculture sectors, which are exempt until 2015 and shielded to 2025. To model this, direct emission intensities and electricity intensities of the outputs of GTEM sectors in 2007 have been applied for all future years to estimate the exposure of the EITES to the emission price. To estimate the applicable shielding rates, the share of the shielded sector, which could be a component, of the sectoral output, has been estimated for each GTEM sector, then the prescribed shielding rates have been multiplied by these shares. The shielding of EITES has been implemented by paying a production subsidy equal to the product of the declining shielding rate and the sum of the emission price on direct emissions and the increase in the cost of electricity relative to the reference case. To model the coverage, a binary coefficient has been used for each sector and region, which is assigned a value of unity if the sector is covered, and zero otherwise.

The technology bundle approach of GTEM has been extended to include the ‘other transport’ sector. Other transport is divided into non-road (which includes rail and pipelines) and four broad types of road vehicle technologies — conventional internal combustion engines, advanced internal combustion/partial hybrid engines, full hybrid vehicles and non-fossil fuel energy vehicles (such as fuel cell, electric or solar vehicles). Each production technique is represented by a Leontief production function, with capital and fuel inputs applied in fixed proportions. To achieve a given level of industry output, outputs from each production technology are chosen to minimise the aggregated production costs over all the techniques — using a CRESH aggregator function.

Endogenous technological change is modelled in emerging electricity and transport technologies via learning functions. The learning function on low emission technologies in the transport and electricity sectors is modelled so that technology costs decline in response to the global uptake of a technology.

Parametric changes

Mechanisms placed in GTEM endogenously change various elasticities of substitution to better represent the behaviour of infant technologies in the short term, and provide a the more mature technologies with a more elastic response in the longer term. To do this, the value of the CRESH parameter associated with each technology is linked with the inverse of its market share (or a

large number such as 50) if the share is very small and the value of the parameter gradually declines as its market share increases over time: the smaller the market share of each technology, the higher the CRESH parameter and the higher the implied elasticity of substitution. This function is to capture the initial responses of infant technologies to given relative price changes. Once the technology matures, the price responsiveness falls. The functional form also produces higher elasticity of substitution parameters than previously used, even for mature technologies, to reflect their long-term flexibility. From 2001-2020, however, the elasticity parameters for each given technology share are scaled down to reflect stickiness in the short-term.

The fuel substitution parameter applied in the residential sector and across non-technology bundle industries changes over time. The parameter size (and therefore the responsiveness of fuel substitution to price changes) increases over time to reflect the long-term development of technologies that enables alternative fuels to be used, provided they are cost effective.

Emission response functions were parameterised in light of consultations with industry and Treasury's own research, including a global literature review, and to broadly represent intra-sectoral substitution opportunities. Similarly, learning functions were parameterised for the electricity and transport technology bundles, with different values for different technologies to reflect their potential for learning-related cost reductions.

The base year values of the elasticity of substitution between primary factors were adjusted so that the value-added share weighted sum of these parameters across sectors is unity in each region. This adjustment keeps the aggregate factor shares in regional value added stable over the longer term.

The base parameters of the household demand system were adjusted so that all cross-price elasticities of demand are positive and own price elasticities are negative. The parameters governing the income elasticity were adjusted so that in the long-term, developing countries did not have unrealistic consumption shares of necessities given that their per capita incomes are assumed to be much higher.

Database changes

Some database adjustments improved the performance of the model. The cost share of primary factors in the total cost of iron and steel, non-ferrous metals, chemicals rubber and plastics, other mining, non-metallic minerals, manufacturing, livestock and food sectors of former Soviet Union were unusually low in the initial database. The wage costs were increased for these sectors as shown in Table A.2. This increased the value of output of these sectors, and to maintain the balance in the SAM, the private household expenditure on these commodities was raised by the same amount. This led to an increase in the GDP of the former Soviet Union region by about \$50 billion at 2001.

Table A.2: Database change: increase in wage bill for former Soviet Union

Sectors	\$US billion at 2001 prices
Iron and steel	3.4
Non-ferrous metals	2.6
Chemical, rubber and plastic products	6.8
Other mining	0.4
Non-metal mining	4.1
Manufacturing	13.9
Livestock	4.6
Food	13.6

Source: Treasury.

Similarly, the cost of capital input was increased by reducing the cost of labour and land in the crops sector of Indonesia and other Asian regions. The share of land in total costs in these regions was significantly higher than in other regions, and led to unusual price impacts under a mitigation scenario. The increase in capital cost is \$2 billion and \$6 billion respectively. The cost of capital in the livestock sector of Indonesia was raised by just under \$0.9 billion, offset by the adjusted cost of land. In all regions, to allow the modelling of land-use change, a small natural resources cost was reallocated as a land cost in the fishing and forestry sector.

In standard GTEM implementation, oil was considered as a fuel commodity and emissions were associated with oil use. This version adjusts the database so that oil is bought only by the petroleum and coal sector, and is a feed-stock which does not emit greenhouse gases. In short, oil has been removed from the set of fuel commodities and does not substitute with other fuels in response to price changes.

In the electricity technology bundle, capacity constraints were imposed on the wind and hydro technologies, and crops and forestry products were incorporated as feed-stock to biomass electricity generation.

A.2.2 G-Cubed model overview

G-Cubed models the global economy and is designed for climate change mitigation policy analysis.¹ An important characteristic of G-Cubed is that economic agents are partly forward-looking: they make decisions based not only on the present day economic situation, but also based on expectations of the future. G-Cubed has limited detail on technologies.

Modelling using the G-Cubed model was conducted in conjunction with the Centre for Applied Macroeconomics Analysis (CAMA) and the Treasury. A report from CAMA covering the joint modelling work is available on the Treasury website.

Key characteristics of G-Cubed

Economic agents are partly forward-looking: they make decisions based on the present economic situation, and expectations of the future.

Adjustment costs in capital are defined, so that structural adjustments take time to occur and impose greater costs on the economy, relative to models that assume capital is perfectly mobile.

The labour market does not adjust instantly to new conditions, but adjusts slowly as the nominal wage rate responds.

The theoretical macroeconomic specifications allow for insights across a broad variable set, such as exchange rates, inflation rates and human wealth. For example, savings rates across countries and the global economy adjust in response to the endogenous supply and demand for savings.

Energy efficiency is captured at a high level as the amount of energy used in the production process responds dynamically to any change in relative prices.

¹ A technical description of the G-Cubed model is provided at McKibbin and Wilcoxon (1998) and at www.gcubed.com.

G-Cubed only allows limited technology detail. Technological change can be captured by adjustments to the amount of capital, labour and intermediate inputs that are required to produce a good. For example, the move to renewable technologies, such as wind and geothermal to produce electricity, can be captured by increasing the amount of capital and decreasing the need for fossil fuel input. No technology detail is specified exogenously; as the model finds the best mix of inputs, given the available prices and the starting point. However, the structure of G-Cubed does not easily allow for the production of energy from fossil fuels without emissions, although this could be approximated by changing emission coefficients or modifying of the production technology. An explicit technology for carbon capture and storage does not yet exist in the model.

Table A.3: Regions and sectors of G-Cubed

Regions	Industry sectors
Australia	Coal mining
United States	Crude oil and gas extraction
European Union	Gas utilities
Japan	Petroleum refining
China	Electric utilities
Rest of OECD	Mining
Former Soviet Union	Durable manufacturing
OPEC	Non-durable manufacturing
Other developing countries	Transportation
	Forestry and wood products
	Agriculture, fishing and hunting
	Services

Source: G-Cubed.

Changes made to the G-Cubed model

Changes to the standard G-Cubed model include: the addition of non-combustion emissions; a permit trading algorithm; adjustments for negative emissions; ability to model a mandatory renewable energy target; and the change to the model simulation starting year.

The addition of the non-combustion emissions to G-Cubed significantly enhances the model. The standard G-Cubed model incorporates emissions from combustion of fossil fuels only. With the addition of non-combustion CO₂, methane (CH₄) and nitrous oxide (N₂O), the model can better evaluate international climate change mitigation policy.

The permit trading algorithm is modelled as an outer loop of the model. The algorithm was used in the recent modelling by the IMF (International Monetary Fund, 2008). This algorithm takes the outputs of the model, calculates the permit trades, emissions and allocations, then creates a new shock file for the model with these adjusted permit trades. This loop is then run until the simulation converges.

In running simulations, Treasury has not used the normal reference case generation algorithm; instead, the 'cycle' mode of the model was activated for generating baselines. This mode allows Treasury to impose the reference scenario assumptions and ensure consistency with the GTEM reference scenario.

To model the CPRS, a number of small changes had to be made, including a lump-sum transfer from industry to allow for the modelling of shielding. An input tax on energy also was added to allow for the modelling of the mandatory Renewable Energy Target.

Due to the solution method and structure of G-Cubed, it is possible for sectors and regions to produce negative emission levels. This is not a desirable feature in the absence of a properly specified backstop technology, so an adjustment was implemented to take account of this.

The adjustment prevents negative emissions by stopping the growth of the emission price once zero emissions are reached. This adjustment is made on a sectoral level. Emissions from each individual sector are prevented from going negative. This adjustment is mainly intended to ensure that countries do not produce excessive negative emissions, then trade these for the emissions of other countries. Without the adjustment, other countries would not take on enough mitigation, and the country producing the negative emissions would have a wealth effect from the transfers.

The standard version of G-Cubed's database year is 2002; however, for the running of the simulations in this report, the database year was moved to 2006. This improves the jumping off point for the simulations.

G-Cubed has previously assumed 1.8 per cent as the long-term growth rate for labour productivity, which Treasury has modified to 1.5 per cent. This requires (for consistency) that the rate of time preference be modified from 2.2 to 2.5 per cent, to keep the underlying steady state real interest rate at 4 per cent.

A.2.3 MMRF model overview

The Monash Multi-Regional Forecasting (MMRF) model is a detailed model of the Australian economy developed by the Centre of Policy Studies (CoPS) at Monash University (Adams et al., 2008). MMRF has rich industry detail (with 58 industrial sectors) and provides results for all eight states and territories (Table A.4). It is also dynamic, employing recursive mechanisms to explain investment and sluggish adjustment in factor markets.

Modelling using the MMRF model was conducted in conjunction with CoPS and the Treasury. A report from CoPS covering the joint modelling with Treasury is available on the Treasury website.

Key characteristics of MMRF

MMRF determines regional supplies and demands of commodities through optimising behaviour of agents in competitive markets. Optimising behaviour also determines industry demands for labour and capital. Labour supply at the national level is determined by demographic factors, while national capital supply responds to rates of return. Labour and capital can cross regional borders so that each region's stock of productive resources reflects regional employment opportunities and relative rates of return.

The assumption of competitive markets implies equality between the basic price and marginal cost in each regional sector. Demand is assumed to equal supply in all markets other than the labour 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 prices received by producers — the basic price of the good or service. The

model recognises margin commodities (for example, retail trade and road transport freight) which are required for each market transaction (the movement of a commodity from the producer to the purchaser). The costs of the margins are included in purchasers' prices but not in basic prices of goods and services.

MMRF recognises two broad categories of inputs: intermediate inputs and primary factors. Firms in each regional sector are assumed to choose the mix of inputs which minimises the costs of production for their level of output. They are constrained in their choice of inputs by a three-level nested production technology. At the first level, intermediate-input bundles, primary-factor bundles and other costs are used in fixed proportions to output. These bundles are formed at the second level. Intermediate-input bundles are combinations of international imported goods and domestic goods. The primary-factor bundle is a combination of labour, capital and land. At the third level, inputs of domestic goods are formed as combinations of goods from each of the eight regions, and the input of labour is formed as a combination of inputs of labour from the nine different occupational categories.

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

Capital creators for each regional sector combine inputs to form units of capital. In choosing these inputs, they cost minimise, subject to technologies similar to that used for current production; the only difference is that they do not use primary factors. The use of primary factors in capital creation is implicitly recognised in the commodities used in capital creation.

MMRF adopts the ORANI specification of foreign demand. Each export-oriented sector in each state faces its own downward-sloping foreign demand curve. Thus, a shock that improves the price competitiveness of an export sector will result in increased export volume, but at a lower world price. By assuming that the foreign demand schedules are specific to product and region of production, the model allows for differential movements in world prices across domestic regions.

The latest version of MMRF incorporates a post-goods and services tax (GST) and contains a detailed treatment of government finances. The government finance module is based, wherever possible, on the structure adopted for the ABS Government Financial Statistics (Australian Bureau of Statistics, 2007). The module has three broad components:

- all of the main items of income for each jurisdiction, including income taxes, taxes on goods and services and taxes on factor inputs;
- all of the main items of expenditure for each jurisdiction, including gross operating expenses, personal benefit payments and grant expenses (which are both an item of expenditure for the federal government and items of income for each of the regional governments); and
- drawing together the changes in government revenue and government expenditure to report the net operating balance and the net lending or borrowing balance for each jurisdiction.

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 state/territory q accumulates according to a standard accumulation relationship, with an allowance for depreciation. In MMRF, investors only take account of current rentals and asset prices when forming current expectations about rates of return (static expectations). Investment depends on expected rates of return relative to rates of interest; domestic savings is determined as a fixed share of household disposable income and the Government's budget position.

National labour market

For this report, the national real wage rate in MMRF is assumed to adjust over time to any policy shock, so that in aggregate, employment remains broadly unchanged. The adjustment is assumed to take about ten years.

Special features for greenhouse policy analysis

MMRF includes:

- an energy and gas emission accounting module, which accounts explicitly for each industry and region recognised in the model;
- equations that allow for inter-fuel substitution in electricity generation by region; and
- mechanisms that allow for the endogenous take-up of mitigation measures in response to greenhouse policy measures.

MMRF tracks emissions of greenhouse gases at a detailed level. It breaks down emissions according to:

- emitting agent (the number of industries plus residential);
- emitting state or territory; and
- emitting activity.

The emitting activities are the burning of fuels (coal, natural gas or petroleum products). MMRF generally models non-combustion emissions as directly proportional to the output of the related industries.

MMRF contains a representation of the operations of the NEM. The NEM covers electricity supply in the NEM-regions: NSW, Victoria, Queensland, South Australia, Tasmania and the ACT. Final demand for electricity in each NEM region continues to be determined within the CGE-core of the model in the same manner as demand for all other goods and services. All of the electricity used in NEM-region r is purchased from the electricity supply industry in that region. Each NEM-supplier sources its electricity from the NEM. The NEM does not have a regional dimension: in effect it is a single industry that sells a single product (electricity) to each NEM-supplier. The NEM sources its electricity from generation industries in each NEM region. Thus, the electricity sold by the NEM to the electricity supplier in Queensland may be sourced from hydro generation in Tasmania. NEM demand for electricity generation is price-sensitive. Thus if the price of hydro generation from Tasmania rises relative to the price of gas generation

from NSW, then NEM demand for generation will shift towards NSW gas generation and away from Tasmania hydro generation.

The explicit modelling of the NEM enables substitution between NEM regions and between different fuel types. It also allows explicitly for inter-state 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 continues to be determined on a state-of-location basis.

Changes made to MMRF

A number of modifications have been made to the model outlined above (Adams et al., 2008).

First, the industry structure of the model was reconfigured. In particular:

- the commodity petroleum and coal products was split into five commodities — petrol, diesel, LPG, aviation fuel (aviation turbine fuel and aviation gasoline) and all other coal products — produced by the petroleum and coal products industry to enable more accurate measurement of transport emissions within the MMRF model;
- the industry and commodity livestock was split into high-emission livestock (sheep and beef), low-emission livestock (chicken and pork) and dairy cattle;
- the pipeline transport industry was combined with the water and transport services industries and commodities; and
- biofuels was modelled as an output of the agriculture cropping industries.

Additional substitution possibilities were incorporated into the model to allow for additional economic responses to emission pricing. In particular:

- the meat and meat products industry was modified to allow it to enable price-based substitution between high- and low-emission livestock;
- a fuel bundle was introduced into household demand for private transport services to enable price-based substitution between petrol, diesel, LPG, biofuels and electricity; and
- technology bundles were introduced into the household demand for private transport services, corresponding to petrol vehicles, diesel vehicles, hybrid vehicles and electric vehicles, to enable price-based substitution between these vehicle types.

Table A.4: Sectoral aggregation in MMRF

Category	Sectors
Agriculture, forestry and fishing	Sheep and beef cattle Dairy cattle Other animals 2 sectors: Agriculture services and fishing, forestry 2 sectors: Grains, other agriculture
Mining	Coal mining Oil mining Gas mining 3 sectors: Iron ore mining, non-ferrous ore mining and other mining
Manufacturing	Meat products Other food, beverages tobacco Textiles, clothing, 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 Non-ferrous metals: alumina, aluminium and other non-ferrous Other manufacturing: metal products, motor vehicles and other manufacturing
Utilities	Electricity generation (6 sectors: coal; gas; oil; nuclear; hydro; other) 3 sectors: Electricity supply, gas supply and water supply
Services	Construction services Trade services Accommodation, hotels, cafes and restaurants Communication services Finance and insurance services Property and business services Dwelling services Public services Other services
Transport	Road transport (2 sectors: passenger; freight) Rail transport (2 sectors: passenger; freight) Water, pipeline and transport services Air transport
Households(a)	Household consumption (3 sectors: electricity services; heating services; transport services).

(a) Sectors are named 'Private transport', 'Private heating' and 'Private electrical' in the MMRF model. They relate to the provision of services from the private stocks of motor vehicles, electrical equipment (not heating) and heating equipment only.

Source: MMRF.

Three dummy industries were also created in MMRF: for private transport services; private heating services; and private electronic equipment services. These dummy industries enable households to treat the energy sources and underlying capital equipment for these services as complements, rather than as substitutes, as is the case in the standard model.

- Modifications to the MMRF emissions database were also undertaken. In particular the input-output tables were updated to the year 2005-06, and the emissions data bases aligned as closely as possible with the latest available emissions data, which is currently for 2005.

The model was also modified to allow it to capture the design features outlined in the *Carbon Pollution Reduction Scheme Green Paper*, in particular, the fuel tax adjustment and EITES shielding arrangements (DCC, 2008).

Marginal abatement cost (MAC) curves were also added to MMRF to capture the response of both fugitive and industrial process emissions in response to emission pricing. The set of industries covered by the MAC curves was expanded from those used previously in MMRF, and the parameterisation of these curves was adjusted. These are discussed in more detail in section B.8.7.

A.3 SECTOR SPECIFIC MODELLING

The CGE models are complemented by a series of bottom-up sector-specific models for electricity generation, transport, land-use change and forestry (LUCF). Detailed analysis of these emission-intensive sectors is useful in understanding the economy's likely response to climate change mitigation policy, particularly over the short to medium term.

Detailed analysis which relies on current views about technology is generally less robust over the long-term, as technology and other mitigation opportunities become more uncertain. As a result, bottom-up modelling of the transport and electricity sectors is limited to 2050. However, technology plays a much smaller role in LUCF emissions, so analysis of this goes to 2100.

A.3.1 Electricity sector modelling

McLennan Magasanik Associates (MMA) provides detailed bottom-up modelling of the Australian electricity generation sector with projections of electricity generation by technology and by state, fuel use, new investments and retirements, and electricity prices.

MMA's models are highly detailed and aim to closely represent actual market conditions including strategic bidding behaviour by individual generators and price setting operations of the market. The models take account of the economic relationships between individual generating plants in the system, with each power plant divided into generating units, with each unit defined by its technical and cost profiles. MMA models retirement for each unit based on age, existing commitments by operators, fuel supply and profitability, with new investment determined based on expected prices, demand and the behaviour of competitors.

A range of fuels and technologies are incorporated, including black and brown coal, natural gas, renewables (including hydro, biomass, solar, wind) as well as new technologies, such as carbon

capture and storage, geothermal and wave. Electricity demand is modelled on an hourly and monthly basis, to capture the daily and seasonal fluctuations in energy use.

A report covering the modelling of the electricity sector is available on the Treasury website (McLennan Magasanik Associates, 2008).

A.3.2 Transport sector modelling

Australian transport sector modelling was conducted with CSIRO in conjunction with the Bureau of Infrastructure, Transport and Regional Economics (BITRE). CSIRO use a partial equilibrium model, the Energy Sector Model (ESM) of the Australian energy sector, which includes detailed transport sector representation (CSIRO, 2008). The ESM was co-developed by CSIRO and ABARE in 2006. The model has an economic decision-making framework based around the cost of alternative fuels and vehicles. It incorporates detailed information about technical fuel and vehicle technical characterisation.

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, and lead times in the availability of new vehicles or plant.

Consumers (both individuals and firms) are assumed to minimise the cost of carrying out a given transport task, 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 for this project, the average vehicle size was assumed to decrease with increases in fuel costs. The availability of alternative technologies also depends, exogenously, on prices. The ESM supply-side exogenous assumptions are largely based on CSIRO's most recent research in conjunction with other major stakeholders (CSIRO, 2008).

A joint report from the BITRE and CSIRO covering details of the transportation sector modelling is available on the Treasury website.

A.3.3 Land use, land-use change and forestry

The Treasury commissioned modelling of the forestry sector from ABARE (for Australia) and from Lawrence Berkeley National Laboratory (for the rest of the world).

ABARE's modelling examines the impact of an emission price on land-use change in the Australian agriculture sector (ABARE, 2008). The framework used is spatially explicit, and involves analysing the opportunities for emission sequestration provided by LUCF on cleared agricultural land. These opportunities are determined when the net present value of returns from forestry investments are compared to the corresponding expected agricultural land value to estimate the potential area of clear agricultural land that is competitive for forestry within each spatial grid cell.

The Lawrence Berkeley National Laboratory use their GCOMAP model (Sathaye et al., 2005). GCOMAP simulates how forest land users respond to changes in prices in forest land and products, and to emission prices.

A report from ABARE covering details of Australia's forestry sector modelling is available on the Treasury website.

A.3.4 Other sectors

While other sectors were not specifically modelled they were analysed in both the reference and policy scenarios. Annex B outlines details of assumptions made on energy efficiency for specific sectors in the reference scenario. Also outlined in Annex B are assumptions made in the policy scenario for emission intensity reductions through marginal abatement cost (MAC) curves for fugitive and industrial process emissions.

A.4 PRICE REVENUE INCIDENCE SIMULATION MODEL (PRISMOD)

Modelling of the impact of the emission prices on households and the consumer price index was undertaken with Treasury's Price Revenue Incidence Simulation Model (PRISMOD). PRISMOD is a large-scale, highly disaggregated model of the Australian economy which captures the flows of goods between industries and final consumers. The data used in PRISMOD comprises the transactions and consumption patterns of 109 industry categories and seven categories of final demand. The 2008 version of the PRISMOD is based on data from the 2004-05 Input-Output Tables (ABS, 2008).

Key characteristics of PRISMOD include:

- the 2008 version of the model is based on 2004-05 input-output tables supplied by the ABS (ABS, 2008);
- 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 on;
- quantities are held fixed: only price impacts are modelled. That is, businesses are assumed to 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 imposition of an emission price will be passed through fully to domestic consumers and exports in the form of higher prices; and
- the model does not provide information as to the timing of price changes. All of the price impacts calculated by the model are 'long term in nature.

A.5 PRICE REVENUE INCIDENCE SIMULATION MODEL — DISTRIBUTION (PRISMOD.DIST)

The distributional implication for households of emission pricing was 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.

A.5.1 Key characteristics of PRISMOD.DIST

- The 2008 version of the model is based on data from the 2003-04 Household Expenditure survey (HES) (ABS, 2005).
- The HES data has been up-rated to 2007-08 using actual CPI item price movements. The totals for a variety of expenditure baskets are then projected to 2010-11 using CPI forecasts and projections.
- The HES data has been 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 the NATSEM's STINMOD model has been used to re-weight the HES data for projected demographic changes.²
- The income and household type variables are also taken from STINMOD.

A.6 AN INTEGRATED MODELLING FRAMEWORK

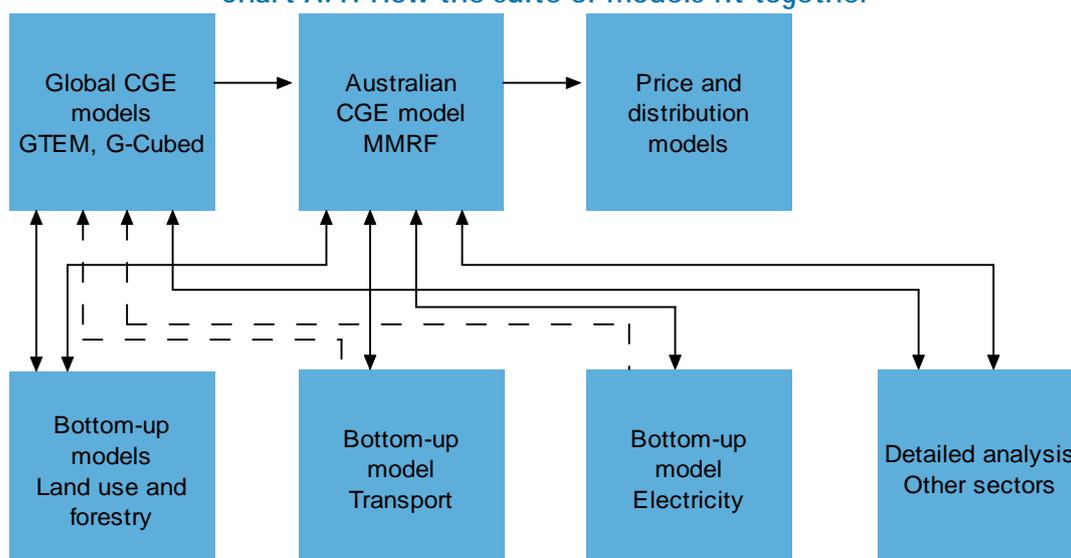
The results from each of these models are drawn together into an integrated set of projections that are broadly consistent at the macroeconomic level and sufficiently detailed in large emission-intensive sectors (Chart A.1).

Modelling of the global economy with GTEM and global land-use change and forestry with GCOMAP 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 the electricity, transport and land-use sectors. G-Cubed is broadly calibrated to the GTEM reference scenario, and provides comparative cost estimates for the policy scenarios, strongly emphasising the macroeconomic adjustment process.

Linking economic models with different economic structures is not straight forward. The report team undertook significant research to ensure the suite of models were linked sensibly.

² 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.

Chart A.1: 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.

Using a suite of models provides a natural hedge against the inherent uncertainty of economic modelling. While input assumptions have been harmonised as much as possible across GTEM, G-Cubed and MMRF, the projections in the three models generated for Australia are not identical. The differences arise primarily from the different structures of the models, and these differences demonstrate the uncertainty surrounding modelling estimates.

To ensure that this report remains tractable, most Australian results are, in the first instance, from MMRF. However, where the Australian results determined in the global models differ significantly, or provide additional insights, these are provided for comparison. Similarly, the global results — including Australia as a region of the world — are from GTEM, with comparative analysis from G-Cubed. Where the bottom-up models provide insights, these results are given primacy.

Since MMRF is a multi-sectoral general equilibrium model of Australia, it takes world market conditions as given. This means that it does not determine endogenously the prices Australia faces in the world market, nor does it project the changes that may occur in demand for Australian exports. GTEM determines such prices and quantities, which are aggregated over all other regions using ‘free on board’ and ‘cost insurance freight’ value shares as weights. This required careful linking to ensure that the world demand curve determined within GTEM was inputted into MMRF in an appropriate way (Table A.5).

A partial-equilibrium representation of the export demand function faced by Australia for each GTEM commodity was derived. Responsiveness of the export demand to world price changes were estimated using GTEM parameters assuming that the rest of the world does not respond to supply-side changes that occurred in Australia. As the world economy responds to a given shock, such as the imposition of an emission price, the export demand faced by Australia shifts. A consistent measure of the shift in the export demand functions was derived and use as input into the MMRF model.

Table A.5: Concordance of GTEM and MMRF sectors

GTEM sector (19 sectors)	MMRF sector (58 sectors)
Livestock	Sheep and beef cattle Dairy cattle Other animals
Crops	3 sectors: Grains, other agriculture
Fishing and forestry	2 sectors: Agriculture services and fishing and forestry
Coal mining	Coal mining
Oil mining	Oil mining
Gas mining	Gas mining
Other mining	3 sectors: 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, pulp and paper products Printing, publishing and recorded media Metal products Motor vehicles Other manufacturing
Petroleum and coal products	Refinery (including petroleum and coal products)
Chemical, rubber and plastic products	2 sectors: Chemicals and rubber and plastic products
Non-metallic minerals	Non-metal construction products Cement
Iron and steel	Iron and steel
Non-ferrous metals	3 sectors: Alumina, aluminium and other non-ferrous
Electricity	Electricity generation (6 sectors: coal; gas; oil; nuclear; hydro; other)
Services	3 sectors: Electricity supply, gas supply and water supply Construction services Trade services Accommodation, hotels, cafes and restaurants Communication services Finance and insurance services Property and business services Dwelling services Public services Other services Household consumption (3 sectors: electricity; heating; transport)
Other transport	Road transport (2 sectors: passenger; freight) Rail transport (2 sectors: passenger; freight)
Air transport	Air transport
Water transport	Water, pipeline and transport services

Source: Treasury from GTEM and MMRF.

GTEM also determines the global emission price that clears the global permit market. The equilibrium permit price trajectory was used as input into the MMRF model.

To ensure bottom-up electricity (and transport) supply-side information was correctly integrated within MMRF often required several iterations. Some models were relatively easy to link, as they took outputs from one model to provide additional detail. For example, PRISM0D was used to determine a highly disaggregated set of industry price impacts from a certain emission price. This information then was fed into PRISM0D.DIST which captured the distributional implications for households.

A.6.1 Electricity generation sector

MMRF was linked with the electricity bottom-up modelling commissioned from MMA. The demand for electricity was modelled in MMRF, with the MMA modelling providing the supply-side detail. MMRF also can model the supply of electricity (electricity generation is a 'technology bundle' industry in MMRF, with six aggregated technologies — coal, gas, oil, nuclear, hydro and non-hydro renewables); however, given the importance of the sector to understanding the Australian mitigation response, more detailed modelling was provided by MMA.

To marry MMRF modelling of the demand for electricity with the MMA modelling of the supply of electricity required a process of iteration. MMRF electricity demand was provided to MMA, together with the emission price. MMA then determined the response of the electricity sector to meet that demand. The MMA modelling then was integrated into MMRF by calibrating the technology shares, fuel efficiency, emission intensity of fuel use and wholesale price (with retail prices determined in MMRF). The new MMRF simulation then was re-run to generate a new level of demand, which was re-supplied to MMA. This process of iteration continued until there convergence between demand and supply.

MMRF electricity demand was divided by MMA into grid and off-grid and modulated into base-load, intermediate and peak demand. NEMCO assumptions for the peak-to-average demand ratio were used until 2018. These trends then were extrapolated until 2025, then the ratio was held constant at the level reached in 2025 for the remainder of the projection period. This assumption has implications for investment in the sector and the technology shares, with gas-fired generation typically more suitable than coal for generating peak demand.

A.6.2 Transport sector

The transportation sector of MMRF was linked with the bottom-up modelling commissioned from the CSIRO and BITRE. The demand for transport was determined jointly between MMRF and the BITRE's suite of transport demand models. With demand for road transport activities from the MMRF as an input, demand for individual fuels and vehicle types was determined using the bottom-up ESM model. The outputs from the ESM were used as input back into the MMRF model. An iterative feedback mechanism linked the MMRF and ESM models to ensure consistency of results. The ESM input and outputs are listed in Table A.6.

A.6.3 Land-use and forestry sector

The forestry sector of MMRF was linked with the bottom-up modelling commissioned from ABARE. Agricultural output prices and land prices were obtained from MMRF and were provided to ABARE, which then provided estimates for establishment rates of forestry plantations and the associated change in forestry sequestration. These estimates were incorporated into MMRF as exogenous inputs.

The global and regional emission price paths obtained from GTEM were provided to the GCOMAP model, which then provided estimates for the net change in emission stocks associated with land-use change and forestry. These then were incorporated into the world regions of GTEM and G-Cubed as exogenous inputs.

Table A.6: Inputs and Outputs of the Energy Sector Model (ESM)

ESM inputs	ESM outputs
Emission price	Engine technology uptake by state
	Internal combustion engine
Transport demand (from MMRF)	Hybrid
Private transport demand	Plug-in hybrid
Road passenger (including buses and taxis)	Full electric
Freight demand (including road and rail)	Uptake by transport mode
Fuel prices	Passenger, bus
From Treasury's oil price assumption	Light commercial vehicle
Electricity prices (from MMRF linked with MMA's model)	Articulated truck and rigid truck
Other exogenous assumptions	Fuel consumption by fuel (and state)
Fuel efficiency assumptions	Petrol
Technology cost assumptions	Diesel (from oil, coal or gas)
Fuel availability assumptions	Liquefied petroleum gas
Emission factors	Biofuels (biodiesel and ethanol blends)
Fuel and other vehicle operating costs	Electricity
Policy settings (such as ethanol targets)	Natural gas and hydrogen
Share of light, medium and heavy passenger vehicles	Greenhouse gas emissions by state

Source: CSIRO, 2008.

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