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Philip Adams,

Janine Dixon,

Mark Horridge

Centre of Policy Studies, Victoria University

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Philip Adams, Janine Dixon and Mark Horridge
Centre of Policy Studies, Victoria University

with contributions from staff at the Productivity Commission.

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Abstract

The Victoria University Regional Model (VURM, formerly known as MMRF) is a dynamic model of Australia's six states and two territories. It models each region as an economy in its own right, with region-specific prices, region-specific consumers, region-specific industries, and so on.

Based on the model's current database, in each region 79 industries produce 83 commodities. Capital is industry and region specific. In each region, there is a single household and a regional government. There is also a Federal government. Finally, there are foreigners, whose behaviour is summarised by demand curves for international exports and supply curves for international imports.

In recursive-dynamic mode, VURM produces sequences of annual solutions connected by dynamic relationships such as physical capital accumulation. Policy analysis with VURM conducted in a dynamic setting involves the comparison of two alternative sequences of solutions, one generated without the policy change and the other with the policy change in place. The first sequence, called the base case projection, serves as a control path from which deviations are measured to assess the effects of the policy shock.

The model includes a number of satellite modules providing more detail on the models government finance accounts, household income accounts, population and demography, and energy and greenhouse gas emissions. Each of the 'satellite' modules is linked into other parts of the model, so that, projections from the model core can feed through into relevant parts of a module and changes in a module can feed back into the model core. The model also includes extensions to the core model theory dealing with links between demography and government consumption, the supply and interstate mobility of labour, and export supplies.

JEL classification: C68, D58, R13.

Keywords: CGE modelling, dynamics, regional economics.

Contents

1 Introduction

The Victoria University Regional Model (VURM) is a multi-regional Computable General Equilibrium (CGE) model of Australia's eight regional economies — the six States and two Territories.[1] Each region is modelled as an economy in its own right, with region-specific prices, region-specific consumers, region-specific industries, and so on. There are four types of agent: industries, households, governments and foreigners.

Based on the model's current database, in each region 79 industries produce 83 commodities. Capital is industry and region specific. In each region, there is a single household and a regional government. There is also a Federal government. Finally, there are foreigners, whose behaviour is summarised by demand curves for international exports and supply curves for international imports.

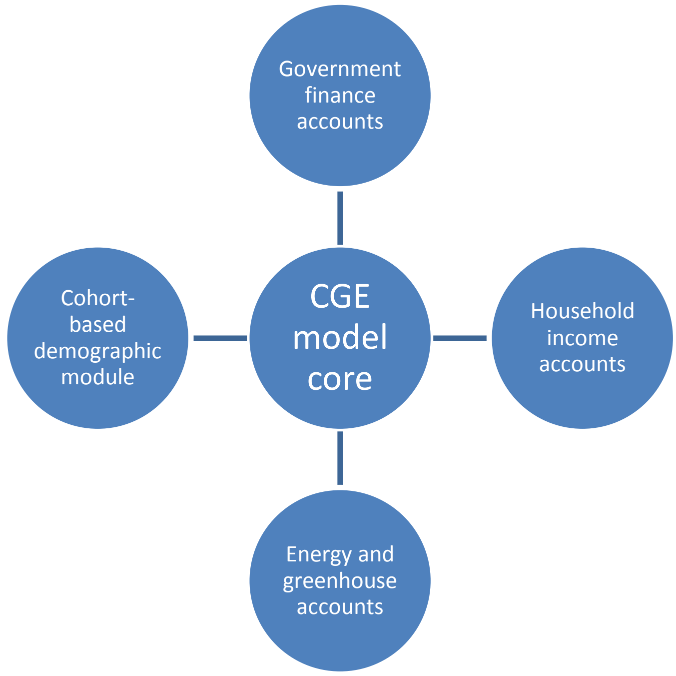
In recursive-dynamic mode, VURM produces sequences of annual solutions connected by dynamic relationships such as physical capital accumulation. Policy analysis with VURM conducted in a dynamic setting involves the comparison of two alternative sequences of solutions, one generated without the policy change and the other with the policy change in place. The first sequence, called the base case projection, serves as a control path from which deviations are measured to assess the effects of the policy shock.

Figure 1.1 outlines diagrammatically the structure of VURM. The model comprises: a CGE core incorporating input-output production and consumption relationships, foreign accounts and the modelling of product and factor markets; and a number of satellite modules providing more detail on the models government finance accounts, household income accounts, population and demography, and energy and greenhouse gas emissions.

Each of the 'satellite' modules is linked into other parts of the model, so that, projections from the model core can feed through into relevant parts of a module and changes in a module can feed back into the model core. The model also includes extensions to the core model theory dealing with links between demography and government consumption, the supply and interstate mobility of labour, and export supplies.

[1] This document uses the term 'region' to refer to states and territories and 'jurisdictions' to refer to the eight states and territories and the Australian Government (referred to as the Federal government).
VURM's origin lies with the Monash Multi Regional Forecasting (MMRF) model. MMRF has been used extensively across a wide range of applications. A good example is Adams and Parmenter (2013)

Figure 1.1 Broad the structure of VURM



The remainder of this document is organised as follows. In Chapter 2, we provide an overview of the model's theoretical structure. The formal description of the CGE model core is given in Chapter 3. This description is organised around the TABLO implementation of the model in GEMPACK.[2]

The next block of thematic chapters discusses the key modules. Each chapter provides additional detail on a particular topic.

- chapter 4 discusses the government finance module;
- chapter 5 details the household income module;
- chapter 6 describes the year-to-year dynamic simulation module;
- chapter 7 describes the cohort-based demographic module; and
- chapter 8 details the energy and greenhouse gas emissions modelling module.

Chapter 9 discusses the different modelling environments (model closures).

Appendix A contains an overview of the method used to solve the model. Appendix B contains an overview of the regional input-output data for 2009-10.

[2] GEMPACK is system for solving large economic models (see Harrison and Pearson, 1996). It automates the process of translating the model specification into a model solution program. As part of this automation, the GEMPACK user creates a text file listing the equations of the model in a language that resembles ordinary algebra. This text file is called the Tablo file.

2 Overview of the model

VURM represents an extension of the Monash Multi-Regional Forecasting (MMRF) model which, itself, is an extension of the Monash Multi-Regional (MMR) model. MMR is a comparative static CGE model of the six State and two Territory economies.[3] MMRF is MMR with many of the dynamic relationships from the MONASH model added to enable the effects of policy and other economic changes to be traced through time.[4] In later version of MMRF and in VURM, a range of developments have been included to enhance the model's capacity for fiscal, demographic, labour market and environmental analysis. In the sub-sections below, we give a brief overview of VUMR's structure, starting with the core equations, followed by additions covering dynamics, fiscal accounting, environmental variables and demography.

General equilibrium core

The nature of markets

VURM determines regional supplies and demands of commodities through optimizing behaviour of agents in competitive markets. Optimizing 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 in response to relative factor returns.

The assumption of competitive markets implies equality between the basic price (i.e., the price received by the producer) and marginal cost of production 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 the basic prices received by producers. The model recognizes margin commodities (e.g., wholesale and retail trade and road transport provided by other firms) which are required for the movement of commodities from producers to the purchasers. The costs of the margins are included in purchasers' prices of goods and services.

Demands for inputs to be used in the production of commodities

VURM recognizes two broad categories of inputs: intermediate inputs and primary factor inputs. Firms in each regional sector are assumed to choose the mix of inputs that minimize the cost of producing their 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 labour, capital and land. At the third level, inputs of domestic goods are formed as combinations of goods sourced from each of the eight

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[3] An initial progress report on the development of MMR is given in Meagher and Parmenter (1993).

[4] MONASH is a dynamic CGE model of the Australian economy built and maintained at the Centre of Policy Studies, Monash University. It is described in Dixon and Rimmer (2002).

[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 O*ther costs* accrues to the households.

domestic regions, and the input of labour is formed as a combination of inputs from eight occupational categories.

Domestic final demand: household, investment and government

In each region, the representative regional household buys bundles of goods to maximize a utility function subject to an aggregate expenditure constraint for the regional household. The bundles are combinations of imported and domestic goods, with domestic goods being combinations of goods from each domestic region. A consumption function is used to determine aggregate household expenditure as a function of household disposable income in the standard model.

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

Regional governments and the Federal government demand commodities from each region. In VURM, there are several ways of modelling government demands, including:

- by a rule such as moving government expenditures with one of 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; and
- through exogenous determination.

Some expenditure on commodities by households and governments will endogenously vary over time with the structure of the population and other demographic and economic factors. In VURM, it is possible to link changes in expenditures on particular commodities (such as health) to particular changes in the structure of the population.

Where expenditure on individual products is exogenously or endogenously determined, an appropriate rule needs to be applied to determine expenditure on other commodities for a given aggregate spending constraint.

Foreign demand (international exports)

VURM adopts the ORANI[6] specification of foreign demand. Each standard exporting sector in each region faces its own downward-sloping foreign demand curve. Thus, a shock that reduces the unit costs of an export sector will initially 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 model allows for differential movements in foreign-currency prices across domestic regions.

The standard treatment of export demand is augmented in VURM by a mechanism that allows the price of the exported product to differ from the price of the product with the same name produced for the local market. Such differences may arise due to existing contractual arrangements, availability (or lack thereof) of infrastructure and other factors that impede the rate at which supplies can be switched between domestic and export markets in response to relative price changes. The introduction of transformation between the domestic and export markets allows for the possibility of a price wedge between users and the returns to producers from domestic and

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

export sales, respectively, to differ. Over time, the revised treatment allows producers to change production decisions switching between domestic and export markets in order to equilibrate unit returns across markets**.**

Regional labour markets

The modelling of the labour market in VURM can be configured in different ways depending on what assumptions are made about regional labour supplies, regional unemployment rates and regional wage differentials.

Earlier applications of VURM variously involved setting:

- regional labour supplies and unemployment rates exogenous and determining regional wage differentials endogenously;
- regional wage differentials and regional unemployment rates exogenous and determining regional labour supplies endogenously (via interregional migration or changes in regional participation rates); and
- regional labour supplies and wage differentials exogenous and determining regional unemployment rates endogenously.

The second approach was adopted by CoPS to examine Australia's emissions trading scheme (Adams and Parmenter, 2013). Under this treatment, with regional participation rates exogenous, workers move freely (and instantaneously) across regional borders in response to changes in relative regional unemployment rates. With regional wage rates indexed to the national wage rate, regional employment is determined by demand.

The most recent application of VURM adopted a more flexible modelling of the *supply* of labour compared to earlier applications (PC, 2012). This involved:

- determining the national supply of labour by applying age, gender and region-specific labour force participation rates to the age and gender-specific level of the population;
- allowing the national supply of labour in each occupation group to adjust over time on the basis of changes in the relative real (after tax) wages; and
- allowing the supply of labour by occupation to move between regions on the basis of changes in the real (after tax) wage differentials for the occupational group, across regions.

The *demand* for regional employment by occupational group is modelled as varying in response to differences in real unit labour costs to employers across occupational groups.

Under this approach, changes in unit labour costs for each occupational group paid by industry are equal to the change in the real wage rate for that occupation received by workers plus any taxes paid by industry on those wages. The change (but not necessarily the level) of real wages is modelled as being the same across regions for each occupation. With regional unemployment and participation rates exogenous, workers move between regions and occupations on the basis of the relative competiveness of employers. With national population determined by demographic factors, the population and number of households in each region are assumed to change in line with regional employment. This approach is available in VURM.

Dynamic equations

Physical capital accumulation

In VURM dynamic equations, investment undertaken in one year is assumed to become operational at the start of next year. Under this assumption, capital in an industry and region accumulates according to:

- the quantity of capital available at the start of a year;
- the quantity of new capital created during the year; and
- the depreciation during the year.

Given a starting value for capital and with a mechanism for explaining investment, the VURM model traces out the time paths of each regional industries' productive capital stocks.

Following the approach taken in the MONASH model (Dixon and Rimmer, 2002, Section 16), investment in an one year is determined as increasing function of the ratio of the expected rate of return on investment to required rate of return. In standard closures of the model, the required rate of return is treated as an exogenous variable which can be moved to achieve a given growth rate in capital.

In VURM, 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 in VURM, allows investors to form expectations about rates of return that are consistent with model-determined present values of the rentals earned from productive activity (rational expectations).[7]

Lagged adjustment process in the national labour market

In all dynamic policy simulations, it is assumed that deviations in the national real wage rate from its base-case level would increase through time in inverse proportion to a deviation 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 to the unemployment rate are largely eliminated after about ten years. This is consistent with macroeconomic modelling in which the NAIRU is exogenous.

Given the second treatment of regional labour markets outlined above, 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 also rise (fall) by the same percentage amount, and regional employment adjusts immediately. Regional labour supplies adjust to stabilize relative regional unemployment rates.

If labour is assumed to vary between occupations, then occupation-specific real wage rates rise (fall) differentially with a uniform national change in the unemployment rate. The projected changes in occupation-specific real wages would depend on the impact of the change in the unemployment rate on the relative competiveness of industries and the industry by occupational composition of the workforce. The average real wage may vary between regions to the extent that the occupational composition of the workforce varies between regions.

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

Demography

VURM models changes in national and regional populations as arising from the three sources:

- net natural population increase in persons (that is, births less deaths);
- net foreign migration in persons (that is, immigration less emigration); and
- net interregional migration in persons (that is, interregional arrivals less interregional departures).

In VURM, values for each change can be specified outside the model, that is, they are treated as exogenous. Changes in population over time and its distribution between regions are therefore traced through successive updates to the model data base using exogenously specified population scenarios or shocks, expressed in persons.

The application of this method relies on demographic modelling outside of VURM and the application of shocks derived in such modelling to the corresponding demographic aggregates in VURM. Such an approach does not allow for feedback effects between the impacts of changes in the relative competitiveness of industries and the associated redistribution of economic activity between regions, and the distribution of the workforce (and the population more generally) across regions. It also does not allow for the integrated modelling of the impacts of demographic change on demand for government and other services (such as health services, other social services and support arrangements) and feedback effects on activity.

To enable the integrated modelling of economic and demographic changes, VURM includes a fully operational cohort-based demographic model. It uses a 'stock–flow' approach to calculate the population in each region by age and gender. Under this approach, births and deaths are modelled endogenously for individual cohorts of the population based on age, gender and region-of-residence. The conceptual approach used to model fertility and mortality is based on earlier spreadsheet-based models developed by the Productivity Commission (see for example Cuxon *et al.*, 2008). The VURM implementation differs from standalone demographic modelling in that it includes the additional functionality to allow for the endogenous modelling of population movements between jurisdictions due to changes in the relative competiveness of regional industries.

Detailed fiscal accounting

The government finance module is based, as far as practicable, on the structure adopted in the ABS *Government Financial Statistics* (GFS, Cat. no. 5512.0). For each jurisdiction, the module has three broad components:

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

Items in the government finance module overlap with items in the CGE core. For example, indirect taxes — such as taxes on commodity sales and taxes on the use of primary factors (including payroll tax) — in the CGE-core of the model are distinguished according to the level of government and jurisdiction levying the tax. Three components are delineated: regional sales taxes, federal sales tax (specifically, the wine equalisation and luxury car taxes) and the GST. The federal and regional taxes are modelled as *ad valorem* rates of tax levied on the basic price of the underlying flow. The GST is modelled as applying to the price inclusive of trade and transport margins. In addition, indirect taxes on the use of primary factors are also distinguished according to the level of government and jurisdiction. For example, regional payroll tax is identified separately from payroll-based levies by the federal government (such as the superannuation guarantee charge).

Environmental accounting

VURM includes an environmental module to facilitate the modelling of energy and greenhouse issues. The module includes:

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

Energy and emissions accounting

VURM includes an accounting for all domestic emissions, except those arising from land clearing and land-use change. It does not include emissions from the combustion of Australian exports by the importing economy, but does include any fugitive or combustion emissions arising in Australia from the extraction or production of those exports.

VURM tracks emissions of greenhouse gases according to: emitting agent (79 industries and the household sector); emitting region (8 regions); and emitting activity (5 activities). Most of the emitting activities involve the burning of fuels (coal, natural gas and 2 different types of petroleum products). A residual category, named *Activity*, covers non-combustion emissions such as emissions from mines and agricultural emissions not arising from burning of the fuel. *Activity* emissions are assumed to be proportional to the level of activity in the relevant industries (animal-related agriculture, coal, oil and gas mining, cement manufacture, etc.).

This classification results in an $80 \times 8 \times 5$ matrix of emissions. Emissions are measured in terms of carbon-dioxide equivalents, $C0_2$-e.

Carbon taxes and prices

VURM treats an emissions price/tax 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 the production of the relevant industries.

Because sales taxes in VURM are generally assumed to be *ad valorem* and carbon taxes are generally levied on the quantity of CO_2-e emitted, equations are required to translate a carbon tax into an *ad valorem* tax-equivalent. On one side of this relation, $C0_2$-e tax revenue is determined by:

- the specific tax rate expressed in \$A per tonne of $C0_2$-e;
- the quantity of emissions measured in tonnes of $C0_2$-e; and
- a price index used to preserve nominal homogeneity within the model.

On the other side, the *ad valorem* tax revenue is determined by:

- the percentage *ad valorem* rate;
- the basic price of the underlying taxed flow to conform to the accounting in VURM; and
- the quantity of the underlying product flow that is subject to the carbon tax.

To translate from specific to *ad valorem* the two sides of the relation are set equal to each other.

Inter-fuel substitution

Many earlier versions of VURM contained 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, $C0_2$-e taxes could induce abatement only through activity effects.

Later versions of VURM and VURM overcome this limitation in two ways:

- first, by introducing inter-fuel substitution in electricity generation using the "technology bundle" approach;[9] and
- second, by introducing a weak form of input substitution in sectors other than electricity generation to mimic "KLEM substitution".[10]

Electricity-generating industries are differentiated according to the type of fuel used. There is also an end-use supplier (*Electricity supply*) in each region and a single dummy industry (*NEM*) covering the six regions that form Australia's National Electricity Market (New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory and Tasmania). Electricity flows to the local end-use supplier either directly in the case of Western Australia and the Northern Territory or *via* the *NEM* in the remaining regions. Further details of the operation of *NEM* are given below.

Purchasers of electricity from the generation industries (the NEM in the case of those regions in the NEM or the *Electricity supply* industry in each non-NEM region) can substitute between the different generation technologies in response to changes in generation prices, with the elasticity of substitution between the technologies typically set at around 5.

For other energy-intensive commodities used by industries, VURM allows for a weak form of input substitution. If the price of cement (say) rises by 10 per cent relative to the average price of other inputs to construction, the construction industry will use 1 per cent less cement and a little more labour, 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 set at 0.25. This price-induced input substitution is especially important in an ETS scenario, where outputs of emitting industries are made more expensive.

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[8] Composite commodities are CES aggregations of domestic and imported products with the same name. The composite of primary factors is a CES aggregation of labour, capital and land inputs.

[9] The technology bundle approach has its origins in the work done at CoPS 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), labour (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 (2007).

The National Electricity Market

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

Final demand for electricity in each NEM region 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-region *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, the *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 Tasmania rises relative to the price of gas generation from New South Wales, then *NEM* demand will shift towards New South Wales gas generation and away from Tasmanian hydro generation.

The explicit modelling of the NEM enables substitution between generation types in different NEM regions. It also allows for interregional trade in electricity, without having to trace explicitly the bilateral flows. Note that Western Australia and the Northern Territory are not part of the NEM and electricity supply and generation in these regions is determined on a region-of-location basis.[11]

This modelling of the NEM is adequate for many VURM simulations. However, for the emissions trading simulations reported in Adams and Parmenter (2013), for example, much of it was overwritten by results from Frontier's detailed bottom-up model of the electricity system. The VURM electricity-system structure described above provides a suitable basis for interfacing VURM with the bottom-up model.

[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.

3 TABLO implementation of the basic model

3.1 Introduction

In this chapter, we present a formal description of the linear form of the CGE core of VURM. Our description is organised around excerpts from the TABLO file, which implements the model in GEMPACK. The TABLO language in which the file is written is a depiction of conventional algebra, with names for variables and coefficients chosen to be suggestive of their economic interpretations.

We base our description on the TABLO file for a number of reasons. First, familiarity with the TABLO code allows the reader ready access to the programs used to conduct simulations with the model and to convert the results to readable form. Both the input and the output of these programs employ the TABLO notation. Second, familiarity with the TABLO code is essential for users interpreting model results and who may wish to change the model. Finally, by documenting the TABLO form of the model, we ensure that our description is complete and accurate.

In the balance of this introduction, we provide a summary of the TABLO syntax. The remainder of this chapter is devoted to the exposition of the core VURM equation system. The equations are grouped under the following headings:[12]In addition to the key equations listed in this and subsequent chapters, the model also includes numerous equations covering, among other things, intermediate working and reporting variables and supplementary equations to meet the needs of specific applications.

3.1.1 TABLO syntax and conventions observed in the TABLO representation

Each equation in the TABLO description is linear in the changes (percentage or absolute) of the model's variables. For example, the industry labour demand equations appear as:

```
Equation E_x1lab_o # Industry demand for effective labour by region #
(all,i,IND)(all,q,REGDST)
x1lab_o(i,q) = x1prim(i,q) + a1lab_o(i,q) + a1lab_io(q) +
    nata1lab_o(i) + nata1lab_io -
  SIGMA1FAC(i,q)*[p1lab_o(i,q) + a1lab_o(i,q) +
   a1lab_io(q) + nata1lab_o(i) + nata1lab_io - p1prim(i,q)] +
  [V1CAP(i,q)/[tiny + V1LAB_O(i,q) + V1CAP(i,q)]]*
    (twistlk(i,q) + twistlk_i(q) + nattwistlk_i);
```

The first element is the identifier for the equations, which must be unique. In the VURM code, all equation identifiers are of the form *E_<variable>,* where <variable> is the variable that is notionally explained by the equation in the model.[13] The identifier is followed by descriptive text between the # symbols. The description appears in certain GEMPACK generated report files. The expression (all,i,IND)(all,q,REGDST) signifies that the equations are defined over all elements of the set IND (the set of industries) and REGDST (the set of domestic regions of use).

[12] Other components of the TABLO code, such as variable and coefficient declarations and formulae, are not included in this description. Readers wishing to learn more about these features are referred to the GEMPACK documentation (available with the GEMPACK software).
[13] All of the equations in VURM are solved simultaneously.

Within the equation, we generally distinguish between change variables and levels coefficients by using lower-case script for variables and upper-case script for coefficients. Note, however, that the GEMPACK solution software ignores case. Thus, in the excerpt above, the variables are x1lab_o(i,q), x1prim(i,q), a1lab_o(i,q,), a1lab_io(q), nata1lab_o(i), nata1lab_io, p1lab_o(i,q), p1prim(i,q), twistlk(i,q), twistlk_i(q) and nattwistlk_i. The coefficients are: SIGMA1FAC, which is the fixed elasticity of substitution between labour and other primary factors; V1CAP(i,q), the value of payments to capital used in industry in in region q; and V1LAB_O(i,q), the value of payments to labour used in industry i in region q. A semicolon signals the end of the TABLO statement.

Typically, set names appear in upper-case characters in the TABLO code. The size and elements in each set may be tailored to meet the specific requirements of particular applications. The main sets in VURM are:

COM	commodities;
IND	industries;
MARGCOM	margin commodities (a subset of COM);
MARGIND	margin industries (a subset of IND);
TEXP	traditional exports (a subset of COM);
TOUR	tourism exports (a subset of COM);
NTEXP	non-traditional exports (a subset of COM);
REGDST	regional destinations of goods;
ALLSRC	all sources of goods including foreign imports;
REGSRC	domestic sources of goods (a subset of ALLSRC); and
OCC	occupation types.

3.1 Overview of the CGE core

Figure 3.1 is a schematic representation of the core's input-output database. It reveals the basic structure of the core. The columns identify the following agents or categories of demand:

1. domestic producers, which are divided into I industries in Q regions;
2. investors, which are divided into I industries in Q regions;
3. a single representative household in each of the Q regions;
4. an aggregate foreign purchaser of exports from each of the Q regions;
5. a regional government in each of the Q regions;
6. a federal government that operates in each of the Q regions;
7. inventory accumulation in each of the Q regions; and
8. a single national electricity market.

The rows show the structure of the purchases made by each of the agents identified in the columns. Each of the C commodity types identified in the model can be obtained within the region, from other regions or imported from overseas. The source-specific commodities are used by industries as inputs to current production and capital formation, are consumed by households and governments, are exported, accumulate as inventories, and a subset are used in the national electricity market. Only locally produced goods appear in the export column (i.e., there are no re-exports of imports sourced from another region or overseas).

VURM distinguishes between basic and purchasers' prices (box 3.1). To make this distinction, there are M domestically produced goods that are used as margin services, which are required to transfer commodities from their source to their user.

Various types of regional and federal government commodity tax are also payable on the purchases.[14]

[14] Commodity taxes in VURM may apply to the use of goods and services as well as margin services.

Figure 3.1: The CGE core input-output database

ABSORPTION MATRIX

		1	2	3	4	5	6	7	8	
		Producers	Investors	House-holds	Exports	Regional govt	Federal govt	Stocks	NEM	Total
	Size	I × Q	I × Q	Q	Q	Q	Q	Q	1	
Basic Flows	C × S	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS	V7BAS	V8BAS	Sales (part*)
NEM	1	V1NEM								
Margins	C × S × M	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	V6MAR			Sales (part**)
Taxes: Regional	C × S	V1TAXS	V2TAXS	V3TAXS						
Taxes: Federal	C × S	V1TAXF	V2TAXF	V3TAXF	V4TAXF					
Taxes: GST	C × S	V1GST	V2GST	V3GST	V4GST					
Labour	O	V1LAB								
Capital	1	V1CAP								
Land	1	V1LND								
Other Costs	1	V1OCT								
Total		Costs								

C = Number of commodities

I = Number of industries

M = Number of margin service commodities

O = Number of occupation types

Q = Number of domestic destination regions

S = Number of source regions
= Q+1: Domestic regions plus foreign imports

* Total for domestically produced non-margin commodities equals total production (SALES in the MAKE matrix)

** Total for domestically produced margin commodities for both basic and margin use equals total production (SALES in the MAKE matrix)

	MAKE MATRIX	
Size	I × Q	Total
C × Q	MAKE	Sales
Total	Costs	

Box 3.1: Price measures in VURM

The ABS *Input-Output Tables* (Cat. no. 5209.0.55.001) on which the model is based distinguish between 'basic prices' and 'purchasers' prices'. In general terms, the ABS defines the 'basic price' of a good or service to be the amount that the producer receives from the sale of a good or service. The 'purchasers' price' is defined to be the amount paid by the purchaser to take delivery of that good or service, and includes any additional transport and other charges separately paid by the purchaser to take delivery of that good or service (referred to as 'margin services') as well as any taxes payable (net of any subsidies) on that good or service.

The purchasers' price of a good or service is the basic price of that good or service *plus* net taxes levied on that good or service *plus* the cost of any margin services paid.

VURM retains this distinction between the 'basic price' and 'purchasers' price'. Basic values are flows of goods or services valued at basic prices (denoted in a variable or coefficient name by the suffix BAS), while purchasers' values are flows valued at purchasers' prices (denoted by the suffix PURA or PURO).

Users of goods and services in VURM make their purchasing decisions based on purchasers' prices. As, the taxes and margin services payable frequently differ by type of user — producers, households, government, exporters, etc — the purchasers' prices are differentiated in VURM by type of user. The variable p0a(c,s) reflects the basic price of commodity c from source s, while purchasers' prices are denoted by p1a, p2a, p3a, p4a, p5a, p6a, and p8a.

Source: Based on ABS 2009, *Australian National Accounts: Input-Output Tables — Electronic Publication 2005-06* (Cat. no. 5209.0.55.001).

As well as intermediate inputs, inputs to current production consists of:

- aggregate payments to three categories of primary factor inputs (including any taxes on their use in production): labour (divided into O occupations), fixed capital, and agricultural land; and
- a residual 'other costs' category, which covers various miscellaneous industry expenses.

The electricity supply industry in some regions also uses inputs from the national electricity market.

The row totals for the commodity and margin services rows collectively detail the total sales of each commodity. Similarly, the column totals detail the total cost of domestic production.

Each cell in the input-output table contains the name of the corresponding matrix of the values (in some base year) of flows of commodities, indirect taxes or primary factor income for a category of demand. For example, V2MAR is a 5-dimensional array showing the cost of the M margins services on the flows of C commodities, both domestically and imported (S), to I investors in Q regions.

The theoretical structure of the CGE core includes: demand equations required for our eight users/categories of demand; equations determining commodity and factor prices; market clearing equations; definitions of commodity tax rates; and reporting aggregates.

As indicated by the listing of chapter sections in the introduction to this chapter, the remainder of this chapter is organised thematically around the basic structure of the CGE core in figure 3.1, starting at the top-left hand corner and progressing from left to right and then downwards to the bottom-right hand corner. The discussion of the CGE core finishes with the regional and economy-wide reporting measures characteristic of the CGE core.

3.1.1 Naming system for variables in the CGE core

The following conventions are used (as far as possible) in naming variables of the CGE core. Names consist of a prefix, a main user number and a source dimension. The prefixes are:

a ⇔ technological change or change in preference (taste);
f ⇔ shift variable;
nat ⇔ a national aggregate of the corresponding regional variable;
p ⇔ price; and
x ⇔ quantity demanded.

The main user numbers are:

1 ⇔ industries, use in current production;
2 ⇔ industries, use in capital creation;
3 ⇔ households;
4 ⇔ foreign exports;
5 ⇔ regional governments;
6 ⇔ federal government;
7 ⇔ inventories;
8 ⇔ National Electricity Market (NEM); and
0 ⇔ general – without a specific user.

The source dimensions are:

a ⇔ all sources, i.e., 8 domestic source regions and 1 foreign;
r ⇔ domestic source regions only;
t ⇔ two sources, i.e., a domestic-composite and 1 foreign;
c ⇔ domestic-composite only; and
o ⇔ domestic-foreign composite only.

The following are examples of the above notational conventions:

p1a ⇔ the price (p) of a commodity averaged over all sources (a) for use in current production (1); and
x2c ⇔ demand (x) for the domestic-composite commodity (c) in capital creation (2).

Ordinary change variables, as opposed to percentage change variables, are indicated by the prefix d_. Thus, d_x2c is the ordinary ($m) change equivalent of the percentage-change variable x2c.

Some variable names also include a suffix description, such as:

cap ⇔ fixed capital;
imp ⇔ imports;
lab ⇔ labour;
lnd ⇔ agricultural land;
marg ⇔ margin services;
oct ⇔ other costs; and
nem ⇔ national electricity market.

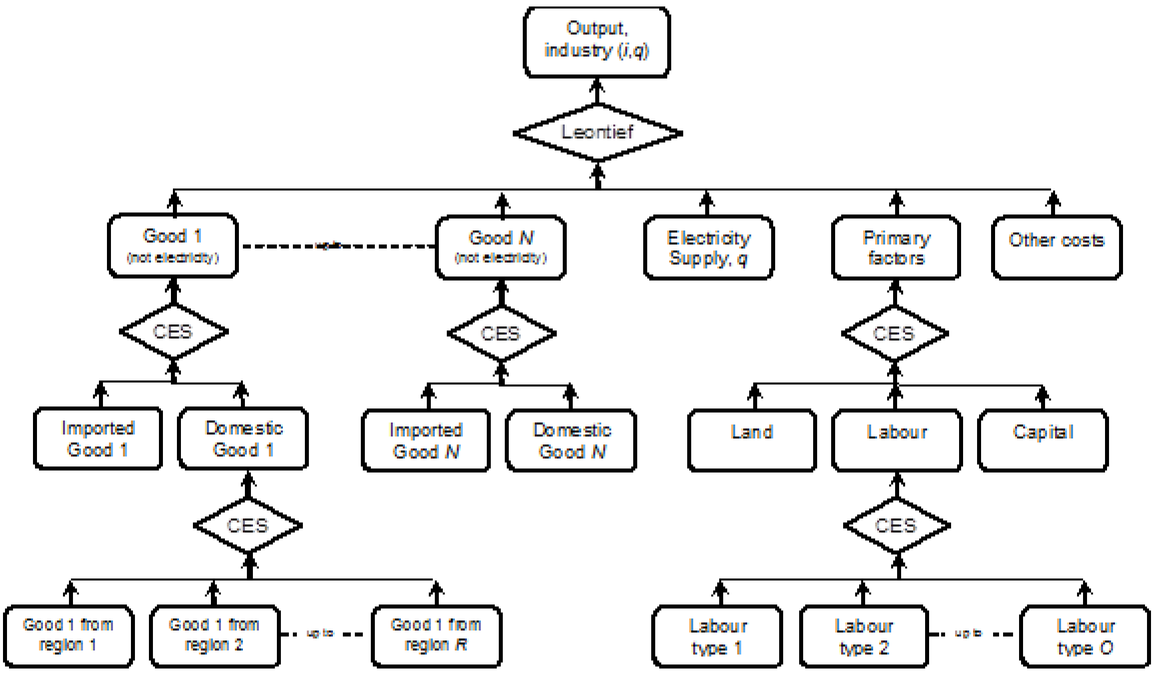
3.2 The production process

VURM recognises two broad categories of inputs: intermediate inputs and primary factors. Industries in each region are assumed to choose the mix of inputs that minimises the costs of production for their level of output. They are constrained in their choice of inputs by a production technology of several branches, each with a number of levels (or nests). The VURM production theory distinguishes between the electricity supply industry and all other industries in each region. These distinctions are made necessary by VURM's modelling of the national electricity market. Figure 3.2 describes the input structure of production for all non-electricity supply industries.

At the first level, each intermediate-input bundle, the primary-factor bundle and other costs are used in fixed proportions to output. These bundles are formed at the second level. At the second level, the primary-factor bundle is a constant-elasticity-of-substitution (CES) combination of labour, fixed capital and agricultural land. Each intermediate-input bundle is a CES combination of a 'domestic-composite' and internationally imported good. At the third level, the domestic-composite is formed as CES combination of goods from each of the eight regions, and the labour-composite input is a CES combination of labour inputs from the different occupational categories.

We now proceed to describe the derivation of the input demand functions working upwards from the bottom of the tree in Figure 3.2. We begin with the intermediate-input branches on the LHS of Figure 3.2.

Figure 3.2: Production technology for non-electricity supply industry i in region q



3.2.1 Demands for domestic and imported intermediate inputs (E_x1a to E_x1o)

At the bottom of the nest (level 3 in Figure 3.2), industry i in region q chooses intermediate input type c from domestic region s (X1A(c,s,i,q)) to minimise the cost:

$$\sum_{s \in regsrc} P1A(c,s,i,q) \times X1A(c,s,i,q) \qquad (E3.1)$$

of a domestic-composite bundle

$$X1C(c,i,q) = \underset{s \in regsrc}{CES}\left\{X1A(c,s,i,q)\right\} \qquad c \in COM \ i \in IND \ q \in REGDST \qquad (E3.2)$$

where the domestic-composite bundle (X1C(c,i,q)) is exogenous at this level of the nest. The notation CES{} represents a CES function defined over the set of variables enclosed in the curly brackets. The subscript indicates that the CES aggregation is over all elements s of the set of regional sources (REGSRC), where REGSRC is a subset of ALLSRC. The CES specification means that inputs of the same commodity type produced in different regions are not perfect substitutes for one another. This is an application of the so-called Armington (1969, 1970) specification typically imposed on the use of domestically produced commodities and foreign-imported commodities in national CGE models such as ORANI.

By solving the above problem, we generate the industries' demand equations for domestically produced intermediate inputs to production.[15] The percentage-change forms of these demand equations are given by equation *E_x1a* at the end of this section.

On the RHS of *E_x1a*, the first IF statement refers to inputs from the domestic sources. Within the first IF statement, the first term is the percentage change in the demand for the domestic-composite (x1c(c,i,q)). In the absence of changes in prices and technology, it is assumed that the use of input c from all domestic sources expands proportionately with industry (i,q)'s overall usage of the domestic-composite. The second term in the first IF statement allows for price substitution. The percentage-change form of the price-induced substitution term is an elasticity of substitution, SIGMA1C(c), multiplied by the percentage change in the price from the regional source relative to the cost of the regional composite, i.e., an average price of the commodity across all regional sources.[16] Lowering of a source-specific price, relative to the average, induces substitution in favour of that source. The second term in the price-induced substitution part of the LHS of *E_x1a* allows for technological change. If a1a(c,s,i,q) is set to –1, then we are allowing for a 1 per cent input-(c,s) saving technical change by industry (i,q).

The percentage change in the average price of the domestic-composite commodity c, p1c(c,i,q), is given by equation *E_p1c*. In *E_p1c*, the coefficient V1PURT(c,"domestic",i,q) is the total purchasers' value of commodity c from all domestic sources used by industry i in region q, and V1PURA(c,s,i,q) is the cost of commodity c from domestic source s used by industry i in region q. Hence, p1c(c,i,q) is a cost-weighted Divisia index of individual prices from the regional sources. Note that in cases where V1PURT(c,s,i,q) equals zero, *E_p1c* would leave the corresponding p1c undefined. To avoid this problem, the function ID01(V1PURT(c,s,i,q)) returns the value of 1 when V1PURT(c,s,i,q) = 0.

At the next level of the production nest (level 2 in figure 3.2), firms decide on their demands for the domestic-composite commodities and the foreign-imported commodities following a pattern similar to the previous nest. Here, the firm chooses a cost-minimising mix of the domestic-composite commodity and the foreign-imported commodity:

$$P1A(c,"imp",i,q) \times X1A(c,"imp",i,q) + P1C(c,i,q) \times X1C(c,i,q)$$

$$c \in COM \quad i \in IND \quad q \in REGDST \qquad \text{(E3.3)}$$

where: "imp" refers to the foreign import, subject to the production function:

[15] For details on the solution of input demands given a CES production function, and the linearization of the resulting levels equation, see Dixon, Bowles and Kendrick (1980), and Horridge, Parmenter and Pearson (1993).
[16] In level terms, the price relativities correspond to the ratio of the price in the source region relative to that of the national composite.

$$X1O(c,i,q) = CES\left\{\frac{X1A(c,"imp",i,q)}{A1A(c,"imp",i,q)}, \frac{X1C(c,i,q)}{A1A(c,\circ,i,q)}\right\} \quad c \in COM\ i \in IND\ q \in REGDST \quad (E3.4)$$

where: $A1A(c,\circ,i,q)$ is a composite of the domestic $A1A(c,s,i,q)$ terms.

As with the problem of choosing the domestic-composite, the Armington assumption is imposed on the domestic-composite and the foreign import by the CES specification (E3.4).

The solution to the problem specified by (E3.3) and (E3.4) yields the input demand functions for the domestic-composite and the foreign import; represented in their percentage-change form by equations *E_x1c* and *E_x1a* (second IF statement). These equations show, respectively, that the demands for the domestic-composite commodity (X1C(c,i,q)) and for the foreign import (X1A(c,"imp",i,q)) are proportional to demand for the domestic-composite/foreign-import aggregate (X1O(c,i,q)) and to a price term. The X1O(c,i,q) are exogenous to the producer's problem at this level of the nest. Common with the previous nest, the percentage-change form of the price term is an elasticity of substitution, SIGMA1O(c), multiplied by the percentage change in the price of the domestic-composite (p1c(c,i,q) in equation *E_x1c*) or of the foreign import (p1a(c,"imp",i,q) in equation *E_x1a*) relative to the price of the domestic-composite/foreign-import aggregate (p1o(c,i,q) in equations *E_x1c* and *E_x1a*).

On the RHS of *E_x1a* and *E_x1c* are additional terms involving the variables twistsrc(c,q), twistsrc_c(q), and nattwistsrc_c. These variables allow for cost-neutral twists in import/domestic preferences for commodity c used by industries in region q.

To see how the cost-neutral aspect works, assume zero values for the 'a' terms and no changes in prices in *E_x1a* and *E_xlc*. Also, assume x1o(c,i,q) = 0 and tiny = 0.0000001.[17] Under these assumptions:

$$x1c(c,i,q) = -\frac{V1PURT(c,"imp",i,q)}{V1PURO(c,i,q)+0.0000001} \times \left(twistsrc(c,q) + twistsrc\_c(q) + nattwistsrc\_c\right)$$

and

$$x1a(c,"imp",i,q) = \frac{V1PURT(c,"dom",i,q)}{V1PURO(c,i,q)+0.0000001} \times \left(twistsrc(c,q) + twistsrc\_c(q) + nattwistsrc\_c\right)$$

Taking account of the fact that:

$$\frac{V1PURT(c,"domestic",i,q)}{V1PURO(c,i,q)} + \frac{V1PURT(c,"imp",i,q)}{V1PURO(c,i,q)} = 1$$

we see that:

$$x1c(i,j,q) - x1a(i,"imp",j,q) = -\left(twistsrc(c,q) + twistsrc\_c(q) + nattwistsrc\_c\right) \quad (E3.5)$$

Hence, in the absence of changes in prices and 'a' terms, if twistsrc(c,q) were set at -10, then all industries in region q would increase their ratio of domestic to imported inputs of commodity c by 10 per cent. In other words, there is a 10 per cent twist by all industries in favour of the use of domestic good c relative to imported good c. Similarly, if twistsrc_c(q) were set at -10, then all

[17] The purpose of the coefficient "TINY" is to avoid division by zero. In this example, if V1PURO(c,i,q) = 0 for any c,i,q-flow, the model is still able to solve for x1c(c,i,q) and x1a(c,s,i,q). It does not matter that a nonsensical result is found for x1c(c,i,q) and x1a(c,s,i,q) because these variables are percentage changes of a zero base. If V1PURO(c,i,q) > 0, the effect of adding "TINY" is negligible.

industries in region q would increase their ratio of domestic to imported inputs of all commodities by 10 per cent. If nattwistsrc_c was set at -10, then all industries in all regions would increase their ratio of domestic to imported inputs of all commodities by 10 per cent.

We have now arrived at the top level of the production nest (level 1 in Figure 3.2). Each total intermediate input composite, the primary-factor composite and 'other costs' are combined using a Leontief production function, MIN(), given by:

$$\mathrm{X1TOT(i,q)} = \frac{1}{\mathrm{A1(i,q)}} \times$$

$$\mathrm{MIN}\left\{ \frac{\mathrm{X1O(c,i,q)}}{\mathrm{A1O(c,i,q)} \times \mathrm{ACOM(c,q)} \times \mathrm{AGREEN(c,i,q)} \times \mathrm{ACOMIND(c,i,q)} \times \mathrm{ELECSUB(c,i,q)}}, \frac{\mathrm{X1PRIM(i,q)}}{\mathrm{A1PRIM(i,q)} \times \mathrm{A1PRIM\_I(q)} \times \mathrm{NATA1PRIM\_I}}, \frac{\mathrm{X1OCT(i,q)}}{\mathrm{A1OCT(i,q)}} \right\}$$

$i \in \mathrm{IND}$ $q \in \mathrm{REGDST}$ (E3.6)

In equation 3.6, X1TOT(i,q) is the gross output of industry i in region q and the A variables are Hicks-neutral technical change terms. X1O(c,i,q), X1PRIM(i,q) and X1OCT(i,q) are, respectively, the demands by industry i in region q for the intermediate-input composite for commodity c, the primary-factor composite and other costs. The cost minimisation solution to this production function is for effective units (allowing for technical change) for each composite input to be used in fixed proportion to output. For intermediate inputs, this is indicated in equation *E_x1o*.

The equation also includes two additional technology variables, AGREEN(c,i,q) and ELECSUB(c,i,q). AGREEN allows for price-induced substitution between effective units of intermediate inputs, especially those inputs that are energy intensive (e.g., gas and coal). ELECSUB allow for price-based substitution in the demand by the electricity-supply industry for different for electricity generation technologies.

```
Equation E_x1a # Demand for c from s by industry i in q #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
x1a(c,s,i,q) - a1a(c,s,i,q) =
IF{s ne "imp",
  x1c(c,i,q) - SIGMA1C(c)*[p1a(c,s,i,q) + a1a(c,s,i,q) - p1c(c,i,q)]} +
IF{s eq "imp",
  x1o(c,i,q) - SIGMA1O(c)*[p1a(c,"imp",i,q) + a1a(c,"imp",i,q) -
p1o(c,i,q)] +
   (V1PURT(c,"domestic",i,q)/(tiny+V1PURO(c,i,q)))*
     (twistsrc(c,q) + twistsrc_c(q) + nattwistsrc_c)};

Equation E_p1o # Price of domestic/imp composite, User 1 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
ID01(V1PURO(c,i,q))*p1o(c,i,q) =
  sum{s,ALLSRC, V1PURA(c,s,i,q)*(p1a(c,s,i,q) + a1a(c,s,i,q))};

Equation E_p1c # Price of domestic-composite, User 1 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
ID01(V1PURT(c,"domestic",i,q))*p1c(c,i,q) =
  sum{s,REGSRC, V1PURA(c,s,i,q)*(p1a(c,s,i,q) + a1a(c,s,i,q))};
```

```
Equation E_x1c # Demand for domestic-composite, User 1 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
x1c(c,i,q) =
  x1o(c,i,q) - SIGMA1O(c)*[p1c(c,i,q) - p1o(c,i,q)] -
  (V1PURT(c,"imp",i,q)/(tiny+V1PURO(c,i,q)))*
    (twistsrc(c,q) + twistsrc_c(q) + nattwistsrc_c);

Equation E_x1o # Demands for composite inputs, User 1 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
x1o(c,i,q) = x1tot(i,q) +
a1(i,q) + a1o(c,i,q) + acom(c,q) + natacom(c) + acomind(c,i,q) + aind(i,q)
+ agreen(c,i,q) + elecsub(c,i,q);
```

3.2.2 Demands for primary factors

3.1.1.1 Demand for the primary-factor composite (E_x1prim to E_p1prim)

At the highest level of the primary factor branch and recalling the Leontief specification of the production function in figure 3.2, the demand for the primary factor bundle is directly proportion to the percentage change in gross output, x1tot(i,q), as indicated in equation *E_x1prim*.

Equation *E_x1prim* includes a number of technological change terms (a1(i,q), a1prim(i,q), etc.) that allow for changes in output per unit of primary factors. The technology variables identified by the word 'prim' are specific to primary factor efficiencies. The technology variable a1 relates to all inputs, intermediate as well as primary factor.

Equation *E_p1prim* determines the effective price of the primary-factor composite.

```
Equation E_x1prim
# Price of the effective primary-factor composite by industry & state #
(all,i,IND)(all,q,REGDST)
x1prim(i,q) =
x1tot(i,q) + a1(i,q) + a1prim(i,q) + a1prim_i(q) + nata1prim(i) +
nata1prim_i;

Equation E_p1prim # Effective price term for factor demand equations #
(all,i,IND)(all,q,REGDST)
ID01[V1PRIM(i,q)]*p1prim(i,q) =
    V1LAB_O(i,q)*
    [p1lab_o(i,q) + a1lab_o(i,q) + a1lab_io(q) + nata1lab_o(i) +
nata1lab_io] +
    V1CAP(i,q)*  [p1cap(i,q) + a1cap(i,q)] +
    V1LND(i,q)*  [p1lnd(i,q) + a1lnd(i,q)];
```

3.1.1.2 Demand for primary factors — labour, capital and agricultural land (E_x1lab to E_p1lnd)

The composition of demand for primary factors — labour, capital and agricultural land — is determined at the next level of the primary-factor branch of the production nest. Derivation of each component follows the same CES pattern as the previous nests. Here, the total cost of primary-factors used in industry i in region q is given by:

$$P1LAB\_O(i,q) \times X1LAB\_O(i,q) + P1CAP(i,q) \times X1CAP(i,q) + P1LND(i,q) \times X1LND(i,q)$$

$i \in IND \; q \in REGDST$ (E3.7)

where: P1LAB_O(i,q), P1CAP(i,q) and P1LND(i,q) are, respectively, the unit costs of the labour composite, capital and agricultural land for industry i in region q; and X1LAB_O(i,q), X1CAP(i,q) and X1LND(i,q) are, respectively, the demands for the labour composite, capital and agricultural land for industry i in region q.

Producers choose units of primary factors to minimise the total cost of production subject to substitution possibilities given by the function:

$$X1PRIM(i,q) = CES\left\{\frac{X1LAB\_O(i,q)}{A1LAB\_O(i,q)}, \frac{X1CAP(i,q)}{A1CAP(i,q)}, \frac{X1LND(i,q)}{A1LND(i,q)}\right\}$$

$i \in IND \; q \in REGDST$ (E3.8)

where: X1PRIM(i,q) is the overall demand for primary factors by industry i in region q. The CES function above allows us to impose factor-specific technological change via the variables A1LAB_O(i,qVURM), A1CAP(i,q) and A1LND(i,q). Note that in the coding of the model, instead of one labour-saving technological variable (AlLAB_O), there are several each general to one or more of industry, region and occupation. This allows for greater flexibility in closure choice and for improved efficiencies in computation.

The percentage-change form solutions to this problem are given by equations *E_x1lab_o*, *E_p1cap* and *E_p1lnd*. From these equations, we see that, for a given level of technical change, each industries' demand for the labour composite, capital and land are proportional to their overall demand for primary factors (x1prim(i,q)) and a relative price term. The relative price term is an elasticity of substitution (SIGMA1FAC(i,q)) multiplied by the difference between the (percentage) change in each primary factor's input price and the (percentage) change in the overall effective cost of primary factor inputs in industry i in region q. Changes in the relative prices of the primary factors induce substitution in favour of relatively cheaper factors. The percentage change in the average effective cost of primary factors (p1prim(i,q)), given by equation *E_p1prim*, is again a cost-weighted Divisia index of individual prices and technical changes.

A group of twist terms, twistlk(i,q), twistlk_i(q), and nattwistlk_i, appears in equations *E_x1lab_o* and *E_p1cap*. A positive value for twistlk(i,q) causes a cost-neutral twist towards labour and away from capital in regional industry (i,q). A negative value for twistlk(i.q) causes a twist towards capital and away from labour. The coefficient attached to the twist terms in *E_x1lab_o* is the share of the cost of capital in the total cost of labour and capital for industry i in region q. The coefficient attached to the twist terms in *E_p1cap* is the negative of the share of the cost of labour in the total cost of capital and labour for industry (i,q).

```
! Labour composite !
Equation E_x1lab_o # Industry demand for effective labour by state #
(all,i,IND)(all,q,REGDST)
x1lab_o(i,q) = x1prim(i,q) + a1lab_o(i,q) + a1lab_io(q) +
        natal1ab_o(i) + natal1ab_io -
    SIGMA1FAC(i,q)*[p1lab_o(i,q) + a1lab_o(i,q) +
        a1lab_io(q) + natal1ab_o(i) + natal1ab_io - p1prim(i,q)] +
    [V1CAP(i,q)/[TINY + V1LAB_O(i,q) + V1CAP(i,q)]]*
        (twistlk(i,q) + twistlk_i(q) + nattwistlk_i);
```

```
! Capital !
Equation E_p1cap # Industry demands for capital #
(all,i,IND)(all,q,REGDST)
x1cap(i,q) = x1prim(i,q) + a1cap(i,q) -
    SIGMA1FAC(i,q)*[p1cap(i,q) + a1cap(i,q) - p1prim(i,q)] -
    [V1LAB_O(i,q)/[TINY+V1LAB_O(i,q)+V1CAP(i,q)]]*
        (twistlk(i,q) + twistlk_i(q) + nattwistlk_i);

! Agricultural land !
Equation E_p1lnd # Industry demands for land #
(all,i,IND)(all,q,REGDST)
x1lnd(i,q) = x1prim(i,q) + a1lnd(i,q) -
    SIGMA1FAC(i,q)*[p1lnd(i,q) + a1lnd(i,q) - p1prim(i,q)];
```

3.1.1.3 Demand for labour by occupation (E_x1lab to E_p1lab_o)

At the lowest-level nest in the primary-factor branch of the production tree in Figure 3.2, producers choose a composite labour input (expressed in terms of hours worked) from the O occupational groups to minimise the costs of labour inputs. This cost minimising behaviour gives rise to the labour demand equations for each occupation in VURM.

Producers in industry i in region q choose inputs of occupation-specific labour type o, X1LAB(i,q,o), so as to minimise the total cost of labour:

$$\sum_{o\in occ} \text{P1LAB}(i,q,o)\times \text{X1LAB}(i,q,o) \qquad i\in IND\ q\in REGDST \qquad (E3.9)$$

subject to:

$$\text{X1LAB\_O}(i,q)=\underset{o\in occ}{\text{CES}}\{\text{X1LAB}(i,q,o)\} \qquad i\in IND\ q\in REGDST \qquad (E3.10)$$

Exogenous to this problem are the price paid by regional industry (i,q) for each occupation-specific labour type (P1LAB(i,q,o)) and each regional industries' demand for the effective labour input (X1LAB_O(i,q)).

The solution to this problem, in percentage-change form, is given by equations *E_x1lab* and *E_p1lab_o*. Equation *E_x1lab* indicates that the demand for labour type o is proportional to the demand for the effective labour composite and to a relative price term. The relative price term consists of an elasticity of substitution, SIGMA1LAB(i,q), multiplied by the percentage change in the price of occupation o (p1lab(i,q,o)) relative to the average price of labour in industry i of region q (p1lab_o(i,q))). Changes in the relative prices of the occupations induce substitution in favour of relatively cheaper occupations. The percentage change in the average price of labour is given by equation *E_p1lab_o*. The coefficient V1LAB(i,q,o) is total cost of labour for occupation o employed by industry i in region q (the 'wage bill'). The coefficient V1LAB_O(i,q) is the total wage bill of industry i in region q. Thus, p1lab_o(i,q) is a Divisia index of the p1lab(i,q,o).

```
! Labour !
 Equation E_x1lab # Industry demand for effective labour by region &
occupation #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
x1lab(i,q,o) =
    x1lab_o(i,q) + a1lab(i,q,o) + a1lab_i(q,o) + nata1lab_i(o) -
        SIGMA1LAB(i,q)*[p1lab(i,q,o) + a1lab(i,q,o) + a1lab_i(q,o) +
            nata1lab_i(o) - p1lab_o(i,q)];

Equation E_p1lab_o
# Price to producers of effective labour composite by industry & region #
(all,i,IND)(all,q,REGDST)
ID01[V1LAB_O(i,q)]*p1lab_o(i,q) = sum{o,OCC, V1LAB(i,q,o)*
     [p1lab(i,q,o) + a1lab(i,q,o) + a1lab_i(q,o) + nata1lab_i(o)]};
```

3.2.3 Demands for other costs (E_x1oct to E_p1octinc)

The final branch of the production nest deals with 'other costs', which allow for costs not explicitly identified in VURM, such as working capital and the costs of holding inventories.

Recalling the Leontief specification of the production function from above, the demand for other costs at the top level of the nest is directly proportion to gross output, X1TOT(i,q), as indicated in equation *E_x1oct*.

The levels form of *E_p1octinc* is specified as:

$$\mathrm{P1OCTINC}(i,q) = \mathrm{P3TOT}(i,q) \times \mathrm{F1OCTINC}(i,q) \qquad i \in \mathrm{IND}\ q \in \mathrm{REGDST} \qquad \text{(E3.11)}$$

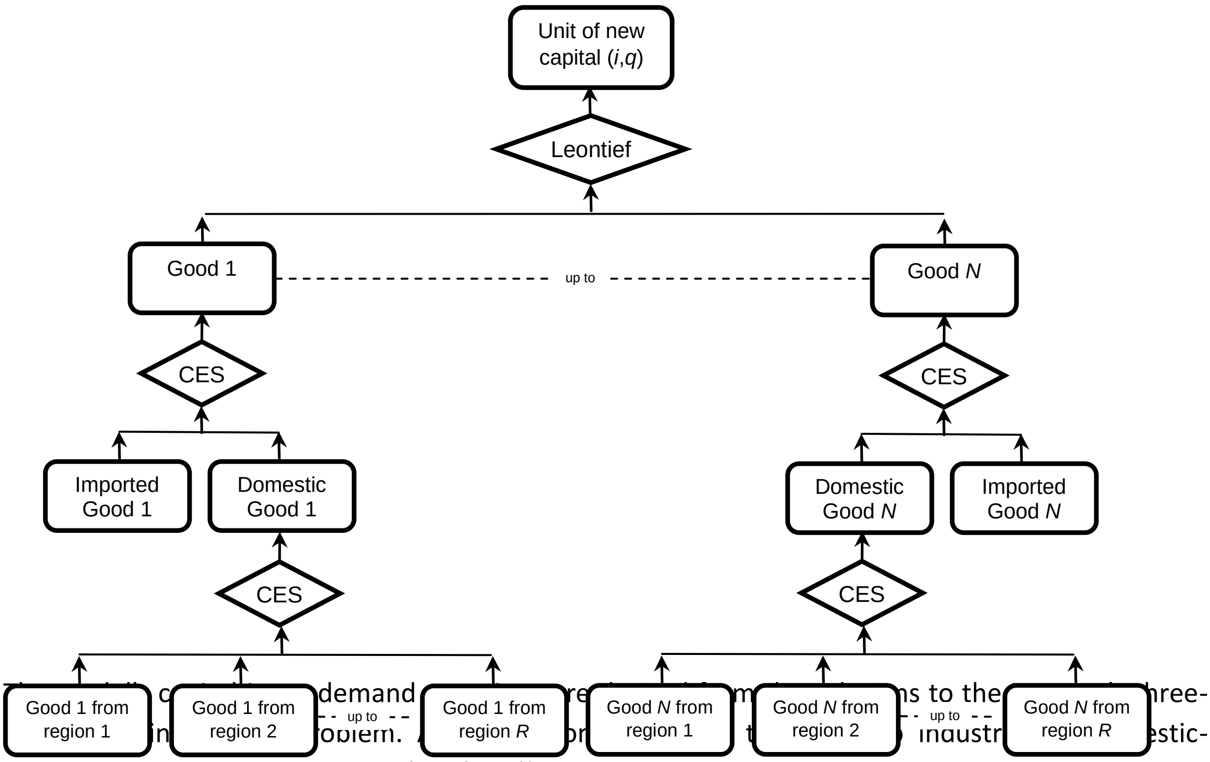
where: P3TOT(q) is the level of the consumer price index (CPI) in region q; and F1OCT(i,q) is a shift variable. If F1OCTINC(i,q) is constant, then the price of other costs for industry i in region q moves with the CPI in q. Changes in F1OCTINC(i,q) cause changes in the price of other costs relative to the CPI. *E_p1octinc* is the percentage change form of (E3.11).

```
! Demand for other costs !
Equation E_x1oct # Industry demands for other costs #
(all,i,IND)(all,q,REGDST)
x1oct(i,q) = x1tot(i,q) + a1(i,q) + a1oct(i,q);

Equation E_p1oct # Indexing of prices of other costs #
(all,i,IND)(all,q,REGDST)
p1octinc(i,q) = p3tot(q) + f1octinc(i,q);
```

3.3 Investment demand (E_x2a to E_x2o)

Capital creators for each regional industry combine inputs to form units of capital. In choosing these inputs, they minimise costs subject to technologies similar to that in figure 3.2. Figure 3.3 shows the nesting structure for the production of new units of fixed capital. Capital is produced with inputs of domestically produced and imported commodities. Primary factors are used indirectly as inputs to the production of goods and services used for capital formation.

Figure 3.3: Structure of investment demand



commodity composites of good c (X2C(c,i,q)) is minimised subject to the CES production function:

$$X2C(c,i,q) = \underset{s \in regsrc}{CES}\{X2A(c,s,i,q)\} \qquad c \in COM \; i \in IND \; q \in REGDST \qquad (E3.12)$$

where: the X2A(c,s,i,q) are the demands of industry i in region q for commodity c from domestic region s for use in the creation of capital. Similarly, at the second level of the nest, the total cost of the domestic/foreign-import composite (X2O(c,i,q)) is minimised subject to the CES production function:

$$X2O(c,i,q) = CES\{X2A(c,"imp",i,q), X2C(c,i,q)\} \qquad c \in COM \; i \in IND \; q \in REGDST \qquad (E3.13)$$

where: the X2A(c,"imp",i,q) are demands for the foreign imports.

The equations describing the demand for the source-specific inputs (*E_x2a*, *E_x2c*, *E_p2c* and *E_p2o*) are similar to the corresponding equations describing the demand for intermediate inputs to current production (i.e., *E_x1a*, *E_x1c*, *E_p1c* and *E_p1o*). The main difference is the lack of technological change terms in the investment equations at this level. However, the twistsrc terms do appear in the investment equations.

At the top level of the nest, the total cost of commodity composites is minimised subject to the Leontief function:

$$X2TOT(i,q) = \underset{c \in com}{MIN}\{\frac{X2O(c,i,q)}{A2(q) \times ACOM(c,q)}\} \qquad i \in IND \; q \in REGDST \qquad (E3.14)$$

where: the total amount of investment in each industry (X2TOT(i,q)) is exogenous to the cost-minimisation problem, the A2(q) terms are technological-change variables in the use of inputs in capital creation, the ACOM(c,q) terms are technological-change variables in all uses of commodity c in region q, and the NATACOM(c) terms are technological change variables in all uses of commodity c nationally.

As a consequence of the Leontief specification of the production function for investment, demand for the composite commodity inputs at the top level of the nest are in direct proportion to X2TOT(i,q), as indicated in equations *E_x2o*. Note the similarity between this equation and *E_x1o*.

Determination of the number of units of capital to be formed for each regional industry (i.e., determination of X2TOT(i,q)) depends on the nature of the experiment being undertaken. For comparative-static experiments, a distinction is drawn between the short run and long run. In short-run experiments (where the year of interest is one or two years after the shock to the economy), capital stocks in regional industries are exogenously determined.

In long-run comparative-static experiments (where the year of interest is five or more years after the shock), it is assumed that the aggregate capital stock adjusts to preserve an exogenously determined economy-wide rate of return, and that the allocation of capital across regional industries adjusts to satisfy exogenously specified relationships between relative rates of return and relative capital growth. Industries' demands for investment goods are determined by exogenously specified investment/capital ratios.

In year-to-year dynamic experiments, regional industry demand for investment is determined via dynamic equations like (E2.1) and (E2.2). Details of the determination of investment and capital, when VURM is run in dynamic mode, are provided in chapter 4.

```
Equation E_x2a # Demand for c from s for investment in region q, User 2 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
x2a(c,s,i,q) =
IF{s ne "imp",
    x2c(c,i,q) - SIGMA2C(c)*[p2a(c,s,i,q) - p2c(c,i,q)]} +
IF{s eq "imp",
    x2o(c,i,q) - SIGMA2O(c)*[p2a(c,"imp",i,q)- p2o(c,i,q)]+
    (V2PURT(c,"domestic",i,q)/(TINY + V2PURO(c,i,q)))*
        (twistsrc(c,q) + twistsrc_c(q) + nattwistsrc_c)};

Equation E_p2o # Price of domestic/imp composite, User 2 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
ID01[V2PURO(c,i,q)]*p2o(c,i,q) =
    sum{s,ALLSRC, V2PURA(c,s,i,q)*p2a(c,s,i,q)};

Equation E_p2c # Price of domestic composite, User 2 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
ID01[V2PURT(c,"domestic",i,q)]*p2c(c,i,q) =
    sum{s,REGSRC, V2PURA(c,s,i,q)*p2a(c,s,i,q)};
```

```
Equation E_x2c # Demand for domestic composite, User 2 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
x2c(c,i,q) = x2o(c,i,q) - SIGMA2O(c)*[p2c(c,i,q) - p2o(c,i,q)] -
    [V2PURT(c,"imp",i,q)/(TINY + V2PURO(c,i,q))]*
        (twistsrc(c,q) + twistsrc_c(q) + nattwistsrc_c);

Equation E_x2o # Demands for composite inputs, User 2 #
(all,c,COM)(all,i,IND)(all,q,REGDST)
x2o(c,i,q) - a2(q) - acom(c,q) - natacom(c) = x2tot(i,q);
```

3.4 Household demand (E_x3o to E_x3c)

Each regional household determines the optimal composition of its consumption bundle by choosing domestic-import composite commodities to maximise a Stone-Geary utility function subject to a regional household budget constraint. The regional household budget constraint is determined by regional household disposable income (discussed in chapter 6), while aggregate expenditure is determined by a Keynesian consumption function (discussed below).

Figure 3.4 outlines the structure of regional household demand, which follows nearly the same nesting pattern as that of investment demand. The only difference is that commodity composites are aggregated by a Stone-Geary, rather than a Leontief function, leading to the linear expenditure system (LES) in which the demand for each commodity varies in proportion to household expenditure and the price of that commodity (i.e., the Engel curves are straight lines).

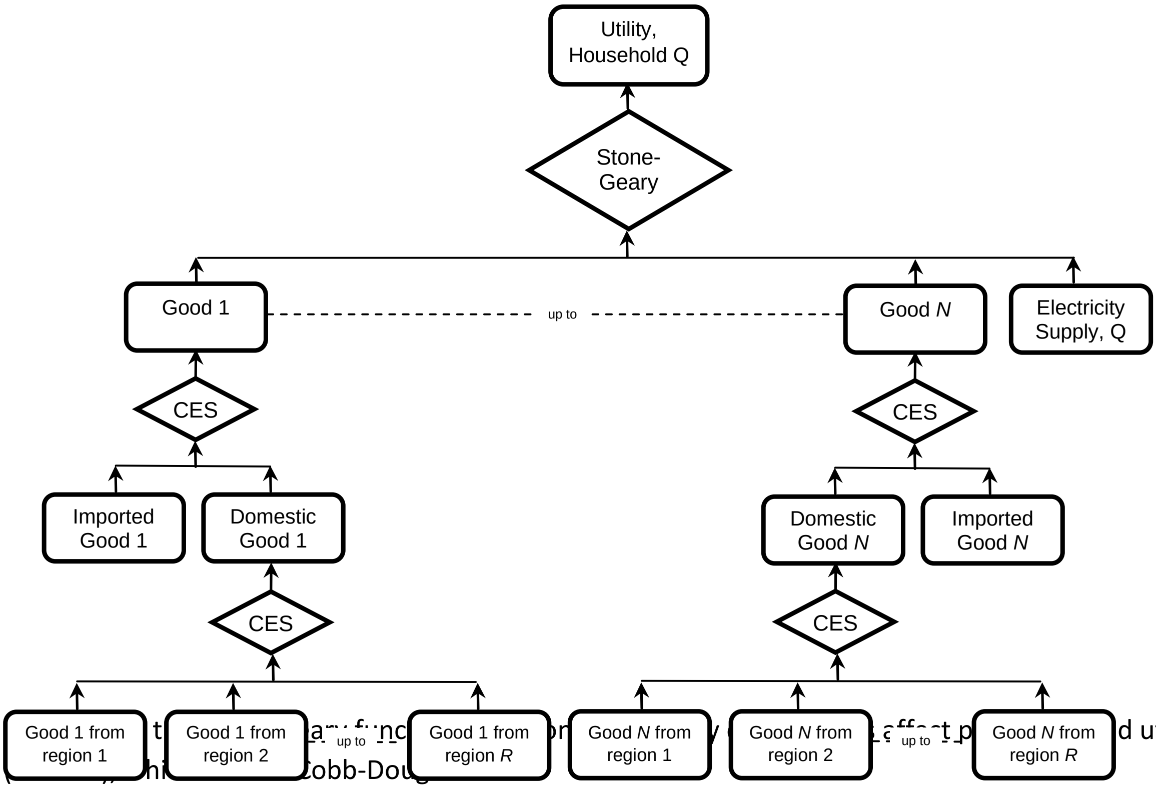
The equations for the two lower nests determining the sourcing of commodities in household demand (*E_x3a*, *E_p3o*, *E_p3c* and *E_x3c*) are similar to the corresponding equations for intermediate and investment demands (contained in 3.1.1 and 3.1.2).[18]

In the nesting structure, therefore, the equations determining the commodity composition of household demand is determined by the Stone-Geary nest of the structure. To analyse the Stone-Geary utility function, it is helpful to divide total economy-wide consumption of each commodity composite (X3O(c,q)) into two components: a subsistence (or minimum) part (X3SUB(c,q)) and a luxury (or supernumerary) part (X3LUX(c,q)):

$$\mathrm{X3O(c,q)} = \mathrm{X3SUB(c,q)} + \mathrm{X3LUX(c,q)} \qquad c \in COM \;\; q \in REGDST \qquad (E3.15)$$

[18] For details on the derivation of demands in the Linear Expenditure System, see Dixon, Bowles and Kendrick (1980) and Horridge *et al.* (1993).

Figure 3.4: Structure of household demand



$$\text{UTILITY}(q) = \frac{1}{\text{QHOUS}(q)} \times \sum_{c \in com} \text{X3LUX}(c,q)^{\text{A3LUX}(c,q)} \qquad q \in \text{REGDST} \qquad \text{(E3.16)}$$

where:

$$\sum_{c \in com} \text{A3LUX}(c,q) = 1 \qquad q \in \text{REGDST}.$$

Because the Cobb-Douglas form gives rise to exogenous budget shares for spending on luxuries:

$$\text{P3O}(c,q) \times \text{X3LUX}(c,q) = \text{A3LUX}(c,q) \times \text{W3LUX}(q) \qquad c \in \text{COM} \; q \in \text{REGDST} \qquad \text{(E3.17)}$$

A3LUX(i,q) may be interpreted as the marginal budget share of total spending on luxuries (W3LUX(q)).

Rearranging (E3.17), substituting into (E3.15) and linearising gives equation *E_x3o*, which gives household demand for each composite commodity.

The first term on the RHS of equation *E_x3o* denotes the percentage change in subsistence demand, which is proportional to: the percentage change in the number of households; and to a taste-change variable (a3sub(c,q)), but not dependent on any price terms. The percentage change in subsistence demand is weighted by the share of subsistence expenditure on commodity c in total expenditure on commodity c, 1-B3LUX(c,q), where B3LUX(c,q) is the share of supernumerary expenditure on commodity c in total expenditure on commodity c.

The second term on the righ-hand side of equation *E_x3o* denotes the percentage change in supernumerary demand, which is proportional to: the percentage change in total regional household supernumerary expenditure (w3lux(q)); a taste-change variable (a3lux(c,q)); and the percentage change in price of commodity c (p3o(c,q)). The percentage change in supernumerary demand is weighted by the share of supernumerary expenditure on commodity c in total expenditure on commodity c (B3LUX(c,q)).

Equation *E_utility* is the percentage-change form of (E3.16) — the Stone-Geary utility function. The form adopted disregards any taste changes.

Equations *E_a3sub* and *E_a3lux* provide the default settings for the taste-change variables (a3sub(i,q) and a3lux(i,q)), which allow the average budget shares to be shocked, via the a3com(c,q), in a way that preserves the pattern of expenditure elasticities.

The equations described determine the composition of regional household demands, but do not determine aggregate regional consumption.

Aggregate regional household consumption is determined in VURM by a *Keynesian* consumption function, which denotes nominal consumer spending (W3TOT(q)) as a proportion of regional household disposable income (WHINC_DIS(q)). The proportion is referred to as the regional average propensity to consume (APC(q)). VURM also allows for a national average propensity to consume (NATAPC). In level terms, nominal regional household consumption is:

$$W3TOT(q) = NATAPC \times APC(q) \times VHIC\_DIS(q) \qquad c \in COM \; q \in REGDST \qquad (E3.18)$$

Equation *E_apc* is the linearised form of Equation (E3.15).

Total regional household supernumerary expenditure (w3lux(q)) is linked to regional household consumption (w3tot(q)) via the linear expenditure system FRISCH 'parameter', which denotes the ratio of total to supernumerary household expenditure in region q. The share of supernumerary expenditure on commodity c in total expenditure on commodity c in region q (B3LUX(c,q)) is derived from the FRISCH parameter and the household expenditure elasticities (EPS(c,q)).

```
Equation E_x3o # Household demand for composite commodities #
(all,c,COM)(all,q,REGDST)
x3o(c,q) = (1 - B3LUX(c,q))*[qhous(q) + a3sub(c,q)] +
    B3LUX(c,q)*[w3lux(q) + a3lux(c,q) - p3o(c,q)];

Equation E_a3lux # Default setting for luxury taste shifter #
(all,c,COM)(all,q,REGDST)
a3lux(c,q) = a3sub(c,q) - sum{k,COM, DELTA(k,q)*a3sub(k,q)};

Equation E_a3sub # Default setting for subsistence taste shifter #
(all,c,COM)(all,q,REGDST)
a3sub(c,q) = a3tot(c,q) - sum{k,COM, S3O(k,q)*a3tot(k,q)};

Equation E_utility # Change in utility disregarding taste change terms #
(all,q,REGDST)
utility(q) = w3lux(q) - qhous(q) - sum{c,COM, DELTA(c,q)*p3o(c,q)};

Equation E_x3a # Demand for goods by source, User 3 #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
x3a(c,s,q) =
IF{s ne "imp",
    x3c(c,q) - SIGMA3C(c)*[p3a(c,s,q) - p3c(c,q)]} +
IF{s eq "imp",
    x3o(c,q) - SIGMA3O(c)*[p3a(c,"imp",q) - p3o(c,q)] +
     (V3PURT(c,"domestic",q)/(TINY+V3PURO(c,q)))*
        (twistsrc(c,q) + twistsrc_c(q) + nattwistsrc_c)};
```

```
Equation E_p3o # Price of domestic/imp composite, User 3 #
(all,c,COM)(all,q,REGDST)
ID01[V3PURO(c,q)]*p3o(c,q) = sum{s,ALLSRC, V3PURA(c,s,q)*p3a(c,s,q)};

Equation E_p3c # Price of domestic composite, User 3 #
(all,c,COM)(all,q,REGDST)
ID01[V3PURT(c,"domestic",q)]*p3c(c,q) = sum{s,REGSRC,
V3PURA(c,s,q)*p3a(c,s,q)};

Equation E_x3c # Demand for domestic composite, User 3 #
(all,c,COM)(all,q,REGDST)
x3c(c,q) = x3o(c,q) - SIGMA3O(c)*[p3c(c,q) - p3o(c,q)] -
    [V3PURT(c,"imp",q)/(TINY + V3PURO(c,q))]*
        (twistsrc(c,q) + twistsrc_c(q) + nattwistsrc_c);

Equation E_apc # Average propensity to consume #
(all,q,REGDST)
w3tot(q) = apc(q) + natapc + whinc_dis(q);
```

3.5 Foreign export demand

To model export demand, commodities in VURM are divided into six groups:

- traditional exports, which comprise the bulk of exports;
- non-traditional exports, which comprise mainly utilities and local services;
- tourism services exports, which comprise travel and hospitality services (hotels, cafes & accommodation, road passenger transport, air transport and other services);
- communications services exports;
- water transport services exports; and
- other transport services exports.

The distinction between traditional and non-traditional exports is based on the relative shares of exports in the total sales of each commodity, with exports accounting for a larger share of total sales for traditional exports than for non-traditional exports.

Each of the six categories of export demand is modelled differently.

3.5.1 Traditional exports (E_x4rA)

The traditional-export commodities (i.e., commodities in the set TEXP) are modelled as facing downward-sloping foreign-export demand functions:

$$X4R(c,s) = F4Q(c,s) \times NATF4Q\_C \times F4Q\_C(s) \times NATF4Q(c) \times \left(\frac{P4R(i,s)}{F4P(c,s) \times NATF4P\_C \times F4P\_C(s) \times NATF4P(c)} \right)^{SIGMAEXP(c)}$$

$c \in TEXP \quad s \in REGSRC \qquad (E3.19)$

X4R(c,s) is the export volume of commodity c from region s. The coefficient SIGMAEXP(c) is the (constant) own-price elasticity of foreign-export demand. As SIGMAEXP(c) is negative, (E3.20) says that traditional exports are a negative function of their foreign-currency prices on world markets (P4R(c,s)). The variables F4Q(c,s) and F4P(c,s) allow for horizontal (quantity) and vertical (price) shifts in the world demand schedules. The variables NATF4Q_C and NATF4P_C allow for economy-wide horizontal and vertical shifts in the demand schedules. The variables F4Q_C(s) and F4P_C(s), and NATF4Q(c) and NATF4P(c) allow for source specific and commodity specific economy wide shifts in the demand schedules, respectively. *E_x4rA* is the percentage-change form of (E3.20).

```
Equation E_x4rA # Export demand functions - traditional exports #
(all,c,TEXP)(all,s,REGSRC)
x4r(c,s) - f4q(c,s) - natf4q_c - f4q_c(s) - natf4q(c) =
[0 + IF[V4BAS(c,s) ne 0, SIGMAEXP(c)]]*
        [p4r(c,s) - f4p(c,s) - natf4p_c - f4p_c(s) - natf4p(c)] +
f_x4r1(c,s);
```

3.5.2 Non-traditional exports (E_x4r_ntrad to E_p4r_ntrad)

E_x4r_ntrad specifies the export demand for the non-traditional export commodities (i.e., commodities in the set NTEXP). In VURM, the commodity composition of aggregate non-traditional exports is exogenised by treating non-traditional exports as a Leontief aggregate. Thus, as shown in *E_x4rB*, with the shift variable fntrad(c,s) set to zero, the export demand for non-traditional export commodity c from source-region s moves by the common non-traditional export percentage, x4r_ntrad(s). The common percentage change is explained by equation *E_x4r_ntrad*. This equation relates movements in demand for non-traditional exports from region s to movements in the average foreign currency price of those exports via a constant-elasticity demand curve, similar to those for traditional exports. The elasticity of demand is given by the coefficient SIGMAEXPNTR, which is set to -5. Under this treatment, non-traditional exports respond as a group to changes in the group's international competitiveness.

We use the shift variables in equations *E_x4r_ntrad* to simulate various types of vertical and horizontal shifts in the export demand schedule for non-traditional exports from region s. For example, if f4q_ntrad(s) has a non-zero value, then we impose a horizontal shift on the group's export demand curve.

To simulate changes in the commodity composition of non-traditional exports, we can use non-zero settings for the shift variables in *E_x4rB*. For example, to cause the export volume of non-traditional component 'Construction' in region s to change by a given percentage amount, we can make x4r("Construction",s) exogenous by freeing up fntrad("Construction",s). In this case, the model would endogenously determine the value for fntrad("Construction",s) that reconciles the exogenously imposed setting of x4r("Construction",s) with the simulated value for x4r_ntrad(s).

Movements in the average foreign-currency price of non-traditional exports from region s (p4r_ntrad(s)) are determined via equation *E_p4r_ntrad*. The coefficient V4NTRAD(s) is the aggregate purchasers' value of non-traditional exports from region s.

```
Equation E_x4r_ntrad # Export demand functions, non-traditional aggregate #
(all,s,REGSRC)
x4r_ntrad(s) - f4q_ntrad(s) - natf4q_c - f4q_c(s)   =
    SIGMAEXPNTR*[p4r_ntrad(s) - f4p_ntrad(s) - natf4p_c - f4p_c(s)];

Equation E_x4rB # Individual exports linked to non-traditional aggregate #
(all,c,NTEXP)(all,s,REGSRC)
x4r(c,s) =
[0 + IF[V4BAS(c,s) ne 0, 1]]*x4r_ntrad(s) + fntrad(c,s) + f_x4r1(c,s);
```

```
Equation E_p4r_ntrad # Foreign-currency price of non-traditional aggregate
#
(all,s,REGSRC)
ID01[V4NTRAD(s)]*p4r_ntrad(s) = sum{c,NTEXP, V4PURR(c,s)*p4r(c,s)};
```

3.5.3 Tourism services exports (E_x4r_tour to E_p4r_tour)

These equations specify demands by foreign visitors in region s for tourism services (i.e., for commodities in the set TOUR). The foreign elasticity of demand for tourism services is set in the code at –5

The equations for tourism exports are similar to the equations for non-traditional exports. We adopt a similar 'bundle' approach to explaining exports of tourism services. Foreigners are viewed as buying a bundle of tourism services. The price of the tourism bundle is a Divisia index of the prices of all tourism exports.

The bundle-specification for tourism exports, which is also adopted in MONASH, is theoretically attractive. It is reasonable to think of foreign tourists as buying service bundles consisting of a fixed combination of commodities (say, an air ticket, a certain number of nights accommodation, and food), with the number of bundles purchased being sensitive to the cost of a 'bundle', but with little scope for substitution within the bundle. In other words, it is reasonable to think of the export demands for tourism commodities being tightly linked, each being determined not by movements in their individual price, but by movements in their overall average price.

```
Equation E_x4r_tour # Export demand functions, tourism aggregate #
(all,s,REGSRC)
x4r_tour(s) - f4q_tour(s) - natf4q_c - f4q_c(s)   =
    SIGMAEXPNTR*[p4r_tour(s) - f4p_tour(s) - natf4p_c - f4p_c(s)];

Equation E_x4rC # Individual exports linked to tourism aggregate #
(all,c,TOUR)(all,s,REGSRC)
x4r(c,s) =
[0 + IF[V4BAS(c,s) ne 0, 1]]*x4r_tour(s) + ftour(c,s) + f_x4r1(c,s);

Equation E_p4r_tour # Foreign-currency price of tourism exports #
(all,s,REGSRC)
ID01[sum{cc,TOUR, V4PURR(cc,s)}]*p4r_tour(s) =
sum{c,TOUR,V4PURR(c,s)*p4r(c,s)};
```

3.5.4 Communications services exports (E_x4rD)

This equation explains exports of commodities in the set COMMUNIC. This set contains a single element, communication services. Following the treatment in MONASH, exports of communications services from source s are driven by the volume of foreign imports of communications services into s (X0IMP(c,s), for c∈ COMMUNIC). This is based on the observation that communication exports consist mainly of charges by Australian telephone companies for distributing incoming phone calls, and of charges by Australian post for delivering foreign mail within Australia. Accordingly, on the assumption that outgoing communications generate incoming communications, the volume of communications imports drives the volume of communications exports. The variable fcommunic(c,s) for c∈ COMMUNIC allows for shifts in the ratio of communication exports to imports in region s.

```
Equation E_x4rD # Communication exports move with communication imports #
(all,c,COMMUNIC)(all,s,REGSRC)
x4r(c,s) = x0imp(c,s) + fcommunic(c,s) + f_x4r1(c,s);
```

3.5.5 Water transport services exports (E_x4r_trad to E_x4rE)

E_x4rE when activated deals with exports of commodities in the set WATTRANS. This set contains a single element, water transport services. Following the treatment in MONASH, exports of water transport freight in region s are assumed to move in line with the aggregate volume of traditional exports as found in equation *E_x4r_trad*. The rationale is that the main use of water transport services outside Australia is for the shipment of bulk traditional exports, especially, iron ore, coal, liquefied natural gas and grain. The variable fwattrans(c,s) for c∈ WATTRANS allows for shifts in the ratio of water transport exports to the volume of traditional exports.

```
Equation E_x4r_trad # Volume of traditional exports from region s #
(all,s,REGSRC)
x4r_trad(s) = sum{c,TEXP, V4PURR(c,s)/sum{cc,TEXP, V4PURR(cc,s)}*x4r(c,s)};

Equation E_x4rE # Exports of water transport move with traditional exports
#
(all,c,WATTRANS)(all,s,REGSRC)
x4r(c,s) = x4r_trad(s) + fwattrans(c,s) + f_x4r1(c,s);
```

3.5.6 Other transport services exports (E_x4rF)

E_x4rF deals with exports of commodities in the set OTHTRANS. This set contains a single element, other transport services. Again, we follow the MONASH treatment. Exports of other transport services consist mainly of harbour and airport services provided to foreign ships and planes in Australia. The MONASH treatment recognises three reasons for these trips to Australia: (a) to carry Australian passengers to and from Australia; (b) to carry foreign passengers to and from Australia; and (c) to facilitate commodity trade. In the current version of VURM, the volume of air transport services imported is used as a proxy for (a), the volume of tourism exports is used a proxy for (b), and the aggregate volume of traditional exports is used as a proxy for (c). The weights shown in *E_x4rF* are essentially guesses. The shift variable fothtrans_s(i,s) allows for extraneous shifts.

```
Equation E_x4rF # Other transport exports move with selected average of
trade #
(all,c,OTHTRANS)(all,s,REGSRC)
x4r(c,s) =
   0.25*x0imp("AirTrans",s) + 0.25*x4r_tour(s) + 0.5*x4r_trad(s) +
    fothtrans(c,s) + f_x4r1(c,s);
```

3.6 Government consumption demand (E_x5a to E_x6a)

Equation *E_x5a* determines regional government demand for commodities for current consumption. In *E_x5a*, regional government consumption is constrained to preserve a constant ratio with regional private consumption expenditure (X3TOT(q)). The shift variables f5a(c,s,q), f5tot(q) and natf5tot allow for shifts in the ratio of X5A(c,s,q) to X3TOT(q). To impose a non-uniform change in the ratio, we can use non-zero settings for the ‘f5a’ variables. To impose a uniform change in any region, we can use non-zero settings for the ‘f5tot’ variables, and to impose a uniform change across all regions, we can use a non-zero setting for natf5tot.

Equation *E_x6a* determines federal government demand for commodities for current consumption. *E_x6a* operates in a similar way to to *E_x6a* for regional government demand except that federal government consumption is constrained to preserve a constant ratio with national private consumption expenditure (natx3tot). The shift variables f6a(c,s,q), f6tot(q) and natf6tot allow for shifts in the ratio of X6A(c,s,q) to NATX3TOT. To impose a non-uniform change in the ratio, we can use non-zero settings for the 'f6a' variables. To impose a uniform change in any region, we can use non-zero settings for the 'f6tot' variables, and to impose a uniform change across all regions, we can use a non-zero setting for natf6tot.

The linking of regional and federal government current consumption expenditure to the cohort-based demographic module is discussed in chapter 5.

```
Equation E_x5aA # Regional government consumption (standard) #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
x5a(c,s,q) = x3tot(q) + f5a(c,s,q) + f5tot(q) + natf5tot;

Equation E_x6aA # Federal government consumption (standard) #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
x6a(c,s,q) = natx3tot + f6a(c,s,q) + f6tot(q) + natf6tot;
```

3.7 Inventory accumulation (E_d_x7r to E_d_w7r)

Inventories of commodity c in region s are assumed to accumulate in proportion to output of commodity c in region s. In equation *E_d_x7r*, the ordinary change in inventories, d_x7r(c,s), is used instead of percentage change, because the volume of inventories may be zero or negative. The shift term d_fx7r(c,s) allows for a change in the ratio of inventories to output.

Equation *E_d_w7r* gives the value of the change in inventories by including the price terms. Margins and taxes are assumed not to apply to inventories, so they are valued at basic prices.

```
Equation E_d_x7r # Stocks follow domestic output #
(all,c,COM)(all,s,REGSRC)
100*ID01[LEVP7R(c,s)]*d_x7r(c,s) = V7BAS(c,s)*x0com_i(c,s) + d_fx7r(c,s);

Equation E_d_w7r # Value of change in inventory accumulation #
(all,c,COM)(all,s,REGSRC)
d_w7r(c,s) = 0.01*V7BAS(c,s)*p0a(c,s) + LEVP7R(c,s)*d_x7r(c,s);
```

3.8 National Electricity Market services demand

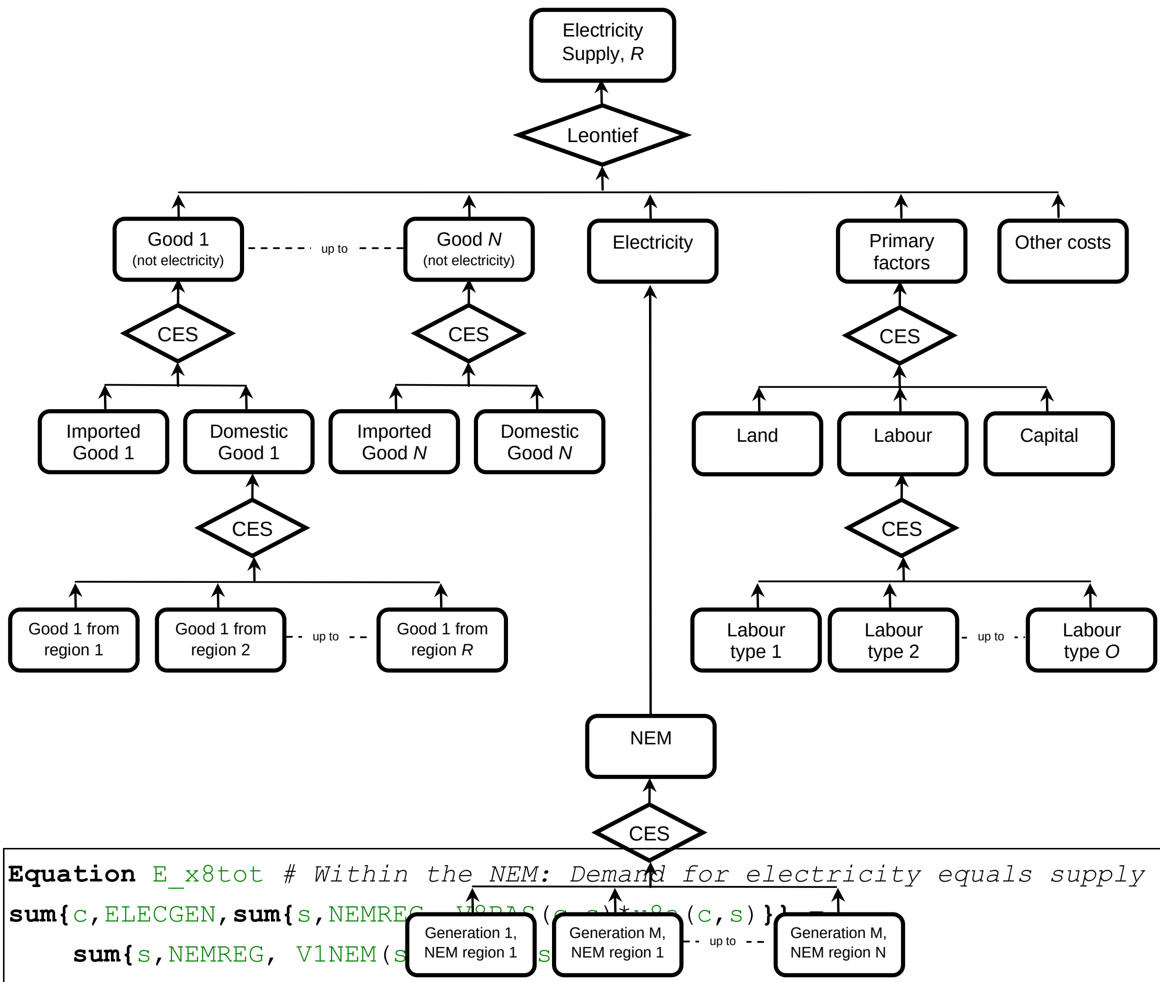
3.8.1 Electricity demands within the NEM (E_x8aA to E_anem)

Figure 3.5 describes the structure of input demands by electricity supply industries within the NEM. Electricity supply industries within the NEM source their electricity from the NEM. Equation *E_x1NEMB* describes the souring of electricity from the NEM. The NEM pools demands by all electricity suppliers within the NEM region (presently all states and territories other than WA and NT), and matches these demands with total supplies of power by generators within the NEM. This matching of demand and supply is described by Equation *E_x8tot*. The NEM minimises the cost of total power supplied within the NEM by choosing between competing generators across all NEM regions. In satisfying total electricity demands within the NEM region, the NEM's ability to substitute between alternative sources of generation across different regions is constrained by a CES function.

The resulting source- and generation-specific NEM electricity demand equations are described by Equation *E_x8aC*.

```
! Generation substitution inside the NEM !
Equation E_x8aA # NEM demand for generation outside of NEM states = 0 #
(all,c,COM)(all,s,NOTNEMREG)
x8a(c,s) - a8a(c,s)  = 0*d_unity;

Equation E_x8aB # NEM demand for non-generation = 0 #
(all,c,NOTGENCOM)(all,s,NEMREG)
x8a(c,s) - a8a(c,s) = 0*d_unity;

Equation E_x8aC # NEM demand for generation from NEM states #
(all,c,ELECGEN)(all,s,NEMREG)
x8a(c,s) - a8a(c,s) - anem =
    x8tot -SIGMAELEC(s)*[p8a(c,s) + a8a(c,s) + anem - p8tot];

Equation E_x1NEMA # NEM supply to retailers outside of NEM states = 0 #
(all,q,NOTNEMREG)
x1NEM(q) = 0*d_unity;

Equation E_x1NEMB # NEM supply to retailers inside NEM states #
(all,q,NEMREG)
x1NEM(q) = sum{i,ELECSUPPLY, x1tot(i,q) + a1(i,q)};
```

Figure 3.5: Production technology for electricity supply industry in NEM region R

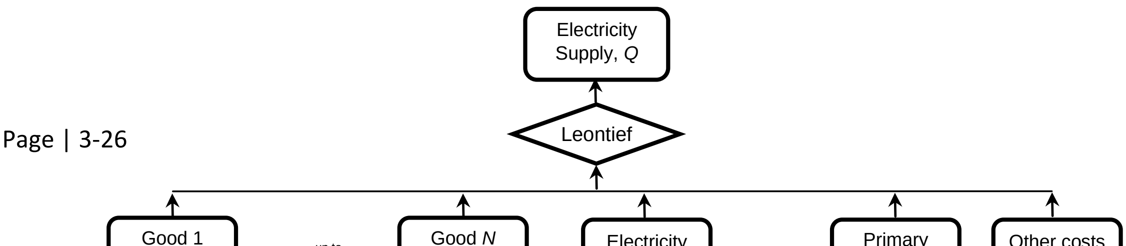



```
Equation E_x8tot # Within the NEM: Demand for electricity equals supply #
sum{c,ELECGEN,sum{s,NEMREG, V8BAS(c,s)}*x8a(c,s)}} =
    sum{s,NEMREG, V1NEM(s [illegible]

Equation E_p8tot # NEM generation price #
sum{c,ELECGEN,sum{s,NEMREG, V8BAS(c,s)}}*p8tot =
    sum{c,ELECGEN,sum{s,NEMREG, V8BAS(c,s)*(p8a(c,s) + a8a(c,s) + anem)}};

Equation E_anem
# Allows for changes to anem to offset cost effects of a8a #
sum{c,ELECGEN,sum{s,NEMREG, V8BAS(c,s)}}*anem =
    -sum{c,ELECGEN,sum{s,NEMREG, V8BAS(c,s)*a8a(c,s)}};
```

3.8.2 Electricity demands outside the NEM (E_elecsub to E_p1elec)

Figure 3.6 describes the structure of input demands by electricity suppliers in regions outside the NEM. This differs from Figure 3.2 and 3.4 only in the sourcing of electricity. The electricity supply industry in non-NEM region Q must source its electricity from generators within region Q. Electricity suppliers in regions outside the NEM minimise the cost of the electricity they purchase from local generators subject to a CES specification of imperfect substitution possibilities across alternative local generators. The resulting input demand and per-unit cost equations are given by *E_elecsub* and *E_p1elec* in the above TABLO-excerpt.

Figure 3.6: Production technology for electricity supply industry in non-NEM region Q



```
! Generation substitution outside of the NEM !
Equation E_elecsub # Electricity substitution effect outside of the NEM #
(all,c,COM)(all,i,IND)(all,q,REGDST)
elecsub(c,i,q) = -ISGEN(c)*SIGMAELEC(q)*[p1o(c,i,q) + a1(i,q) +
  a1o(c,i,q) + acom(c,q) + natacom(c) + acomind(c,i,q) + aind(i,q) -
p1elec(q)];

Equation E_p1elec # General price of electricity generation outside of the
NEM #
(all,q,REGDST)
ID01[sum{i,ELECSUPPLY,sum{c,ELECGEN, V1PURO(c,i,q)}}]*p1elec(q) =
    sum{i,ELECSUPPLY,sum{c,ELECGEN, V1PURO(c,i,q)*
        [p1o(c,i,q) + a1(i,q) + a1o(c,i,q) + acom(c,q) + natacom(c) +
            acomind(c,i,q) + aind(i,q)]}};
```

3.9 Margin services

3.9.1 Demand for margin services (E_x1marg to E_x6marg)

Commodities in the set MARGCOM can be used as margin services. Typical elements of MARGCOM are wholesale and retail trade, road freight, rail freight, water transport and air transport. These commodities, in addition to being consumed directly by the users (e.g., consumption of transport when taking holidays or commuting to work), are also consumed to facilitate trade (e.g., the use of transport to ship commodities from point of production to point of consumption). The latter type of demand for transport is a so-called demand for margin services.

Equations *E_x1marg*, *E_x2marg*, *E_x3marg, E_x4marg, E_x5marg* and *E_x6marg* give the demands by users 1 to 6 for margin services. As indicated in figure 3.1, we assume that there are no margins on inventory accumulation. For margins other than road and rail freight, equations *E_x1marg* to *E_x6marg* indicate that the demands are proportional to the commodity flows with which the margins are associated. For example, the demand for margin type r on the flow of commodity c from source s to industry i in region q for use in current production (x1marg(c,s,i,q,r)) moves with the underlying demand (x1a(c,s,i,q)). In each equation, there is a technological variable specific to that user (a1marg(q,r), etc.), and two non user-specific term acom(r,q), representing technological change in the use of margin service r per unit of demand in region q , and natacom(r), representing technological change in the use of margin service r per unit of demand across all regions and users.

The final variable in each equation, modalsub1(c,s,q,r) etc, captures substitution between road and rail transport (discussed in section 3.2.7.1).

```
Equation E_x1marg # Margins on sales to producers #
(all,c,COM)(all,i,IND)(all,q,REGDST)(all,s,ALLSRC)(all,r,MARGCOM)
x1marg(c,s,i,q,r) - a1marg(q,r) - acom(r,q) - natacom(r) =
    x1a(c,s,i,q) + modalsub1(c,s,i,q,r);

Equation E_x2marg # Margins on sales to capital creators #
(all,c,COM)(all,q,REGDST)(all,s,ALLSRC)(all,i,IND)(all,r,MARGCOM)
x2marg(c,s,i,q,r) - a2marg(q,r) - acom(r,q) - natacom(r) =
    x2a(c,s,i,q) + modalsub2(c,s,i,q,r);

Equation E_x3marg # Margins on sales to household consumption #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)(all,r,MARGCOM)
x3marg(c,s,q,r) - a3marg(q,r) - acom(r,q) - natacom(r) =
    x3a(c,s,q) + modalsub3(c,s,q,r);

Equation E_x4marg # Margins on exports: factory gate to port #
(all,c,COM)(all,r,MARGCOM)(all,s,REGSRC)
x4marg(c,s,r) - a4marg(s,r) - acom(r,s) - natacom(r) =
    x4r(c,s) + modalsub4(c,s,r);

Equation E_x5marg # Margins on sales to regional government consumption #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)(all,r,MARGCOM)
x5marg(c,s,q,r) - a5marg(q,r) - acom(r,q) - natacom(r) =
    x5a(c,s,q) + modalsub5(c,s,q,r);
```

```
Equation E_x6marg # Margins on sales to federal government consumption #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)(all,r,MARGCOM)
x6marg(c,s,q,r) - a6marg(q,r) - acom(r,q) - natacom(r) =
    x6a(c,s,q) + modalsub6(c,s,q,r);
```

3.9.2 Road-Rail substitution in margin use (E_p1modalsub to E_modalsub6)

VURM allows for substitution in the use of road and rail freight margin services used in production. Specifically, for a flow from region s to region q, substitution is allowed between road freight and rail freight provided by region q. The substitution is based on relative margin-supply prices. If in region q, the price of road freight increases relative to the price of rail freight, then there will be substitution away from road freight towards rail freight in all margin uses of the two in region q.

The substitution effects are modelled by introducing into equations *E_x1marg* to *E_x6marg* the substitution terms modalsub1 to modalsub6. The calculations for the substitution terms for each of the six users are similar, and are given by the equations *E_modalsub1* to *E_modalsub6*. In equation *E_modalsub1*, modalsub1(c,s,i,q,r) depends on a relative price term involving the price of margin r (r = 'RoadTrans' or 'RailTrans') in region q relative to the average price of road and rail transport in region q. The coefficient ISROADRAIL(r) equals one when r is 'RoadTrans' or 'RailTrans', and is zero otherwise, so that modalsub1(c,s,i,q,r) = 0 for margins other than road and rail transport. SIGROADRAIL is the inter-modal substitution elasticity for road and rail. If the price of road transport increases relative to the price of rail transport for margin use on the flow of commodity c from source s to industry i in region q, then modalsub(c,s,i,q,"RoadTrans") will be negative, and have a negative effect on the use of road transport to facilitate the flow of commodity c from source s to industry i in region q (x1marg(c,s,i,q,"RoadTrans").

Movements in the average prices of road and rail freight for each user of freight (p1modalsub(c,s,i,q), p2modalsub(c,s,i,q), p3modalsub(c,s,q), p4modalsub(c,q), p5modalsub(c,s,q) and p6modalsub(c,s,q)) are explained by equations *E_p1modalsub* to *E_p6modalsub*. In these equations, the 'MAR' coefficients are matrices of data showing the cost of the margins services on the flows of goods, both domestically produced and imported, to users.

```
Equation E_modalsub1 # Road/rail substitution in demand for production #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)(all,r,MARGCOM)
modalsub1(c,s,i,q,r) = -ISROADRAIL(r)*SIGROADRAIL*
    [p0a(r,q) - p1modalsub(c,s,i,q)];

OMITTED: E_modalsub2 to E_modalsub6 follow the same pattern as E_modalsub1

Equation E_p1modalsub # Average price of margins which substitute, user 1 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
ID01[sum{r,MARGCOM,ISROADRAIL(r)*V1MAR(c,s,i,q,r)}]*p1modalsub(c,s,i,q) =
    sum{r,MARGCOM,ISROADRAIL(r)*V1MAR(c,s,i,q,r)*p0a(r,q)};

OMITTED: E_p2modalsub to E_p6modalsub follow the same pattern as
E_p1modalsub
```

3.10 Indirect taxes on products (E_d_t1F to E_d_t4gst)

VURM makes provision for three types of product (or indirect) taxes:

- regional government taxes on products;
- federal government taxes on products; and
- the goods and services tax (GST).

The GST is reported separately, as its tax base differs from the other product taxes. (GST is frequently levied on other taxes on products.)

Variables denoting regional government product taxes end in an 'S' (for state), and those for the federal government end in an 'F'. In keeping with the general convention, the number in the variable name indicates the relevant category of demand (1=production, 2=investment, etc).

As indicated in figure 3.1, it is assumed that no product taxes apply to demand by regional and federal governments, demand for use in inventories or demand by the NEM.[19] It is further assumed that regional product taxes are not levied on the sale of international exports (i.e., there is no V4TAXS).

While provision is made for product taxes in VURM, the data in the database determines whether or not the tax is levied on each element. For example, while provision is made for the GST to be applied to all export sales, it only applies to a limited number of exports in the model database.

This block of equations pertaining to indirect taxes on products contains the default rules for setting federal and regional sales-tax rates (not GST) for producers (*E_d_t1F* and *E_d_t1S*), investors (*E_d_t2F* and *E_d_t2S*), households (*E_d_t3F* and *E_d_t3S*), and exports (*E_d_t4F*)[20], and GST rates (*E_d_t1GST* to *E_d_t4GST*). Non-GST sales taxes are treated as *ad valorem* tax on the price received by the producer, while GST taxes are treated as *ad valorem* tax on the price received by the producer plus any markup due to margins (freight, etc) applying to the underlying flow. The sales-tax variables (d_t1F(c,s,i,q), etc) are ordinary changes in the percentage tax rates, i.e., the percentage-point changes in the tax rates. Thus, a value of d_t1F(c,s,i,q) of 20 means the percentage tax rate on commodity c from source s used as an input to current production in industry i in region q increased from, say, 24 to 44 per cent.

For each user, the sales-tax and GST equations allow for variations in tax rates across commodities, their sources and their destinations via changes to a wide range of shift variables. In the federal non-GST sales tax equation *E_d_t1F*, the coefficient ISFUEL(c) equals one when c is a greenhouse gas emitting fuel (VURM commodities 'Petroleum' and 'CoalOilGas'), and is zero otherwise. The variable d_t1Fgas is the *ad valorem* equivalent of any carbon-dioxide equivalent ($C0_2$-e) tax imposed on the use of fuel in current production. Conversion from a $C0_2$-e tax, which is imposed on tonnes of $C0_2$-e emissions, to the *ad valorem* d_t1Fgas occurs in the greenhouse gas module (see section 8.5). Note that d_t1Fgas is a federal tax, not a regional tax.

[19] The supply of electricity, however, is subject to taxation.
[20] Note that there are no regional sales taxes on exports in VURM.

```
! Indirect tax rates !
Equation E_d_t1F # Federal tax rate (not GST) on sales to User 1 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
d_t1F(c,s,i,q) = {0 + IF(V1TAXF(c,s,i,q) gt 0,1)}*
  [d_tF+d_t1F_csiq+d_t1F_si(c,q)+d_t1F_siq(c)+d_tFs(s)+d_tFq(q)+d_tFc(c)] +
    ISFUEL(c)*d_t1Fgas(COM2FUEL(c),i,q) + d_tFgascs(c,s);

Equation E_d_t1S # Regional tax  rate on sales to User 1 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
d_t1S(c,s,i,q) = {0 + IF(V1TAXS(c,s,i,q) gt 0,1)}*
    [d_t1S_si(c,q)+d_t1S_siq(c)+d_tSs(s)+d_tSq(q)+d_tSc(c)+d_tScq(c,q)];

Equation E_d_t2F # Federal tax rate (not GST) on sales to User 2 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
d_t2F(c,s,i,q) =  {0 + IF(V2TAXF(c,s,i,q) gt 0,1)}*
  [d_tF+d_t2F_csiq+d_t2F_si(c,q)+d_t2F_siq(c)+d_tFs(s)+d_tFq(q)+d_tFc(c)] +
    d_tFgascs(c,s);

Equation E_d_t2S # Regional tax  rate on sales to User 2 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
d_t2S(c,s,i,q) =  {0 + IF(V2TAXS(c,s,i,q) gt 0,1)}*
    [d_t2S_si(c,q)+d_t2S_siq(c)+d_tSs(s)+d_tSq(q)+d_tSc(c)+d_tScq(c,q)];

Equation E_d_t3F # Federal tax rate (not GST)on sales to User 3 #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
d_t3F(c,s,q) =  {0 + IF(V3TAXF(c,s,q) gt 0,1)}*
    [d_tF+d_t3F_csq+d_t3F_s(c,q)+d_t3F_sq(c)+d_tFs(s)+d_tFq(q)+d_tFc(c)] +
    ISFUEL(c)*d_t3Fgas(COM2FUEL(c),q) + d_tFgascs(c,s);

Equation E_d_t3S # Regional tax  rate on sales to User 3 #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
d_t3S(c,s,q) =  {0 + IF(V3TAXS(c,s,q) gt 0,1)}*
    [d_t3S_s(c,q)+d_t3S_sq(c)+d_tSs(s)+d_tSq(q)+d_tSc(c)+d_tScq(c,q)];

Equation E_d_t4f # Federal tax rate (not GST) on sales to User 4 #
(all,c,COM)(all,s,REGSRC)
d_t4f(c,s) = {0 + IF(V4TAXF(c,s) gt 0,1)}*
    [d_tF+d_tFs(s)+d_tFc(c)+d_t4f_cs+d_t4f_s(c)+d_tFs(s)+d_tFc(c)] +
    d_tFgascs(c,s);

Equation E_d_t1GST
# %-Point change in tax rate on commodity sales to 1: GST #;
 (all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
d_t1GST(c,s,i,q) =
    {0 + IF(V1GST(c,s,i,q) gt 0,1)}*[d_tGST + d_tGSTq(q) + d_t0(q)];

Equation E_d_t2GST
# %-Point change in tax rate on commodity sales to 2: GST #;
 (all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
d_t2GST(c,s,i,q) =
    {0 + IF(V2GST(c,s,i,q) gt 0,1)}*[d_tGST + d_tGSTq(q) + d_t0(q)];
```

```
Equation E_d_t3GST
# %-Point change in tax rate on commodity sales to 3: GST #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
d_t3GST(c,s,q) =
    {0 + IF(V3GST(c,s,q) gt 0,1)}*[d_tGST + d_tGSTq(q) + d_t0(q) +
d_t3Fcomp];

Equation E_d_t4GST
# %-Point change in tax rate on commodity sales to 4: GST #;
 (all,c,COM)(all,s,REGSRC)
d_t4GST(c,s) =
    {0 + IF(V4GST(c,s) gt 0,1)}*[d_tGST + d_tGSTq(s) + d_t0(s)];
```

3.11 Labour use, prices and incomes

We now turn our attention to the fifth last row in figure 3.1 dealing with labour income from production.

Reflecting taxes on the use of labour in production, a distinction is made between the nominal wage-bill paid by industry and the income accruing to labour.

The nominal wage-bill is the total cost to producers of employing labour. It includes any taxes, such as payroll tax, levied on the use of labour in production paid by producers. It does not include any income tax subsequently paid by employees.

In level terms, the wage-bill on the use of occupation o in industry i in region q is:

$$\mathrm{V1LAB(i,q,o)} = \mathrm{P1LAB(i,q,o)} \times \mathrm{X1LAB(i,q,o)} \quad i \in \mathrm{IND}\ q \in \mathrm{REGDST}\ o \in \mathrm{OCC} \qquad \text{(E3.20)}$$

where: P1LAB(i,q,o) is the hourly wage paid by industry; and X1LAB(i,q,o) is total hours worked (employment).

The total wage-bill for the economy is:

$$\mathrm{NATV1LAB\_IO} = \sum_{i \in \mathrm{IND}} \sum_{q \in \mathrm{REGDST}} \sum_{o \in \mathrm{OCC}} \mathrm{P1LAB(i,q,o)} \times \mathrm{X1LAB(i,q,o)}$$

3.11.1 Hourly wage rate paid to labour

3.1.1.4 Nominal hourly wage rate (E_p1lab to E_natpwage_io)

In equation *E_p1lab*, the percentage change in the hourly wage paid by industry i in region q for occupation o (p1lab(i,q,o)) is set equal to the percentage change in the nominal hourly wage rate paid to labour (pwage(i,q,o)) plus any federal and regional taxes on the use of labour in production (d_t1labF(i,q) and d_t1labS(i,q), respectively).

Equation *E_pwage* determines the nominal hourly wage rate. The equation allows significant flexibility in setting of the wage rates. The nominal hourly wage rate is indexed to the regional consumer price index (p3tot(q)). The 'fpwage' variables allow for deviations in wages relative to the regional consumer price index. For example, a value for fpwage_io of 1 for all regions, with all other shift variables set to zero, means that money wage rates in each region will rise by 1 per cent relative to the regional consumer price index.

Using the model's standard closure (see chapter 9), equation *E_pwage_io* effectively explains fpwage_io(q), rather than the LHS variable, pwage_io(q). In the standard closure, wage differentials across regions are fixed so that pwage_io(q) is indexed to the national wage rate, natpwage_io. With pwage_io(q) determined in this way, *E_pwage_io* ensures that the appropriate adding-up conditions holds via endogenous changes in fpwage_io.

```
Equation E_p1lab
# Effective price of labour (p1lab) related to the wage rate (pwage) #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
p1lab(i,q,o) = pwage(i,q,o) + IF{V1LAB(i,q,o) ne 0,
        [V1LABINC(i,q,o)/V1LAB(i,q,o)]*(d_t1labF(i,q) + d_t1labS(i,q))};

Equation E_pwage # Flexible setting of money wages #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
pwage(i,q,o) = {0 + IF(V1LAB(i,q,o) ne 0, 1)}*[p3tot(q) +
natfpwage_io + natfpwage_i(o) + fpwage_io(q) + fpwage_i(q,o) +
fpwage(i,q,o)];

Equation E_pwage_i # Regional wage rate for occupation o #
(all,q,REGDST)(all,o,OCC)
EMPLOY_I(q,o)*pwage_i(q,o) = sum{i,IND, EMPLOY(i,q,o)*pwage(i,q,o)};

Equation E_pwage_o # Flexible setting of money wages #
(all,i,IND)(all,q,REGDST)
ID01[EMPLOY_O(i,q)]*pwage_o(i,q) = sum{o,OCC, EMPLOY(i,q,o)*pwage(i,q,o)};

Equation E_pwage_io # Region-wide nominal wage received by workers #
(all,q,REGDST)
EMPLOY_IO(q)*pwage_io(q) = sum{o,OCC, EMPLOY_I(q,o)*pwage_i(q,o)};

Equation E_natpwage_i # National wage rate for occupation o #
(all,o,OCC)
NATEMPLOY_I(o)*natpwage_i(o) = sum{q,REGDST, EMPLOY_I(q,o)*pwage_i(q,o)};

Equation E_natpwage_io # Aggregate nominal wages of workers #
sum{o,OCC,sum{q,REGDST, EMPLOY_I(q,o)}}*natpwage_io =
    sum{o,OCC,sum{q,REGDST, EMPLOY_I(q,o)*pwage_i(q,o)}};
```

3.1.1.5 *Real hourly wage rate* (E_rwage_c to E_natrwage_c)

Consequently, equation *E_rwage_c* expresses the percentage change in the real wage to consumers, denoted by the suffix '_c'. It uses the regional consumer price index as deflator (p3tot(q)) to represent change in real purchasing power of the nominal hourly wage in the hands of labour by region. Analogously, equations *E_natrwage_i* and *E_natrwage_c* determine the percentage changes in the national real wage to consumers by occupation and the overall national real wage to consumers, respectively.

```
Equation E_rwage_c # Consumer real wage rate by region #
(all,q,REGDST)
rwage_c(q) = pwage_io(q) - p3tot(q);

Equation E_natrwage_i # National real wage for occupation o: consumer #
(all,o,OCC)
natrwage_i(o) = natp1lab_i(o) - natp3tot;

Equation E_natrwage_c # National real wage: consumer #
natrwage_c = natpwage_io - natp3tot;
```

3.11.2 Unit labour costs

3.1.1.6 Nominal unit labour costs (E_p1lab_o to E_natp1labio)

The variable p1lab(I,q,o) denotes the percentage change in the nominal unit cost of occupation o employed in industry i in region q. This represents the total cost incurred by employers.

The remaining equations in this section define occupational, industry and regional averages for nominal unit labour costs. *E_p1lab_o*, for example, defines the cost of labour (its price) for occupation o in industry i in region q.

```
Equation E_p1lab_o
# Price to producers of effective labour composite by industry & region #
(all,i,IND)(all,q,REGDST)
ID01[V1LAB_O(i,q)]*p1lab_o(i,q) = sum{o,OCC, V1LAB(i,q,o)*
     [p1lab(i,q,o) + a1lab(i,q,o) + a1lab_i(q,o) + nata1lab_i(o)]};

Equation E_natp1lab_i # National unit cost of labour by occupation #
(all,o,OCC)
NATV1LAB_I(o)*natp1lab_i(o) =
    sum{i,IND,sum{q,REGDST, V1LAB(i,q,o)*p1lab(i,q,o)}};

Equation E_natp1lab_o # Economy-wide unit cost of labour by industry #
(all,i,IND)
ID01[NATV1LAB_O(i)]*natp1lab_o(i) =
            sum{o,OCC,sum{q,REGDST, V1LAB(i,q,o)*p1lab(i,q,o)}};

Equation E_p1lab_io
# Price to producers of effective labour composite by region #
(all,q,REGDST)
V1LAB_IO(q)*p1lab_io(q) = sum{i,IND, V1LAB_O(i,q)*p1lab_o(i,q)};

Equation E_natp1lab_io # Aggregate nominal wages paid by producers #
NATV1LAB_IO*natp1lab_io = sum{q,REGDST, V1LAB_IO(q)*p1lab_io(q)};
```

3.1.1.7 Real unit labour costs (E_rwage_p to natrwage_p)

Consequently, equation *E_rwage_p* expresses the real unit labour costs to producers, denoted by the suffix '_p'. It uses the gross regional product deflator (p0gspexp(q)) to represent the change in the real cost of labour to producers. Equation *E_natrwage_p* determines the percentage change in the national real unit labour costs.

```
Equation E_rwage_p # Real unit cost of labour by region #
(all,q,REGDST)
rwage_p(q) = p1lab_io(q) - p0gspexp(q);

Equation E_natrwage_p # National real unit cost of labour #
natrwage_p = natp1lab_io - p0gdpexp;
```

3.11.3 Employment

3.1.1.8 Hours worked (E_x1lab_i to E_natx1lab_io)

The variable x1lab(I,q,o) denotes the percentage change in hours worked by occupation o in industry i in region q. The quantity of labour inputs used by producers is determined by solving the cost minimisation problem for a given level of gross output and primary factor use.

Equation *E_x1lab_i* defines the percentage change in regional employment for each of the eight occupational skill groups. Equation *E_natx1lab_i* defines the analogous percentage change in employment for the eight occupations at the national level. Equation *E_natx1lab_o* defines the percentage change in employment by national industry. Equation *E_natx1lab_io* defines the percentage change in aggregate national employment.

Each of these categories of employment change is aggregated using nominal wage-bill weights (V1LAB(I,q,o)).

```
Equation E_x1lab_i # Demand for labour by region & occupation #
(all,o,OCC)(all,q,REGDST)
V1LAB_I(q,o)*x1lab_i(q,o) = sum{i,IND, V1LAB(i,q,o)*x1lab(i,q,o)};

Equation E_natx1lab_i # National demand for labour by occupation #
(all,o,OCC)
NATV1LAB_I(o)*natx1lab_i(o) = sum{q,REGDST, V1LAB_I(q,o)*x1lab_i(q,o)};

Equation E_natx1lab_o # Aggregate employment (wage-bill weights) #
(all,i,IND)
ID01[NATV1LAB_O(i)]*natx1lab_o(i) = sum{q,REGDST,
V1LAB_O(i,q)*x1lab_o(i,q)};

Equation E_natx1lab_io # Aggregate employment (hours)(wage-bill weights) #
NATV1LAB_IO*natx1lab_io = sum{q,REGDST, V1LAB_IO(q)*x1lab_io(q)};
```

3.1.1.9 *Persons employed* (E_x1emp to E_d_unro)

For each occupation and regional industry, equation *E_x1emp* links the use of labour in production (x1lab(i,q,o)) to changes in the number person employed (x1emp(i,q,o)) and average hours worked (r_x1lab_x1emp(I,q,o)).

Equation *E_d_unro* determines the ordinary (percentage point) change in the unemployment rate for each occupation and region. The change in the unemployment rate is the difference between the growth in the supply of labour in persons (lab(q,o)) and person employed (x1emp)i(q,o)).

```
Equation E_x1emp # Employment (hours) linked to employment (persons) #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
x1lab(i,q,o) = x1emp(i,q,o) + r_x1lab_x1emp(i,q,o);

Equation E_d_unro # %-Point change in state unemployment rate by occ #
(all,q,REGDST)(all,o,OCC)
LABSUP(q,o)*d_unro(q,o) = EMPLOY_I(q,o)*[lab(q,o) - x1emp_i(q,o)];
```

3.11.4 Cost of employing labour

3.1.1.10 *The nominal wage bill* (E_w1lab_io to E_natw1lab_io)

The percentage change in the wage bill — the cost to industry of employing labour — implied by equation (E3.20) is implicitly:

$$\mathrm{p1lab}(\mathrm{i},\mathrm{q},\mathrm{o}) + \mathrm{x1lab}(\mathrm{i},\mathrm{q},\mathrm{o})$$

These variables are used to update the wage-bill coefficient V1LAB(i,q,o), which is used, either directly or indirectly, to aggregate most labour market variables (price of labour, hours worked and wage bills). This approach is in line with that used in the ORANI suite of models.

Equations *E_w1lab_io* and *E_natw1lab_io* determine the percentage changes in the regional and national payments by industry to labour (i.e., the wage bill), respectively.

```
Equation E_w1lab_io # Aggregate payments to labour by region #
(all,q,REGDST)
V1LAB_IO(q)*w1lab_io(q) =
    sum{i,IND,sum{o,OCC, V1LAB(i,q,o)*(p1lab(i,q,o) + x1lab(i,q,o))}};

Equation E_natw1lab_io # Aggregate payments to labour #
NATV1LAB_IO*natw1lab_io = sum{q,REGDST, V1LAB_IO(q)*w1lab_io(q)};
```

3.11.5 Taxes on the use of labour in production

3.1.1.11 Federal and regional tax rates (E_d_t1labF to E_d_t1labS)

The taxation of payments to labour and other primary factors used in production is discussed in box 3.2.

Equations *E_d_t1labF* and *E_d_t1labS* detail the percentage point changes in the federal and regional tax rates, respectively, on labour income (termed payroll tax rates in the TABLO code).

```
Equation E_d_t1labF # %-Point change in payroll tax rate - federal #
(all,i,IND)(all,q,REGDST)
d_t1labF(i,q) = {0+ IF(sum{o,OCC, V1LABTXF(i,q,o)} gt 0,1)}*
    (d_t1labF_i(q) + d_t1labF_iq + d_t0("Federal")) + d_Ft1labF(i,q);

Equation E_d_t1labS # %-Point change in payroll tax rate - regional #
(all,i,IND)(all,q,REGDST)
d_t1labS(i,q) = {0+ IF(sum{o,OCC, V1LABTXS(i,q,o)} gt 0,1)}*
    (d_t1labS_i(q) + d_t1labS_iq + d_t0(q)) + d_Ft1labS(i,q);
```

Box 3.2: Taxation of primary factors used in production

This box explains the relationships between the prices of primary factors inclusive of indirect taxes and the price of primary factors excluding those taxes by reference to taxes on labour income (such as payroll tax). For the purposes of taxation, income accruing to other costs (see below) is treated in a comparable manner to income accruing to labour, capital and land.

The tax-inclusive price of labour is represented by the unit cost variable, P1LAB. This treatment is also applied to capital income (P1CAP), the returns to land (P1LND) and income accruing to other costs (P1OCT). The tax-exclusive prices, which represent unit-income to the owners of the primary factors, are labelled PWAGE, P1CAPINC, P1LNDINC and P1OCTINC, respectively.

In the case of the model, we assume that the cost of each factor is:

$$\mathrm{P1FACTCOST} = \mathrm{P1INC} \times (1 + \mathrm{TF}/100 + \mathrm{TS}/100) \qquad \text{(E3.21)}$$

where: P1FACTCOST is the tax-inclusive price of the primary factor; P1INC is the tax-exclusive price; TF is the percentage rate of federal tax (a number like 5.0); and TS is the percentage rate of regional tax (a number like 5.0). Note that the base for both taxes is the unit income price.

In percentage-change terms, (E3.46) is:

$$\mathrm{p1factcost} = \mathrm{p1inc} + \frac{1}{1+\mathrm{TF}/100+\mathrm{TS}/100} \times (\mathrm{dTF} + \mathrm{dTS}) \qquad \text{(E3.22)}$$

which, after noting from (E3.21) that:

$$\frac{1}{1+\mathrm{TF}/100+\mathrm{TS}/100} = \frac{\mathrm{P1INC}}{\mathrm{P1FACTCOST}}$$

is the general form of equations E_*p1lab*, *E_p1capinc*, *E_p1lndinc* and *E_p1octinc*. Note that the equation for the price of labour is labelled E_p1lab, not E_pwage. In the standard longer-run closure (see chapter 9), the national real wage rate is fixed, as are wage differentials across regions, and so via the equations in section 3.4.8 the percentage changes in money wage rates by region, industry and occupation are determined. Thus, *E_p1lab* puts in place the percentage change in tax-inclusive price (p1lab).

3.1.1.12 Federal and regional tax revenue collections (E_d_w1labtxF to E_d_w1labtxS)

Equations *E_d_w1labtxF* and *E_d_w1labtxS* detail the change in the federal and regional revenue collections from taxes on labour used in production, respectively (termed payroll tax collections in the TABLO code). In keeping with the conventions adopted by the ABS in the *Government Finance Statistics* (see chapter 5), federal government 'payroll tax collections' in the model database cover the superannuation guarantee charge levied in 2005-06 by the Australian Government.

```
Equation E_d_w1labtxF # Change in payroll tax collections - federal #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
100*d_w1labtxF(i,q,o) =
V1LABTXF(i,q,o)*{pwage(i,q,o) + x1lab(i,q,o)} +
V1LABINC(i,q,o)*d_t1labF(i,q);

Equation E_d_w1labtxS # Change in payroll tax collections - regional #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
100*d_w1labtxS(i,q,o) =
V1LABTXS(i,q,o)*{pwage(i,q,o) + x1lab(i,q,o)} +
V1LABINC(i,q,o)*d_t1labS(i,q);
```

3.11.6 Income paid to employees — labour income (E_w1labinc_i to E_natw1labinc_i)

Net payments by producers to labour is the gross cost of employing that labour less any federal and regional taxes on the use of that labour. It does not include any income taxes subsequently payable on that income by employees (which are assumed to be domestic households).

Equations *E_w1labinc_i* and *E_natw1labinc_i* determine the percentage changes in regional and national labour income. They use the hourly wage rate after taxes on the use of labour in production (pwage(i,q,o)), rather than the gross cost of labour (p1lab(I,q,o)), as it is already on an after production tax basis.

```
Equation E_w1labinc_i # Labour income by state (V1LAB-V1LABTAX) #
(all,q,REGDST)
sum{o,OCC, V1LABINC_I(q,o)}*w1labinc_i(q) =
    sum{o,OCC,sum{i,IND, V1LABINC(i,q,o)*(pwage(i,q,o) + x1lab(i,q,o))}};

Equation E_natw1labinc_i # Labour income (V1LAB-V1LABTAX) #
sum{o,OCC,sum{q,REGDST, V1LABINC_I(q,o)}}*natw1labinc_i =
    sum{o,OCC,sum{q,REGDST,sum{i,IND,
        V1LABINC(i,q,o)*(pwage(i,q,o) + x1lab(i,q,o))}}};
```

3.12 Capital use, prices and incomes

We now turn our attention to the fourth last row in figure 3.1 dealing with income accruing to the owners of capital from it use in the production process.

3.12.1 Average cost of capital (E_p1cap_i to E_natp1cap_i)

The variable p1cap(i,q) is the gross cost to producers in industry i in region q of a unit of physical capital (sometimes referred to as fixed capital). It is also referred to as the gross rental price of capital. The net rental price of capital, p1capinc(i,q), that drives investment in VURM is the gross rental price of capital less any federal and regional taxes levied on the use of capital in production.

Equations *E_p1cap_i* and *E_natp1cap_i* are regional and economy-wide unit cost of capital, respectively. Equation *E_natp1cap* determines the unit cost of capital by national industry.

```
Equation E_p1cap_i # Average unit cost of capital in region q #
(all,q,REGDST)
p1cap_i(q) = w1cap_i(q) - x1cap_i(q);

Equation E_natp1cap # Aggregate rental price of capital by industry #
(all,i,IND)
ID01[NATV1CAP(i)]*natp1cap(i) = sum{q,REGDST,V1CAP(i,q)*p1cap(i,q)};

Equation E_natp1cap_i # Aggregate nominal capital rentals #
natp1cap_i = natw1cap_i - natx1cap_i;
```

3.12.2 Use of physical capital (E_x1cap_i to E_natx1cap_i)

The variable x1cap(i,q) is the quantity of capital used in production in industry i in region q. The quantity of capital used by producers is determined by solving the cost minimisation problem for a given level of gross output and primary factor use.

Equations *E_x1cap_i* and *E_natx1cap_i*, respectively, determine the regional and national use of capital in production. Equation *E_natx1cap* determines the quantity of capital used by national industry.

```
Equation E_x1cap_i # Aggregate usage of capital (rental weights) #
(all,q,REGDST)
V1CAP_I(q)*x1cap_i(q) = sum{i,IND, V1CAP(i,q)*x1cap(i,q)};

Equation E_natx1cap # Aggregate usage of capital by industry (rental
weights) #
(all,i,IND)
ID01[NATV1CAP(i)]*natx1cap(i) = sum{q,REGDST, V1CAP(i,q)*x1cap(i,q)};

Equation E_natx1cap_i # Aggregate usage of capital (rental weights) #
NATV1CAP_I*natx1cap_i = sum{q,REGDST, V1CAP_I(q)*x1cap_i(q)};
```

3.12.3 Cost of using capital in production (E_w1cap_i to E_natw1cap_i)

The percentage change in aggregate payments to capital analogous to equation (E3.20) is:

$$\mathrm{p1cap(i,q) + x1cap(i,q)}$$

These variables are used to update the gross aggregate payments to capital coefficient V1CAP(i,q), which is used to aggregate most capital market variables.

Equations *E_w1cap_i* and *E_natw1cap_i*, respectively, determine the regional and national payments to physical capital used in production.

```
Equation E_w1cap_i
# Aggregate payments to capital (excluding additional return) #
(all,q,REGDST)
V1CAP_I(q)*w1cap_i(q) = sum{i,IND,V1CAP(i,q)*(p1cap(i,q) + x1cap(i,q))};
```

```
Equation E_natw1cap_i # Aggregate payments to capital #
NATV1CAP_I*natw1cap_i = sum{q,REGDST,V1CAP_I(q)*w1cap_i(q)};
```

3.12.4 Taxes on the use of capital in production

3.1.1.13 Federal and regional tax rates (E_d_tlcapF to E_d_w1captxS)

Equations *E_d_t1capF* and *E_d_t1capS* detail the percentage point changes in the federal and regional tax rates, respectively, on the use of capital in production.

```
Equation E_d_t1capF # %-Point change in property tax rate - federal #
(all,i,IND)(all,q,REGDST)
d_t1capF(i,q) = {0 + IF(V1CAPTXF(i,q) gt 0, 1)}*
    (d_t1capF_i(q) + d_t1capF_iq + d_t0("Federal")) + d_Ft1capF(i,q);

Equation E_d_t1capS # %-Point change in property tax rate – regional #
(all,i,IND)(all,q,REGDST)
d_t1capS(i,q) = {0 + IF(V1CAPTXS(i,q) gt 0, 1)}*
    (d_t1capS_i(q) + d_t1capS_iq + d_t0(q)) + d_Ft1capS(i,q);
```

3.1.1.14 Federal and regional tax revenue collections (E_d_w1captxF to E_d_w1captxS)

Equations *E_d_w1captxF* and *E_d_w1captxS* detail the change in the federal and regional revenue collections from taxes on the use of capital in production, respectively.

```
Equation E_d_w1captxF # Change in property tax collections - federal #
(all,i,IND)(all,q,REGDST)
100*d_w1captxF(i,q) =
V1CAPTXF(i,q)*{p1capinc(i,q) + x1cap(i,q)} + V1CAPINC(i,q)*d_t1capF(i,q);

Equation E_d_w1captxS # Change in property tax collections – regional #
(all,i,IND)(all,q,REGDST)
100*d_w1captxS(i,q) =
V1CAPTXS(i,q)*{p1capinc(i,q) + x1cap(i,q)} + V1CAPINC(i,q)*d_t1capS(i,q);
```

3.12.5 Payments to the owners of capital — capital income (E_p1capinc to E_w1capinc_i)

Net payments by producers to the owners of physical capital is the gross cost of employing that capital less any federal and regional taxes on the use of that capital. It does not include any income taxes subsequently payable on that income by the owners of capital (which are assumed to be domestic and foreign households).

Equation *E_p1capinc* determines the percentage change in per unit income paid to the owners of capital. The specification of this equation is based on the discussion in box 3.1.

Equation *E_w1capinc* determines the percentage change in regional capital income from the net rental price of capital (p1capinc(i,q)), which is already on an after production tax basis. The resulting measure does not include any addition return from export sales (discussed in chapter 8), which is accounted for separately.

```
Equation E_p1capinc # Price of capital (p1cap) related to the unit income
on capital (p1capinc) #
(all,i,IND)(all,q,REGDST)
p1cap(i,q) = p1capinc(i,q) + IF{V1CAP(i,q) ne 0,
    [V1CAPINC(i,q)/V1CAP(i,q)]*(d_t1capF(i,q) + d_t1capS(i,q))};
```

```
Equation E_w1capinc_i
# Capital income by state (V1CAP-V1CAPTAX) (excluding the additional
return) #
(all,q,REGDST)
V1CAPINC_I(q)*w1capinc_i(q) =
    sum{i,IND, V1CAPINC(i,q)*(p1capinc(i,q) + x1cap(i,q))};
```

3.13 Returns to land from production

We now turn our attention to the third last row in figure 3.1 dealing with income accruing to the use of agricultural land in production.

3.13.1 Average cost of agricultural land (E_p1lnd_i to E_natp1lnd_i)

The variable p1lnd(i,q) is the gross cost to producers in industry i in region q of a unit of (agricultural) land (section 3.3.2).

Equations *E_p1lnd_i* and *E_natp1lnd_i* determine the regional and economy-wide unit cost of agricultural land, respectively. Equation *E_natp1lnd* determines the unit cost of agricultural land by national industry.

```
Equation E_p1lnd_i # Average unit cost of agricultural land in region q #
(all,q,REGDST)
p1lnd_i(q) = w1lnd_i(q) - x1lnd_i(q);

Equation E_natp1lnd # Unit-income on land by national industry #
(all,i,IND)
ID01[NATV1LND(i)]*natp1lnd(i) = sum{q,REGDST, V1LND(i,q)*p1lnd(i,q)};

Equation E_natp1lnd_i # Aggregate unit cost of agricultural land #
natp1lnd_i = natw1lnd_i - natx1lnd_i;
```

3.13.2 Use of agricultural land in production (E_x1lnd_i to E_natx1lnd_i)

The variable x1lnd(i,q) is the quantity of agricultural land used in production by industry i in region q (section, 3.3.2). The quantity of land used is determined by solving the cost minimisation problem for a given level of gross output and primary factor use. In the standard short- and long-run closures (chapter 9), the quantity of land used (x1lnd) is held fixed for each regional industry.

Equations *E_x1lnd_i* and *E_natx1lnd_i*, respectively, determine the regional and national quantity of agricultural land used in production. Equation *E_natx1lnd* determine the quantity of agricultural land by national industry.

```
Equation E_x1lnd_i # Aggregate stock of land (land-rent weights) #
(all,q,REGDST)
V1LND_I(q)*x1lnd_i(q) = sum{i,IND, V1LND(i,q)*x1lnd(i,q)};

Equation E_natx1lnd # National usage of land by industry #
(all,i,IND)
ID01[NATV1LND(i)]*natx1lnd(i) = sum{q,REGDST, V1LND(i,q)*x1lnd(i,q)};

Equation E_natx1lnd_i # Aggregate usage of land #
ID01[NATV1LND_I]*natx1lnd_i = sum{q,REGDST, V1LND_I(q)*x1lnd_i(q)};
```

3.13.3 Cost of using agricultural land in production (E_w1lnd_i to E_natw1lnd_i)

The percentage change in aggregate payments to land used in production analogous to equation (E3.20) is:

$$\mathrm{p1lnd(i,q) + x1lnd(i,q)}$$

These variables are used to update the gross payments to land coefficient V1LND(i,q), which is used to aggregate most land variables.

Equations *E_w1lnd_i* and *E_natw1lnd_i*, respectively, determine the regional and national cost of agricultural land used in production.

```
Equation E_w1lnd_i # Aggregate payments to land #
(all,q,REGDST)
V1LND_I(q)*w1lnd_i(q) = sum{i,IND,V1LND(i,q)*(p1lnd(i,q) + x1lnd(i,q))};

Equation E_natw1lnd_i # Aggregate payments to land #
NATV1LND_I*natw1lnd_i = sum{q,REGDST, V1LND_I(q)*w1lnd_i(q)};
```

3.13.4 Taxes on the use of agricultural land in production

3.1.1.15 Federal and regional tax rates (E_d_tllndF to E_d_w1lndS)

Equations *E_d_t1lndF* and *E_d_t1lndS* detail the percentage point changes in the federal and regional tax rates, respectively, on the use of agricultural land in production. These equations are based on the discussion in box 3.1.

```
Equation E_d_t1lndF
# %-Point change in tax rate on agricultural land - federal #
(all,i,IND)(all,q,REGDST)
d_t1lndF(i,q) = {0+ IF(V1LNDTXF(i,q) gt 0,1)}*
    (d_t1lndF_i(q) + d_t1lndF_iq + d_t0("Federal")) + d_Ft1lndF(i,q);

Equation E_d_t1lndS
# %-Point change in tax rate on agricultural land - regional #
(all,i,IND)(all,q,REGDST)
d_t1lndS(i,q) = {0+ IF(V1LNDTXS(i,q) gt 0,1)}*
    (d_t1lndS_i(q) + d_t1lndS_iq + d_t0(q)) + d_Ft1lndS(i,q);
```

3.1.1.16 Federal and regional tax revenue collections (E_d_w1lndtxF to E_d_w1lndtxS)

Equations *E_d_w1lndtxF* and *E_d_w1lndtxS*, respectively, detail the change in the federal and regional revenue collections from taxes on the use of agricultural land in production.

```
Equation E_d_w1lndtxF # Change in agricultural land tax collections -
Federal #
(all,i,IND)(all,q,REGDST)
100*d_w1lndtxF(i,q) =
V1LNDTXF(i,q)*{p1lndinc(i,q) + x1lnd(i,q)} + V1LNDINC(i,q)*d_t1lndF(i,q);

Equation E_d_w1lndtxS # Change in agricultural land tax collections - State
#
(all,i,IND)(all,q,REGDST)
100*d_w1lndtxS(i,q) =
V1LNDTXS(i,q)*{p1lndinc(i,q) + x1lnd(i,q)} + V1LNDINC(i,q)*d_t1lndS(i,q);
```

3.13.5 Payments to the owners of agricultural land — land income (E_w1lndinc_i)

Net payments by producers to the owners of agricultural land is the gross cost of employing that land less any federal and regional taxes on the use of that land. It does not include any income taxes subsequently payable on that income by the owners of land (which are assumed to be domestic and foreign households).

Equation *E_p1lndinc* determines the percentage change in per unit income paid to the owners of land. The specification of this equation is based on the discussion in box 3.1.

Equation *E_w1lndinc* determines the percentage change in regional capital income from the net price of a unit of land (p1lndinc(i,q)), which is already on an after production tax basis.

```
Equation E_p1lndinc
# Price of land (p1lnd) related to the unit income on land (p1lndinc) #
(all,i,IND)(all,q,REGDST)
p1lnd(i,q) = p1lndinc(i,q) + IF{V1LND(i,q) ne 0,
    [V1LNDINC(i,q)/V1LND(i,q)]*(d_t1lndF(i,q) + d_t1lndS(i,q))};

Equation E_w1lndinc_i # Land income by state (V1LND-V1LNDTAX) #
(all,q,REGDST)
V1LNDINC_I(q)*w1lndinc_i(q) =
    sum{i,IND, V1LNDINC(i,q)*(p1lndinc(i,q) + x1lnd(i,q))};
```

3.14 Other costs used in production

We now turn our attention to the second last row in figure 3.1 dealing with the income accruing to other costs used in production.

3.14.1 Average cost of other costs (E_p1oct_i to E_natp1oct_i)

The variable p1oct(i,q) is the price of a 'unit' of other costs in industry i in region q.

Equations *E_p1oct_i* and *E_natp1oct_i* determine the regional and economy-wide unit price of other costs, respectively. Equation *E_natp1oct* determines the unit price of other costs by national industry.

```
Equation E_p1oct_i # Average unit cost of other costs in state q #
(all,q,REGDST)
p1oct_i(q) = w1oct_i(q) - x1oct_i(q);

Equation E_natp1oct_i # Aggregate price of other cost ticket payments #
natp1oct_i = natw1oct_i - natx1oct_i;

Equation E_natp1oct_i # Aggregate price of other cost ticket payments #
natp1oct_i = natw1oct_i - natx1oct_i;
```

3.14.2 Use of other costs in production (E_x1oct_i to E_natx1oct_i)

The variable x1oct(i,q) is the quantity of other costs used by producers in industry i in region q. The quantity of other costs used by producers is linked to changes in gross output through the Leontief assumption.

Equations *E_x1oct_i* and *E_natx1oct_i*, respectively, determine the regional and national quantity of other costs used in production. Equation *E_natx1oct* determine the quantity of other costs by national industry.

```
Equation E_x1oct_i # Aggregate quantity of other costs #
(all,q,REGDST)
V1OCT_I(q)*x1oct_i(q) = sum{i,IND, V1OCT(i,q)*x1oct(i,q)};

Equation E_natx1oct # National usage of other costs by industry #
(all,i,IND)
ID01[NATV1OCT(i)]*natx1oct(i) = sum{q,REGDST, V1OCT(i,q)*x1oct(i,q)};

Equation E_natx1oct_i # Aggregate usage of other costs #
ID01[NATV1OCT_I]*natx1oct_i = sum{q,REGDST, V1OCT_I(q)*x1oct_i(q)};
```

3.14.3 Cost of using other costs in production (E_w1oct_i to E_natw1oct_i)

The percentage change in aggregate payments to other costs used in production analogous to equation (E3.20) is:

$$\mathrm{p1oct(i,q) + x1oct(i,q)}$$

These variables are used to update the gross payments to land coefficient V1OCT(i,q), which is used to aggregate most other cost variables.

Equations *E_w1oct_i* and *E_natw1oct_i*, respectively, determine the regional and national payments to other costs used in production.

```
Equation E_w1oct_i # Aggregate other cost ticket payments #
(all,q,REGDST)
V1OCT_I(q)*w1oct_i(q) = sum{i,IND,V1OCT(i,q)*(p1oct(i,q)+x1oct(i,q))};

Equation E_natw1oct_i # Aggregate other cost ticket payments #
NATV1OCT_I*natw1oct_i = sum{q,REGDST, V1OCT_I(q)*w1oct_i(q)};
```

3.14.4 Taxes on the use of other costs in production

3.1.1.17 Federal and regional tax rates (E_d_tloctF to E_d_t1octS)

Equations *E_d_t1octF* and *E_d_t1octS* detail the percentage point changes in the federal and regional tax rates, respectively, on the use of other costs in production. These equations are based on the discussion in box 3.1.

```
Equation E_d_t1octF # %-Point change in tax rate on other costs - federal #
(all,i,IND)(all,q,REGDST)
d_t1octF(i,q) = {0+ IF(V1OCTTXF(i,q) gt 0,1)}*
    (d_t1octF_i(q) + d_t1octF_iq + d_t0("Federal")) + d_Ft1octF(i,q);

Equation E_d_t1octS
# %-Point change in tax rate on other costs - regional #
(all,i,IND)(all,q,REGDST)
d_t1octS(i,q) = {0+ IF(V1OCTTXS(i,q) gt 0,1)}*
    (d_t1octS_i(q) + d_t1octS_iq + d_t0(q)) + d_Ft1octS(i,q);
```

3.1.1.18 Federal and regional tax revenue collections (E_d_w1octtxF to E_d_w1octtxS)

Equations *E_d_w1octtxF* and *E_d_w1octtxS* detail the change in the federal and regional revenue collections from taxes on the use of other costs in production, respectively.

```
Equation E_d_w1octtxF # Change in tax collected on other costs - federal #
(all,i,IND)(all,q,REGDST)
100*d_w1octtxF(i,q) =
V1OCTTXF(i,q)*{p1octinc(i,q) + x1oct(i,q)} + V1OCTINC(i,q)*d_t1octF(i,q);

Equation E_d_w1octtxS # Change in tax collected on other costs – regional #
(all,i,IND)(all,q,REGDST)
100*d_w1octtxS(i,q) =
V1OCTTXS(i,q)*{p1octinc(i,q) + x1oct(i,q)} + V1OCTINC(i,q)*d_t1octS(i,q);
```

3.14.5 Payments to the owners of other costs — other cost income (E_w1octinc_i)

Net payments by producers to the owners of other costs is the gross cost of employing those costs less any federal and regional taxes on their use (discussed in section 3.15.4). It does not include any income taxes subsequently payable on that income by the owners of other costs (which are assumed to be domestic and foreign households).

Equation *E_p1lndinc* determines the percentage change in per unit income paid to the owners of other costs. The specification of this equation is based on the discussion in box 3.1.

Equation *E_w1octinc_i* determines the percentage change in regional capital income from the unit price of other costs (p1octinc(i,q)), which is already on an after production tax basis.

```
Equation E_p1octinc_i # Unit income on other costs by state #
(all,q,REGDST)
V1OCTINC_I(q)*p1octinc_i(q) = sum{i,IND, V1OCTINC(i,q)*p1octinc(i,q)};

Equation E_w1octinc_i # Other cost income by region (V1OCT-V1OCTTAX) #
(all,q,REGDST)
V1OCTINC_I(q)*w1octinc_i(q) =
    sum{i,IND, V1OCTINC(i,q)*(p1octinc(i,q) + x1oct(i,q))};
```

3.15 Commodity supply (the MAKE matrix) (E_x1tot to E_p0aA)

We now turn our attention to the insert to figure 3.1 dealing with total sales and total costs. These concepts are related using the MAKE matrix.

The MAKE matrix in VURM details the supply of each commodity by each regional industry. In the ABS *Input-Output Tables*, the MAKE matrix is referred to as the *Supply table*.

The MAKE matrix in VURM is denoted by the coefficient MAKE(c,i,q). It details the value of sales of commodity c from industry ifrom region q.

Equation *E_x1tot* relates movements in the average price received by industry i in region q to movements in the prices of products produced by industry i. On the RHS, the coefficient MAKE_C(i,q) is the output of all commodities by industry i in region q. In the current version of the model, there is a one to one relationship between industries and commodities, so MAKE_C(i,q) is equal to MAKE(c,i,q) for commodity c where it corresponds to industry i.

Equation *E_x0com* explains the commodity composition of the multiproduct industries. It specifies that the percentage change in the supply of commodity c by multiproduct industry i is made up of two parts. The first is x1tot(i,q), the percentage change in the overall level of output of industry i. The second is a price-transformation term. This compares the percentage change in the price received by industry i for product c with the weighted average of the percentage changes in the prices of all industry i's products. The derivation of equation *E_x0com* is detailed in section 11 of Dixon *et al.* (1982). In this version of the model, where there are no multiproduct industries, it is a theoretical consideration only.

Equation *E_p0aA* explains the percentage change in overall output of commodity c in region q in terms of the industry-specific outputs of c in q.

```
Equation E_x1tot_i # Aggregate output (sales weights) #
(all,q,REGDST)
sum{i,IND, MAKE_C(i,q)}*x1tot_i(q) = sum{i,IND, MAKE_C(i,q)*x1tot(i,q)};

Equation E_x0com # Supplies of commodities by regiojnal industry #
(all,c,COM)(all,i,IND)(all,q,REGDST)
x0com(c,i,q) = x1tot(i,q) + SIGMA1OUT(i)*[p0com(c,q) - p1tot(i,q)];

Equation E_p0aA # Total output of domestic commodities #
(all,c,COM)(all,q,REGDST)
ID01[MAKE_I(c,q)]*x0com_i(c,q) = sum{i,IND, MAKE(c,i,q)*x0com(c,i,q)};
```

3.16 Market clearing for commodities (E_x0com_iA to E_x0imp)

Equations *E_x0com_iA*, *E_x0com_iB* and *E_x0imp* impose the condition that demand equals supply for domestically produced margin and non-margin commodities and for imported commodities (the 'no lost goods' condition).

The output of regional industries producing margin commodities must equal the direct demands by the model's eight users and their demands for the commodity as a margin. Note that the specification of equation *E_x0comA* imposes the assumption that margins are produced in the destination region, with the exception that margins on exports are produced in the source region. We write the market-clearing equations in terms of basic values. On the LHS of *E_x0com_iA*, the coefficient SALES(r,s) is the basic value of the output of domestic margin good r produced in region s. On the RHS, the coefficients are the basic values of the eight users' demands plus the basic values of margin demands by producers, investors, households and foreigners.

In equation *E_x0com_iB*, changes in the outputs of the non-margin regional industries are set equal to the changes in direct demands of the model's eight users. The equation is similar to *E_x0com_iA*, except that it excludes the margin demands.

Equation *E_x0impa* imposed supply/demand balance for imported commodities. Import supplies are equal to the demands of the users excluding foreigners, i.e., all exports involve some domestic value added.

```
Equation E_x0com_iA  # Demand equals supply for margin commodities #
(all,r,MARGCOM)(all,s,REGSRC)
ID01[SALES(r,s)]*x0com_i(r,s) =
sum{q,REGDST,sum{i,IND,
    V1BAS(r,s,i,q)*x1a(r,s,i,q) + V2BAS(r,s,i,q)*x2a(r,s,i,q) } +
V3BAS(r,s,q)*x3a(r,s,q) + V5BAS(r,s,q)*x5a(r,s,q) + V6BAS(r,s,q)*x6a(r,s,q)
} +
    V4BAS(r,s)*x4r(r,s) + V8BAS(r,s)*x8a(r,s) +
        100*LEVP7R(r,s)*d_x7r(r,s) +
sum{c,COM,sum{ss,ALLSRC,sum{i,IND,
V1MAR(c,ss,i,s,r)*x1marg(c,ss,i,s,r) + V2MAR(c,ss,i,s,r)*x2marg(c,ss,i,s,r)
} +
    V3MAR(c,ss,s,r)*x3marg(c,ss,s,r) + V5MAR(c,ss,s,r)*x5marg(c,ss,s,r) +
    V6MAR(c,ss,s,r) *x6marg(c,ss,s,r) } + V4MAR(c,s,r) *x4marg(c,s,r) };

 Equation E_x0com_iB # Demand equals supply for non-margin commodities #
(all,r,NONMARGCOM)(all,s,REGSRC)
ID01[SALES(r,s)]*x0com_i(r,s) =
sum{q,REGDST,sum{i,IND,
    V1BAS(r,s,i,q)*x1a(r,s,i,q) + V2BAS(r,s,i,q)*x2a(r,s,i,q) } +
        V3BAS(r,s,q)*x3a(r,s,q) +
            V5BAS(r,s,q)*x5a(r,s,q) + V6BAS(r,s,q)*x6a(r,s,q) } +
                V4BAS(r,s)*x4r(r,s) +
                    V8BAS(r,s)*x8a(r,s) + 100*LEVP7R(r,s)*d_x7r(r,s);
```

3.17 Zero pure profits

As is typical of ORANI-style models, the price system underlying VURM is based on two assumptions: (i) that there are no pure profits in the production or distribution of commodities; and (ii) that the price received by the producer is uniform across all customers. The separate modelling of export supplies relaxes the second of these assumptions (see section 8.4 of chapter 8). This section sets out the accounting in the basic model.

Also in the tradition of ORANI, is the presence of two types of price equations: (i) zero pure profits in current production, capital creation and importing and (ii) zero pure profits in the distribution of commodities to users. The zero pure profits condition in current production, capital creation and importing is imposed by setting unit prices received by producers of commodities (i.e., the commodities' basic values) equal to unit costs. Zero pure profits in the distribution of commodities is imposed by setting the prices paid by users equal to the commodities' basic value plus commodity taxes and the cost of margins.

3.17.1 Basic prices in current production (E_p1cost to E_a)

Equations *E_p1cost* and *E_a* impose the zero pure profits condition in current production. Given the constant returns to scale which characterise the model's production technology, equation *E_p1cost* defines the percentage change in the price received per unit of output by industry i of region q net of any additional returns from export sales (p1cost(i,q)) as a cost-weighted average of the percentage changes in effective input prices. The percentage changes in the effective input prices represent: (i) the percentage change in the cost per unit of input; and (ii) the percentage change in the use of the input per unit of output (i.e., the percentage change in the technology variable). These cost-share-weighted averages define percentage changes in the average costs of production. Setting output prices equal to average costs imposes the competitive zero pure profits condition, assuming no additional returns from export sales.

In equation *E_a*, a(i,q) is defined as an aggregation of all the different types of technological change that affect the costs of industry i in region q. All input-augmenting technological change a1(i,q) appears as a negative on the LHS because its weighting coefficient is total costs. The various different types of input specific technological change appear on the RHS of the equation with weights reflecting their influence on industry i's unit costs.

The mathematical derivation of the zero pure profits condition in current production is similar (although slightly more complex) to the derivation of the zero pure profits condition in capital creation, which is given below.

```
Equation E_p1cost # Cost of production by industry & region #
(all,i,IND)(all,q,REGDST)
ID01[COSTS(i,q) - ADDRETURN(i,q)]*p1cost(i,q) =
   sum{c,COM,sum{s,ALLSRC, V1PURA(c,s,i,q)*p1a(c,s,i,q)}} +
                V1LAB_O(i,q)*p1lab_o(i,q) +
                V1CAP(i,q)*p1cap(i,q) +
                V1LND(i,q)*p1lnd(i,q) +
                V1OCT(i,q)*p1oct(i,q) +
                ISSUPPLY(i)*V1NEM(q)*p8tot +
                COSTS(i,q)*a(i,q);

Equation E_a # Technical change by industry-current production #
(all,i,IND)(all,q,REGDST)
ID01[COSTS(i,q)]*[a(i,q) - a1(i,q)] =
sum{c,COM,sum{s,ALLSRC, V1PURA(c,s,i,q)*a1a(c,s,i,q)}} +
             sum{c,COM, V1PURO(c,i,q)*
      (a1o(c,i,q) + acom(c,q) +  natacom(c) + acomind(c,i,q) +
           aind(i,q) + agreen(c,i,q))} +
        V1PRIM(i,q)*(a1prim(i,q) + a1prim_i(q) + nata1prim(i) +
nata1prim_i) +
        V1LAB_O(i,q)*(a1lab_o(i,q) + nata1lab_io) +
        [V1CAP(i,q) + ADDRETURN(i,q)]*a1cap(i,q) +
        V1LND(i,q)*a1lnd(i,q) +
        V1OCT(i,q)*a1oct(i,q);
```

3.17.2 Basic prices in capital creation (E_p2tot)

Equation *E_p2tot* imposes zero pure profits in capital creation. *E_p2tot* determines the percentage change in the price of new units of capital (p2tot(i,q)) as the percentage change in the effective average cost of producing the unit.

Total investment by industry i in region q is given by:

$$
\begin{aligned}
& X2TOT(i,q) \times P2TOT(i,q) \\
& = V2TOT(i,q) \\
& = \sum_{c \in COM} \sum_{s \in ALLSRC} V2PURA(c,s,i,q) \\
& = \sum_{c \in COM} \sum_{s \in ALLSRC} X2A(c,s,i,q) P2A(c,s,i,q)
\end{aligned}
\qquad i \in IND \; q \in regdst,
$$

or in percentage change form:

$$
\begin{aligned}
& V2TOT(i,q)\left(x2tot(i,q) + p2tot(i,q)\right) \\
& = \sum_{c \in COM} \sum_{s \in ALLSRC} V2PURA(c,s,i,q)\left(x2a(c,s,i,q) + p2a(c,s,i,q)\right)
\end{aligned}
\qquad i \in IND \; q \in REGDST,
$$

Recalling from section 3.1.2 that:

$$
\begin{aligned}
& \sum_{s \in ALLSRC} V2PURA(c,s,i,q) x2a(c,s,i,q) \\
& = \sum_{s \in DOMSRC} V2PURA(c,s,i,q) x2a(c,s,i,q) + V2PURA(c,"imp",i,q) x2a(c,"imp",i,q) \\
& = \sum_{s \in DOMSRC} V2PURA(c,s,i,q) \begin{pmatrix} x2o(c,s,i,q) - SIGMA2O(c)\left(p2c(c,i,q) - p2o(c,i,q)\right) \\ -SIGMA2C(c)\left(p2a(c,s,i,q) - p2c(c,i,q)\right) \end{pmatrix} \\
& +V2PURA(c,"imp",i,q)\left(x2o(c,i,q) - SIGMA2C\left(p2a(c,"imp",i,q) - p2o(c,i,q)\right)\right) \\
& = \sum_{s \in ALLSRC} V2PURA(c,s,i,q)\left(x2o(c,s,i,q)\right) \\
& = \sum_{s \in ALLSRC} V2PURA(c,s,i,q)\left(x2tot(i,q) + a2(q) + acom(c,q)\right)
\end{aligned}
$$

the x2tot(i,q) terms may be cancelled to leave:

$$
V2TOT(i,q)\left(p2tot(i,q)\right) = \sum_{c \in COM} \sum_{s \in ALLSRC} V2PURA(c,s,i,q)\left(a2(q) + acom(c,q) + p2a(c,s,i,q)\right)
$$

$i \in IND \; q \in REGDST$.

```
Equation E_p2tot # Zero pure profits in capital creation #
(all,i,IND)(all,q,REGDST)
ID01[V2TOT(i,q)]*p2tot(i,q) =
    sum{c,COM,sum{s,ALLSRC, V2PURA(c,s,i,q)*p2a(c,s,i,q)}};
```

3.17.3 Basic prices in importing (E_p0aB)

Zero pure profits in imports of foreign-produced commodities is imposed by equation *E_p0aB*. The price received by the importer for the c^{th} commodity (p0a(c,“imp”)) is given as the product of the foreign c.i.f. (cost, insurance, freight) price of the import (NATP0CIF(c)), the exchange rate (PHI) and one plus the rate of tariff (the so-called power of the tariff: POWTAR(c))[21].

[21] If the tariff rate is 20 per cent, the power of tariff is 1.20. If the tariff rate is increased from 20 per cent to 25 per cent, the percentage change in the power of the tariff is 4, i.e., 100(1.25-1.20)/1.20 = 4.

```
Equation E_p0B # Zero pure profits in importing #
(all,c,COM)
p0a(c,"imp") = natp0cif(c) + phi + powtar(c);
```

3.17.4 Zero pure profits in distribution and purchasers' prices (E_p1a to E_p6a)

The remaining zero-pure-profits equations relate the purchasers' prices to the producers' price, the cost of margins and commodity taxes. Eight classes of users are recognised in VURM (see figure 3.1). Aero pure profits in the distribution of commodities to non-inventory users are imposed by the equations *E_p1a*, *E_p2a*, *E_p3a*, *E_p4r*, *E_p5a*, *E_p6a* and *E_p8a*.

The tax variables appearing on the RHS of each equation are change variables. Specifically, they are percentage-point changes in rates of *ad valorem* sales taxes. For example, d_t3S(c,s,q) is the percentage point change in the *ad valorem* rate of regional tax imposed in region q on sales to consumption of commodity c from source s.

On current production, investment, household consumption, and exports, three types of tax are imposed. For federal (V1TAXF etc) and regional (V1TAXS etc) taxes, the base is the basic value of the flow, i.e. V1BAS etc. However, for the GST, the base is the value of the basic flow plus margins and federal and regional taxes. Using households as an example, the purchaser's value in region q of commodity c from source s is:

$$\begin{aligned}&\mathrm{V3PURA}(c,s,q)=\mathrm{V3BAS}(c,s,q)+\mathrm{V3TAXF}(c,s,q)+\mathrm{V3TAXS}(c,s,q)\\&+\mathrm{V3GST}(c,s,q)+\sum_{m\in \mathrm{MARGCOM}}\mathrm{V3MAR}(c,s,q,m)\end{aligned} \tag{E3.23}$$

The definition of the federal tax rate is:

$$\mathrm{T3F}(c,s,q)=\frac{\mathrm{V3TAXF}(c,s,q)}{\mathrm{V3BAS}(c,s,q)}\times 100 \tag{E3.24}$$

The definition of the regional tax rate is:

$$\mathrm{T3S}(c,s,q)=\frac{\mathrm{V3TAXS}(c,s,q)}{\mathrm{V3BAS}(c,s,q)}\times 100 \tag{E3.25}$$

The definition of the GST rate uses a different base, and is:

$$\mathrm{T3GST}(c,s,q)=\frac{\mathrm{V3GST}(c,s,q)}{\mathrm{V3GSTBASE}(c,s,q)}\times 100 \tag{E3.26}$$

where:

$$\begin{aligned}&\mathrm{V3GSTBASE}(c,s,q)=\mathrm{V3BAS}(c,s,q)+\mathrm{V3TAXF}(c,s,q)\\&+\mathrm{V3TAXS}(c,s,q)+\sum_{m\in \mathrm{MARGCOM}}\mathrm{V3MAR}(c,s,q,m)\end{aligned} \tag{E3.27}$$

The percentage change form of 3.21 is therefore:

$$\mathrm{V3PURA}(c,s,q)\times\left[\mathrm{p3a}(c,s,q)+\mathrm{x3a}(c,s,q)\right]$$

$$=\left(1+\frac{\mathrm{T3GST}(c,s,q)}{100}\right)\times\left\{\begin{array}{l}\left[\mathrm{V3BAS}(c,s,q)+\mathrm{V3TAXF}(c,s,q)+\mathrm{V3TAXS}(c,s,q)\right]\\ \times\left(\mathrm{p0a}(c,s)+\mathrm{x3a}(c,s,q)\right)\\ +\mathrm{V3BAS}(c,s,q)\times\left[\mathrm{d\_T3F}(c,s,q)+\mathrm{d\_T3S}(c,s,q)\right]\\ +\sum_{m\in \mathrm{MARGCOM}}\mathrm{V3MAR}(c,s,q,m)\times\left[\mathrm{p0}(m,q)+\mathrm{x3marg}(c,s,q,m)\right]\end{array}\right\} \quad \text{(E3.28)}$$

$$+\mathrm{V3GSTBASE}(c,s,q)\times\mathrm{d\_T3GST}(c,s,q)$$

Note the use of ordinary change variables for the tax rates.

Recalling from section 3.3.4 the definition of margin use:

$$\mathrm{x3marg}(c,s,q,m)=\mathrm{x3a}(c,s,q)+\mathrm{a3marg}(q,m)+\mathrm{acom}(m,q)+\mathrm{modalsub3}(c,s,q,m) \quad \text{(E3.29)}$$

substitute E3.27 into E3.26 and cancel the x3a(c,s,q) terms to arrive at the definition of the household purchaser's price in region q for commodity c from source s:

$$\mathrm{V3PURA}(c,s,q)\left[\mathrm{p3a}(c,s,q)\right]$$

$$=\left(1+\frac{\mathrm{T3GST}(c,s,q)}{100}\right)\left\{\begin{array}{l}\left[\mathrm{V3BAS}(c,s,q)+\mathrm{V3TAXF}(c,s,q)+\mathrm{V3TAXS}(c,s,q)\right]\left(\mathrm{p0a}(c,s)\right)\\ +\mathrm{V3BAS}(c,s,q)\left[\mathrm{d\_T3F}(c,s,q)+\mathrm{d\_T3S}(c,s,q)\right]\\ +\sum_{m\in \mathrm{MARGCOM}}\mathrm{V3MAR}(c,s,q,m)\left[\begin{array}{l}\mathrm{p0}(m,q)+\mathrm{a3marg}(q,m)\\ +\mathrm{acom}(m,q)+\mathrm{modalsub3}(c,s,q,m)\end{array}\right]\end{array}\right\}$$

$$+\mathrm{V3GSTBASE}(c,s,q)\mathrm{d\_T3GST}(c,s,q)$$

(E3.30)

Note that:

$$\sum_{m\in \mathrm{MARGCOM}}\mathrm{V3MAR}(c,s,q,m)\left(\mathrm{modalsub3}(c,s,q,m)\right)=0$$

Therefore, equation E3.28 is equivalent to E_p3a in the TABLO code.

```
Equation E_p1a # Purchasers prices - User 1 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
ID01[V1PURA(c,s,i,q)]*p1a(c,s,i,q) = (1 + T1GST(c,s,i,q)/100)*{
    [V1BAS(c,s,i,q) + V1TAXF(c,s,i,q) + V1TAXS(c,s,i,q)]*p0a(c,s) +
     V1BAS(c,s,i,q)*[d_t1F(c,s,i,q) + d_t1S(c,s,i,q)] +
    sum{r,MARGCOM, V1MAR(c,s,i,q,r)*
             [p0a(r,q) + a1marg(q,r) + acom(r,q) + natacom(r)]}} +
    V1GSTBASE(c,s,i,q)*d_t1GST(c,s,i,q);

Equation E_p2a # Purchasers prices - User 2 #
(all,c,COM)(all,s,ALLSRC)(all,i,IND)(all,q,REGDST)
ID01[V2PURA(c,s,i,q)]*p2a(c,s,i,q) = (1 + T2GST(c,s,i,q)/100)*{
    [V2BAS(c,s,i,q) + V2TAXF(c,s,i,q) + V2TAXS(c,s,i,q)]*p0a(c,s) +
     V2BAS(c,s,i,q)*[d_t2F(c,s,i,q) + d_t2S(c,s,i,q)] +
    sum{r,MARGCOM,V2MAR(c,s,i,q,r)*
             [p0a(r,q) + a2marg(q,r) + acom(r,q) + natacom(r)]}} +
    V2GSTBASE(c,s,i,q)*d_t2GST(c,s,i,q);
```

```
Equation E_p3a # Purchasers prices - User 3 #
(all,c,COM)(all,q,REGDST)(all,s,ALLSRC)
ID01[V3PURA(c,s,q)]*p3a(c,s,q) = (1 + T3GST(c,s,q)/100)*{
    [V3BAS(c,s,q) + V3TAXF(c,s,q) + V3TAXS(c,s,q)]*p0a(c,s) +
     V3BAS(c,s,q)*[d_t3F(c,s,q) + d_t3S(c,s,q)] +
    sum{r,MARGCOM,V3MAR(c,s,q,r)*
            [p0a(r,q) + a3marg(q,r) + acom(r,q) + natacom(r)]}} +
    V3GSTBASE(c,s,q)*d_t3GST(c,s,q);

Equation E_p4a # Purchasers' prices - User 4 ($A) #
(all,c,COM)(all,s,REGSRC)
ID01[V4PURR(c,s)]*p4a(c,s) = (1 + T4GST(c,s)/100)*{
    V4BAS(c,s)*p4(c,s) + V4TAXF(c,s)*p0a(c,s) +
    [V4BAS(c,s)/POWERP4MARK(c,s)]*d_t4f(c,s) +
    sum{r,MARGCOM,V4MAR(c,s,r)*
            [p0a(r,s) + a4marg(s,r) + acom(r,s) + natacom(r)]}} +
    V4GSTBASE(c,s)*d_t4GST(c,s);

Equation E_p4r # Purchasers' price - User 4 (foreign currency) #
(all,c,COM)(all,s,REGSRC)
p4r(c,s) + phi = p4a(c,s);

Equation E_p5a # Purchasers prices - User 5 #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
ID01[V5PURA(c,s,q)]*p5a(c,s,q) = V5BAS(c,s,q)*p0a(c,s) +
sum{r,MARGCOM,V5MAR(c,s,q,r)*[p0a(r,q) + a5marg(q,r) + acom(r,q) +
natacom(r)]};

Equation E_p6a # Purchasers prices - User 6 #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
ID01[V6PURA(c,s,q)]*p6a(c,s,q) = V6BAS(c,s,q)*p0a(c,s) +
sum{r,MARGCOM,V6MAR(c,s,q,r)*[p0a(r,q) + a6marg(q,r) + acom(r,q) +
natacom(r)]};

Equation E_p8a # Purchasers prices - User 8 #
(all,c,COM)(all,s,ALLSRC)
p8a(c,s) = p0a(c,s);
```

3.18 Regional income and expenditure reporting variables

3.18.1 Gross regional product on the income side

Gross regional product on the income side consists of the payments to the factors of production – labour, capital and land, plus other costs, total indirect taxes and tariffs, plus the real value of technological improvements in production, investment, and the use of margins. The regional value of each of these components is initially derived before being combined to derive gross regional product on the income side.

3.1.1.19 Regional factor income components (E_w1cap_i to E_w1octinc_i)

Nominal regional factor payments are given in equations *E_w1cap_i*, *E_w1lab_io* and *E_w1lnd_i* for payments to capital, labour and agricultural land, respectively. The regional nominal payments to other costs are given in equation *E_w1oct_i*.

The derivation of the factor payments and other cost regional aggregates are straightforward. Equation *E_w1cap_i*, for example, is derived as follows. The total value of payments to capital in region q (V1CAP_I(q)) is the sum of the payments of the i industries in region q (V1CAP(i,q)), where the industry payments are a product of the unit rental value of capital (P1CAP(i,q)) and the number of units of capital employed (X1CAP(i,q)):

$$\mathrm{V1CAP\_I(q)} = \sum_{i \in IND} \mathrm{P1CAP(i,q)} \times \mathrm{X1CAP(i,q)} \qquad q \in \mathrm{REGDST} \qquad \text{(E3.31)}$$

Equation (E3.31) can be written in percentage changes as:

$$\mathrm{V1CAP\_I(q)} \times \mathrm{w1cap\_i(q)} = \sum_{i \in IND} \mathrm{V1CAP(i,q)} \times (\mathrm{p1cap(i,q)} + \mathrm{x1cap(j,q)}) \qquad q \in \mathrm{REGDST} \qquad \text{(E3.32)}$$

giving equation E_w1cap_i, where the variable w1cap_i(q), is the percentage change in rentals to capital in region q and has the definition:

$$\mathrm{w1cap\_i(q)} = 100\left(\frac{\Delta \mathrm{V1CAP\_I(q)}}{\mathrm{V1CAP\_I(q)}}\right) \qquad q \in \mathrm{REGDST} \qquad \text{(E3.33)}$$

The regional income equations are given by *E_w1capinc_i*, *E_w1labinc_io*, *E_w1lndinc_i* and *E_w1octinc_i*. The differences between payments to factors and factor incomes are the taxes paid on that factor of production, which are a wedge between the price paid by the producer and the price received by the owner of the factor. Using capital as an example, the total value of income from capital in region q is V1CAPINC(q), where income is a product of the unit price received (P1CAPINC(q)) and the quantity employed:

$$\mathrm{V1CAPINC\_I(q)} = \sum_{i \in IND} \mathrm{P1CAPINC(i,q)} \times \mathrm{X1CAP(i,q)} \qquad q \in \mathrm{REGDST} \qquad \text{(E3.34)}$$

In percentage change form, this is:

$$\mathrm{V1CAPINC\_I(q)} \times \mathrm{w1capinc\_i(q)} = \sum_{i \in IND} \mathrm{V1CAPINC(i,q)} \times (\mathrm{p1capinc(i,q)} + \mathrm{x1cap(j,q)}) \qquad q \in \mathrm{REGDST} \qquad \text{(E3.35)}$$

where:

$$\mathrm{w1capinc\_i(q)} = 100\left(\frac{\Delta \mathrm{V1CAPINC\_I(q)}}{\mathrm{V1CAPINC\_I(q)}}\right) \qquad q \in \mathrm{REGDST} \qquad \text{(E3.36)}$$

giving VURM equation *E_w1capinc_i.*

Note, that the relationships between p1capinc(i,q) and p1cap(i,q), pwage(i,q,o) and p1lab(i,q,o), p1lndinc(i,q) and p1lnd(i,q), and p1octinc(i,q) and p1oct(i,q) are discussed in section 3.5.9.

```
Equation E_w1cap_i
# Aggregate payments to capital (excluding additional return) #
(all,q,REGDST)
V1CAP_I(q)*w1cap_i(q) = sum{i,IND,V1CAP(i,q)*(p1cap(i,q) + x1cap(i,q))};
```

```
Equation E_w1capinc_i
# Capital income by region (V1CAP-V1CAPTAX) (excluding the additional
return) #
(all,q,REGDST)
V1CAPINC_I(q)*w1capinc_i(q) =
    sum{i,IND, V1CAPINC(i,q)*(p1capinc(i,q) + x1cap(i,q))};

Equation E_w1lab_io # Aggregate payments to labour #
(all,q,REGDST)
V1LAB_IO(q)*w1lab_io(q) =
    sum{i,IND,sum{o,OCC, V1LAB(i,q,o)*(p1lab(i,q,o) + x1lab(i,q,o))}};

Equation E_w1labinc_i # Labour income by region (V1LAB-V1LABTAX) #
(all,q,REGDST)
sum{o,OCC, V1LABINC_I(q,o)}*w1labinc_i(q) =
    sum{o,OCC,sum{i,IND, V1LABINC(i,q,o)*(pwage(i,q,o) + x1lab(i,q,o))}};

Equation E_natw1labinc_i # Labour income (V1LAB-V1LABTAX) #
sum{o,OCC,sum{q,REGDST, V1LABINC_I(q,o)}}*natw1labinc_i =
    sum{o,OCC,sum{q,REGDST,sum{i,IND,
        V1LABINC(i,q,o)*(pwage(i,q,o) + x1lab(i,q,o))}}};

Equation E_w1lnd_i # Aggregate payments to land #
(all,q,REGDST)
V1LND_I(q)*w1lnd_i(q) = sum{i,IND,V1LND(i,q)*(p1lnd(i,q) + x1lnd(i,q))};
Equation E_w1lndinc_i # Land income by region (V1LND-V1LNDTAX) #
(all,q,REGDST)
V1LNDINC_I(q)*w1lndinc_i(q) =
    sum{i,IND, V1LNDINC(i,q)*(p1lndinc(i,q) + x1lnd(i,q))};

Equation E_w1oct_i # Aggregate other cost ticket payments #
(all,q,REGDST)
V1OCT_I(q)*w1oct_i(q) = sum{i,IND,V1OCT(i,q)*(p1oct(i,q)+x1oct(i,q))};

Equation E_w1octinc_i # Other cost income by region (V1OCT-V1OCTTAX) #
(all,q,REGDST)
V1OCTINC_I(q)*w1octinc_i(q) =
    sum{i,IND, V1OCTINC(i,q)*(p1octinc(i,q) + x1oct(i,q))};
```

3.1.1.20 Regional indirect tax revenues (E_wtaxf_c to E_natwgst)

In this block of equations, the percentage changes in regional aggregate revenue raised from indirect commodity taxes are computed. Equation *E_wtaxf_c* gives aggregate revenue from federal sales taxes by region. Equation *E_wtaxs_c* gives aggregate regional sales taxes by region. *E_wtaxs* gives aggregate regional sales taxes by commodity and region. The equations in the remainder of the section give aggregate federal and regional taxes by user, region, and commodity, as well as GST revenue by user, region and commodity.

The bases for the federal and region non-GST sales taxes are the regional basic values of the corresponding commodity flows. Hence, for any component of sales tax, we can express revenue (say VTAX), in levels, as the product of the base (BAS) and the tax rate (T), i.e.,

$$\text{VTAX} = \text{BAS} \times \frac{\text{T}}{100}.$$

Hence:

$$\Delta\text{VTAX} = \Delta\text{BAS} \times \frac{\text{T}}{100} + \text{BAS} \times \frac{\Delta\text{T}}{100} \tag{E3.37}$$

The basic value of the commodity is the product of the producer's price (P0) and output (XA):

$$\text{BAS} = \text{P0} \times \text{XA} \tag{E3.38}$$

Using (E3.37) and (E3.38), we can derive the tax revenue equations as follows:

$$\text{VTAX} \times \text{wtax} = \text{VTAX} \times (\text{xa} + \text{p0}) + \text{BAS} \times \text{d\_T}$$

where:

$$\text{wtax} = 100 \times \frac{\Delta\text{VTAX}}{\text{VTAX}}$$

$$\text{p0} = 100\left(\frac{\Delta\text{P0}}{\text{P0}}\right)$$

$$\text{xa} = 100\left(\frac{\Delta\text{XA}}{\text{XA}}\right)$$

and

$\text{d\_T} = \Delta\text{T}$.

The base for the GST is the basic value plus federal and region non-GST sales taxes plus margins. Using households as an example, and recalling the definitions (E3.24) and (E3.25), GST revenue from households in region q, V3GST_CS(q), is

$$\text{V3GST\_CS}(q) = \sum_{c \in \text{COM}} \sum_{s \in \text{ALLSRC}} \frac{\text{T3GST}(c,s,q)}{100} \text{V3GSTBASE}(c,s,q) \tag{E3.39}$$

Thus:

$$\Delta\text{V3GST\_CS}(q) = \sum_{c \in \text{COM}} \sum_{s \in \text{ALLSRC}} \begin{pmatrix} \dfrac{\Delta\text{T3GST}(c,s,q)}{100} \text{V3GSTBASE}(c,s,q) \\ + \dfrac{\text{T3GST}(c,s,q)}{100} \Delta\text{V3GSTBASE}(c,s,q) \end{pmatrix} \tag{E3.40}$$

or:

$$\text{V3GST\_CS}(q) \times \text{w3gst\_cs}(q) = \sum_{c \in \text{COM}} \sum_{s \in \text{ALLSRC}} \begin{pmatrix} \Delta\text{T3GST}(c,s,q) \times \text{V3GSTBASE}(c,s,q) \\ + \text{T3GST}(c,s,q) \times \begin{pmatrix} \Delta\text{V3BAS}(c,s,q) + \Delta\text{V3TAXF}(c,s,q) \\ + \Delta\text{V3TAXS}(c,s,q) + \sum_{m \in \text{MARGCOM}} \Delta\text{V3MAR}(c,s,q,m) \end{pmatrix} \end{pmatrix} \tag{E3.41}$$

which is equivalent to VURM equation *E_w3gst_cs*, where:

$$\text{w3gst\_cs}(q) = \frac{\Delta\text{V3GST\_CS}(q)}{\text{V3GST\_CS}(q)} \times 100 \tag{E3.42}$$

```
Equation E_wtaxf_c # Total federal sales tax (not GST) on 1, 2, 3, 4 #
(all,q,REGDST)
ID01[VTAXF_C(q)]*wtaxf_c(q) =
    V1TAXF_CSI(q)*w1taxf_csi(q) + V2TAXF_CSI(q)*w2taxf_csi(q) +
    V3TAXF_CS(q)*w3taxf_cs(q) + V4TAXF_C(q)*w4taxf_c(q);

OMITTED: E_wnattaxf to  E_wtaxs

Equation E_w1taxf_csi
# Federal revenue from commodity taxes (not GST) on current production #
(all,q,REGDST)
ID01[V1TAXF_CSI(q)]*w1taxf_csi(q)  = sum{c,COM,sum{s,ALLSRC,sum{i,IND,
   V1TAXF(c,s,i,q)*{p0a(c,s) + x1a(c,s,i,q)} +
V1BAS(c,s,i,q)*d_t1F(c,s,i,q)}}};
Equation E_w1taxs_csi
# Region revenue from commodity taxes on current production #
(all,q,REGDST)
ID01[V1TAXS_CSI(q)]*w1taxs_csi(q)  = sum{c,COM,sum{s,ALLSRC,sum{i,IND,
   V1TAXS(c,s,i,q)*{p0a(c,s) + x1a(c,s,i,q)} +
V1BAS(c,s,i,q)*d_t1S(c,s,i,q)}}};

OMITTED: E_w1gst_csi to E_w2tax3_cs

Equation E_w3gst_cs # GST on consumption #
(all,q,REGDST)
ID01[V3GST_CS(q)]*w3gst_cs(q) = sum{c,COM,sum{s,ALLSRC, [
    V3GSTBASE(c,s,q)*d_t3GST(c,s,q) + T3GST(c,s,q)*{
    d_w3bas(c,s,q) + d_w3taxf(c,s,q) + d_w3taxs(c,s,q) +
    sum{r,MARGCOM, d_w3mar(c,s,q,r)}}]}};

 OMITTED: E_w3taxf_s to E_natwgst, which follow the same pattern as the
equations above.
```

3.1.1.21 Gross regional product on the income side equations (E_x0gspinc to E_w0gspinc)

This section contains the equations for determining gross regional product on the income side. In the TABLO implementation, gross regional product is referred to as gross state product (GSP).

On the income side, GRP consist of payments to the factors of production – labour, capital and land, plus other costs, total indirect taxes and tariffs, plus the real value of technological improvements in production, investment, and the use of margins.

There are three equations that determine the percentage changes in nominal and real GRP on the income side. Equation *E_x0gspinc* determines the percentage change in *real* gross state product — the volume of production in each region. Equation *E_p0gspexp* determines the percentage change in the gross state product deflator — the price of production in each region. From these two measures, equation *E_w0gspexp* determines the percentage change in *nominal* gross state product — the value of production in each region.

The first four terms on the RHS of *E_x0gspinc* cover the factors of production, and the lengthy fifth term accounts for all federal and regional sales taxes, tariffs and GST revenue. The sixth term accounts for technological improvements in the production process, and the seventh term accounts for technological improvements in the creation of capital. The final term accounts for technological improvements in margin use, which are weighted by the basic value of margins and the component of GST attributed to margin use.

For each regional industry, equations *E_a* and *E_a0mar* determine average technical change in industry production and in margin use, respectively.

Equation *E_p0gspinc* determines the regional GSP deflator on the income side at market prices. It is analogous to equation *E_x0gspexp*, except that the quantity variables on the RHS (e.g., x1cap_i) are replaced with corresponding price indexes (e.g., p1cap_i) and that the technological change variables enter with plus signs, rather than with negative signs.

```
Equation E_x0gspinc # Real GSP from the income side #
(all,q,REGDST)
V0GSPINC(q)*x0gspinc(q) =
    V1LND_I(q)*x1lnd_i(q) + V1CAP_I(q)*x1cap_i(q) +
    V1LAB_IO(q)*x1lab_io(q) + V1OCT_I(q)*x1oct_i(q) +
    sum{c,COM,sum{s,ALLSRC,sum{i,IND,
        (V1TAXF(c,s,i,q) + V1TAXS(c,s,i,q))*x1a(c,s,i,q) +
        T1GST(c,s,i,q)/100 * {
            V1BAS(c,s,i,q)*x1a(c,s,i,q) +
            (V1TAXF(c,s,i,q) + V1TAXS(c,s,i,q))*x1a(c,s,i,q) +
            sum{r,MARGCOM, V1MAR(c,s,i,q,r)*x1marg(c,s,i,q,r)}} +
        (V2TAXF(c,s,i,q) + V2TAXS(c,s,i,q))*x2a(c,s,i,q) +
        T2GST(c,s,i,q)/100 * {
            V2BAS(c,s,i,q)*x2a(c,s,i,q) +
            (V2TAXF(c,s,i,q) + V2TAXS(c,s,i,q))*x2a(c,s,i,q) +
            sum{r,MARGCOM, V2MAR(c,s,i,q,r)*x2marg(c,s,i,q,r)}} } +
        (V3TAXF(c,s,q) + V3TAXS(c,s,q))*x3a(c,s,q) +
        T3GST(c,s,q)/100 * {
            V3BAS(c,s,q)*x3a(c,s,q) +
            (V3TAXF(c,s,q) + V3TAXS(c,s,q))*x3a(c,s,q) +
            sum{r,MARGCOM, V3MAR(c,s,q,r)*x3marg(c,s,q,r)}} } +
        V4TAXF(c,q)*x4r(c,q) + V0TAR(c,q)*x0imp(c,q) +
        T4GST(c,q)/100 * {
            V4BAS(c,q)*x4r(c,q) +
            V4TAXF(c,q)*x4r(c,q) +
            sum{r,MARGCOM, V4MAR(c,q,r)*x4marg(c,q,r)}}} -
    sum{k,IND, [COSTS(k,q) - ADDRETURN(k,q)]*a(k,q)} -
    sum{c,COM,sum{i,IND, V2PURO(c,i,q)*[a2(q) + acom(c,q) + natacom(c)]}} -
    V0MAR(q)*a0mar(q);
```

```
Equation E_p0gspinc # State GSP deflator from the income side #
(all,q,REGDST)
V0GSPINC(q)*p0gspinc(q) =
    V1LND_I(q)*p1lnd_i(q)    + V1CAP_I(q)*p1cap_i(q) +
    V1LAB_IO(q)*p1lab_io(q)  + V1OCT_I(q)*p1oct_i(q) +
sum{c,COM,sum{s,ALLSRC,sum{i,IND,
(1 + T1GST(c,s,i,q)/100)*[
    [V1TAXF(c,s,i,q)*p0a(c,s) + V1BAS(c,s,i,q)*d_t1F(c,s,i,q)] +
    [V1TAXS(c,s,i,q)*p0a(c,s) + V1BAS(c,s,i,q)*d_t1S(c,s,i,q)] ] +
    V1GSTBASE(c,s,i,q)*d_t1GST(c,s,i,q) + T1GST(c,s,i,q)/100* {
    V1BAS(c,s,i,q)*p0a(c,s) + sum{r,MARGCOM, V1MAR(c,s,i,q,r)*p0a(r,q)}} +
(1 + T2GST(c,s,i,q)/100)*[
    [V2TAXF(c,s,i,q)*p0a(c,s) + V2BAS(c,s,i,q)*d_t2F(c,s,i,q)] +
    [V2TAXS(c,s,i,q)*p0a(c,s) + V2BAS(c,s,i,q)*d_t2S(c,s,i,q)] ] +
    V2GSTBASE(c,s,i,q)*d_t2GST(c,s,i,q) + T2GST(c,s,i,q)/100* {
    V2BAS(c,s,i,q)*p0a(c,s) + sum{r,MARGCOM, V2MAR(c,s,i,q,r)*p0a(r,q)}}} +
(1 + T3GST(c,s,q)/100)*[
    [V3TAXF(c,s,q)*p0a(c,s) + V3BAS(c,s,q)*d_t3F(c,s,q)] +
    [V3TAXS(c,s,q)*p0a(c,s) + V3BAS(c,s,q)*d_t3S(c,s,q)] ] +
    V3GSTBASE(c,s,q)*d_t3GST(c,s,q) + T3GST(c,s,q)/100* {
    V3BAS(c,s,q)*p0a(c,s) + sum{r,MARGCOM, V3MAR(c,s,q,r)*p0a(r,q)}} } +
(1 + T4GST(c,q)/100)*[
    [V4TAXF(c,q)*p0a(c,q) + V4BAS(c,q)*d_t4f(c,q)] ] +
    V4GSTBASE(c,q)*d_t4GST(c,q) + T4GST(c,q)/100* {
    [V4BAS(c,q)/POWERP4MARK(c,q)]*p0a(c,q) +
    sum{r,MARGCOM, V4MAR(c,q,r)*p0a(r,q)}} +
    [V0TAR(c,q)*(natp0cif(c) + phi) + V0IMP(c,q)*powtar(c)] } +
sum{k,IND, [COSTS(k,q) - ADDRETURN(k,q)]*a(k,q)} +
sum{c,COM,sum{i,IND, V2PURO(c,i,q)*(a2(q) + acom(c,q))}} +
V0MAR(q)*a0mar(q);

Equation E_w0gspinc # Value of GSP from the income side #
(all,q,REGDST)
w0gspinc(q) = p0gspinc(q) + x0gspinc(q);
```

```
Equation E_a # Technical change by industry-current production #
(all,i,IND)(all,q,REGDST)
ID01[COSTS(i,q)]*[a(i,q) - a1(i,q)] =
sum{c,COM,sum{s,ALLSRC, V1PURA(c,s,i,q)*a1a(c,s,i,q)}} +
             sum{c,COM, V1PURO(c,i,q)*
      (a1o(c,i,q) + acom(c,q) +  natacom(c) + acomind(c,i,q) +
            aind(i,q) + agreen(c,i,q))} +
        V1PRIM(i,q)*(a1prim(i,q) + a1prim_i(q) + nata1prim(i) +
nata1prim_i) +
        V1LAB_O(i,q)*(a1lab_o(i,q) + nata1lab_io) +
        V1CAP(i,q)*a1cap(i,q) +
        V1LND(i,q)*a1lnd(i,q) +
        V1OCT(i,q)*a1oct(i,q);

Equation E_a0mar # Average change in margin-specific technical change #
(all,q,REGDST)
V0MAR(q)*a0mar(q) =
sum{c,COM,
    sum{r,MARGCOM,
        sum{s,ALLSRC,
            sum{i,IND,
V1MAR(c,s,i,q,r)*(a1marg(q,r) + acom(r,q) + natacom(r)) +
    V2MAR(c,s,i,q,r)*(a2marg(q,r) + acom(r,q) + natacom(r))} +
        V3MAR(c,s,q,r)*(a3marg(q,r) + acom(r,q) + natacom(r)) +
            V5MAR(c,s,q,r)*(a5marg(q,r) + acom(r,q) + natacom(r)) +
                V6MAR(c,s,q,r)*(a6marg(q,r) + acom(r,q) + natacom(r))} +
                    V4MAR(c,q,r)*(a4marg(q,r) + acom(r,q) + natacom(r))}};
```

3.18.2 Gross regional product on the expenditure side

The definition of gross regional product on the expenditure side is based on the regional components of the standard definition of GDP — the sum of household consumption, investment, regional and federal government expenditure, foreign exports, and inventory accumulation, less foreign imports — plus inter-regional exports less inter-regional imports, and sales into the NEM (national electricity market) less purchases from the NEM. The regional value of each of these components is initially derived before being combined to derive gross regional product on the expenditure side.

3.1.1.22 Regional expenditure components (E_luxexp to E_x0cif_c)

As with the income-side components, each expenditure-side component is a definition. As with all definitions within the model, the defined variable and its associated equation could be deleted without affecting the rest of the model. The exception is regional household consumption expenditure (see equations *E_w3lux*, *E_x3tot* and *E_p3tot*). It may seem that the variable w3tot(q) is determined by the equation *E_w3lux*. This is not the case. Nominal household consumption is determined either by a macro-style consumption function or, say, by a constraint on the regional trade balance. Equation *E_w3lux* plays the role of a budget constraint on household expenditure.

```
Equation E_luxexp # Household budget constraint #
(all,q,REGDST)
V3TOT(q)* w3tot(q) =
    sum{c,COM,sum{s,ALLSRC, V3PURA(c,s,q)*(x3a(c,s,q) + p3a(c,s,q))}};

Equation E_x3tot # Real household consumption #
(all,q,REGDST)
x3tot(q) = w3tot(q) - p3tot(q);

Equation E_x2tot_i # Real investment #
(all,q,REGDST)
V2TOT_I(q)*x2tot_i(q) = sum{i,IND, V2TOT(i,q)*x2tot(i,q)};

Equation E_w2tot_i # Total nominal investment #
(all,q,REGDST)
w2tot_i(q) = x2tot_i(q) + p2tot_i(q);

Equation E_w5tot
# Aggregate nominal value of regional government consumption #
(all,q,REGDST)
w5tot(q) = x5tot(q) + p5tot(q);

Equation E_x5tot # Aggregate real regional government consumption #
(all,q,REGDST)
V5TOT(q)*x5tot(q) = sum{c,COM,sum{s,ALLSRC,V5PURA(c,s,q)*x5a(c,s,q)}};

Equation E_w6tot # Nominal federal government consumption #
(all,q,REGDST)
w6tot(q) = x6tot(q) + p6tot(q);

Equation E_x6tot # Real federal government consumption #
(all,q,REGDST)
V6TOT(q)*x6tot(q) = sum{c,COM,sum{s,ALLSRC, V6PURA(c,s,q)*x6a(c,s,q)}};

Equation E_x56tot # Aggregate real government consumption in region q #
(all,q,REGDST)
[V5TOT(q) + V6TOT(q)]*x56tot(q) = [V5TOT(q)*x5tot(q) + V6TOT(q)*x6tot(q)];

Equation E_d_w7tot # Change in nominal inventory accumulation #
(all,q,REGDST)
d_w7tot(q) = sum{c,COM, d_w7r(c,q)};

Equation E_d_x7tot # Change in real inventory accumulation #
(all,q,REGDST)
LEVP7R_C(q)*d_x7tot(q) = sum{c,COM, LEVP7R(c,q)*d_x7r(c,q)};

Equation E_x0gne
# Real gross national expenditure (final local absorption) #
(all,q,REGDST)
V0GNE(q)*x0gne(q) =
    V3TOT(q)*x3tot(q) + V2TOT_I(q)*x2tot_i(q) + V5TOT(q)*x5tot(q) +
    V6TOT(q)*x6tot(q) + 100*LEVP7R_C(q)*d_x7tot(q);
```

```
Equation E_x4tot # Export volume index #
(all,q,REGDST)
sum{c,COM, V4PURR(c,q)}*x4tot(q) = sum{c,COM, V4PURR(c,q)*x4r(c,q)};

Equation E_natx0cif # Import volumes (cif weights) #
(all,c,COM)
ID01[NATV0CIF(c)]*natx0cif(c) = sum{q,REGDST, V0CIF(c,q)*x0imp(c,q)};

Equation E_natx4r # Export volumes #
(all,c,COM)
ID01[NATV4R(c)]*natx4r(c) = sum{q,REGSRC, V4PURR(c,q)*x4r(c,q)};

Equation E_x0cif_c # Import volume index #
(all,q,REGDST)
sum{c,COM, V0CIF(c,q)}*x0cif_c(q) = sum{c,COM, V0CIF(c,q)*x0imp(c,q)};
```

3.1.1.23 Gross regional product on the expenditure side equations (E_w0gspexp to E_w0gspexp)

This section contains equations for gross regional product on the expenditure side. In the TABLO implementation, gross regional product is referred to as gross state product (GSP).

There are three equations that determine the percentage changes in nominal and real GSP. Equation *E_x0gspexp* determines the percentage change in *real* gross state product — the volume of production in each region. Equation *E_p0gspexp* determines the percentage change in the gross state product deflator — the price of production in each region. Equation *E_p0gspexp*, is analogous to the equation for real GSP from the expenditure-side at market prices, *E_x0gspexp*, but with the quantity variables on the RHS (e.g., x3tot) replaced with corresponding price indexes (e.g., p3tot). From these two measures, equation *E_w0gspexp* determines the percentage change in *nominal* gross state product — the value of production in each region.

```
Equation E_x0gspexp # Real GSP from the expenditure side #
(all,q,REGDST)
V0GSPEXP(q)*x0gspexp(q) =
    V3TOT(q)*x3tot(q) + V2TOT_I(q)*x2tot_i(q) + V5TOT(q)*x5tot(q) +
    V6TOT(q)*x6tot(q) + 100*LEVP7R_C(q)*d_x7tot(q) +
    VSEXP_C(q)*xsexp_c(q) - VSIMP_C(q)*xsimp_c(q) +
    V4TOT(q)*x4tot(q) - V0CIF_C(q)*x0cif_c(q) +
   [sum{c,COM, V8BAS(c,q)*x8a(c,q)} - V1NEM(q)*x1NEM(q)];

Equation E_p0gspexp # State GSP deflator from the expenditure side #
(all,q,REGDST)
V0GSPEXP(q)*p0gspexp(q) =
    V3TOT(q)*p3tot(q) + V2TOT_I(q)*p2tot_i(q) + V5TOT(q)*p5tot(q) +
    V6TOT(q)*p6tot(q) + V7TOT(q)*p7tot(q) +
    VSEXP_C(q)*psexp_c(q) - VSIMP_C(q)*psimp_C(q) +
    V4TOT(q)*(p4r_c(q) + phi) - V0CIF_C(q)*(p0cif_c(q) + phi) +
    sum{c,COM, V8BAS(c,q)*p0a(c,q)} - V1NEM(q)*p8tot;

Equation E_w0gspexp # Value of GSP from the expenditure side #
(all,q,REGDST)
w0gspexp(q) = p0gspexp(q) + x0gspexp(q);
```

3.18.3 Gross regional product at factor cost (E_x0gspfc to E_w0gspfc)

This section contains equations that define GSP at factor cost, which is the payments to the factors of production, plus the cost savings from technological improvements. This is equivalent to the income definition of GDP less indirect taxes at the regional level.

Equation *E_x0gspfc* determines the percentage change in *real* gross state product at factor cost. Equation *E_p0gspfc* determines the percentage change in the gross state product at factor cost price deflator. From these two measures, equation *E_w0gspfc* determines the percentage change in *nominal* gross state product at factor cost.

```
Equation E_x0gspfc # Real GSP at factor cost #
(all,q,REGDST)
V0GSPFC(q)*x0gspfc(q) =
    V1LNDINC_I(q)*x1lnd_i(q)  + V1CAPINC_I(q)*x1cap_i(q) +
    sum{c,COM, ADDEXPINC(c,q)*x4r(c,q)} +
    sum{o,OCC, V1LABINC_I(q,o)*x1lab_i(q,o)} + V1OCTINC_I(q)*x1oct_i(q) -
    sum{k,IND, [COSTS(k,q) - ADDRETURN(k,q)]*a(k,q)} -
    sum{c,COM,sum{i,IND, V2PURO(c,i,q)*[a2(q) + acom(c,q) + natacom(c)]}} -
    V0MAR(q)*a0mar(q);

Equation E_p0gspfc # State GSP deflator at factor cost #
(all,q,REGDST)
V0GSPFC(q)*p0gspfc(q) =
  V1LNDINC_I(q)*p1lndinc_i(q)   + V1CAPINC_I(q)*p1capinc_i(q) +
  sum{o,OCC, V1LABINC_I(q,o)}*pwage_io(q)   + V1OCTINC_I(q)*p1octinc_i(q) +
sum{k,IND, [COSTS(k,q) - ADDRETURN(k,q)]*a(k,q)} +
sum{c,COM,sum{i,IND, V2PURO(c,i,q)*(a2(q) + acom(c,q) + natacom(c))}} +
V0MAR(q)*a0mar(q);

Equation E_w0gspfc # Value of GSP at factor cost #
(all,q,REGDST)
w0gspfc(q) = p0gspfc(q) + x0gspfc(q);
```

3.18.4 Inter-regional trade flows (E_xsflo to E_wsexp_c)

The derivation of the quantity and price aggregates for the interregional trade flows involves an intermediate step represented by equations *E_xsflo, E_xsflo_c* and *E_psflo_c*. These equations determine inter- and intra- regional nominal trade flows in basic values.[22] To determine the interregional trade flows, say for interregional exports in *E_xsexp_c*, the intraregional trade flow (the second term on the RHS of *E_xsexp_c*) is deducted from the total of inter- and intra- regional trade flows (the first term on the RHS of *E_xsexp_c*).

[22] The determination in basic values reflects the convention in VURM that all margins and commodity taxes are paid in the region which absorbs the commodity.

```
Equation E_xsflo # Volumes of interregion trade (inc diagonal term) #
(all,c,COM)(all,s,REGSRC)(all,q,REGDST)
ID01[VSFLO(c,s,q)]*xsflo(c,s,q) =
sum{i,IND, V1BAS(c,s,i,q)*x1a(c,s,i,q) + V2BAS(c,s,i,q)*x2a(c,s,i,q)} +
    V3BAS(c,s,q)*x3a(c,s,q) + V5BAS(c,s,q)*x5a(c,s,q) +
V6BAS(c,s,q)*x6a(c,s,q);

Equation E_xsflo_c # Interregion trade flows (inc diagonal term) #
(all,s,REGSRC)(all,q,REGDST)
ID01[VSFLO_C(s,q)]*(psflo_c(s,q) + xsflo_c(s,q)) =
sum{c,COM,sum{i,IND,
    V1BAS(c,s,i,q)*(p0a(c,s) + x1a(c,s,i,q)) +
    V2BAS(c,s,i,q)*(p0a(c,s) + x2a(c,s,i,q)) } +
    V3BAS(c,s,q)*(p0a(c,s) + x3a(c,s,q)) + V5BAS(c,s,q)*(p0a(c,s) +
x5a(c,s,q))+
    V6BAS(c,s,q)*(p0a(c,s) + x6a(c,s,q)) };

Equation E_psflo_c # Price index - interregion trade flows #
(all,s,REGSRC)(all,q,REGDST)
ID01[VSFLO_C(s,q)]*psflo_c(s,q) =
sum{c,COM,sum{i,IND,
    V1BAS(c,s,i,q)*p0a(c,s) + V2BAS(c,s,i,q)*p0a(c,s) } +
    V3BAS(c,s,q)*p0a(c,s) + V5BAS(c,s,q)*p0a(c,s) + V6BAS(c,s,q)*p0a(c,s)};

Equation E_psexp_c # Price index - interregion exports #
(all,s,REGSRC)
ID01[VSEXP_C(s)]*psexp_c(s) =
    sum{q,REGDST, VSFLO_C(s,q)*psflo_c(s,q)} - VSFLO_C(s,s)*psflo_c(s,s);
 Equation E_psimp_c # Price index - interregion imports #
(all,q,REGDST)
ID01[VSIMP_C(q)]*psimp_C(q) =
    sum{s,REGSRC, VSFLO_C(s,q)*psflo_c(s,q)} - VSFLO_C(q,q)*psflo_c(q,q);

Equation E_xsexp_c # Interregion exports #
(all,s,REGSRC)
ID01[VSEXP_C(s)]*(psexp_c(s) + xsexp_c(s)) =
sum{q,REGDST, VSFLO_C(s,q)*(psflo_c(s,q) + xsflo_c(s,q))} -
    VSFLO_C(s,s)*(psflo_c(s,s) + xsflo_c(s,s));

Equation E_xsimp_c # Interregion imports #
(all,q,REGDST)
ID01[VSIMP_C(q)]*(psimp_C(q) + xsimp_c(q)) =
sum{s,REGSRC, VSFLO_C(s,q)*(psflo_c(s,q) + xsflo_c(s,q))} -
    VSFLO_C(q,q)*(psflo_c(q,q) + xsflo_c(q,q));

Equation E_wsimp_c # Interregion imports, value #
(all,q,REGDST)
ID01[VSIMP_C(q)]*wsimp_c(q) =
sum{s,REGSRC, VSFLO_C(s,q)*(psflo_c(s,q) + xsflo_c(s,q))} -
    VSFLO_C(q,q)*(psflo_c(q,q) + xsflo_c(q,q));
```

```
Equation E_wsexp_c # Interregion exports, value #
(all,s,REGSRC)
ID01[VSEXP_C(s)]*wsexp_c(s) =
sum{q,REGDST, VSFLO_C(s,q)*(psflo_c(s,q) + xsflo_c(s,q))} -
    VSFLO_C(s,s)*(psflo_c(s,s) + xsflo_c(s,s));
```

3.18.5 Regional tariff revenue (E_w0tar_c)

Equation *E_w0tar_c* determines tariff revenue on imports absorbed in region q (w0tar_c(q)). Equation *E_w0tar_c* is similar in form to equations such as *E_w1taxs_csi*, discussed in section 3.19.1. However, the tax-rate term in equation *E_w0tar_c*, powtar(c), refers to the percentage change in the power of the tariff rather than the percentage-point change in the tax rate (as is the tax-rate term in the commodity-tax equations of section 3.19.1). The basic value of imports is equal to the c.i.f foreign currency value multiplied by the nominal exchange rate and the power of the tariff:

$$\mathrm{V0IMP}(c,q) = \mathrm{V0CIF}(c,q) \times \mathrm{PHI} \times \mathrm{POWTAR}(c) \qquad c \in \mathrm{COM},\ q \in \mathrm{REGDST} \qquad (E3.43)$$

Tariff revenue from commodity c absorbed in region q, V0TAR(c,q) is given by:

$$\mathrm{V0TAR}(c,q) = \mathrm{V0CIF}(c,q) \times \mathrm{PHI} \times (\mathrm{POWTAR}(c) - 1) \qquad c \in \mathrm{COM},\ q \in \mathrm{REGDST} \qquad (E3.44)$$

Hence:

$$\Delta\mathrm{V0TAR}(c,q) = \Delta\mathrm{V0CIF}(c,q) \times \mathrm{PHI} \times (\mathrm{POWTAR}(c) - 1)$$
$$+\mathrm{V0CIF}(c,q) \times \Delta\mathrm{PHI} \times (\mathrm{POWTAR}(c) - 1) + \mathrm{V0CIF}(c,q) \times \mathrm{PHI} \times \Delta\mathrm{POWTAR}(c)$$

$$c \in \mathrm{COM},\ q \in \mathrm{REGDST} \qquad (E3.45)$$

or:

$$\mathrm{V0TAR}(c,q) \times \mathrm{w0tar}(c,q) = \mathrm{V0TAR}(c,q) \times$$
$$(\mathrm{x0imp}(c,q) + \mathrm{natp0cif}(c) + \mathrm{phi}) + \mathrm{V0IMP}(c,q) \times \mathrm{powtar}(c)$$

$$c \in \mathrm{COM},\ q \in \mathrm{REGDST} \qquad (E3.46)$$

where:

$$\mathrm{w0tar}(c,q) = \frac{\Delta\mathrm{V0TAR}(c,q)}{\mathrm{V0TAR}(c,q)} \times 100 \qquad c \in \mathrm{COM},\ q \in \mathrm{REGDST} \qquad (E3.47)$$

Equation E3.44 aggregated over commodities gives VURM equation *E_w0tar_c*. Note that the c.i.f. price of imports has no regional dimension as imports are assumed to have the same c.i.f. price in all regions.

```
Equation E_w0tar_c # Aggregate tariff revenue #
(all,q,REGDST)
ID01[V0TAR_C(q)]*w0tar_c(q) =
    sum{c,COM,V0TAR(c,q)*(natp0cif(c) + phi + x0imp(c,q)) +
              V0IMP(c,q)*powtar(c)};
```

3.18.6 Regional current account balance (E_d_TAB to E_d_FORINTINCA)

This section of the code contains a fairly detailed description of the balance of payments accounts for each region (see table B.7 of Appendix B). The resulting measures are subsequently used in calculating gross regional product (GRP), which is defined as nominal GRP less net factor income to foreigners.[23]

By definition, the balance on current account (CAB) equals the balance on trade account (TAB) plus the balance on income account (IAB) plus net foreign transfers from foreigners to Australians (NCT). The balance on income account is the income to Australians from foreign assets less the costs of servicing Australia's foreign liabilities. Net foreign transfers include foreign aid and social security payments, gifts, alimony, inheritances and labour income.

Equation *E_d_TAB* explains for region q the change in TAB as the change in value of exports less the change in value of imports, both valued in Australian dollars. Changes in exports and imports come from the CGE-core.

Equation *E_d_IAB* defines the change in IAB is the sum of changes in net interest payments (FORINTINC) and in net inflow of factor income (FORCAPINC).

We do not attempt the type of detailed modelling of the credit and debit sides of FORINTINC and FORCAPINC as is undertaken, for example, in the MONASH model[24]. Instead, we model just the net flows.

The change in FORINTIC is determined in equation *E_d_FORINTINC* as a function of:

- any exogenous change in the foreign rate of interest on debt (d_FORINT), which is assumed to be uniform across regions;
- any endogenous change in the net stock of regional foreign debt (d_NFD(q)); and
- any exogenous change in the valuation effect associated with foreign interest income (d_VALD) which is assumed to be uniform across regions.

Regional net foreign liabilities comprise net foreign debt plus net foreign equity. It is assumed that the net stock of regional foreign debt is a fixed share of total regional net foreign liabilities.

We assume, in Equation *E_d_FORCAPINC* that FORCAPINC moves with:

- any endogenous change in the net after-tax flow of income from capital, land and other costs accruing to foreigners (w1ncapinc(i,q), p1lndinc(i,q), x1lnd(i,q), p1octinc(i,q) and x1oct(i,q));
- any exogenously imposed change in the Australian tax rate on income accruing to foreigners (d_tgosinc);
- any exogenously imposed changes in the foreign ownership share of each regional industry's capital stock (d_FORSHR(I,q)); and
- any exogenously imposed change in the valuation effect associated with foreign capital income (d_VALE) which is assumed to be uniform across regions.

All the variables and coefficients on the RHS of this equation come from elsewhere in the model: income flows from the CGE-core, tax rates from the government finance module (discussed in chapter 5), and foreign ownership from the household income module (discussed in chapter 6).

[23] VURM uses the suffix 'gnp' in the variable and coefficient names denoting gross regional product to parallel the corresponding national measure, gross national product.
[24] See Section 25 of Dixon and Rimmer (2002).

```
Equation E_d_TAB # Change (A$m) in balance on trade account #
(all,q,REGDST)
100*d_TAB(q) = V4TOT(q)*(p4r_c(q) + phi + x4tot(q)) -
               V0CIF_C(q)*(p0cif_c(q) + phi + x0cif_c(q));

Equation E_d_IAB # Change (A$m) in balance on foreign income account #
(all,q,REGDST)
d_IAB(q) = d_FORINTINC(q) + d_FORCAPINC(q) + d_FORETSINC(q);

Equation E_d_NATIAB
# Change (A$m) in balance on national foreign income account #
d_NATIAB = sum{q,REGDST, d_IAB(q)};

Equation E_d_NCT # Change (A$m) in net current transfers into Australia #
(all,q,REGDST)
d_NCT(q) = NCT(q)/100*w0gspinc(q) + d_FNCT(q) + d_FNATNCT;

Equation E_d_CAB # Change (A$m) in balance on current account #
(all,q,REGDST)
d_CAB(q) = d_TAB(q) + d_IAB(q) + d_NCT(q);

Equation E_d_FORCAPINCA # Change (A$m) in net inflow of foreign income #
(all,q,REGDST)
100*d_FORCAPINC(q) =
-100*TGOSINCFAC*sum{i,IND, FORSHR(i,q)*
    [V1NCAPINC(i,q) + V1LNDINC(i,q) + V1OCTINC(i,q)]}*d_VALE +
-VALE*TGOSINCFAC*sum{i,IND, FORSHR(i,q)*
[V1NCAPINC(i,q)*w1ncapinc(i,q) + V1LNDINC(i,q)*(p1lndinc(i,q) + x1lnd(i,q))
+
 V1OCTINC(i,q)*(p1octinc(i,q) + x1oct(i,q))]} +
-100*VALE*sum{i,IND, FORSHR(i,q)*
[V1NCAPINC(i,q) + V1LNDINC(i,q) + V1OCTINC(i,q)]}*d_tgosinc +
-100*VALE*TGOSINCFAC*sum{i,IND,
[V1NCAPINC(i,q) + V1LNDINC(i,q) + V1OCTINC(i,q)]*d_FORSHR(i,q)};
```

3.18.7 Gross regional expenditure (E_x0gne to E_p0gne)

The equations in this section determine the changes in the quantity and price of gross regional expenditure, which are the regional equivalents of gross national product. Gross national expenditure is the sum of private consumption, government consumption and investment (i.e., final demand) and is equivalent to regional domestic absorption. In the TABLO implementation, gross regional expenditure is given eth suffix 'gne'.

Equations *E_x0gne* and *E_p0gne* determine the percentage changes in the quantity and price of gross regional expenditure, respectively. The price of regional gross national expenditure is used in the definition of real gross national product (GNP) (discussed in section 3.19.8).

```
Equation E_x0gne
# Real gross national expenditure (final local absorption) #
(all,q,REGDST)
V0GNE(q)*x0gne(q) =
    V3TOT(q)*x3tot(q) + V2TOT_I(q)*x2tot_i(q) + V5TOT(q)*x5tot(q) +
    V6TOT(q)*x6tot(q) + 100*LEVP7R_C(q)*d_x7tot(q);

Equation E_p0gne # State GNE deflator #
(all,q,REGDST)
[V3TOT(q) + V2TOT_I(q) + V5TOT(q) + V6TOT(q) + V7TOT(q)]*p0gne(q) =
    V3TOT(q)*p3tot(q) + V2TOT_I(q)*p2tot_i(q) + V5TOT(q)*p5tot(q) +
    V6TOT(q)*p6tot(q) + V7TOT(q)*p7tot(q);
```

3.18.8 Net regional product (E_x0nnp to E_w0nnp)

Regional net national product (NNP), is defined as GNP less depreciation of fixed capital. Real and nominal NNP at the regional levels are explained in equations *E_x0nnp* to *E_nw0nnp*.

```
Equation E_x0nnp # Real NNP by region #
(all,q,REGDST)
x0nnp(q) = w0nnp(q) - p0gne(q);

Equation E_w0nnp # Value of NNP by region #
(all,q,REGDST)
V0NNP(q)*w0nnp(q) = V0GNP(q)*w0gnp(q) -
    sum{i,IND, DEPR(i)*CAPSTOCK(i,q)*(p2tot(i,q) + x1cap(i,q))};
```

3.18.9 Regional expenditure and import price indexes (E_p3tot to E_p0cif_c)

These equations deal with the main remaining regional price indexes. For example, p3tot(q), the percentage change in the price of household consumption in region q is defined in equation *E_p3tot*.

The final equation shown in this excerpt is for the duty-paid price of imports in domestic currency. This is different from the cif-weighted price index defined in equation *E_natp0cif_c*, which is the price used in the calculation of GDP.

```
Equation E_p3tot # Consumer price index #
(all,q,REGDST)
V3TOT(q)*p3tot(q) = sum{c,COM,sum{s,ALLSRC, V3PURA(c,s,q)*p3a(c,s,q)}};

OMITTED: similar equations for the prices of the other expenditure-side
GSP-components.

Equation E_p0cif_c
# Foreign-currency import price index, cif, for region q #
(all,q,REGDST)
V0CIF_C(q)*p0cif_c(q) = sum{c,COM, V0CIF(c,q)*natp0cif(c)};
```

3.19 National income and expenditure reporting variables

This section discusses the national aggregates and reporting variables, which are mostly defined as weighted-average of their regional counterparts.

3.19.1 Gross domestic product on the income side

Gross domestic product on the income side is consists of the payments to the factors of production – labour, capital and land, plus other costs, total indirect taxes and tariffs, plus the real value of technological improvements in production, investment, and the use of margins. The regional value of each of these components is initially derived before being combined to derive gross domestic product on the income side.

3.1.1.24 National income components (E_natw1cap_i to E_nata0mar)

This set of equations defines economy-wide variables as aggregates of regional variables. As VURM is a bottom-up regional model, all behavioural relationships are specified at the regional level. Hence, national variables are simply add-ups of their regional counterparts. Note that we depart from our notational conventions when labelling the gross domestic product (GDP) variables (e.g., x0gdpinc) by not including the prefix 'nat'. It is assumed that the 'GDP' is sufficient to distinguish all such variables as national variables.

```
Equation E_natw1cap_i # Aggregate payments to capital #
NATV1CAP_I*natw1cap_i = sum{q,REGDST,V1CAP_I(q)*w1cap_i(q)};

OMITTED: Similar equations for labour, land and other costs

Equation E_natw0tar_c # Aggregate tariff revenue #
NATV0TAR_C*natw0tar_c = sum{q,REGDST, V0TAR_C(q)*w0tar_c(q)};

Equation E_natx1lab_io # Aggregate employment (hours)(wage-bill weights) #
NATV1LAB_IO*natx1lab_io = sum{q,REGDST, V1LAB_IO(q)*x1lab_io(q)};

OMITTED: Similar equations for labour, land and other costs

Equation E_natx2tot # National real investment by industry #
(all,i,IND)
ID01[NATV2TOT(i)]*natx2tot(i) = sum{q,REGDST, V2TOT(i,q)*x2tot(i,q)};

OMITTED: Similar equations for other elements of expenditure-side GDP
```

3.1.1.25 Regional indirect tax revenues (E_wtaxf_c to E_natwgst)

This block of equations derives the percentage changes in national aggregate revenue raised from indirect commodity taxes. Equation *E_wnattaxf* gives the national aggregate revenue from federal sales taxes by region, and. equation *E_wtaxs* gives aggregate regional sales taxes by commodity and region. The equations in the remainder of the section give aggregate federal and regional taxes by user, region, and commodity, as well as GST revenue by user, region and commodity. The final equation in this group, *E_natwgst*, gives aggregate national GST revenue.

The rational for the formulations used is set out in section 3.19.1.

3.1.1.26 Gross domestic product on the income side equations (E_x0gdpinc to E_w0gdpinc)

Equations *E_x0gdpinc*, *E_p0gdpinc* and *E_w0gdpinc*, respectively, determine the percentage changes in the real GDP, the GDP price deflator and nominal GDP on the income side as share-weighted averages of the corresponding regional variables.

```
Equation E_x0gdpinc # Real from the income side #
V0GDPINC*x0gdpinc = sum{q,REGDST, V0GSPINC(q)*x0gspinc(q)};

Equation E_p0gdpinc # GDP deflator from the income side #
V0GDPINC*p0gdpinc = sum{q,REGDST, V0GSPINC(q)*p0gspinc(q)};
```

```
Equation E_w0gdpinc # Nominal GDP from the income side #
V0GDPINC*w0gdpinc = sum{q,REGDST, V0GSPINC(q)*w0gspinc(q)};
```

3.19.2 Gross domestic product on the expenditure side (E_x0gdpexp to E_w0gdpexp)

Equations *E_x0gdpexp*, *E_p0gdpexp* and *E_w0gdpexp*, respectively, determine the percentage changes in the real GDP, the GDP price deflator and nominal GDP on the expenditure side as share-weighted averages of the corresponding regional variables.

```
Equation E_x0gdpexp # Real GDP from the expenditure side #
V0GDPEXP*x0gdpexp = sum{q,REGDST, V0GSPEXP(q)*x0gspexp(q)};

Equation E_p0gdpexp # GDP deflator from expenditure side #
V0GDPEXP*p0gdpexp = sum{q,REGDST, V0GSPEXP(q)*p0gspexp(q)};

Equation E_w0gdpexp # Nominal GDP from the expenditure side #
V0GDPEXP*w0gdpexp = sum{q,REGDST, V0GSPEXP(q)*w0gspexp(q)};
```

3.19.3 Gross domestic product at factor cost (E_x0gdpfc to E_w0gdpfc)

Equations *E_x0gdpfc E_p0gdpfc* and *E_w0gdpfc*, respectively, determine the percentage changes in the real, price deflator and nominal of GDP at factor cost as share-weighted averages of the corresponding regional variables.

```
Equation E_x0gdpfc # Real GDP at factor cost #
V0GDPFC*x0gdpfc = sum{q,REGDST, V0GSPFC(q)*x0gspfc(q)};

Equation E_p0gdpfc # National price of GDP at factor cost #
V0GDPFC*p0gdpfc = sum{q,REGDST, V0GSPFC(q)*p0gspfc(q)};

Equation E_w0gdpfc # National value of GDP at factor cost #
V0GDPFC*w0gdpfc = sum{q,REGDST, V0GSPFC(q)*w0gspfc(q)};
```

3.19.4 Gross national product (E_natx0gnp to E_natw0gnp)

The percentage change in gross national product (GNP) is given in equation *E_natw0gnp*.

Real GNP is deduced by deflating nominal GNP by the price deflator for gross national expenditure (GNE). Deflating by an expenditure deflator yields a real measure of income accruing to Australians in terms of the purchasing power over goods and services purchased by Australians. Equation *E_natx0gnp* is the percentage change-form of the equation for national real GNP.

```
Equation E_natx0gnp # Real national GNP by state #
natx0gnp  = natw0gnp - natp0gne;

Equation E_natw0gnp # Value of national GNP #
NATV0GNP*natw0gnp = sum{q,REGDST, V0GNP(q)*w0gnp(q)};
```

3.19.5 Net national product (E_natx0nnp to E_natw0nnp)

The equations in this section relate to net national product (NNP), which is defined as GNP less depreciation of fixed capital. Real and nominal NNP at the national levels are explained in equations *E_natx0nnp* and *E_natw0nnp*, respectively.

```
Equation E_natx0nnp # Real national NNP by region #
natx0nnp  = natw0nnp - natp0gne;
```

```
Equation E_natw0nnp # Value of national NNP #
NATV0NNP*natw0nnp = sum{q,REGDST, V0NNP(q)*w0nnp(q)};
```

3.19.6 Gross national expenditure (E_natx0gne to E_natp0gne)

The price of gross national expenditure (GNE) is defined in equation *E_natp0gne*. GNE is the sum of private consumption, government consumption and investment and is equivalent to domestic absorption. This price index is calculated in an analogous way to the regional equation (discussed in section 3.19.2).

```
Equation E_natx0gne # Real gross national expenditure (equivalent to final
national absorption) #
NATV0GNE*natx0gne = sum{q,REGDST,V0GNE(q)*x0gne(q)};

Equation E_natp0gne # National price of GNE #
sum{q,REGDST,
    [V3TOT(q) + V2TOT_I(q) + V5TOT(q) + V6TOT(q) + V7TOT(q)]}*natp0gne =
sum{q,REGDST,
    [V3TOT(q)*p3tot(q) + V2TOT_I(q)*p2tot_i(q) + V5TOT(q)*p5tot(q) +
     V6TOT(q)*p6tot(q) + V7TOT(q)*p7tot(q)]};
```

3.19.7 National current account balance (E_d_TAB to E_d_Natforintinc)

This section extends the discussion in section 3.19.6 on regional current account balances to determine the corresponding national balances.

The equations relating to national changes in the current account balances are:

- *E_d_NATTAB*, which determines the national change in the trade account balance;
- *E_d_NATTABGDP*, which determines the change in the national trade account balance as a proportion of nominal GDP;
- *E_d_NATIAB*, which determines the national change in the foreign income account balance;
- *E_d_NATIABGDP*, which determines the change in the national income-account balance as a proportion of nominal GDP;
- *E_d_NATNCT*, which determines the national change in net current transfers;
- *E_d_NATCAB*, which determines the national change in the current account balance;
- E_d_NATCABGDP, which determines the change in the national current-account balance as a proportion of nominal GDP; and
- *E_d_NATFORCAPINC*, which determines the net inflow of factor income into Australia.

```
Equation E_d_NATTAB # Change (A$m) in balance on national trade account #
d_NATTAB = sum{q,REGDST, d_TAB(q)};

Equation E_d_NATTABGDP # Change in trade-account balance to GDP ratio #
d_NATTABGDP = 1/V0GDPINC*d_NATTAB - (NATTABGDP/100)*w0gdpexp;

Equation E_d_NATIAB
# Change (A$m) in balance on national foreign income account #
d_NATIAB = sum{q,REGDST, d_IAB(q)};

Equation E_d_NATIABGDP # Change in income-account balance to GDP ratio #
d_NATIABGDP = 1/V0GDPINC*d_NATIAB - (NATIABGDP/100)*w0gdpexp;
```

```
Equation E_d_NATNCT # Change (A$m) in national net current transfers #
d_NATNCT = sum{q,REGDST, d_NCT(q)};

Equation E_d_NATCAB # Change (A$m) in balance on national current account #
d_NATCAB = sum{q,REGDST, d_CAB(q)};

Equation E_d_NATCABGDP # Change in current-account balance to GDP ratio #
d_NATCABGDP = 1/V0GDPINC*d_NATCAB - (NATCABGDP/100)*w0gdpexp;

Equation E_d_NATFORCAPINC # Change (A$m) in national FORCAPINC #
d_NATFORCAPINC = sum{q,REGDST, d_FORCAPINC(q)};
```

3.19.8 Other national price indexes (E_natp3tot to E_realdev)

Equation *E_natp3tot*, derives the percentage change in the national price of household consumption (natp3tot).

The next equation, equation *E_natp0cif_c*, derives the percentage change in the duty-paid price of imports in domestic currency and uses cif-values as weights.

The economy-wide terms-of-trade, nattot, is defined in equation *E_nattot*. Australia's terms of trade measures the price of goods and services exported from Australia relative to the price of goods and services imported into Australia. Equation *E_nattot* explains the percentage change in the terms of trade as the difference between the percentage change in the foreign-currency export price index and the percentage change in the foreign-currency import price index.

The final two equations in this section explain movements in the national average basic price for commodity c and in the competitiveness of the national economy. Changes in competitiveness are measured by movements in the real exchange rate: depreciation means improvement; appreciation means deterioration. The real exchange rate is defined as the ratio of the cost of producing tradable products in Australia relative to the foreign cost of producing similar products all in the same currency. The domestic cost of production is proxied using the GDP price deflator. The foreign cost is proxied using the price index of imports expressed in Australian dollars. Equation *E_realdev*, therefore, explains the percentage change in real devaluation (realdev) as the percentage change in domestic-currency price of imports less the percentage change in the GDP price deflator.

```
Equation E_natp3tot # Consumer price index #
NATV3TOT*natp3tot = sum{q,REGDST, V3TOT(q)*p3tot(q)};

Equation E_natp0cif_c # National foreign-currency import price (cif
weights) #
NATV0CIF_C*natp0cif_c = sum{q,REGDST, V0CIF_C(q)*p0cif_c(q)};

Equation E_nata0mar
# National average change in margin specific technical change #
NATV0MAR*nata0mar = sum{q,REGDST, V0MAR(q)*a0mar(q)};

Equation E_nattot # National terms of trade #
nattot = natp4r_c - natp0cif_c;

Equation E_natp0a # Aggregate doemstic basic prices by commodities #
(all,c,COM)
ID01[sum{s,REGSRC, MAKE_I(c,s)}]*natp0a(c) =
        sum{s,REGSRC, MAKE_I(c,s)*p0a(c,s)};
```

```
Equation E_natp0com
# National weighted-average basic price of production (inc additional
return) #
(all,c,COM)
ID01[sum{q,REGDST, SALES(c,q)}]*natp0com(c) =
        sum{q,REGDST, SALES(c,q)*p0com(c,q)};

Equation E_realdev # Foreign competitiveness of national economy #
realdev = (natp0cif_c + phi) - p0gdpexp;
```

4 Government finance module

This chapter details the government finance module in VURM, which determines the financial position of each jurisdictional government. [25]

Changes in each item of government revenue and expenditure are linked to changes in the model core through the use of relevant drivers of underlying economic activity (usually expressed in percentage change form) and, in the case of government taxes, to the relevant average tax rates.

Changes in the government finance module also feedback into the model core.[26] For example, for the average tax rate on non-labour primary factor income used in the model core, the coefficient TGOSINC, is calculated by dividing 'Income taxes levied on enterprises' in the government finance module (the coefficient VGFSI_132) by 'Non-labour primary factor income, after taxes on production' in the model core (the coefficient V1GOSINC_I).

The government finance module database for 2005-06 includes all nine jurisdictional governments in Australia: the eight State and Territory governments (including local government); and the Australian Government. It contains data for the reference year 2005-06 sourced from the 2008-09 editions of ABS *Government Finance Statistics* (Cat. no. 5512.0) and ABS *Taxation Revenue Australia* (Cat. no. 5506.0).[27] The database is expressed in $ million and is detailed in tables 4.6 to 4.8 at the end of this chapter.

The structure of the module is based on the framework used in the ABS *Government Financial Statistics* (GFS) (Cat. no. 5512.0), which provides standardised financial data across jurisdictional governments on a financial year basis. This ABS GFS framework is expanded to include additional taxation information from ABS *Taxation Revenue Australia* (Cat. no. 5506.0).

The chapter is divided into three sections:

- 4.1 Government revenue
- 4.2 Government expenditure
- 4.3 Government budget balances

In the module, a standard naming convention is used to identify each component of government revenue or expenditure. The prefix in each variable name denotes which of the three sections the variable relates to:

- a change in nominal government revenue is denoted by the prefix 'd_wgfsi_';
- a change in nominal government expenditure is denoted by the prefix 'd_wgfse_'; and
- a change in the nominal fiscal position is denoted by the prefix 'd_wgfs'.

---

[25] References to 'regional government' in this chapter, and in the government finance module, include local government. Government in the government finance module relates to the 'total public sector' as defined by the ABS in *Government Financial Statistics* (Cat. no. 5512.0).

[26] As it is not possible, at this stage, to reconcile the items of government revenue and expenditure in the ABS *Input-Output Tables* (Cat. no. 5209.0.55.001) on which the model core is based to the detailed revenue and expenditure categories in ABS *Government Finance Statistics* (Cat. no. 5512.0), the government finance module cannot, at this stage, be fully integrated with data from the model core. For example, ABS *Government Finance Statistics* report revenue collected from federal taxes on the provision of goods and services in 2005-06 amounted to $67 882 million, whereas the ABS *Input-Output Tables* report that taxes, net of subsidies, on production of $79 495 million.

[27] Other tax revenue from ABS *Taxation Revenue Australia* has been adjusted to align with the total from ABS *Government Finance Statistics* that is net of intragovernmental transfers.

The three digit suffix in each variable name identifies the relevant component of government revenue or expenditure. The relevant three digit codes for each module are set out in tables 4.1, 4.2 and 4.3, respectively. For example the variable d_wgfsi_121("Vic") denotes the change in payroll tax revenue collected by the Victorian government, and the variable d_wgfse_100("WA") denotes the change in gross operating expenses of the Western Australian government. Suffixes ending in 0 denote the relevant sub-totals (for example, d_wgfsi_010 denotes total taxes on goods and services, d_wgfsi_011 to d_wgfsi_018). Suffixes ending in 000 denote the relevant grand totals (for example, d_wgfsi_000 denotes total GFS revenue for each jurisdictional government).[28] Most variables in the government finance module are defined over all jurisdictions to maintain flexibility should government financial arrangements change and to simplify processing.[29]

The equation names reflect the variable being determined. Each equation generally consists of two blocks:

- the first for regional governments (the equation name generally ends with an 'A'); and
- the second for the federal government (the equation name generally ends with a 'B').

4.1 Government revenues (E_d_wgfsi_000A to E_d_wgfsi_500B)

The government finance module separately identifies 19 individual sources of government revenue and a number of revenue aggregates (table 4.1).

Changes in each item of government revenue are linked to those in the model core through the use of relevant drivers of underlying economic activity (usually expressed in percentage change form) and, in the case of taxes, to the relevant average tax rates. The relevant drivers are set out in table 4.5 at the end of this chapter. As far as practicable, the drivers for the changes in taxation revenue in the government finance module are the changes in appropriate tax collections in the model core. This is facilitated by having commodity taxes in the model core separately identified by type: federal government non-GST, regional government non-GST, and federal government GST.

[28] The initial levels coefficient that corresponds to each variable adopts a similar naming convention, but with a 'V' replacing the 'd_w' in each variable name. The coefficient VGFSI_100, for example, is the levels counterpart of the variable d_wgsi_100.

[29] For example, the federal government is the only source of age pension payments. However, the variable d_wgfsi_230 is defined over all jurisdictional governments for completeness. In the case of age pension payments, the elements corresponding to the regional governments are set to zero.

Table 4.1 Government revenue items in the government finance module

GFS revenue item	*Suffix*	*Variable*	*Coefficient*
Taxation revenue	100	d_wgfsi_100	VGFSI_100
Taxes on the provision of goods and services	110	d_wgfsi_110	VGFSI_110
General taxes	111	d_wgfsi_111	VGFSI_111
Goods & services tax (GST)	112	d_wgfsi_112	VGFSI_112
Excises and levies	113	d_wgfsi_113	VGFSI_113
Taxes on international trade	114	d_wgfsi_114	VGFSI_114
Taxes on gambling	115	d_wgfsi_115	VGFSI_115
Taxes on insurance	116	d_wgfsi_116	VGFSI_116
Taxes on use of motor vehicles	117	d_wgfsi_117	VGFSI_117
Other taxation revenue[a]	118	d_wgfsi_118	VGFSI_118
Factor inputs	120	d_wgfsi_120	VGFSI_120
Payroll	121	d_wgfsi_121	VGFSI_121
Property	122	d_wgfsi_122	VGFSI_122
Taxes on income	130	d_wgfsi_130	VGFSI_130
Income taxes levied on individuals	131	d_wgfsi_131	VGFSI_131
Income taxes levied on enterprises	132	d_wgfsi_132	VGFSI_132
Income taxes levied on non-residents	133	d_wgfsi_133	VGFSI_133
Federal government grants to regional government	200	d_wgfsi_200	VGFSI_200
GST-tied	210	d_wgfsi_210	VGFSI_210
Other	220	d_wgfsi_220	VGFSI_220
Sales of Goods and services	300	d_wgfsi_300	VGFSI_300
Interest receipts	400	d_wgfsi_400	VGFSI_400
Other GFS revenue	500	d_wgfsi_500	VGFSI_500
(minus) Removal of greenhouse tax revenue under grandfathering	600	d_wgfsi_600	VGFSI_600
GFS Revenue	**000**	**d_wgfsi_000**	**VGFSI_000**

[a] Other taxation revenue as published in *Taxation Revenue Australia* plus an adjustment to align total tax revenue with that in ABS *Government Finance Statistics*.

With respect to GST revenue, the treatment adopted in the government finance module follows its treatment in the ABS *Government Finance Statistics*: it is levied by the federal government and redistributed in its entirety to regional governments through GST-tied grants. The distribution of GST revenue to regional governments in the model database reflects the payments actually made in 2005-06. These payments reflect the Commonwealth Grants Commission (CGC) relativities for that year and regional populations as at 31 December 2005. The equation determining the allocation of GST-tied grants to each regional government includes a region-specific shift-term to allow for changes in the Commonwealth Grants Commission relativities. However, the model does not explicitly model the process by which the Grants Commission determines the GST (or any other) relativities.

In the case of income taxes, there are three types identified in the model. All accrue to the federal government (see table 4.7). Taxes on individuals are linked to salaried labour income via a single average tax rate. The tax rate is likened to the average PAYE rate. No allowance is made for any tax-free thresholds, or for marginal rates of taxation. Taxes on enterprises are linked to income from capital, land and other costs. Income from these sources is calculated by deducting property taxes from the cost of capital, land and other costs. Again, no allowance is made for any tax-free thresholds, or for marginal tax rates. Finally, taxes on non-residents are linked, simply, to nominal GDP.

The module also makes provision for any loss in government revenue from handing back the income notionally gained from the sale of carbon emissions permits under grandfathering arrangements (the variable d_wgfsi_600 and coefficient VGFSI_600) (discussed in chapter 7).

```
! Subsection 3.1.3: Equations for government income
---------------------------------!
! Total GFSI revenue !
Equation E_d_wgfsi_000A
# GFSI: Regional government total GFS revenue #
(all,g,REGDST)
d_wgfsi_000(g) =
    d_wgfsi_100(g) + d_wgfsi_200(g) + d_wgfsi_300(g) + d_wgfsi_400(g) +
        d_wgfsi_500(g);

Equation E_d_wgfsi_000B
# GFSI: Federal government total GFS revenue #
d_wgfsi_000("Federal") =
    d_wgfsi_100("Federal") + d_wgfsi_200("Federal") +
d_wgfsi_300("Federal") +
    d_wgfsi_400("Federal") + d_wgfsi_500("Federal") + d_wgfsi_600;

! Total taxation revenue !
Equation E_d_wgfsi_100
# GFSI: Government taxation revenue - total #
(all,g,GOVT)
d_wgfsi_100(g) = d_wgfsi_110(g) + d_wgfsi_120(g) + d_wgfsi_130(g);

! Taxes on provision of goods and services !
Equation E_d_wgfsi_110
# GFSI: Government taxes on the provision of goods and services #
(all,g,GOVT)
d_wgfsi_110(g) =
    d_wgfsi_111(g) + d_wgfsi_112(g) + d_wgfsi_113(g) + d_wgfsi_114(g) +
    d_wgfsi_115(g) + d_wgfsi_116(g) + d_wgfsi_117(g) + d_wgfsi_118(g);

! General taxes (sales tax) !
Equation E_d_wgfsi_111A
# GFSI: Regional government taxes on goods and services - general taxes #
(all,g,REGDST)
100*d_wgfsi_111(g) = VGFSI_111(g)*wtaxs_c(g);

Equation E_d_wgfsi_111B
# GFSI: Federal government taxes on goods and services - general taxes #
100*d_wgfsi_111("Federal") = VGFSI_111("Federal")*wnattaxf;
```

```
! Goods and Services Tax (GST) !
Equation E_d_wgfsi_112A
# GFSI: Regional government taxes on goods and services - GST #
(all,q,REGDST)
100*d_wgfsi_112(q) = 0;

Equation E_d_wgfsi_112B
# GFSI: Federal government taxes on goods and services - GST #
100*d_wgfsi_112("Federal") = VGFSI_112("Federal")*natwgst;

! Excises and levies !
Equation excA
(all,g,REGDST)
ID01[sum{i,EXCISE,V1TAXS_SI(i,g)+V2TAXS_SI(i,g)+V3TAXS_S(i,g)}]*exc(g) =
sum{c,EXCISE, V1TAXS_SI(c,g)*w1taxs_si(c,g) + V2TAXS_SI(c,g)*w2taxs_si(c,g)
+ V3TAXS_S(c,g)*w3taxs_s(c,g)};

Equation E_d_wgfsi_113A
# GFSI: Regional government taxes on goods and services - excises #
(all,q,REGDST)
100*d_wgfsi_113(q) = VGFSI_113(q)*exc(q);

Equation excB
ID01[sum{q,REGDST,sum{i,EXCISE,V1TAXF_SI(i,q)+V2TAXF_SI(i,q)+V3TAXF_S(i,q)}
}]*exc("Federal") =
sum{q,REGDST,sum{c,EXCISE, V1TAXF_SI(c,q)*w1taxf_si(c,q) +
    V2TAXF_SI(c,q)*w2taxf_si(c,q) + V3TAXF_S(c,q)*w3taxf_s(c,q)}};

Equation E_d_wgfsi_113B
# GFSI: Federal government taxes on goods and services - excises #
100*d_wgfsi_113("Federal") = VGFSI_113("Federal")*exc("Federal");

! Taxes on international trade !
Equation E_d_wgfsi_114
# GFSI: Government taxes on goods and services - international trade #
(all,g,GOVT)
100*d_wgfsi_114(g) = VGFSI_114(g)* [
IF{g ne "Federal", 0*natp3tot} + IF{g eq "Federal", natw0tar_c +
f_wgfsi_114}];

! Taxes on gambling !
Equation gamA
(all,g,REGDST)
ID01[sum{i,GAMBLE,V1TAXS_SI(i,g)+V2TAXS_SI(i,g)+V3TAXS_S(i,g)}]*gam(g) =
sum{c,GAMBLE, V1TAXS_SI(c,g)*w1taxs_si(c,g) + V2TAXS_SI(c,g)*w2taxs_si(c,g)
+ V3TAXS_S(c,g)*w3taxs_s(c,g)};

Equation E_d_wgfsi_115A
# GFSI: Regional government taxes on goods and services - gambling #
(all,q,REGDST)
100*d_wgfsi_115(q) = VGFSI_115(q)*gam(q);
```

```
Equation gamB
ID01[sum{q,REGDST,sum{i,GAMBLE,V1TAXF_SI(i,q)+V2TAXF_SI(i,q)+V3TAXF_S(i,q)}
}]* gam("Federal") =
sum{q,REGDST,sum{c,GAMBLE, V1TAXF_SI(c,q)*w1taxf_si(c,q) +
    V2TAXF_SI(c,q)*w2taxf_si(c,q) + V3TAXF_S(c,q)*w3taxf_s(c,q)}};

Equation E_d_wgfsi_115B # GFSI: Taxes on goods and services - gambling #
100*d_wgfsi_115("Federal") = VGFSI_115("Federal")*gam("Federal");

! Taxes on insurance !
Equation insA
(all,q,REGDST)
ID01[sum{i,INSURE,V1TAXS_SI(i,q)+V2TAXS_SI(i,q)+V3TAXS_S(i,q)}]*ins(q) =
sum{c,INSURE, V1TAXS_SI(c,q)*w1taxs_si(c,q) + V2TAXS_SI(c,q)*w2taxs_si(c,q)
+ V3TAXS_S(c,q)*w3taxs_s(c,q)};

Equation E_d_wgfsi_116A
# GFSI: Regional government taxes on goods and services - insurance #
(all,q,REGDST)
100*d_wgfsi_116(q) = VGFSI_116(q)*ins(q);

Equation insB
ID01[sum{q,REGDST,sum{i,INSURE,V1TAXF_SI(i,q)+V2TAXF_SI(i,q)+V3TAXF_S(i,q)}
}]*ins("Federal") =
sum{q,REGDST,sum{c,INSURE, V1TAXF_SI(c,q)*w1taxf_si(c,q) +
    V2TAXF_SI(c,q)*w2taxf_si(c,q) + V3TAXF_S(c,q)*w3taxf_s(c,q)}};

Equation E_d_wgfsi_116B
# GFSI: Federal government taxes on goods and services - insurance #
100*d_wgfsi_116("Federal") = VGFSI_116("Federal")*ins("Federal");

! Taxes on motor vehicles !
Equation motA
(all,q,REGDST)
ID01[sum{i,MOTOR,V1TAXS_SI(i,q)+V2TAXS_SI(i,q)+V3TAXS_S(i,q)}]*
    mot(q) =
sum{c,MOTOR, V1TAXS_SI(c,q)*w1taxs_si(c,q) + V2TAXS_SI(c,q)*w2taxs_si(c,q)+
    V3TAXS_S(c,q)*w3taxs_s(c,q)};

Equation E_d_wgfsi_117A
# GFSI: Regional government taxes on goods and services - motor vehicles #
(all,q,REGDST)
100*d_wgfsi_117(q) = VGFSI_117(q)*mot(q);

Equation motB
ID01[sum{q,REGDST,sum{i,MOTOR,V1TAXF_SI(i,q)+V2TAXF_SI(i,q)+V3TAXF_S(i,q)}}
]*mot("Federal") =
sum{q,REGDST,sum{c,MOTOR, V1TAXF_SI(c,q)*w1taxf_si(c,q) +
    V2TAXF_SI(c,q)*w2taxf_si(c,q) + V3TAXF_S(c,q)*w3taxf_s(c,q)}};

Equation E_d_wgfsi_117B
# GFSI: Regional government taxes on goods and services - motor vehicles #
100*d_wgfsi_117("Federal") = VGFSI_117("Federal")*mot("Federal");
```

```
! Other taxes on the provision of goods and services !
Equation E_d_wgfsi_118A
# GFSI: Regional government taxes on goods and services - other #
(all,q,REGDST)
100*d_wgfsi_118(q) =
    VGFSI_118(q)*(p3tot(q) + f_wgfsi_118(q));

Equation E_d_wgfsi_118B
# GFSI: Federal government taxes on goods and services - other #
100*d_wgfsi_118("Federal") =
    VGFSI_118("Federal")*(natp3tot + f_wgfsi_118("Federal"));

! Total taxes on factor inputs !
Equation E_d_wgfsi_120
# GFSI: Government taxes on factor inputs - total #
(all,g,GOVT)
d_wgfsi_120(g) = d_wgfsi_121(g) + d_wgfsi_122(g);

! Tax revenue from factor inputs - payroll !
Equation E_d_wgfsi_121A
# GFSI: Regional government taxes on factor inputs - payroll #
(all,q,REGDST)
d_wgfsi_121(q) = VGFSI_121(q)/
    ID01[sum{o,OCC, V1LABTAXS_I(q,o)}]*sum{o,OCC, d_w1labtxS_i(q,o)} +
    df_wgfsi_121(q);

Equation E_d_wgfsi_121B
# GFSI: Federal government taxes on factor inputs - payroll #
d_wgfsi_121("Federal") = VGFSI_121("Federal")/
    sum{q,REGDST,sum{o,OCC, V1LABTAXF_I(q,o)}}*
    sum{q,REGDST,sum{o,OCC, d_w1labtxF_i(q,o)}} + df_wgfsi_121("Federal");

! Tax revenue from factor inputs - property !
Equation E_d_wgfsi_122A
# GFSI: Regional government taxes on factor inputs - property #
(all,q,REGDST)
d_wgfsi_122(q) = VGFSI_122(q)/
    ID01[V1CAPTAXS_I(q)]*d_w1captxS_i(q) + df_wgfsi_122(q);

Equation E_d_wgfsi_122B
# GFSI: Federal government taxes on factor inputs - property #
d_wgfsi_122("Federal") = VGFSI_122("Federal")/
    sum{q,REGDST,V1CAPTAXF_I(q)}*
    sum{q,REGDST,d_w1captxF_i(q)} + df_wgfsi_122("Federal");

! Total income tax !
Equation E_d_wgfsi_130
# GFSI: Government taxes on income - total #
(all,g,GOVT)
d_wgfsi_130(g) = d_wgfsi_131(g) + d_wgfsi_132(g) + d_wgfsi_133(g);
```

```
! Tax revenue from income - individuals !
Equation E_d_wgfsi_131A
# GFSI: Regional government taxes on income - individuals #
(all,q,REGDST)
d_wgfsi_131(q) = 0;

Equation E_d_wgfsi_131B
# GFSI: Federal government taxes on income - individuals #
100*d_wgfsi_131("Federal") = VGFSI_131("Federal")*
[natpwage_io + natx1lab_io + 100/TLABINC*d_tlabinc + f_wgfsi_131];

! Tax revenue from income - enterprises !
Equation E_d_wgfsi_132A
# GFSI: Regional government taxes on income - enterprises #
(all,q,REGDST)
d_wgfsi_132(q) = 0;

Equation E_natw1gos_i # National value for w1gos_i #
sum{q,REGDST, V1GOSINC_I(q)}*natw1gos_i =
sum{q,REGDST, [V1CAPINC_I(q)*w1capinc_i(q) + 100*d_addreturn_i(q)] +
    V1LNDINC_I(q)*w1lndinc_i(q) + V1OCTINC_I(q)*w1octinc_i(q)};

Equation E_d_wgfsi_132B
# GFSI: Federal government taxes on income - enterprises #
d_wgfsi_132("Federal") = 0.01*VGFSI_132("Federal")*[
    natw1gos_i + 100/TGOSINC*d_tgosinc + f_wgfsi_132 ];

! Tax revenue from income - non-residents !
Equation E_d_wgfsi_133A
# GFSI: Regional government taxes on income - non-residents #
(all,q,REGDST)
d_wgfsi_133(q) = 0;

Equation E_d_wgfsi_133B
# GFSI: Federal government taxes on income - non-residents #
d_wgfsi_133("Federal") =
    0.01*VGFSI_133("Federal")*[w0gdpinc + f_wgfsi_133];

! Total federal grants to states !
Equation E_d_wgfsi_200
# GFSI: Government grants to regional government #
(all,g,GOVT)
d_wgfsi_200(g) = d_wgfsi_210(g) + d_wgfsi_220(g);

! State GST grant income tied to Commonwealth GST grants!
Equation E_d_wgfsi_210A
# GFSI: Regional government grants to regional government - GST tied #
(all,q,REGDST)
d_wgfsi_210(q) =
VGFSI_210(q)/sum{k,REGDST,VGFSI_210(k)}*[d_wgfse_311("federal") +
f_wgfsi_210(q)];
```

```
Equation E_d_wgfsi_210B
# GFSI: Federal government grants to regional government - GST tied #
d_wgfsi_210("federal") = 0;

Equation E_f_wgfsi_210
# To ensure that GST grants to regional government add to total GST
collections #
sum{q,REGDST, VGFSI_210(q)/sum{k,REGDST,VGFSI_210(k)}*f_wgfsi_210(q)} = 0;

Equation E_d_wgfsi_220A
# GFSI: Regional government grants to regional government - Other #
(all,q,REGDST)
d_wgfsi_220(q) = [VGFSI_220(q)/sum{k,REGDST,VGFSI_220(k)}]*[
                                  d_wgfse_312("Federal") + f_wgfsi_220(q)];

Equation E_d_wgfsi_220B
# GFSI: Federal government grants to regional government - Other #
d_wgfsi_220("Federal") = 0;

Equation E_f_wgfsi_220
# GFSI: Federal government grants to regional government - Other balance #
sum{q,REGDST, [VGFSI_220(q)/sum{k,REGDST,VGFSI_220(k)}]*f_wgfsi_220(q)} =
0;

! Sales of goods and services !
Equation E_d_wgfsi_300A
# GFSI: Regional government sales of goods and services #
(all,q,REGDST)
100*d_wgfsi_300(q) = VGFSI_300(q)*[w5tot(q) + f_wgfsi_300(q)];

Equation E_d_wgfsi_300B
# GFSI: Federal government sales of goods and services #
100*d_wgfsi_300("Federal") =
    VGFSI_300("Federal")*[natw6tot + f_wgfsi_300("Federal")];

! Interest receipts !
Equation E_d_wgfsi_400A
# GFSI: Regional government interest receipts #
(all,q,REGDST)
100*d_wgfsi_400(q) = VGFSI_400(q)*[w0gspinc(q) + f_wgfsi_400(q)];

Equation E_d_wgfsi_400B
# GFSI: Federal government interest receipts #
100*d_wgfsi_400("Federal") = VGFSI_400("Federal")*[
    w0gdpinc + f_wgfsi_400("Federal")];

! Other GFS revenues !
Equation E_d_wgfsi_500A
# GFSI: Regional government other revenues #
(all,q,REGDST)
100*d_wgfsi_500(q) = VGFSI_500(q)*[w0gspinc(q) + f_wgfsi_500(q)];
```

```
Equation E_d_wgfsi_500B
# GFSI: Federal government other revenues #
100*d_wgfsi_500("Federal") = VGFSI_500("Federal")*[
    w0gdpinc + f_wgfsi_500("Federal")];
```

4.2 Government expenditure (E_d_wgfse_000 to E_d_wgfse_700B)

The government finance module separately identifies 15 individual sources of government expenses and a number of expense aggregates (table 4.2).

Similar to government revenue, changes in each item of government expenses are linked to those in the model core through the use of relevant drivers of underlying economic activity (usually expressed in percentage change form). In the module, government expenditure is generally indexed to changes in population, unemployment or economic activity, and, in the case of personal benefit welfare payments, to the relevant benefit rates. The relevant drivers are set out in table 4.6 at the end of this chapter.

Table 4.2 Government expense items in the government finance module

GFS expense item	*Suffix*	*Variable*	*Coefficient*
Gross operating expenses[a]	100	d_wgfse_100	VGFSE_100
Personal benefit payments[b]	200	d_wgfse_200	VGFSE_200
Unemployment benefit[c]s	210	d_wgfse_210	VGFSE_210
Disability support pension[d]	220	d_wgfse_220	VGFSE_220
Age pension[e]	230	d_wgfse_230	VGFSE_230
Other personal benefit payments[f]	240	d_wgfse_240	VGFSE_240
Grant expenses	300	d_wgfse_300	VGFSE_300
Federal to regional government: Current	310	d_wgfse_310	VGFSE_310
GST-tied[g]	311	d_wgfse_311	VGFSE_311
Other	312	d_wgfse_312	VGFSE_312
Federal to local government.	320	d_wgfse_320	VGFSE_320
Federal to universities	330	d_wgfse_330	VGFSE_320
Governments to private industries	340	d_wgfse_340	VGFSE_340
Property expenses	400	d_wgfse_400	VGFSE_400
Subsidy expenses	500	d_wgfse_500	VGFSE_500
Capital transfers	600	d_wgfse_600	VGFSE_600
Other GFS expenses[h]	700	d_wgfse_700	VGFSE_700
Government lump-sum transfers to households	800	d_wgfse_800	VGFSE_800
GFS Expenses	**000**	**d_wgfse_000**	**VGFSE_000**

[a] Defined by the ABS as depreciation, employee expenses and other operating expenses. [b] Other current transfers. [c] Newstart, Mature age allowance, Widow allowance and Non-full-time students receiving youth allowance. [d] Disability support pension [e] Age pension, Age pension saving bonus, Self-funded retirees' supplementary bonus, Telephone allowance for Commonwealth seniors health card holders, Utilities allowance, Seniors concession allowance, Widow class B pension, Wife pension (partner age pension) and Wife pension (partner DSP). [f] The balance of other current transfers not accounted for by unemployment benefits, disability support pensions and age pensions. [g] Tied to GST revenue collections to remove the effect of timing differences. [h] Tax expenses plus other current transfers.

With regard to personal benefit welfare payments, the module identifies three key payments by the federal government — unemployment benefits (Newstart Allowance), disability support pensions (DSP) and age pensions — as well as a residual 'other personal benefit payments'. Modelling of each is predicated on the simplifying assumption that there is a single average benefit rate for each type of payment. It is also assumed that the proportion of the population receiving each payment does not change, except for the age pension which, if the cohort-based demographic model is turned on (discussed in chapter 7), increases with the share of the population aged 65 years and over (denoted by the variable ageshare). As a result, for example, disability support pensions are indexed to the product of population, average benefit rate and the CPI (to preserve the homogeneity properties of the model). Data on personal benefit payments in 2005-06 are sourced from the 2009-10 ABS *Year Book* (Cat. no. 1301.0).

With regard to GST expenditures, in keeping with the stated policy intention, it is assumed in the module that the federal government passes all of the GST revenue collected in each financial year on to regional governments. Consequently, federal government GST-tied grant expenses (d_wgfe_311("Federal")) is set equal to the aggregate revenue that regional governments receive from federal government GST-tied grants (d_wgfsi_121). Similarly, other grant expenses paid by the federal government to regional governments (d_wgfe_312("Federal")) is set equal to the aggregate revenue that regional governments receive from federal government other grants (d_wgfsi_122).

The module also makes provision for potential government lump-sum transfers to households (the variable d_wgfsi_800 and coefficient VGFSI_800). These transfers represent a non-distortionary way for government to return any excess revenue to households or as a non-distortionary means of raising revenue from households.

```
! Subsection 3.2.3: Equations for government expenditure
---------------------------------!
! Total GFS expenditure !
Equation E_d_wgfse_000
# GFSE: Total GFS expenses #
(all,g,GOVT)
d_wgfse_000(g) =
    d_wgfse_100(g) + d_wgfse_200(g) + d_wgfse_300(g) + d_wgfse_400(g) +
    d_wgfse_500(g) + d_wgfse_600(g) + d_wgfse_700(g) + d_wgfse_800(g);

! Gross operating expenses !
Equation E_d_wgfse_100A
# GFSE: Regional government gross operating expenses #
(all,q,REGDST)
100*d_wgfse_100(q) = VGFSE_100(q)*(w5tot(q) + f_wgfse_100(q));

Equation E_d_wgfse_100B
# GFSE: Federal government gross operating expenses #
100*d_wgfse_100("Federal") =
    VGFSE_100("Federal")*(natw6tot + f_wgfse_100("Federal"));

! Personal benefit payments - total !
Equation E_d_wgfse_200
# GFSE: Government personal benefit payments - total #
(all,g,GOVT)
d_wgfse_200(g) =
    d_wgfse_210(g) + d_wgfse_220(g) + d_wgfse_230(g) + d_wgfse_240(g);

! Unemployment benefits !
Equation E_d_wgfse_210A
# GFSE: Regional government personal benefit payments - unemployment #
(all,q,REGDST)
d_wgfse_210(q) = 0;

Equation E_d_wgfse_210B
# GFSE: Federal government personal benefit payments - unemployment #
100*d_wgfse_210("Federal") = sum{q,REGDST,VWHINC_210(q)*whinc_210(q)};

! Disability support pension payments !
Equation E_d_wgfse_220A
# GFSE: Regional government personal benefit payments - disability #
(all,q,REGDST)
d_wgfse_220(q) = 0;
```

```
Equation E_d_wgfse_220B
# GFSE: Federal government personal benefit payments - disability #
100*d_wgfse_220("Federal") = sum{q,REGDST,VWHINC_220(q)*whinc_220(q)};

! Age pension payments !
Equation E_d_wgfse_230A
# GFSE: Regional government personal benefit payments - age pension #
(all,q,REGDST)
d_wgfse_230(q) = 0;

Equation E_d_wgfse_230B
# GFSE: Federal government personal benefit payments - age pension #
100*d_wgfse_230("Federal") = sum{q,REGDST,VWHINC_230(q)*whinc_230(q)};

! Other personal benefit payments !
Equation E_d_wgfse_240A
# GFSE: Regional government personal benefit payments - other #
(all,q,REGDST)
d_wgfse_240(q) = 0;

Equation E_d_wgfse_240B
# GFSE: Federal government personal benefit payments - other #
100*d_wgfse_240("Federal") = sum{q,REGDST,VWHINC_240(q)*whinc_240(q)};

! Total grant expenses !
Equation E_d_wgfse_300 # GFSE: Government grant expenses - total #
(all,g,GOVT)
d_wgfse_300(g) =
    d_wgfse_310(g) + d_wgfse_320(g) + d_wgfse_330(g) + d_wgfse_340(g);

! Total federal grants to regional government !
Equation E_d_wgfse_310
# GFSE: Federal government grants to regional government - total #
(all,g,GOVT)
d_wgfse_310(g) = d_wgfse_311(g) + d_wgfse_312(g);

! GFSE: Commonwealth GST grants tied to total GST revenue collections!
Equation E_d_wgfse_311A
(all,q,REGDST)
d_wgfse_311(q) = 0;

Equation E_d_wgfse_311B # GFSE: Federal government GST grants tied to total
GST revenue collections #
d_wgfse_311("Federal") = d_wgfsi_112("Federal");

! Federal grants to regional government - other !
Equation E_d_wgfse_312A
# GFSE: Regional government grants to regional government - Other #
(all,q,REGDST)
d_wgfse_312(q) = 0;
```

```
Equation E_d_wgfse_312B
# GFSE: Federal government grants to regional government - Other #
100*d_wgfse_312("Federal") = VGFSE_312("Federal")*[
    natp3tot + natpop + f_wgfse_312];

! Grants to local government !
Equation E_d_wgfse_320A
# GFSE: Regional government grants to local government #
(all,q,REGDST)
d_wgfse_320(q) = 0;

Equation E_d_wgfse_320B
# GFSE: Federal government grants to local government #
100*d_wgfse_320("Federal") = VGFSE_320("Federal")*[
    w0gdpexp + f_wgfse_320];

! Grants to universities !
Equation E_d_wgfse_330A
# GFSE: Regional government grants to universities #
(all,q,REGDST)
d_wgfse_330(q) = 0;

Equation E_d_wgfse_330B
# GFSE: Federal government rants to universities #
100*d_wgfse_330("Federal") = VGFSE_330("Federal")*[
    w0gdpexp + f_wgfse_330];

! Grants to private industries !
Equation E_d_wgfse_340A
# GFSE: Regional government grants to private industries #
(all,q,REGDST)
100*d_wgfse_340(q) = VGFSE_340(q)*[
    w0gspinc(q) + f_wgfse_340(q)];

Equation E_d_wgfse_340B
# GFSE: Federal government grants to private industries #
100*d_wgfse_340("Federal") = VGFSE_340("Federal")*[
    w0gdpexp + f_wgfse_340("Federal")];

! Property expenses !
Equation E_d_wgfse_400A
# GFSE: Regional government property expenses #
(all,q,REGDST)
100*d_wgfse_400(q) = VGFSE_400(q)*[
    w0gspinc(q) + f_wgfse_400(q)];

Equation E_d_wgfse_400B
# GFSE: Federal government property expenses #
100*d_wgfse_400("Federal") = VGFSE_400("Federal")*[
    w0gdpexp + f_wgfse_400("Federal")];
```

```
! Subsidy expenses !
Equation E_d_wgfse_500A
# GFSE: Regional government subsidy expenses #
(all,q,REGDST)
100*d_wgfse_500(q) = VGFSE_500(q)*[
    w0gspinc(q) + f_wgfse_500(q)];

Equation E_d_wgfse_500B
# GFSE: Federal government subsidy expenses #
100*d_wgfse_500("Federal") = VGFSE_500("Federal")*[
    w0gdpexp + f_wgfse_500("Federal")];

! Capital transfers !
Equation E_d_wgfse_600A
# GFSE: Regional government capital transfers #
(all,q,REGDST)
100*d_wgfse_600(q) = VGFSE_600(q)*[
    w0gspinc(q) + f_wgfse_600(q)];

Equation E_d_wgfse_600B
# GFSE: Federal government capital transfers #
100*d_wgfse_600("Federal") = VGFSE_600("Federal")*[
    w0gdpexp + f_wgfse_600("Federal")];

! Other GFS expenses !
Equation E_d_wgfse_700A
# GFSE: Regional government other GFS expenses #
(all,q,REGDST)
100*d_wgfse_700(q) = ID01[VGFSE_700(q)]*[
    w0gspinc(q) + f_wgfse_700(q)];

Equation E_d_wgfse_700B
# GFSE: Federal government other GFS expenses #
100*d_wgfse_700("Federal") = ID01[VGFSE_700("Federal")]*[
    w0gdpexp + f_wgfse_700("Federal")];
```

4.3 Government budget balances (E_d_wgfsnob to E_d_wgfsbudGDPB)

The government finance module draws together the data on GFS revenue and GFS expenses to derive two summary measures of the overall nominal financial position of each government (table 4.3). The module reports a third summary measure as a share of nominal GSP/GDP.

Table 4.3 Summary measure of financial position in the government finance module

GFS expense item	*Suffix*	*Variable*	*Coefficient*
Net operating balance[a]	nob	d_wgfsenob	VGFSNOB
Net acquisition of non-financial assets[b]	nfa	d_wgfsnfa	VGFSNFA
Change in Net lending/borrowing balance	**bud**	**d_wgfsbud**	**VGFSBUD**

[a] GFS revenue less GFS expenses. [c] Newstart, Mature age allowance, Widow allowance and Non-full-time students receiving youth allowance. [d] Disability support pension [e] Age pension, Age pension saving bonus, Self-funded retirees' supplementary bonus, Telephone allowance for Commonwealth seniors health card holders, Utilities allowance, Seniors concession allowance, Widow class B pension, Wife pension (partner age pension) and Wife pension (partner DSP). [f] The balance of other current transfers not accounted for by unemployment benefits, disability support pensions and age pensions. [g] Tied to GST revenue collections to remove the effect of timing differences. [h] Tax expenses plus other current transfers.

In the module, the 'Net operating balance' is defined as 'GFS revenue' (GFSI_000) *less* 'GFS expenses' (GFSE_000). This is the first concept of government budget balance reported in the model. The change in net operating balance for government g is denoted d_wgfsnob(g) and is determined by equation *E_d_wgfsnob*.

Deducting 'Net acquisition of non-financial assets' from 'Net operating balance' yields 'Net lending/borrowing balance', the second concept of government budget balance that is reported. The change in net lending/borrowing balance for government g is denoted d_wgfsbud(g) and is determined by equation *E_d_wgfsbud*.

The net acquisition of non-financial assets measures the change in each government's stock of non-financial assets due to transactions. As such, it measures the net effect of purchases, sales and consumption (for example, depreciation of fixed assets and use of inventory) of non-financial assets. Another way to think of the concept is that it equals gross fixed capital formation, less depreciation, plus changes (investment) in inventories, plus other transactions in non-financial assets. To model this concept, we first define net government investment as:

$$\mathrm{V2TOTGOV\_NET}(q) = \sum_{i \in IND} \mathrm{GOVSHR}(i,q) \times (1 - \mathrm{FGOVSHR}(i,q)) \times (\mathrm{V2TOT}(i,q) - \mathrm{DEPR}(i) \times \mathrm{VCAP}(i,q))$$

$$q \in \mathrm{REGDST} \qquad \text{(E4.48)}$$

and

$$\mathrm{V2TOTGOV\_NET}(\text{"Federal"}) = \sum_{q \in REGDST} \sum_{i \in IND} \mathrm{GOVSHR}(i,q) \times \mathrm{FGOVSHR}(i,q) \times (\mathrm{V2TOT}(i,q) - \mathrm{DEPR}(i) \times \mathrm{VCAP}(i,q)) \qquad \text{(E4.49)}$$

where:

GOVSHR(i,q) is the share of government ownership in regional industry (i,q) (1 means fully government owned);

FGOVSHR means the share of the federal government in government ownership in regional industry (i,q) (1 means fully federal government owned);

V2TOT(i,q) is total gross investment in regional industry (i,q); and

DEPR(i)×VCAP(i,q) is the value of capital depreciation in regional industry (i,q).

Equations *E_d_wgfsnfaA* (regional governments) and *E_d_wgfsnfaB* (federal government) define the change in net acquisition of non-financial assets (d_wgfsnfa) by applying the percentage change forms of equations (E5.1) and (E5.2) to the initial value taken from the *Government Financial Statistics* for 2005-06.

The final measure of budget balance that we report is the fiscal balance as a fraction of nominal GDP (d_wgfsbudGDP). This is a real variable and is suitable as a target in simulations in which the government budget balance is held fixed as a share of nominal GDP (nominal GSP in the case of regional governments). From a modelling perspective, there are a number of closure choices concerning the budgetary position. The modeller may wish to keep the budget balance of each government exogenous by making a particular tax (transfer) shifter endogenous. There are a number of such shifters written in the code of the model, but more could be added if required.[30]

```
! Subsection 3.3.3: Equations for government budget balances
---------------------------------!
Equation E_d_wgfsnob
# GFS: Governmnet net operating balances #
(all,g,GOVT)
d_wgfsnob(g) = d_wgfsi_000(g) - d_wgfse_000(g);

Equation E_w2totgov_netA
# Percentage change in government net investment - regional #
(all,q,REGDST)
V2TOTGOV_NET(q)*w2totgov_net(q) = sum{i,IND, GOVSHR(i,q)*(1 -
FGOVSHR(i,q))* [
    V2TOT(i,q)*(x2tot(i,q) + p2tot(i,q)) -
    DEPR(i)*VCAP(i,q)*(x1cap(i,q) + p2tot(i,q)) ]};

Equation E_w2totgov_netB
# Percentage change in government net investment - federal#
V2TOTGOV_NET("Federal")*w2totgov_net("Federal") =
    sum{q,REGDST,sum{i,IND, GOVSHR(i,q)*FGOVSHR(i,q)* [
    V2TOT(i,q)*(x2tot(i,q) + p2tot(i,q)) -
    DEPR(i)*VCAP(i,q)*(x1cap(i,q) + p2tot(i,q)) ]}};

Equation E_d_wgfsnfaA
# GFS: Regional government net acquisition of non-financial assets #
(all,q,REGDST)
d_wgfsnfa(q) = VGFSNFA(q)/100*w2totgov_net(q);

Equation E_d_wgfsnfaB
# GFS: Federal government net acquisition of non-financial assets #
d_wgfsnfa("Federal") = VGFSNFA("Federal")/100*w2totgov_net("Federal");

Equation E_d_wgfsbud
# GFS: Government net lending/borrowing balance #
(all,g,GOVT)
d_wgfsbud(g) = d_wgfsnob(g) - d_wgfsnfa(g);
```

[30] From a practical modelling perspective, the modeller must be wary in choosing a suitable tax shifter to be endogenous, if the budget deficit is to be exogenous in absolute or relative terms. If the revenue base of a particular tax is small, moderate changes in government outlays or revenues elsewhere could lead to a change in the sign or the level of the revenue assigned to an endogenous tax shifter or implausible large projected changes in tax rates.

```
Equation E_d_wgfsbudGDPA
# GFS: Regional government net lending/borrowing balance/GSP #
(all,q,REGDST)
d_wgfsbudGDP(q) =
    (1/V0GSPINC(q))*d_wgfsbud(q) - (VGFSBUDGDP(q)/100)*w0gspexp(q);

Equation E_d_wgfsbudGDPB
# GFS: Federal government net lending/borrowing balance/GDP #
d_wgfsbudGDP("Federal") =
    (1/V0GDPINC)*d_wgfsbud("Federal") -
(VGFSBUDGDP("Federal")/100)*w0gdpexp;
```

Table 4.4 Drivers of government revenue in VURM

Source of government revenue	*Drivers*
Taxes on the provision of goods and services	
General taxes	Commodity tax rate, nominal value of usage in production, investment and household consumption
GST	GST tax rates on usage in production, investment, household consumption and exports; real usage and the basic price of goods and services in production, investment, household consumption and exports
Excises and levies	Commodity tax rates on other food, beverages & tobacco, petrol and other petroleum & coal products; real usage and basic price of food, beverages & tobacco petrol and other petroleum & coal products used in production, investment and household consumption
International trade	Import duty rates; foreign currency price of imports; nominal exchange rate; import volumes; consumer price index; shift term
Gambling	Commodity tax rates on hotels, cafes & accommodation and other services; real usage and basic price of hotels, cafes & accommodation and other services used in production, investment and household consumption
Insurance	Commodity tax rates on finance; real usage and basic price of financial services used in production, investment and household consumption
Use of motor vehicles	Commodity tax rates on motor vehicles & parts; real usage and basic price of motor vehicles & parts used in production, investment and household consumption
Other	Consumer price index; shit term
Factor inputs	
Payroll	Payroll tax rate; employment (hours); hourly wage rate; shift term
Property	Property tax rate; capital stock; unit income on capital; shift term
Taxes on income	
Income taxes levied on individuals	Labour income tax rates; employment (hours); hourly wage rate; shift term
Income taxes levied on enterprises	Non-labour income tax rates; capital stock; unit income on capital; quantity of land; unit income on land; other costs; unit income on other costs; shift term
Income taxes levied on non-residents	Real GDP; GDP price deflator; shift term
Commonwealth grants to states	
Current grants	
GST-tied	Commonwealth GST grant expenditure
Other	Commonwealth other current grant expenditure
Sales of goods and services	Real government consumption; government consumption price deflator; shift term
Interest received	Real GDP/GSP; GDP/GSP price deflator; shift term
Other revenue	Real GDP/GSP; GDP/GSP price deflator; shift term

[a] This item comprises revenue earned through the direct provision of goods and services by general government (government departments and agencies) and public enterprises.

Table 4.5 Drivers of government expenditure in VURM

Type of government expenditure	*Drivers*
Gross operating expenses	Real government consumption; government consumption price deflator; shift term
Personal benefit payments	
Unemployment benefits	Unemployment benefit rate; unemployment rate; consumer price index; shift term
Disability support pension	Disability support pension rate; population; consumer price index; shift term
Age pensions	Age pension rate; population; share of population aged 65 years and over, consumer price index; shift term
Other personal benefits	Other personal benefit payment rate; population; consumer price index; shift term
Grant expenses:	
Commonwealth to states: Current	
GST-tied	Nominal value of GST revenue collections
Other current grants	Population; consumer price index; shift term
Commonwealth to local government	Real GDP/GSP; GDP/GSP price deflator; shift term
Commonwealth to universities	Real GDP/GSP; GDP/GSP price deflator; shift term
State, territory and Commonwealth government grants to private sector	Real GDP/GSP; GDP/GSP price deflator; shift term
Property expenses	Real GDP/GSP; GDP/GSP price deflator; shift term
Subsidy expenses	Real GDP/GSP; GDP/GSP price deflator; shift term
Capital transfers	Real GDP/GSP; GDP/GSP price deflator; shift term
Other expenditure	Real GDP/GSP; GDP/GSP price deflator; shift term

5 Household income accounts module

The household income accounts module calculates changes in:

- household income, by summing the income received from various sources;
- household direct taxation, by applying tax rates to the different sources of income; and
- household disposable income, by deducting household direct taxation from their income.

The household disposable income and taxation data in the 2005-06 model database are detailed in table B.5 of Appendix B.

5.1 Household income (E_whinc_000 to E_whinc_300)

Equations *E_whinc_000* calculates the percentage change in regional household income. It draws together changes in different sources of income from:

- the ownership of primary factors used in production (including other costs);
- personal benefit payments from the federal government;
- other sources;
- government lump-sum transfers (usually used to redistribute any fiscal surplus to households in a non-distortionary manner); and
- exogenous sources

In that equation, the variable:

- *whinc_100* is the percentage change in income their ownership of primary factors used in production (determined by equation *E_whinc_100*);
- *whinc_200* is the percentage change in income from personal benefit payments paid by the federal government (equation *E_whinc_200*);
- *whinc_300* is the percentage change in other income (equation *E_whinc_300*);
- *d_whinc_400* is the income to households from the grandfathering of greenhouse permits (discussed in chapter 8);
- *d_whinc_500* is any exogenously imposed change in household income; and
- *d_wgfse_800* is a lump-sum transfer from (to, if negative) regional and/or federal government from the government finance module (discussed in chapter 4). Federal lump-sum transfers are distributed across regionals based on their population share.

5.2 Primary factor income

Household primary factor income consists of income from two broad sources:

- income from the use of labour in production (determined by equation *E_whinc_110*); and
- income from the ownership of all other all other primary factors used in production including other costs (determined by equation *E_whinc_120*).

Equation *E_whinc_110* sets the percentage change in household labour income equal to the percentage change in labour income from the CGE core of VURM (the variable w1labinc_i(q), discussed in chapter 3).

The calculation of the percentage change in all other primary factor income also links into the CGE model core, but its specification is more complicated than that for labour income.

It is assumed that national other primary factor income consists of all income arising from the domestic ownership of capital, agricultural land and other costs used in production:

$$\text{NATOTHER} = \sum_{q \in \text{REGDST}} \sum_{i \in \text{IND}} \text{DOMSHR(i, q)} \times \{\text{V1NCAPINC(i, q)} + \text{V1LNDINC(i, q)} + \text{V1NOCTINC(i, q)}\} \qquad \text{(E5.50)}$$

where:

DOMSHR(I,q) is a coefficient showing the share of industry i in region q that accrues to Australians, as opposed to foreigners;

V1NCAPINC(i,q) is net capital income from industry i in region q;

V1LNDINC(i,s) is land income from industry i in region q; and

V1OCTINC(i,s) is income from *other costs* from industry i in region q.

The term DOMSHR in (E5.1) ensures that primary factor income accruing to foreigners is excluded from the calculation of household income in Australia.

The distribution of NATOTHER across regions is based on the assumption that a portion of income from industry i accrues to regional residents, with the remainder spread across other regions in line with the size of each region's economy. Spreading a portion of income across regions in this way reflects an effort to incorporate the operations of a national share market. Thus, for region q, we have:

$$\text{OTHER(q)} = \sum_{i \in \text{IND}} \text{LOCSHR(i, q)} \times \text{DOMSHR(i, q)} \times \{\text{V1NCAPINC(i, q)} + \text{V1LNDINC(i, q)} + \text{V1NOCTINC(i, q)}\} + \sum_{i \in \text{IND}} \text{CONSHR}(q) \times \left(1 - \text{LOCSHR(i, q)}\right) \times \text{DOMSHR(i, q)} \times \{\text{V1NCAPINC(i, q)} + \text{V1LNDINC(i, q)} + \text{V1NOCTINC(i, q)}\} \qquad \text{(E5.51)}$$

where:

LOCSHR(i,q) is a coefficient showing the income from industry i in region q accruing to locals; and

CONSHR(q) is the share of consumption in region q in national consumption.

Equation *E_whinc_120* is based on the change form of (5.2).

5.2.1 Income from personal benefit payments

The model includes income from four personal benefit payments —unemployment benefit payments (Newstart); disability support pension payments; aged pension payments; and a residual other personal benefit payments. Regional household personal benefit income is broken down into:

- unemployment benefit payments (equation *E_whinc_210*);
- disability support pension payments (equation *E_whinc_220*);
- aged pension payments (equation *E_whinc_230*); and
- all other personal benefit payments (equation *E_whinc_240*).

Changes in the regional household income from each benefit payment changes with:

- the average relevant benefit rate (denoted, respectively, by the variables benefitrate1, benefitrate2, benefitrate3 and benefitrate4);
- changes in regional populations shares; and
- if the cohort-based demographic module is operational (see chapter 7), aged-pension payments also move with changes in the share of the population aged 65 years and over in that region.

Thus, for example, if Victoria's population increases relative to the national population, then the share of all forms of personal benefit payments accruing to Victorians will rise in line with the increase in Victoria's populations share.

Each equation also includes a shift term to enable exogenous changes to benefit payments to be applied to the model or to turn the relevant equation off (by swapping it with the relevant household income variable).

Changes in regional household income by benefit type are linked to changes in federal government expenditure for the corresponding category of expenditure in the government finance module (see chapter 4).

5.2.2 Other household income

Equation *E_whinc_300* links the percentage change in other household income to the percentage change in nominal gross state product (the variable w0gspinc (q), discussed in chapter 3).

5.3 Direct taxes paid by households (E_whtax_000 to E_whtax_120)

In level terms, direct taxes paid by households are calculated by multiplying each item of household primary factor income by the relevant average tax rate on that income. All of the tax rates used in this section are derived in the government finance module (see chapter 4).

Each equation in the household income module is expressed in percentage change form, with changes in the tax rates expressed as ordinary (percentage point) changes to allow for the possibility of zero tax rates.

Equation *E_whtax_110* determines the percentage change in direct taxes paid by regional households on labour income. It is a function of the percentage change in household labour income (whinc_110(q)), the initial level of the tax rate (TLABINC), and the change in tax rate on labour income (d_tlabinc_.

Equation *E_whtax_120* determines the percentage change in direct taxes paid by regional households on all other primary factor income. It is a function of the percentage change in all other primary factor income accruing to domestic households (whinc_120(q)), the initial level of the tax rate (TGOSINC), and the change in tax rate on all other primary factor income (d_tgosinc).

Equation *E_whtax_100* weights the percentage changes in direct taxes on labour and all other primary factor income to derive the percentage change in direct taxes on primary factor income. Equation *E_whtax_000* calculates the overall change in direct taxes paid by regional households. It does not include any indirect taxes paid on household consumption.

5.4 Household disposable income (E_whinc_dis to E_natwhinc_dis)

Household disposable income is household income less direct tax payments.

Equation *E_whinc_dis* determines the percentage change in regional household disposable income (whinc_dis(q)) from the changes in regional household income (whinc_000(q)) and direct taxes paid by those households (whtax_000(q)). Equation *E_natwhinc_dis* determines the corresponding national change.

```
Equation E_d_DOMSHR
(all,i,IND)(all,q,REGDST)
d_DOMSHR(i,q) = -d_FORSHR(i,q);

! Household income
Equation E_whinc_000 # HINC: Total #
(all,q,REGDST)
VHINC_000(q)*whinc_000(q) =
    VHINC_100(q)*whinc_100(q) + VHINC_200(q)*whinc_200(q) +
    VHINC_300(q)*whinc_300(q) + 100*d_whinc_400(q) + 100*d_whinc_500(q) +
    100*d_wgfse_800(q) + 100*C_POP(q)/C_NATPOP*d_wgfse_800("Federal") +
    VGFSE_800("Federal")*(C_POP(q)/C_NATPOP)*(pop(q) - natpop);

Equation E_whinc_100 # HINC: Factor income #
(all,q,REGDST)
VHINC_100(q)*whinc_100(q) =
    VHINC_110(q)*whinc_110(q) + VHINC_120(q)*whinc_120(q);

Equation E_whinc_110 # HINC: Factor income - labour #
(all,q,REGDST)
whinc_110(q) = w1labinc_i(q);

Equation E_w1ncapinc # Capital income net of depreciation #
(all,i,IND)(all,q,REGDST)
ID01(V1NCAPINC(i,q))*w1ncapinc(i,q) =
    {1 - DEPR(i)}*V1CAP(i,q)*(p1cap(i,q) + x1cap(i,q)) -
        100*(d_w1captxF(i,q) + d_w1captxS(i,q));
```

```
Equation E_whinc_120a # HINC: Factor income - non-labour #
(all,q,REGDST)
VHINC_120(q)*whinc_120(q) =
sum{i,IND,
    DOMSHR(i,q)*LOCSHR(i,q)*
 [V1NCAPINC(i,q)*w1ncapinc(i,q) + V1LNDINC(i,q)*(p1lndinc(i,q) +
x1lnd(i,q)) +
  V1OCTINC(i,q) *(p1octinc(i,q) + x1oct(i,q))]} +

C_POP(q)/C_NATPOP*
sum{s,REGDST, sum{i,IND,
    DOMSHR(i,s)*(1 - LOCSHR(i,s))*
 [V1NCAPINC(i,s)*w1ncapinc(i,s) + V1LNDINC(i,s)*(p1lndinc(i,s) +
x1lnd(i,s)) +
  V1OCTINC(i,s) *(p1octinc(i,s) + x1oct(i,s))]}} +

100*sum{i,IND,
    LOCSHR(i,q)*
    [V1NCAPINC(i,q) + V1LNDINC(i,q) + V1OCTINC(i,q)]*d_DOMSHR(i,q)} +

100*C_POP(q)/C_NATPOP*
sum{s,REGDST, sum{i,IND,
    (1 - LOCSHR(i,s))*
    [V1NCAPINC(i,s) + V1LNDINC(i,s) + V1OCTINC(i,q)]*d_DOMSHR(i,q)}} +

100*C_POP(q)/C_NATPOP*sum{r,REGDST, d_FORINTINC(r)};
Equation E_whinc_200 # HINC: Personal benefit payments #
(all,q,REGDST)
VHINC_200(q)*whinc_200(q) =
    VHINC_210(q)*whinc_210(q) + VHINC_220(q)*whinc_220(q) +
    VHINC_230(q)*whinc_230(q) + VHINC_240(q)*whinc_240(q);

Equation E_whinc_210 # HINC: Personal benefit receipts - unemployment
benefits #
(all,q,REGDST)
whinc_210(q) = natp3tot + unemp(q)  + benefitrate1 + f_whinc_210(q);

Equation E_whinc_220 # HINC: Personal benefit receipts - disability #
(all,q,REGDST)
whinc_220(q) = natp3tot + pop(q)  + benefitrate2 + f_whinc_220(q);

Equation E_whinc_230 # HINC: Personal benefit receipts - age #
(all,q,REGDST)
whinc_230(q) = natp3tot + pop(q)  + benefitrate3 + f_whinc_230(q);

Equation E_whinc_240 # HINC: Personal benefit payments - other #
(all,q,REGDST)
whinc_240(q) = natp3tot + pop(q) + benefitrate4 + f_whinc_240(q) ;
```

```
Equation E_whinc_300 # HINC: Other income #
(all,q,REGDST)
whinc_300(q) = w0gspinc(q);

! Household taxation !
Equation E_whtax_000 # HTAX: Total #
(all,q,REGDST)
VHTAX_000(q)*whtax_000(q) = VHTAX_100(q)*whtax_100(q);

Equation E_whtax_100 # HTAX: Tax on income #
(all,q,REGDST)
VHTAX_100(q)*whtax_100(q) =
    VHTAX_110(q)*whtax_110(q) + VHTAX_120(q)*whtax_120(q);

Equation E_whtax_110 # HTAX: Tax on income - labour #
(all,q,REGDST)
VHTAX_110(q)*whtax_110(q) =
    TLABINC*VHINC_110(q)*whinc_110(q) + 100*VHINC_110(q)*d_tlabinc;

Equation E_whtax_120 # HTAX: Tax on income - non-labour #
(all,q,REGDST)
VHTAX_120(q)*whtax_120(q) =
    TGOSINC*VHINC_120(q)*whinc_120(q) + 100*VHINC_120(q)*d_tgosinc;

! Household disposable income
Equation E_whinc_dis # Household disposable income #
(all,q,REGDST)
VHINC_DIS(q)*whinc_dis(q) =
    VHINC_000(q)*whinc_000(q) - VHTAX_000(q)*whtax_000(q);

Equation E_natwhinc_dis # National household disposable income #
sum{q,REGDST, VHINC_DIS(q)}*natwhinc_dis =
    sum{q,REGDST, VHINC_000(q)*whinc_000(q) - VHTAX_000(q)*whtax_000(q)};
```

6 Year-to-year dynamic simulation

This chapter extends the basic comparative-static model presented in chapter 3 to include equations that are essential for year-to-year simulations (i.e. dynamic simulations that trace out the paths for variables over successive years). It has four sections:

6.1 Relationship between capital, investment and expected rates of return

6.2 Relationship between the stock of net foreign liabilities and the balance on current account

6.3 Population and demographic flows

6.4 Equations for year-to-year policy simulations

Chapter 7 further develops the basic dynamic capabilities set out in this chapter through the introduction of a cohort-based demographic module, the linking of selected items of government consumption to the demographic module, the inclusion of occupational transformation in labour supply and the explicit modelling of export supplies.

6.1 Relationship between capital, investment and expected rates of return

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:

$$K_{i,q}(t+1) = (1 - DEP_{i,q}) \times K_{i,q}(t) + Y_{i,q}(t) \qquad \text{(E6.52)}$$

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 (E2.1) traces out the time paths of industries' capital stocks.

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

$$\frac{K_{i,q}(t+1)}{K_{i,q}(t)} = F_{i,q}\left[\frac{EROR_{i,q}(t)}{RROR_{i,q}(t)}\right] \qquad \text{(E6.53)}$$

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.

6.1.1 Capital and investment in year-to-year simulations

In year-to-year dynamics, we interpret a model solution as a vector of changes in the values of variables between two adjacent years. Thus, there is a fixed relationship between capital and investment. In VURM, capital available for production in the current forecast year (year t) is given by initial conditions, with the rate of return in year t adjusting to accommodate the given stock of capital and its utilisation of projected price levels.

In this section, we introduce the equations that allow the percentage change in capital available for production in year t (i.e. the percentage change in capital at the start of year t) to be determined inside the model. We also specify capital supply functions that determine industries' capital growth rates through year t (and thus investment in year t). The functions specify that investors are willing to supply increased funds to industry i in response to increases in i's expected rate of return (we assume static expectations). However, investors are modelled as being cautious. In any year, VURM capital supply functions limit the growth in industry i's capital stock so that disturbances in i's rate of return are eliminated only gradually.

On/off switch for capital in year-to-year simulations (E_f_x1cap)

In comparative static simulations, x1cap(i,q) is either exogenous (short-run) or determined by some rule governing changes in rates of return (long-run). In year-to-year simulations, x1cap(i,q) is set equal to capital available for production in the solution year, cap_t(i,q). Equation *E_f_x1cap* turns on the year-to-year explanation of x1cap, with the shift variable, f_x1cap, exogenous and set to zero change. In comparative static simulations, f_x1cap is endogenous, with one of x1cap or d_r1cap exogenous.

```
Equation E_f_x1cap # Explains x1cap in year-to-year sims - standard #
(all,i,IND)(all,q,REGDST)
x1cap(i,q) = cap_t(i,q) + f_x1cap(i,q);
```

6.1.1.1 Shocks to starting capital in year-to-year simulations (E_cap_t)

The stock of capital available for production in the solution year, year t, is the capital stock existing at the start of the year, or the end of the previous year, year t-1. We denote this stock as QCAP. The corresponding percentage-change variable is cap_t.

The appropriate value for cap_t in a year-to-year computation is the growth rate of capital between the start of year t-1 and the start of year t. Algebraically, using a notation that emphasises the timing of each variable, we want:

$$cap\_t_t(i,q) = 100 \times \left(\frac{QCAP_t(i,q)}{QCAP_{t-1}(i,q)} - 1\right) \qquad i \in ind \; q \in regdst \qquad (E6.54)$$

where $QCAP_t(i,q)$ is the quantity of capital available for production in industry i in region q at the start of the current solution year t. Equation (E6.3) can be rewritten as:

$$cap\_t_t(i,q) = 100 \times \left(\frac{QINV_{t-1}(i,q) - DEPR(i,q) \times QCAP_{t-1}(i,q)}{QCAP_{t-1}(i,q)}\right)$$

$i \in ind \; q \in regdsT$ (E6.55)

where $QINV_{t-1}(i,q)$ is the quantity of investment in industry i in year t-1 and DEPR(i,q) is a fixed parameter representing the rate of capital depreciation for regional industry i.

In making the computation for year t, we could treat $cap\_t_t(i)$ as an exogenous variable and compute its value outside the model in accordance with equation (E6.4). It is more convenient, however, to compute values for $cap\_t_t(i)$ inside the model. This is done using equation E_cap_t.

To understand the levels form of E_cap_t, we start by re-writing (E6.3) as:

$$QCAP_t(i,q) - QCAP_{t-1}(i,q) = (QINV_{t-1}(i,q) - DEPR(i,q) \times QCAP_{t-1}(i,q))$$

$i \in ind \; q \in regdst$ (E6.56)

In year-to-year simulations, we want the initial solution for year t to reflect values for year t-1, since the changes we are simulating are from year t-1 to year t. If this is the case, then the initial value of $QCAP_t(i)$ is $QCAP_{t-1}(i)$. The Euler solution method requires that the initial (database) values for variables form a solution to the underlying levels form of the model. Unless net investment in year t-1 is zero in industry i, then the initial data for a year-t computation will not be a solution to equation (E6.3).

We solve this problem of initial-value by the purely technical device of augmenting equation (E6.3) with an additional exogenous variable UNITY as follows:

$$\begin{aligned} &QCAP_t(i,q) - QCAP_{t-1}(i,q) = \\ &\qquad UNITY \times (QINV_{t-1}(i,q) - DEPR(i,q) \times QCAP_{t-1}(i,q)) \end{aligned} \qquad i \in ind\ q \in regdst \qquad (E6.57)$$

We choose the initial value of UNITY to be 0, so that (E6.6) is satisfied when $QCAP_t(i)$ takes its initial value regardless of the initial value of net investment in industry i. UNITY is often referred to as a 'homotopy parameter'. By moving UNITY to one, we cause the correct deviation in the opening capital stock for year t from its value in the initial solution (i.e., from its value in year t-1).

Equation *E_cap_t* is the change form of (E6.6), after changes in notation. On the RHS of the TABLO equation, the coefficients $QINV@1(i,q)$ and $QCAP@1(i,q)$ are the levels of $QINV(i,q)$ and $QCAP(i,q)$ in the initial solution for year t. Provided that the initial solution is drawn from values for year t-1, then $QINV@1(i,q)$ corresponds to $QINV_{t-1}(i,q)$ in (E6.4) and $QCAP@1(i,q)$ corresponds to $QCAP_{t-1}(i,q)$. The variable d_unity is the ordinary change in UNITY. In year-to-year simulations, d_unity is always set to 1.

```
Equation E_cap_t
# Capital available for production in year-to-year simulations #
(all,i,IND)(all,q,REGDST)
cap_t(i,q) =
[0 + IF[QCAP(i,q) ne 0,
    100*{QINV@1(i,q) - DEPR(i)*QCAP@1(i,q)}/QCAP(i,q)]]*d_unity;
```

Capital available in year t+1 (E_cap_t1)

The availability of capital in any one simulation year is related to investment in the previous year, net of depreciation.

Equation *E_cap_t1* explains the percentage change in the capital stock of industry i in region q at the end of the solution year. The levels form of this equation (with time made explicit) is:

$$QCAP\_T1_t(i,q) = QINV_t(i,q) + (1 - DEPR(i,q)) \times QCAP\_T_t(i,q)$$

$$i \in IND\ q \in REGDST \qquad (E6.58)$$

where $QCAP\_T1_t(i,q)$ is the stock of capital in industry i in region q at the end of year t (or the start of year t+1). Note that equation (E6.7) is satisfied by the initial solution for year t, and so there is no need to introduce the homotopy variable.

Taking ordinary changes of the LHS and the RHS of (E6.5) gives, after dropping the time index, E_cap_t1.

```
Equation E_cap_t1 # Capital at end of year in year-to-year simulations #
(all,i,IND)(all,q,REGDST)
cap_t1(i,q) =
    (1-DEPR(i))*QCAP(i,q)/ID01[QCAP_T1(i,q)]*cap_t(i,q) +
    {1 + IF(QINV(i,q) ne 0, -1 + QINV(i,q)/ID01[QCAP_T1(i,q)])}*x2tot(i,q);
```

Capital growth between the start and end of the solution year (E_d_k_gr)

In year-to-year simulations, growth in capital stocks between the start and end of year t is determined by the expected rate of return on capital (see equation (E6.2). Here we define the level of the growth rate in capital for industry i:

$$K\_GR_t(i,q) = \frac{QCAP\_T1_t(i,q)}{QCAP\_T_t(i,q)} - 1 \times 100 \qquad i \in IND\ q \in REGDST \qquad (E6.59)$$

Equation *E_del_k_gr* explains the year-to-year change in that growth rate in terms of the percentage-change variables cap_t(i,q) and cap_t1(i,q).

```
Equation E_d_k_gr # Change in the capital growth rate between start and end
of solution year (% pts) #
(all,i,IND)(all,q,REGDST)
d_k_gr(i,q) =
    ID01[QCAP_T1(i,q)]/ID01[QCAP(i,q)]*[cap_t1(i,q) - cap_t(i,q)] +
                                       d_fk_gr(i,q);
```

6.1.2 Investment and expected rates of return in year-to-year simulations

Expected rate of return (E_d_eeqror)

Investment is determined by projected differences in expected and actual rates of return. To enable this modelling, it is assumed that the expectation held in period t by owners of capital in industry i for industry i's rate of return in period t+1 can be separated into two parts. One part is called the expected equilibrium rate of return. This is the expected rate of return required to sustain indefinitely the current rate of capital growth in industry j. The second part is a measure of the disequilibrium in i's current expected rate of return. In terms of the notation in the TABLO code:

$$EROR(i,q) = EEQROR(i,q) + DISEQROR(i,q) \qquad i \in IND\ q \in REGDST \qquad (E6.60)$$

where EROR(i,q), EEQROR(i,q) and DISEQROR(i,q) are the levels in year t of the expected rate of return, the expected equilibrium rate of the return and the disequilibrium in the expected rate of return, respectively. Equation *E_d_eeqror* is the change form of (E6.9).

```
Equation E_d_eeqror
# Change in EROR = change in EEROR + change in DISEQROR #
(all,i,IND)(all,q,REGDST)
d_eror(i,q) = d_eeqror(i,q) + d_diseqror(i,q);
```

Expected equilibrium rates of return (E_d_feeqror)

The theory of investment in year-to-year simulations then relates the expected equilibrium rate of return for industry i (EEQROR(i,q)) to the current rate of growth in the capital stock in industry i (K_GR(i,q)). As shown in the upper panel in figure 6.1, the relationship has an inverse logistic form, which has the algebraic form:

$$EEQROR(i,q) = RORN(i,q) + F\_EEQROR(i,q) +$$

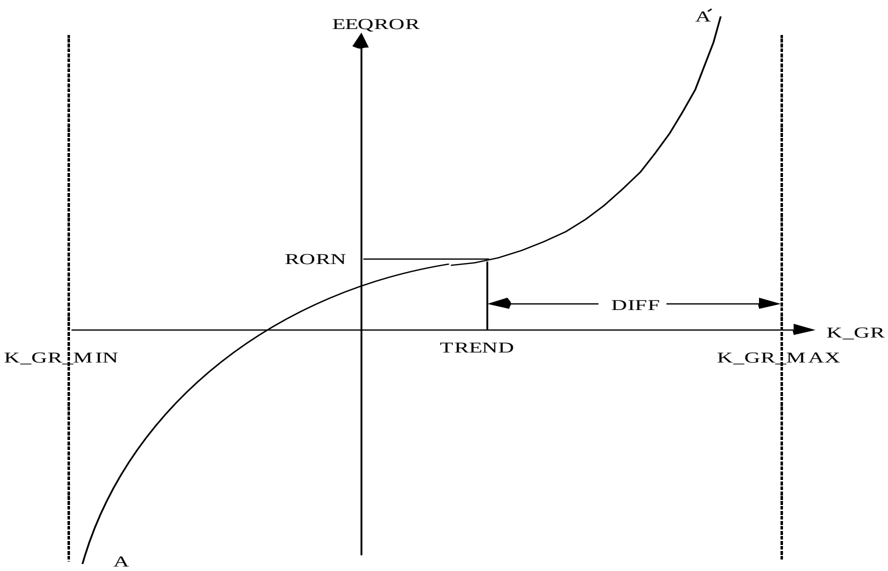
$$\frac{1}{\text{CAP\_SLOPE(i,q)}} \times \{$$
$$[\ln(\text{K\_GR(i,q)} - \text{K\_GR\_MIN(i,q)}) - \ln(\text{K\_GR\_MAX(i,q)} - \text{K\_GR(i,q)})] -$$
$$[\ln(\text{TREND\_K(i,q)} - \text{K\_GR\_MIN(i,q)}) - \ln(\text{K\_GR\_MAX(i,q)} - \text{TREND\_K(i,q)})]\}$$

$i \in IND$ $q \in REGDST$ (E6.61)

where:

RORN is a coefficient representing the industry's 'historical/long-run' rate of return;

Figure 6.1: The equilibrium expected rate of return schedule for industry j



F_EEQROR allows for vertical shifts in the capital supply curves (in the TABLO code there are three shift variables allowing for a nationwide shift, region-wide shifts and shifts that are industry and region specific);

CAP_SLOPE is a coefficient which is correlated with the inverse of the slope of the capital supply curve (the lower panel in figure 6.1) in the region of K_GR = TREND_K (for further details see Dixon and Rimmer, 2002);

K_GR_MIN is a coefficient, which sets the minimum possible rate of growth of capital;

K_GR_MAX is a coefficient, set to the maximum possible rate of growth of capital; and

TREND_K is a coefficient, set to the industry's 'historical/long-run' rate of capital growth.

Equation (E6.8) is explained in Dixon and Rimmer (2002) as follows. Suppose that F_EEQROR and DISEQROR are initially zero. Then according to (E6.7) and (E6.8), for an industry to attract sufficient investment in year t to achieve a capital growth rate of TREND_K it must have an expected rate of return equal to its long-term average (RORN). For the industry to attract sufficient investment in year t for its growth in capital stock to exceed its long-term average (TREND_K), its expected rate of return must be greater than RORN. Conversely, if the expected rate of return on the industry's capital falls below RORN, then investors will restrict their supply of capital to the industry to a level below that required to sustain capital growth at the rate of TREND_K.

The change version of (E6.10) is equation *E_d_feeqror*.

```
Equation E_d_feeqror # Change in expected equilibrium rate of return #
(all,i,IND)(all,q,REGDST)
d_eeqror(i,q) = d_feeqror_iq + d_feeqror_i(q) + d_feeqror(i,q) +
    [1/CAP_SLOPE(i,q)] *
 [1/[K_GR(i,q) - K_GR_MIN(i,q)] + 1/[K_GR_MAX(i,q) -
K_GR(i,q)]]*d_k_gr(i,q);
```

Adjustment of disequilibrium in expected rate of return towards zero (E_d_diseqror)

The initial disequilibrium in the expected rate of return (DISEQROR) is gradually eliminated over time according to the rule:

$$\begin{aligned}&\text{DISEQROR}(i,q) - \text{DISEQROR}@1(i,q) = \\ &\qquad -\text{ADJ\_COEFF}(i,q) \times \text{DISEQROR}@1(i,q) \times \text{UNITY}\end{aligned} \qquad i \in \text{IND} \; q \in \text{REGDST} \qquad \text{(E6.62)}$$

where DISEQROR@1 is the initial value of DISEQROR in a simulation for year t; and ADJ_COEFF is a positive parameter (less than one) determining the speed at which DISEQROR moves towards zero. E_d_diseqror is the change form of (E6.11).

```
Equation E_d_diseqror # Moves disequilibrium rate of return to zero #
(all,i,IND)(all,q,REGDST)
d_diseqror(i,q) = - ADJ_COEFF(i,q)*DISEQROR(i,q)*d_unity;
```

Expected rate of return equals actual rate of return under static expectations (E_d_eror)

This equation enforces the rule that the expected rate of return on capital in industry i in region q in year t equals industry i's actual rate of return in year t under static expectations.

```
Equation E_d_eror # Static expectations: EROR = ROR #
(all,i,IND)(all,q,REGDST)
d_eror(i,q) = d_r1cap(i,q);
```

6.2 Relationship between the stock of net foreign liabilities and the balance on current account (E_d_FNFE to E_d_PASSIVE)

This section of code explains changes in the stock of net foreign liabilities in year-to-year simulations. It is assumed that at the end of the solution year (year t):

$$\text{NFL}(t+1) = \text{NFL}(t) - \text{CAB}(t) + \text{Valuation changes} \qquad \text{(E6.63)}$$

where:

NFL(t+1) is the value of the stock of net foreign liabilities at the end of the solution year (i.e., the value of NFL at the end of t);

NFL(t) is the initial value of the stock of net foreign liabilities in the solution for year t (i.e., the value of NFL at the end of t-1, or the start of t);

CAB(t) is the balance on current account in year t, which is assumed to equal minus the balance on financial account; and

Valuation changes are the price and exchange rate effects that affect the Australian dollar value of the net stock of foreign liabilities in year t.

At this point of VURM's development, we ignore valuation changes. We note, though, that for work in the future, valuation changes can be broken into two parts: that due to changes in equity and other security prices in Australia and that due to changes in the exchange rate (see Dixon and Rimmer, 2002, section 25). Price effects could be handled via equations of the form:

$$\text{Security price effects} = \text{NFL}(t) \times \text{SHFORIN} \times \text{Change in security prices} \qquad \text{(E6.64)}$$

where: SHFORIN is the share of equity and other securities in Australia's stock of (net) foreign liabilities in Australian dollars.

While exchange rate effects could be handled via:

$$\text{Exchange rate effects} = \text{NFL}(t) \times \text{SHFORFC} \times \text{Change in the exchange rate} \qquad \text{(E6.65)}$$

where: SHFORFC is the share of Australia's net stock of foreign liabilities denominated in foreign currency.

In the current implementation, the change in Australia's (net) stock of net foreign liabilities has been disaggregated into changes in foreign equities and changes in foreign debt. The change in net foreign equities (in Australian dollars) at the end of year t is given by equation *d_ACTIVE* as the change in the balance on current account d_CAB in the solution for year t (i.e., the value of the balance on current account at the end of year t-1) attributed to NFE. Equation *d_ACTIVE* apportions the change in the balance on current account to NFE on the basis of the share NFE in total foreign liabilities. The value of net foreign equity liabilities at the end of the solution year is given by equation *E_d_NFL_T1* as the value of the stock at the start of the year plus the value of the current account balance in the solution year.

In the same way, the change in net foreign equities (in Australian dollars) at the end of year t is given by equation *E_d_PASSIVE* as the change in the balance on current account d_CAB in the solution for year t (i.e., the value of the balance on current account at the end of year t-1) attributed to net foreign debt, NFD. The value of net foreign debt liabilities at the end of the solution year is given by equation *E_d_NFD_T1* as the value of the stock at the start of the year plus the value of the current account balance in the solution year.

Note that, via equations *E_d_FNFE* and *E_d_FNDF,* with d_NFE and d_NFD exogenous and unchanged, d_NFE and d_NFD are set equal to d_NFE_T and d_NFD_T, respectively, for year-to-year simulations.

```
! Equity !
Equation E_d_FNFE # Turns off/on the dynamic foreign equity mechanisms #
(all,q,REGDST)
d_NFE(q) = d_NFE_T(q) + d_FNFE(q);

Equation E_d_NFE_T # Change in stock of NFE, start of t #
(all,q,REGDST)
d_NFE_T(q) = ACTIVE@1(q)*d_unity;

Equation E_d_NATNFE_T # Change in national stock of NFE, start of t #
d_NATNFE_T = sum{q,REGDST, d_NFE_T(q)};

Equation E_d_NFE_T1 # Change in stock of NFE, end of t #
(all,q,REGDST)
d_NFE_T1(q) = d_NFE_T(q) + d_ACTIVE(q);
```

```
Equation E_d_NATNFE_T1 # National change in stock of NFE, end of year #
d_NATNFE_T1 = sum{q,REGDST, d_NFE_T1(q)};

Equation E_d_NATNFEGDP # Change in NATNFE_T1 to GDP ratio #
d_NATNFEGDP_T1 = 1/V0GDPINC*d_NATNFE_T1 - (NATNFEGDP_T1/100)*w0gdpexp;

Equation E_d_ACTIVE
(all,q,REGDST)
d_ACTIVE(q) = -NFE(q)/ID01[(NFD(q) + NFE(q))]*d_CAB(q);

! Debt !
Equation E_d_FNFD # Turns off/on the dynamic foreign debt mechanisms #
(all,q,REGDST)
d_NFD(q) = d_NFD_T(q) + d_FNFD(q);

Equation E_d_NFD_T # Change in stock of NFD, start of t #
(all,q,REGDST)
d_NFD_T(q) = PASSIVE@1(q)*d_unity;

Equation E_d_NATNFD_T # Change in national stock of NFD, start of t #
d_NATNFD_T = sum{q,REGDST, d_NFD_T(q)};

Equation E_d_NFD_T1 # Change in stock of NFD, end of t #
(all,q,REGDST)
d_NFD_T1(q) = d_NFD_T(q) + d_PASSIVE(q);

Equation E_d_NATNFD_T1 # National change in stock of NFD, end of year #
d_NATNFD_T1 = sum{q,REGDST, d_NFD_T1(q)};

Equation E_d_NATNFDGDP # Change in NATNFD_T1 to GDP ratio #
d_NATNFDGDP_T1 = 1/V0GDPINC*d_NATNFD_T1 - (NATNFDGDP_T1/100)*w0gdpexp;

Equation E_d_NFL
(all,q,REGDST)
d_NFL(q) = d_NFD(q) + d_NFE(q);

Equation E_d_PASSIVE
(all,q,REGDST)
d_PASSIVE(q) = -NFD(q)/ID01[(NFD(q) + NFE(q))]*d_CAB(q);
```

6.3 Population and demographic flows

Similar to the modelling of growth in capital, population growth, in persons, is assumed to occur in year t and to enter into the national population at the start of year t+1. Under this assumption, population in region q accumulates according to:

$$POP_q(t+1) = POP_q(t) + NNI_q(t) + NFMI_q(t) + NIM_q(t) \qquad \text{(E6.66)}$$

where:

POPq(t) is the population in region q at the start of year t;

NNIq(t) is the net natural increase in population in region q during year t;

NFMq(t) is the net foreign migration into region q during year t; and

NIMq(t) is the net interregional migration into region q during year t.

Within this accumulation framework, regional labour markets in VURM5 can operate in one of two ways:

(1) they can be directly linked to regional demographic and labour market relationships outlined in this section; or

(2) they can be linked to the cohort-based demographic module introduced into VURM5 that can endogenously determines national and regional populations in dynamic simulations using age, gender and region-specific participation rates.

Option (1) can be chosen in both comparative-static and recursive-dynamic versions of the models. Whereas option (2) is appropriately applied in the recursive-dynamic version.

If option (2) is chosen, VURM5 invokes the cohort-based demographic module.

To accommodate flexibility in the modelling of demographic flows, VURM5 also allows for:

- regional populations to be determined exogenously, with at least one aspect of the regional labour market determined endogenously (either regional unemployment, regional participation rates or regional wage relativities); or
- regional labour market variables to be determined exogenously, with regional migration, and hence, of regional population determined endogenously.

With regional population specified exogenously (option A), the labour market and demography block of equations can be configured to determine regional labour supply from the exogenously specified regional population and given settings of regional participation rates and in the ratios of population to population of working age. With labour supply determined, either interregional wage differentials (given regional unemployment rates) or regional unemployment rates (given regional wage differentials) are determined endogenously. With given regional unemployment rates and regional labour supply, regional employment is determined as a residual and wage differentials adjust to accommodate the labour market outcome. Fixing wage differentials determines the demand for labour so that with regional labour supply given, the model will determine regional unemployment rates as a residual.

With regional labour market variables specified exogenously (option B), interregional wage differentials and regional unemployment rates are exogenously specified. The labour market and demography block then determines regional labour supply and regional population for given settings of regional participation rates and ratios of population to population of working age.

This section first sets out the comparative-static application of the basic modelling of population and demographic flows in VURM5 and then outlines the dynamic application of the module.

As described in chapter 8, if operationalised, the cohort-based demographic module determines the relevant demographic and labour market relationships.

6.3.1 Comparative statics (E_natpop to E_r_wage_natwage2)

The equations of this block have been designed to allow sufficient flexibility in the modelling of demographic and the labour market. Importantly, the block allows for the regional population in some regions to be specified exogenously (option A) and the regional labour market variables to be specified exogenously in other regions (option B) in the same simulation.

The equations can be grouped into the following categories: definitions; equations imposing arbitrary assumptions; and national aggregates based on summing regional variables.

Equation *E_pwage_io* allows flexibility in setting movements in regional wage differentials. The percentage change in the wage differential in region q (r_wage_natwage1(q)) is defined as the difference between the percentage change in regional wage received by workers (pwage_io(q)) and the percentage change in wage received by workers across all regions (natpwage_io). In the standard closure of the model (see chapter 9), r_wage_natwage1 is set exogenous for all but one region, with the adding up condition E_natpwage_io (see section 3.4.8) ensuring that the conditions hold for the remaining region. Thus, in this closure average nominal wage rates across regions move together. Equation *E_r_wage_natwage2* is similar to equation *E_pwage_io*, except that it applies to wage rates by occupation.

Equation *E_x1emp* is a key definitional equation. It links the percentage change in employment (hours) (x1lab) to the percentage change in employment (persons) (x1emp) via change in the ratio of average hours worked (r_x1lab_x1emp). The ratio is typically exogenous. Another is equation *E_d_unr* which explains the percentage-point change in the regional unemployment (d_unr(q)) in terms of the percentage changes in regional labour supply (lab(q)) and persons employed (x1emp_io(q)). The final definition of note is equation *E_lab*. This equation defines the percentage change in regional labour supply (lab(q)) in terms of the percentage changes in the regional participation rate (r_lab_wpop(q)) and the regional population of working age (wpop(q)).

Equation *E_qhous* imposes the assumption that regional household formation is proportional to regional population by setting the percentage change in regional household formation (qhous(q)) equal to the percentage change in regional population (pop(q)) when the shift variable r_qhous_pop(q) is exogenous and set to zero change. The default option can be overridden by setting r_qhous_pop(q) to non-zero values.

Many of the remaining equations of this section, *E_natpop*, *E_natlab*, *E_natx1emp_io*, and *E_natunr* determine national aggregate variables by summing the corresponding regional variables.

```
Equation E_natpop # National population #
C_NATPOP*natpop = sum{q,REGDST, C_POP(q)*pop(q)};

Equation E_qhous # Ratio of households to population by region #
(all,q,REGDST)
qhous(q) = pop(q) + r_qhous_pop(q);

Equation E_r_wpop_pop
# Ratio of region working-age population to population #
(all,q,REGDST)
r_wpop_pop(q) = wpop(q) - pop(q);

Equation E_natwpop # National working-age population #
C_NATWPOP*natwpop = sum{q,REGDST,C_WPOP(q)*wpop(q)};

Equation E_x1emp # Employment (hours) linked to employment (persons) #
(all,i,IND)(all,q,REGDST)(all,o,OCC)
x1lab(i,q,o) = x1emp(i,q,o) + r_x1lab_x1emp(i,q,o);

Equation E_x1emp_o # Region employment by industry: persons #
(all,i,IND)(all,q,REGDST)
ID01[EMPLOY_O(i,q)]*x1emp_o(i,q) = sum{o,OCC, EMPLOY(i,q,o)*x1emp(i,q,o)};
```

```
Equation E_natx1emp_o # National employment by industry: persons #
(all,i,IND)
ID01[NATEMPLOY_O(i)]*natx1emp_o(i) =
    sum{q,REGDST,sum{o,OCC, EMPLOY(i,q,o)*x1emp(i,q,o)}};

Equation E_natx1emp_i # National employment by occupation: persons #
(all,o,OCC)
ID01[NATEMPLOY_I(o)]*natx1emp_i(o) =
    sum{i,IND,sum{q,REGDST, EMPLOY(i,q,o)*x1emp(i,q,o)}};

Equation E_x1emp_io # Region employment (persons) #
(all,q,REGDST)
EMPLOY_IO(q)*x1emp_io(q) = sum{i,IND, EMPLOY_O(i,q)*x1emp_o(i,q)};

Equation E_x1emp_i # Region employment by occupation (persons) #
(all,q,REGDST)(all,o,OCC)
EMPLOY_I(q,o)*x1emp_i(q,o) = sum{i,IND, EMPLOY(i,q,o)*x1emp(i,q,o)};

Equation E_natx1emp_io # National employment (persons) #
NATEMPLOY_IO*natx1emp_io = sum{q,REGDST, EMPLOY_IO(q)*x1emp_io(q)};

Equation E_r_wage_natwage1 # Ratio of wage in region q to national wage #
(all,q,REGDST)
r_wage_natwage1(q) = pwage_io(q) - natpwage_io;

Equation E_r_wage_natwage2 # Ratio of wage in region q to national wage #
(all,q,REGDST)(all,o,OCC)
r_wage_natwage2(q,o) = pwage_i(q,o) - natpwage_i(o);

Equation E_r_employ_natemp # Ratio of employment in q to national
employment #
(all,q,REGDST)
r_employ_natemp(q) = x1emp_io(q) - natx1emp_io;

Equation E_f_x1emp_natemp # Real wage/Employment trade off for regional
government #
(all,q,REGDST)
r_employ_natemp(q) = 0.5*{r_wage_natwage1(q) - p3tot(q) + natp3tot} +
                            f_x1emp_natemp(q);

Equation E_unemp # %-Change in persons unemployed by region #
(all,q,REGDST)
{LABSUP_O(q)-EMPLOY_IO(q)}*unemp(q) =
    {LABSUP_O(q)*lab_o(q) - EMPLOY_IO(q)*x1emp_io(q)};

Equation E_natunemp # %-Change in persons unemployed - national #
sum{q,REGDST, [LABSUP_O(q)-EMPLOY_IO(q)]}*natunemp =
    sum{q,REGDST, [LABSUP_O(q)*lab_o(q) - EMPLOY_IO(q)*x1emp_io(q)]};

Equation E_d_unr # %-Point changes in region unemployment rate #
(all,q,REGDST)
LABSUP_O(q)*d_unr(q) = EMPLOY_IO(q)*[lab_o(q) - x1emp_io(q)];
```

```
Equation E_d_natunr # %-Point change in national unemployment rate #
NATLABSUP_O*d_natunr = NATEMPLOY_IO*[natlab_o - natx1emp_io];

Equation E_d_natunro
# %-Point change in national unemployment rate by occ #
(all,o,OCC)
NATLABSUP(o)*d_natunro(o) = NATEMPLOY_I(o)*[natlab(o) - natx1emp_i(o)];

Equation E_d_unro # %-Point change in region unemployment rate by occ #
(all,q,REGDST)(all,o,OCC)
LABSUP(q,o)*d_unro(q,o) = EMPLOY_I(q,o)*[lab(q,o) - x1emp_i(q,o)];
```

6.3.2 Higher-level dynamics (E_f_pop to E_d_natpop_rm)

The dynamic component of the population and demography module effectively annualises shocks that may be applied in a comparative-static simulation.

The first equation, *E_f_pop*, links the percentage change in regional population in the comparative static part of the model (pop) to the year-to-year variable pop_t (the percentage change in population at the start of the solution year). It is assumed that for region r the change in population between the start of the solution year (t) and the end of the solution year equals the sum of natural growth, net foreign migration and net interregional migration. In other words:

$$POP\_T1(q) - POP\_T(q) = POP\_G(q) + POP\_FM(q) + POP\_RM(q) \qquad q \in REGDST \qquad (E6.67)$$

In change form, (E6.67) is E_pop_t1, ie.:

$$POP\_T1(q) \times pop\_t1(q) - POP\_T(q) \times pop\_t(q) = 100 \times [d\_POP\_G(q) + d\_POP\_FM(q) + d\_POP\_RM(q)] \qquad q \in REGDST \qquad (E6.68)$$

In the standard closure, the right-side variables are treated as exogenous.

Alternatively, the variables on the right-side can be determined endogenously by linking population and labour force growth in the model core to the cohort-based demographic module introduced within VURM5. The cohort-based demographic module can be operationalised through the closure changes outlined in chapter 9.

```
Equation E_f_pop # Explains population in year-to-year simulations #
(all,q,REGDST)
pop(q) = pop_t(q) + f_pop(q);

Equation E_pop_t # Population at start of year #
(all,q,REGDST)
C_POP_T(q)*pop_t(q) =
    100*[C_POP_RM@1(q) + C_POP_FM@1(q) + C_POP_G@1(q)]*d_unity;

Equation E_natpop_t # National population at start of year t #
sum{q,REGDST, C_POP_T(q)}*natpop_t = sum{s,REGDST, C_POP_T(s)*pop_t(s)};

Equation E_pop_t1 # Population at end of year t #
(all,q,REGDST)
C_POP_T1(q)*pop_t1(q) - C_POP_T(q)*pop_t(q) =
    100*[d_pop_rm(q) + d_pop_fm(q) + d_pop_g(q)];
```

```
Equation E_natpop_t1 # National population at end of year t #
sum{q,REGDST, C_POP_T1(q)}*natpop_t1 = sum{s,REGDST,
C_POP_T1(s)*pop_t1(s)};

Equation E_d_natpop_fm # Ordinary change in foreign migration, Australia #
d_natpop_fm = sum{q,REGDST, d_pop_fm(q)};

Equation E_d_natpop_g # Ordinary change in natural population, Australia #
d_natpop_g = sum{q,REGDST, d_pop_g(q)};

Equation E_d_natpop_rm # Ordinary change in region migration, Australia #
d_natpop_rm = sum{q,REGDST, d_pop_rm(q)};
```

6.4 Equations for year-to-year policy simulations

6.4.1 Specifying changes in a policy simulation in terms of a deviation from values in the basecase

In most CGE analyses, it is assumed either that:

- real wages remain unaffected and (national) employment adjusts; or
- real wages adjust to a shock so that there is no effect on (national) employment.

Option 1 is typical of a short-run modelling environment, and option 2 of a longer-run environment (see chapter 9).

VURM allows for a third, intermediate position (or partial adjustment), where the deviation in the consumer (after-tax) real wage rate in a policy simulation, from its basecase level, varies in proportion to the deviation in national employment from its basecase level.

This can be expressed algebraically as:

$$\left(\frac{\text{C\_RW\_POLICY(t)}}{\text{C\_RW\_BASE(t)}} - 1\right) = \left(\frac{\text{C\_RW\_POLICY(t} - 1)}{\text{C\_RW\_BASE(t} - 1)} - 1\right) + \text{LAB\_SLOPE} \times \left(\frac{\text{C\_EMP\_POLICY(t)}}{\text{C\_EMP\_BASE(t)}} - 1\right) \tag{E6.69}$$

where:

$\left(\frac{\text{C\_RW\_POLICY(t)}}{\text{C\_RW\_BASE(t)}} - 1\right)$ is the proprtional deviation in the national consumer (after-tax) real wage rate in year t from its basecase level;

$\left(\frac{\text{C\_RW\_POLICY(t}-1)}{\text{C\_RW\_BASE(t}-1)} - 1\right)$ is the proprtional deviation in last year's ratio brought forward to this year;

$\left(\frac{\text{C\_EMP\_POLICY(t)}}{\text{C\_EMP\_BASE(t)}} - 1\right)$ is the proprtional deviation in employment in year t from its basecase level;

and

LAB_SLOPE is a positive coefficient (with a value like 0.7).

To operationalise this dynamic relationship between the values in the basecase and policy simulations involves four steps:

1. setting the growth rates in national real wages and employment from the model core;
2. transferring the required values from the basecase to the policy simulation;
3. calculating the lagged changes; and

4. calculating the required deviation in the national consumer real (after-tax) wage rate in the policy scenario from the deviation in employment.

Setting the growth rates in national real wages and employment from the model core (E_natrwage_ct to E_empdev)

The first step involves specifying the percentage changes in national real wages and national employment from the model core to use in the deviation analysis.

Equation *E_natrwage_ct* calculates the percentage change in the national real after-tax wage rate received by consumers. It is calculated as the percentage change in the national real before-tax wage rate received by consumers (natrwage_c) less the percentage change in the tax rate on labour income (100/(1-TLABINC)*d_tlabinc).[31]

Equations *E_rwdev* and *E_empdev* specify the growth rate in national real wages and national employment to use in the deviation analysis, respectively. Equations *E_rwdev* links the deviation in the national real wage (rwdev) to the national real after-tax wage rate received by consumers derived in equation *E_natrwage_ct* (natrwage_ct). Equations *E_empdev* links the deviation in the national employment (empdev) to the percentage change in national hours worked from the model core (natx1lab_io).

```
Equation E_natrwage_ct
# National consumer real wage rate, after income tax #
natrwage_ct = natrwage_c - 100/(1-TLABINC)*d_tlabinc;

Equation E_rwdev # Equates rwdev with natrwage_ct #
rwdev = natrwage_ct;

Equation E_empdev # Equates empdev with natx1lab_io #
empdev = natx1lab_io;
```

Transferring the required values from the basecase to the policy simulation (E_f_emp to E_f_rw)

The second step involves transferring the required values for national real wages and national employment from the basecase simulation to the policy simulation. This enables values in the policy simulation to be expressed as deviations from the (pre-determined) values in the basecase. This is done by equations *E_f_rw* and *E_f_emp*.

The transfer equations are of the form:

$$\text{xfor} = \text{x} - \text{f\_x} \qquad \text{(E6.70)}$$

where:

x is the value of a variable in the basecase simulation that is to be transferred to the policy simulation (e.g., real wage rate growth);

f_x is the variable in the policy simulation that is given the forecast simulation value of x; and

xfor is the difference between x and f_x.

In a basecase simulation, f_x is exogenous and equal to zero. This results in xfor $=$ x.

[31] d_labinc is the ordinary change in the national tax rate on labour income, and TLABINC is the level of the national tax rate (see chapter 3).

In a policy simulation, xfor is exogenous and f_x is endogenous and equal to x by definition.

As the RUNMONASH software gives all exogenous variables in a policy simulation (other than those exogenously shocked) their values in the basecase simulation, the exogenous variable xfor in a policy simulation takes on the value of x in the bascecase simulation, as required.

```
Equation E_f_emp
# Introduces forecast employment into deviation simulation #
empfor = natx1lab_io + f_emp;

Equation E_f_rw
# Introduces real wage rate (after tax) into deviation sims. #
rwfor = natrwage_ct + f_rw;
```

Calculating the lagged changes in the national real wage rate and national employment (E_rwdev_l to E_empfor_l)

The third step involves calculating the lagged deviations in the national real wage rate and national employment.

Equation:

- *E_rwdev_l* calculates the percentage change in the national consumer real after-tax wage rate between years t-2 and t-1 in the policy simulation;
- *E_rwfor_l* calculates the percentage change in the national consumer real after-tax wage rate between years t-2 and t-1 in the basecase simulation;
- *E_empdev_l* calculates the percentage change in national employment between years t-1 and t in the policy simulation; and
- *E_empfor_l* calculates the percentage change in national employment between years t-1 and t in the basecase simulation.

These equations are of the form:

$$x\_l = 100 \times \frac{X@1}{X\_L@1} \times d\_unity \qquad \text{(E6.71)}$$

where:

x_l is the percentage change in X lagged one year (i.e., the percentage change in X in t-1);

X@1 is the initial value of X in a simulation for year t (i.e., the value of X at the end of t-1 brought forward);

X_L@1 is the initial value of X in a simulation for year t-1 (i.e., the value of X at the end of t-2, or the start of t-1); and

d_unity is the homotopy variable which has the value of 1 in year-to-year simulations.

The coefficients X@1 and X_L@1 in equation E6.20 are, respectively, updated using the percentage change variables x and x_l.

```
Equation E_rwdev_l # Equation explaining rwdev lagged one year #
rwdev_l = 100*(C_RWDEV@1-C_RWDEV_L@1)/C_RWDEV_L*d_unity;

Equation E_rwfor_l # Equation explaining rwfor lagged one year #
rwfor_l = 100*(C_RWFOR@1/C_RWFOR_L@1- 1)*d_unity;
```

```
Equation E_empdev_l # Equation explaining empdev lagged one year #
empdev_l = 100*(C_EMPDEV@1/C_EMPDEV_L@1- 1)*d_unity;

Equation E_empfor_l # Equation explaining empfor lagged one year #
empfor_l = 100*(C_EMPFOR@1/C_EMPFOR_L@1- 1)*d_unity;
```

Calculating the required deviation in the national real wage rate in the policy scenario (E_d_frwage_ct to E_fempdampen)

The final step involves calculating the required deviation in the national consumer real (after-tax) wage rate in the policy simulation.

VURM does this be estimating the change form of (E6.15), which is:

$$\frac{\text{C\_RW\_POLICY}}{\text{C\_RW\_BASE}}(\text{rwdev} - \text{rwfor}) = \frac{\text{C\_RW\_POLICY\_L}}{\text{C\_RW\_BASE\_L}}(\text{rwdev\_l} - \text{rwfor\_l}) + \text{LAB\_SLOPE} \times \frac{\text{C\_EMP\_POLICY}}{\text{C\_EMP\_BASE}}(\text{empdev} - \text{empfor}) \quad \text{(E6.72)}$$

where:

rwdev is the percentage change in the consumer real after-tax wage rate between years t-1 and t in the policy simulation;

rwfor is the percentage change in the consumer real after-tax wage rate between years t-1 and t in the basecase simulation;

rwdev_l is the percentage change in the consumer real after-tax wage rate between years t-2 and t-1 in the policy simulation;

rwfor_l is the percentage change in the consumer real after-tax wage rate between years t-2 and t-1 in the basecase simulation;

empdev is the percentage change in national employment between years t-1 and t in the policy simulation; and

empfor is the percentage change in national employment between years t-1 and t in the basecase simulation.

Equation *E_d_frwage_ct* calculates the proportional deviation in the real wage rate in year t in the policy simulation from its basecase value. It is equal to the proportional deviation in the real wage rate in year t-1 plus a coefficient (LAB_SLOPE) times the proportional deviation in employment in year t. The coefficient LAB_SLOPE is chosen so that the employment effects of a shock to the economy are largely eliminated after 5 years (that i.e., a coefficient of 0.7 is adopted as the default). In other words, after about 5 years, the benefits of favourable shocks, such as outward shifts in export demand curves or improvement in productivity, are realised almost entirely as increases in real wage rates.

The switch variable d_frwage_ct is endogenous in standard policy simulations, denoting that the equation is turned off (see chapter 9).

Equations *E_d_empdampen* and *E_d_fempdampen* force the deviation in national employment to zero. They are generally put in place via a closure swap 7-8 years after the exogenous shock to ensure that the long-run condition of zero change in national employment is met (see chapter 9).

```
Equation E_d_frwage_ct # Relates %devrw to %devemp in year-to-year sims. #
(C_RWDEV/C_RWFOR)*[rwdev - rwfor] =
    (C_RWDEV_L/C_RWFOR_L)*[rwdev_l - rwfor_l] +
    LAB_SLOPE*(C_EMPDEV/C_EMPFOR)*[empdev - empfor] + 100*d_frwage_ct;

Equation E_d_empdampen # Forces the long-run employment deviation to zero #
(C_EMPDEV/C_EMPFOR)*[empdev - empfor] =
   0.5*(C_EMPDEV_L/C_EMPFOR_L)*[empdev_l - empfor_l] + 100*d_empdampen;

Equation E_d_fempdampen # Forces EMPDAMPEN back to zero #
d_empdampen = -0.5*EMPDAMPEN@1*d_unity + d
```

7 Extensions to the basic model

This chapter sets out the extensions to the basic model outlined in chapters 2, 3 and 4 made by the Productivity Commission to assess the *Impacts of COAG Reforms* (PC, 2012).

This background to the extensions and the equations in the VURM TABLO implementation are described under the following section headings:

7.1 Cohort-based demographic module

7.2 Linking government consumption to the cohort-based demographic module

7.3 Labour supply by occupation

7.4 Export supply

7.1 Cohort-based demographic module

As described in chapters 2 and 4, the standard model has a rudimentary modelling of demographic change. It stylistically incorporates the three main sources of demographic change by region:

- net natural increase (i.e., births less deaths);
- net foreign migration (i.e., immigration less emigration); and
- net interstate migration (i.e., interstate arrivals less departures).

These changes are read in from the model database for each simulation year and are adjusted to account for changes applied as shocks in the preceding simulation year.[32] For example, the annual increase in the Australian population in the 2005-06 database is just over 300 000 people per year. This means that, unless the corresponding change variable (d_pop_g) is shocked, the population in all subsequent years will increase by just over 300 000 people. Suppose that a shock of 50 is applied to d_pop_g (signifying an increase of an additional 50 000 people), then the population in the following year, and in all subsequent years, would increase by 350 000 (i.e., 300 000 plus 50 000).

This approach could be extended by using an external demographic model to calculate the required changes to the demographic variables. The Productivity Commission adopted this approach in modelling the potential benefits of the National Reform Agenda (PC, 2006).

To overcome the need to link VURM to an external demographic model, VURM5 incorporates a fully operational cohort-based demographic model with age, gender and region (state) cohorts to allow for more realistic modelling of policies with a longer-term focus and those that impact on, or are influenced by, demographic characteristics, such as ageing of the population and changes in fertility and mortality rates and foreign migration. This approach also allows for feedback effects between sources of demographic and economic change (such as the effect of wage differentials on interstate migration).

[32] As the model database is based on the ABS input-output tables for the financial year 2005-06, a simulation year effectively corresponds to a financial year.

7.1.1 Background

The new demographic module is based on a series of demographic modelling tools developed by the Productivity Commission. These tools were initially developed for its study into the *Economic Implications of an Ageing Australia* (PC, 2005a) and have subsequently given rise to:

- a spreadsheet MoDEM demographic model (Cuxon et al. 2008) that was used in modelling the *Potential Benefits of the National Reform Agenda* (PC, 2006);[33] and
- a spreadsheet model of fertility called FERTMOD (Lattimore, 2008) that was used in *Recent Trends in Australian Fertility* (Lattimore and Pobke, 2008).

The new demographic module in VURM extends the national demographic relationships in MoDEM to the eight states and territories (hereafter referred to as regions).[34]

All demographic modelling adopts numerous simplifying assumptions that make the demographic accounting tractable. The assumptions made in the new demographic module are generally those adopted in FERTMOD and/or MODEM. These assumptions are similar to those made by the ABS in its demographic projections of the national population.

7.1.2 Outline of the new demographic module

Basic structure

The new demographic module models the effect of demographic change on subsets of the population based on age, gender and region (referred to as 'cohorts'). This makes it a 'cohort component' model. It uses a 'stock–flow' approach to calculate regional populations by age and gender. The 2005-06 database consists of the estimated resident population (ERP) for 1 616 cohorts as at 30 June 2005. Each cohort represents a unique combination of:

- 101 age groups: 100 single year age cohorts — *0 years old* to *99 years old* — and an open ended *100 years and over* cohort;
- two genders: male and female; and
- eight regions: New South Wales, Victoria, Queensland, South Australia, Western Australia, Tasmania, the Northern Territory and the Australian Capital Territory.[35]

The age, gender and region cohort data that underpin the 2005-06 database for the new demographic module is sourced from the ABS *Census of Population and Housing* (ABS 2009a).[36] The database is discussed in more detail in appendix B.

In each simulation year, the number of people in each age, gender and region cohort changes according to:

- the net inflow through overseas migration (i.e., immigration less emigration);

---

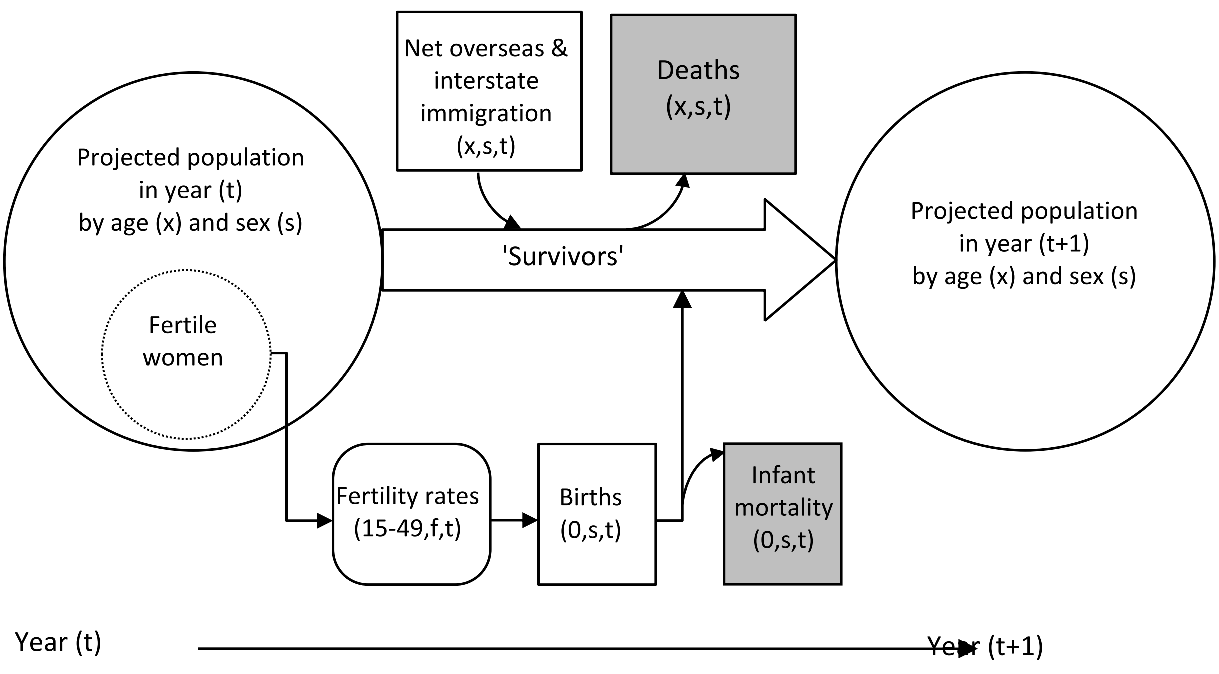
[33] The version of MoDEM referred to in this documentation is version 2.0.
[34] In the demographic module, state or region refers to state-of-residence unless otherwise stated.
[35] The model database does not include *Other territories* — Jervis Bay, Christmas Island and Cocos (Keeling) Islands — which the ABS also includes in the estimated resident population (ERP) for Australia. This means that the total population in the demographic model database is less than the official Australian ERP published by the ABS.
[36] The database also takes into account changes in the population in 2005-06 attributable to the 'intercensal variation', which arises from ex-post adjustments made by the ABS to reconcile its population projections with those flowing from the official *Census of Population and Housing*.

- the net inflow through interstate migration (i.e., interstate arrivals less departures);
- deaths, and
- births for the group aged '0 year olds' (figure 7.1).

People who do not die or leave the region are one year older by the end of the simulation year and join the next age cohort. This approach is similar to that used by Penec (2009).

The new demographic module is linked into the model core to determine population, working-age population and labour supply. The module is expressed in level terms and adopts the practice in VURM of reporting all population and labour market variables in thousands of people.

Figure 7.1: Operation of the demographic module



Births (E_totbirths to E_netbirths)

Births are calculated using a two-step process:

- total births in each region are calculated; and
- total births are split into male and female births.

First, equation *E_totbirths* calculates the number of births in each region by multiplying age and region-specific fertility rates (ASFR) by the average number of women of that age in that region during the simulation year, aggregated across all childbearing ages (aged 15 to 49 years). The average number of women is defined as the initial population of each age and region cohort for women (COHORT@1) plus half of the estimated change in population for that cohort during the simulation year (0.5*popchange)). The ASFR in the model database are for the financial year 2005-06 and are estimated as the average of published ABS ASFR for the calendar years 2005 and 2006 (sourced from ABS 2009b).[37]

Second, equation *E_births1* calculates the number of male births in each region by applying the share of total births in that region that are male (a region-specific sex ratio) (MALESHARE) to the total number of births (totbirths). The region-specific sex ratios used are sourced from ABS (2009b). Equation *E_births2* calculates female births as total births less male births. [38]

In keeping with the practice used by the ABS in compiling its demographic statistics, any deaths of newborns are recorded as deaths. This means that births are recorded on a gross basis and not the net basis used in MoDEM. A similar 'gross demographic accounting' approach is used to record net overseas and net interstate migration (described in section 7.1.2.5 and 7.1.2.6). Equation *E_dieatbirth1* calculates the deaths of newborn babies, using the age-specific mortality rate (MRTB@1). The derivation of the mortality rates used are discussed in the next section.

Equation *E_netbirths* calculates the number of newborn babies alive at the end of the simulation year.

The demographic module allows the ASFR rates to change over time to allow for timing and tempo effects that enable the total fertility rate and the distribution of ASFRs to vary independently. The methodology used follows Lattimore (2008).

```
Equation E_totbirths # Total births by state (000) #
(all,q,REGDST)
totbirths(q) =
    1/1000*sum{c,CHBA,ASFR(c,q)*{COHORT@1(c,"female",q)*d_unity
    + 0.5*popchange(c,"female",q)}};

Equation E_births1 # Male births by state (000) #
(all,x,BABY)(all,q,REGDST)
births(x,"male",q) = MALESHARE(q)*totbirths(q);

Equation E_births2 # Female births by state (000) #
(all,x,BABY)(all,q,REGDST)
births(x,"female",q) = totbirths(q) - births(x,"male",q);

Equation E_births3 # Total births by state - other ages (000) #
(all,x,NOTYOUNGEST)(all,g,GENDER)(all,q,REGDST)
births(x,g,q) = 0;
```

[37] The ABS publishes age-specific fertility rates on a financial-year basis for women age 15 to 49 grouped in 5 year intervals. The ABS assigns births to women below 15 years of age to the 15–19 year old age group and births to women over 49 to the 45–49 year old age group. These financial-year ASFR were allocated to single years of age by multiplying the financial-year ASFR for each age group by the ratio of the average ASFR for each single year of age from the two calendar years spanning the financial year to the calendar-year average for the relevant 5 year age group. The resulting ASFR in each region have been converted from a 'year of registration' to a 'year of occurrence' basis to align with the births component of the ABS estimated resident population in the model database (a scalar between 0.990 for New South Wales and 1.015 for the Northern Territory).

[38] Births increase the 0 year old cohort only. To make the demographic accounting in TABLO easier for the other age cohorts, the births variable is defined over all age groups. Equation *E_births3* sets the number of births in the remaining 100 age groups to zero.

```
Equation E_dieatbirth1 # Deaths of newborn babies - newborn babies (000) #
(all,x,BABY)(all,g,GENDER)(all,q,REGDST)
dieatbirth(x,g,q) = -MRTB@1(g,q)*births(x,g,q);

Equation E_netbirths # Live births by state (000) #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
netbirths(x,g,q) = births(x,g,q) + dieatbirth(x,g,q);
```

Deaths (E_d_mrtb1 to E_natdeaths)

Deaths are calculated in an analogous way to the first step in estimating births described above, but using age, gender and region-specific mortality rates instead of ASFR. This approach follows that adopted in the MoDEM demographic module.

The number of deaths is calculated for four distinct sub-groups of the population:

- those initially in each cohort;
- those joining each cohort from overseas;
- those joining each cohort from interstate; and
- newborn babies.

The total number of deaths is the total of these four sub-groups.

The basic approach to calculating the number of deaths for each cohort in these four sub-groups is similar, although the mortality rates used differ and the calculation differs slightly depending on the age of the cohort.

The remainder of each cohort at the beginning of the simulation year that does not migrate interstate or move overseas remains within the region for the full simulation year. The number of deaths for this group is estimated by applying the full-year mortality rate for that age, gender and region cohort to the beginning of year population for that cohort less the number of people that leave the region.

In keeping with the approach used in PC (2005) and MoDEM, the mortality rates in the new demographic module have been converted from an 'exact age' basis to an 'age at last birthday' basis to align with the ERP in the model database. The methodology for doing this is set out in PC (2005b, 2005c). The 'exact age' mortality rate by age, gender and region used are sourced from the ABS *Life Tables, 2005-2007* (ABS 2008).

The resulting measure indicates the number of deaths that occur, not the age at which those deaths occur (as death may occur at the 'beginning of year' age in the database or after their birthday at the next age). The model assumes that ageing occurs uniformly, with the number of deaths calculated using the methodology described above being divided equally between their initial age and the next age group for all age groups except the 0 year olds and the 100 years and over groups. The number of deaths for each cohort other than these two exceptions consists of half of the deaths from the cohort below and half from its own-age cohort (equation *E_deaths2*). As people do not leave the 100 years and over cohort through ageing, the number of deaths for this cohort is half of those for the 99 year olds and all of those for the 100 years and over cohort (equation *E_deaths3*). Deaths for 0 year olds is the gender and region-specific mortality rate for newborn babies multiplied by the number of newborn babies plus half of the deaths of those initially aged 0 years at the beginning of the simulation year (equation *E_deaths1*).

A similar approach is used to estimate the number of deaths of immigrants and interstate arrivals, except that only half the age, gender and region-specific mortality rates are used, as, on average, these groups are only in the destination region for half a year (included in equations *E_deaths1* to *E_deaths3*).

If desired, the age, gender and region-specific mortality rates can be varied by:

- specifying annual percentage change improvement factors — this approach is based on that used by the Australian Government Actuary (2009, p. 35);
- using the annual percentage change improvement factors specified in the database (the annual average improvement in mortality on an 'age at last birthday' basis between 1980–82 to 2006–08 derived from the ABS *Life Tables* and smoothed by applying a Hodrick-Prescott filter); or
- specifying exogenous annual percentage change improvements in mortality rates by age, gender and/or region.

In the TABLO implementation:

- the variables d_mrtb and d_mort denote the ordinary changes in mortality rates for newborn babies and the rest of the population, respectively;
- the coefficient IXSCALE denotes the gender and region-specific scalars for improvements in mortality rates;
- the variables MRTB@1 and MORT@1 denote the mortality rates for newborn babies and the rest of the population, respectively;
- the coefficients IB and IX denote the percentage changes in mortality rates for newborn babies and the rest of the population, respectively;
- the variable mortimprove denotes the percentage changes in mortality rates by region;
- the shift terms f_natmort, f_natmortb, f_natmort, f_mort_g and f_mort_a enable the mortality rates to be exogenously changed by age, gender and/or region; and
- the shift terms f_mrtb1, f_mrtb2, f_mrtb3, f_mort1, f_mort2 and f_mort3 enable the respective equations to be turned on or off, as required.

```
! 10.4.4.4.a Calculate mortality rate to be applied in the current
simulation year !

! Change in mortality rate based on improvement factor - newborn babies!
Equation E_d_mrtb1
# Ordinary change in the mortality rate of newborn babies #
(all,g,GENDER)(all,q,REGDST)
d_mrtb(g,q) = IF{SIMYEAR<=PeriodN(q),
    IXSCALE(g,q)*IB(g,q)/100*MRTB@1(g,q)*d_unity} + f_mrtb1(g,q);

! Change in mortality rate based on exogenous change - newborn babies !
Equation E_d_mrtb2
# Ordinary change in the mortality rate of newborn babies #
(all,g,GENDER)(all,q,REGDST)
d_mrtb(g,q) = f_natmort + f_natmortb + f_mrtb2(g,q);
```

```
! Change in mortality rate based on exogenous percentage changes - newborn
babies !
Equation E_d_mrtb3 # Ordinary change in the mortality rate #
(all,g,GENDER)(all,q,REGDST)
d_mrtb(g,q) = IXSCALE(g,q)*MRTB@1(g,q)/100*mortimprove(q) + f_mrtb3(g,q);

! Change in mortality rate based on improvement factor - all other ages !
Equation E_d_mort1 # Ordinary change in the mortality rate #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
d_mort(x,g,q) = IF{SIMYEAR<=PeriodN(q),
    IXSCALE(g,q)*IX(x,g,q)/100*MORT@1(x,g,q)*d_unity} + f_mort1(x,g,q);

! Change in mortality rate based on exogenous change - all other ages !
Equation E_d_mort2 # Ordinary change in the mortality rate #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
d_mort(x,g,q) = f_natmort + f_mort_g(x,q) + f_mort_a(g,q) + f_mort2(x,g,q);

!Change in mortality rate based on exogenous percentage changes - all ages!
Equation E_d_mort3 # Ordinary change in the mortality rate #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
d_mort(x,g,q) = IXSCALE(g,q)*MORT@1(x,g,q)/100*mortimprove(q) +
    f_mort3(x,g,q);

! 10.4.4.b Calculate deaths in the current simulation year !

! Total deaths !
Equation E_deaths1 # Deaths (000) - newborn babies #
(all,x,BABY)(all,g,GENDER)(all,q,REGDST)
deaths(x,g,q) =
- MRTB@1(g,q)*births(x,g,q)
- 0.5*MORT@1(x,g,q)*{COHORT@1(x,g,q)*d_unity + nim(x,g,q) + nom(x,g,q)};

Equation E_deaths2
# Deaths (000) - all other ages except newborn & oldest #
(all,x,CORE)(all,g,GENDER)(all,q,REGDST)
deaths(x,g,q) =
- 0.5*MORT@1(x-1,g,q)*{COHORT@1(x-1,g,q)*d_unity + nim(x-1,g,q) + nom(x-
1,g,q)}
- 0.5*MORT@1(x,g,q)*{COHORT@1(x,g,q)*d_unity + nim(x,g,q) + nom(x,g,q)};

Equation E_deaths3 # Deaths (000) - oldest #
(all,x,OLDEST)(all,g,GENDER)(all,q,REGDST)
deaths(x,g,q) =
- 0.5*MORT@1(x-1,g,q)*{COHORT@1(x-1,g,q)*d_unity + nim(x-1,g,q) + nom(x-
1,g,q)}
- MORT@1(x,g,q)*{COHORT@1(x,g,q)*d_unity + nim(x,g,q) + nom(x,g,q)};

! Deaths of newborn babies (000) !
Equation E_dieatbirth1 # Deaths of newborn babies - newborn babies (000) #
(all,x,BABY)(all,g,GENDER)(all,q,REGDST)
dieatbirth(x,g,q) = -MRTB@1(g,q)*births(x,g,q);
```

```
Equation E_dieatbirth2 # Deaths of newborn babies - all other ages (000) #
(all,x,NOTYOUNGEST)(all,g,GENDER)(all,q,REGDST)
dieatbirth(x,g,q) = 0;

! Deaths occurring at the beginning-of-year age (ie before their birthday)
- all other ages !
Equation E_dieatage1 # Deaths occurring at BOY age (000) #
(all,x,NOTOLDEST)(all,g,GENDER)(all,q,REGDST)
dieatage(x,g,q) =
    -0.5*MORT@1(x,g,q)*[COHORT@1(x,g,q)*d_unity + nim(x,g,q) + nom(x,g,q)];

! Deaths occurring at the beginning-of-year age (ie before their birthday)
- oldest !
Equation E_dieatage2 # Deaths occurring at BOY age (000) #
(all,x,OLDEST)(all,g,GENDER)(all,q,REGDST)
dieatage(x,g,q) =
    -MORT@1(x,g,q)*[COHORT@1(x,g,q)*d_unity + nim(x,g,q) + nom(x,g,q)];

! Deaths occurring at the end -of-year age (ie after their birthday) -
newborn babies !
Equation E_dieolder1 # Deaths occurring at EOY age (000) #
(all,x,BABY)(all,g,GENDER)(all,q,REGDST)
dieolder(x,g,q) = 0;

! Deaths occurring at the end -of-year age (ie after their birthday) - all
other ages !
Equation E_dieolder2 # Deaths occurring at EOY age (000) #
(all,x,NOTYOUNGEST)(all,g,GENDER)(all,q,REGDST)
dieolder(x,g,q) =
-0.5*MORT@1(x-1,g,q)*[COHORT@1(x-1,g,q)*d_unity + nim(x-1,g,q) + nom(x-
1,g,q)];

! State deaths (000) !
Equation E_statedeaths # State deaths (000) #
(all,q,REGDST)
statedeaths(q) = sum{x,AGE,sum{g,GENDER, deaths(x,g,q)}};

! National deaths (000) !
Equation E_natdeaths # National deaths (000) #
natdeaths = sum{x,AGE,sum{g,GENDER,sum{q,REGDST, deaths(x,g,q)}}};
```

Net natural increase (E_nni to E_natnni)

Equation *E_nni* reports the net natural increase in population for each age, gender and region. Net natural increase is calculated as births less deaths. Equations *E_statenni* and *E_natnni* aggregate the net natural increase to the regional and national levels.

```
! Net natural increase (000) !
Equation E_nni # Net natural increase (births + deaths) (000) #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
nni(x,g,q) = births(x,g,q) + deaths(x,g,q);
```

```
! State net natural increase (000) !
Equation E_statenni # State net natural increase (000) #
(all,q,REGDST)
statenni(q) = statebirths(q) + statedeaths(q);

! National net natural increase (000) !
Equation E_natnni # Total net natural increase (000) #
natnni = natbirths + natdeaths;
```

Net overseas migration (Eactualnom to E_natnom)

Net overseas migration is modelled in terms of net flows of immigrants over emigrants.

In VURM5, net overseas migration can be specified:

- in aggregate for each region and allocated to cohorts using the age, gender and regional overseas migration shares in the model database;
- for each individual age, gender and region-specific cohort; or
- as a function of the national population at the beginning of the year (say 0.6 per cent).

Like MoDEM, the new demographic module adopts the assumption that net overseas migration occurs uniformly throughout the year. This is equivalent to assuming that all net overseas migration occurs on 31 December of the simulation year. This means that, on average, immigrants are only in the destination region for half of each simulation year. It is assumed that half of all immigrants have a birthday in the six months prior to the end of the simulation year and their age is increased by one year for each simulation year.

The net overseas migration data used in the model database are sourced from ABS (2010b).

```
Equation E_actualnom
# Actual net overseas migration on an age at migration basis (000) #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
actualnom(x,g,q) = f_nom(x,g,q) +
ABS[C_NOM(x,g,q)]/C_STATEOM(q)*f_nom_s(q);

!Link changes in net overseas migration to population in projection period!
Equation E_projectnom
# Projection of net overseas migration on an age at migration basis (000) #
projectnom = NOM2POP*C_NATPOP*d_unity + f_natnom;

Equation E_om # Net overseas migration on an age at migration basis (000) #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
om(x,g,q) =
    (1-PROJECTION)*actualnom(x,g,q) + PROJECTION*OMSHARE(x,g,q)*projectnom;

Equation E_nom1 # Net overseas migration on an EOY-age basis (000) #
(all,x,BABY)(all,g,GENDER)(all,q,REGDST)
nom(x,g,q) = 0.5*om(x,g,q);

Equation E_nom2 # Net overseas migration on an EOY-age basis (000) #
(all,x,CORE)(all,g,GENDER)(all,q,REGDST)
nom(x,g,q) = 0.5*[om(x-1,g,q) + om(x,g,q)];
```

```
Equation E_nom3 # Net overseas migration on an EOY-age basis (000) #
(all,x,OLDEST)(all,g,GENDER)(all,q,REGDST)
nom(x,g,q) = 0.5*om(x-1,g,q) + om(x,g,q);

Equation E_d_nom
# Ordinary change net overseas migration on an EOY-age basis (000) #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
d_om(x,g,q) = nom(x,g,q) - C_NOM(x,g,q)*d_unity;

! State net overseas migration (000) !
Equation E_statenom
# State net overseas migration on an EOY-age basis (000) #
(all,q,REGDST)
statenom(q) = sum{x,AGE,sum{g,GENDER, nom(x,g,q)}};

! National net overseas migration (000) !
Equation E_natnom
# National net overseas migration on an EOY-age basis (000) #
natnom = sum{x,AGE,sum{g,GENDER,sum{q,REGDST, nom(x,g,q)}}};
```

Net interstate migration (E_nim1 to E_natnim)

Similar to net overseas migration, interstate migration is also modelled in net terms (i.e., interstate arrivals less departures) and is also assumed to occur midway through the simulation year.

Interstate migration is modelled by linking interstate migration in the demographic module to movements in the supply of labour between regions in the core of the model.[39] This approach is based on that used in the previous benchmark model, as applied to assess the *Potential* Benefits *of the National Reform Agenda* (PC, 2006).

As discussed in chapter 3, the supply of labour in the model core can move between regions in response to occupational-specific differences in real wage changes. The variable nim_xg represents the net migration of labour supply by region (expressed in 000 of people) from the model core (described in section 7.3).

Equation *E_nim1* links interstate migration for each age, gender and region cohort in the demographic module (the variable nim) to regional net migration of labour supply (the variable nim_xg) in all regions other than that specified in the set ADJUSTSTATE, which is set to New South Wales in the demographic module database. Net migration of labour supply by region is mapped to the age and gender cohorts in that region using the initial age and gender population shares in the demographic model database.

Equation *E_nim2* ensures that interstate migration in ADJUSTSTATE exactly offsets that in the rest of Australia, such that interstate migration by age and gender sum to zero across all regions so that there is no net change in population nationally from interstate migration.

By linking interstate migration in the demographic module to movements in the labour market between regions in the model core, it is assumed that those of working age and not in the labour

[39] This does not assume that the level of real wages is the same across states for a given occupation, just that the growth rate in those wages is the same.

force and children aged less than 15 years of age (those not of working age) move in proportion with those in the labour force (akin to assuming that all members of a household move together when a worker moves interstate).[40]

A consequence of this approach is that interstate migrants are assumed to take on the characteristics of workers and/or residents in their destination region — such as employment status, productivity levels and wage rates (and not those prevailing in the source region before the move).

This approach to modelling interstate migration means that changes in labour supply drive:

- the change in the working-age population in each region; and
- the change in the population in each region.

These changes are discussed in section 7.1.3.

Equation *E_d_nim* calculates the ordinary change in net interstate migration on an end-of-year basis for each age, gender and region cohort. Equations *E_statenim* and *E_natnim* aggregate the net interstate migration at the regional and national levels (the latter should sum to zero).

The net interstate migration data contained in the model database for the new demographic module is sourced from ABS (2010b).

```
Formula (initial)
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
STATEPOPSH(x,g,q) = COHORT@1(x,g,q)/STATEPOP(q);

Equation E_nim1 # Interstate migration on an EOY-age basis (000) #
(all,y,AGE)(all,g,GENDER)(all,q,ROA)
nim(y,g,q) = STATEPOPSH(y,g,q)*nim_xg(q);

Equation E_nim2
# Interstate migration in adjustment state on an EOY-age basis (000) #
(all,x,AGE)(all,g,GENDER)(all,q,ADJUSTSTATE)
nim(x,g,q) = -sum{z,ROA,nim(x,g,z)};

Equation E_d_nim
# Ordinary change interstate migration on an EOY-age basis (000) #
(all,x,AGE)(all,g,GENDER)(all,q,REGDST)
d_nim(x,g,q) = nim(x,g,q) - C_NIM(x,g,q)*d_unity;

Equation E_statenim
# State net interstate migration on an EOY-age basis (000) #
(all,q,REGDST)
statenim(q) = sum{x,AGE,sum{g,GENDER,nim(x,g,q)}};

Equation E_natnim
# Total net interstate migration on an EOY-age basis (000) #
natnim = sum{x,AGE,sum{g,GENDER,sum{q,REGDST,nim(x,g,q)}}};
```

[40] In this framework, interstate migration driven by lifestyle, environmental and other non-economic factors is modelled exogenously.

7.1.3 Integrating the cohort-based demographic module into VURM

If operationalised by setting the parameter ISCOHORT=1, the cohort-based demographic module is linked into the core of VURM to determine endogenously the value of certain coefficients in the model core rather than reading their values from the database, which occurs when ISCOHORT=0.[41]

- The population of each region into the model core (the coefficient C_POP_RD) is linked to the population in that region, summed across all ages and both genders, in the cohort-based demographic module.
- The working-age population in each region into the model core (the coefficient C_WPOP_RD is linked to the population in that region aged 15 years and over in the demographic module.
- The regional supply of labour by occupation in the model core (the coefficient LABSUP_RD) is determined by applying age, gender and region-specific participation rates (denoted by the coefficient PARTRATE) to the number of people in each cohort in the demographic module. The age, gender and region-specific participation rates are initially read in from the demographic model database (from the header 'PART' in the file that corresponds to the logical file COHORTDATA), which are sourced from ABS (2010a). The occupational distribution of the supply of labour is initially assumed to remain unchanged, but allowed to vary in response to differences in real wages during the course of the simulation year (discussed in section 7.2).

In addition, the variables pop_rd, wpop_rd and lab_o_rd, respectively, represent the percentage changes in regional population, regional working-age population and the national supply of labour from the cohort-based demographic module. These variables can be made to feed into the corresponding variables in the model core (pop, wpop and natlab_o, respectively) by setting the corresponding shift terms(f_pop_rd, f_wpop_rd and f_natlab_o_rd, respectively) exogenous.[42]

The linking between the model core and the cohort-based demographic module flows in both directions also flows in the opposite direction, with changes in interstate migration of the labour force in the model core feeding into the change in interstate migration in the demographic module (discussed in section 7.1.2).

```
Equation E_pop_rd
# Percentage change in state population from cohort-based demographic
module #
(all,q,REGDST)
pop_rd(q) = 100*[1/C_POP(q)]*sum{y,AGE,sum{g,GENDER,popchange(y,g,q)}};

Equation E_f_pop_rd
# Link state population in model core to cohort-based demographic module #
(all,q,REGDST)
pop(q) = pop_rd(q) + f_pop_rd(q);
```

[41] If the parameter ISDEMOD=0, the population, work-age population and labour supply in each region are determined as per the discussion in chapter 4.

[42] These variables can be made exogenous by, respectively, swapping them with f_pop, r_wpop_pop and natlab_o (se chapter 9).

```
Equation E_wpop_rd
# State working-age population from cohort-based demographic module #
(all,q,REGDST)
wpop_rd(q) =
100*[1/C_WPOP(q)]*sum{y,WORKINGAGE,sum{g,GENDER,popchange(y,g,q)}};

Equation E_f_wpop_rd
# Link state working-age population to cohort-based demographic module #
(all,q,REGDST)
wpop(q) = wpop_rd(q) + f_wpop_rd(q);
```

Labour market (E_prate to E_natlab_o)

Equation *E_prate* determines the percentage change in the participation rate for each age, gender and region cohort during a simulation year. These participation rates can be updated by shocking any of the shift terms on the RHS of the equation — f_partrate, f_natpartrate_r and f_natpartrate. The variable prate on the LHS of the equation updates the coefficient PARTRATE.

Equation *E_natlab_o_rd* calculates the percentage change in the total national labour supply (the variable natlab_o_rd). It does so from the change in the working-age population and participation by age, gender and region from the cohort-base demographic module.

Equation *E_f_natlab_o_rd* allows the percentage change in the national supply of labour from the cohort-based demographic module (natlab_o_rd) to feed through into the national supply of labour in the model core (natlab_o) when the shift term f_natlab_o_rd is exogenous. The equation can be turned off by swapping the shift term f_natlab_o_rd with either the national participation rate (natpartrate) or the national supply of labour (natlab_o_).

Equation *E_natlab_o* combines the percentage change in the national supply of labour the percentage change in the working-age population (natwpop) to determine the percentage change in the aggregate labour force participation rate (natpartrate).

The modelling of labour supply using age and gender cohorts and integration of the cohort-based demographic module into the VURM core is illustrated diagrammatically in figure 7.2 at the end of this section.

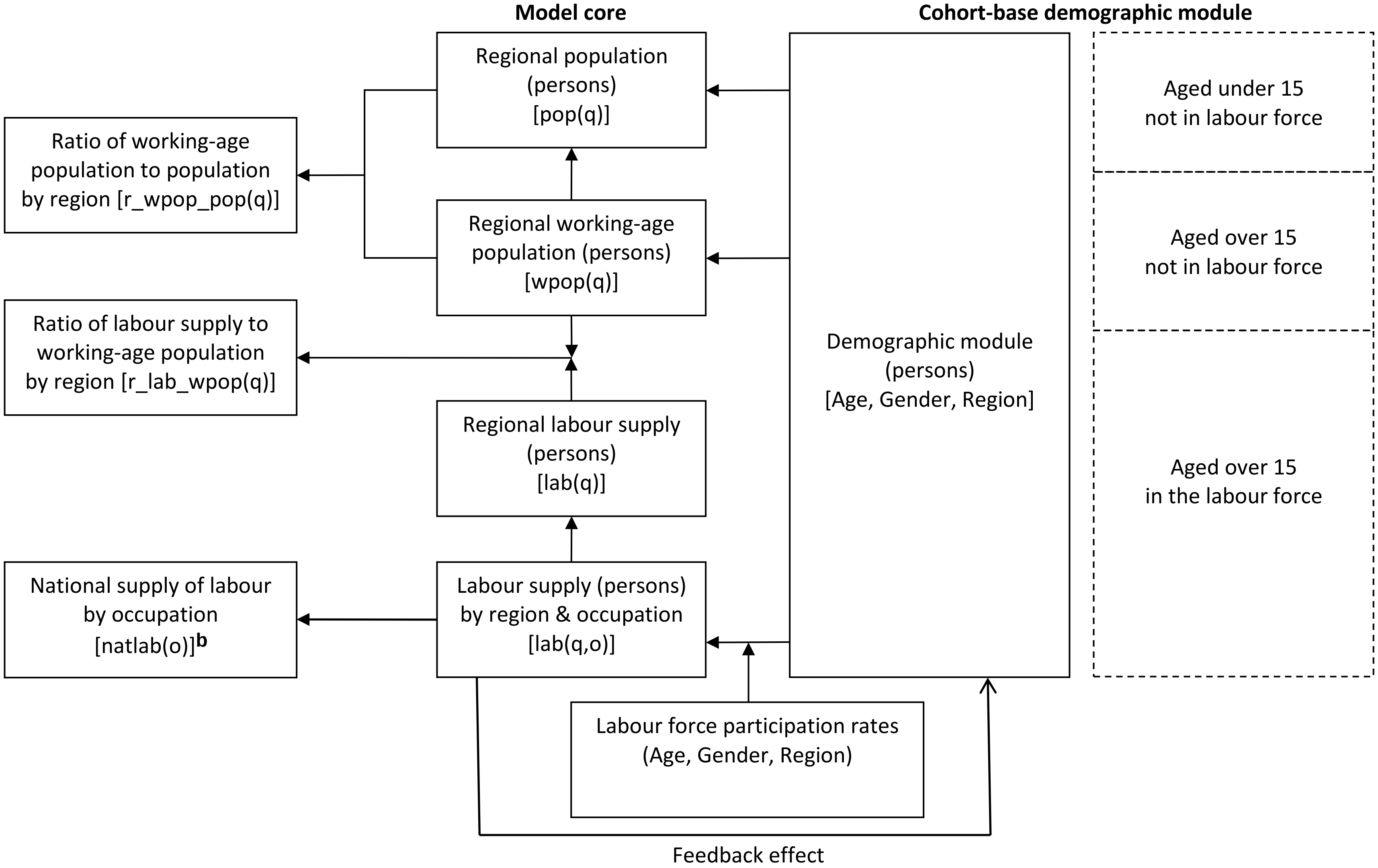
The endogenous modelling of interstate migration means that the working-age population and population in each region in the model core can vary and is not known *a priori*. As a result, the region-specific participation rates in the model core (r_lab_wpop) are calculated within the model from the changes in labour supply and working-age population in the model core rather than being exogenously specified, as they were in chapter 3.

Similarly, the ratio of working-age population to population in each region in the model core (r_wpop_pop), which was exogenous in chapter 3, is calculated from the changes in working-age population and population in the model core.

```
Equation E_prate
# % Change in the participation rate by age, gender & state #
(all,x,WORKINGAGE)(all,g,GENDER)(all,q,REGDST)
prate(x,g,q) = f_natpartrate + f_partrate_q(x,g) + F_partrate(x,g,q);
```

```
Coefficient (all,x,WORKINGAGE)(all,g,GENDER)(all,q,REGDST)
PARTRATE(x,g,q) # Participation rate (%) #;
Read PARTRATE from file COHORTDATA header "PART";
Assertion (all,x,WORKINGAGE)(all,g,GENDER)(all,q,REGDST)
PARTRATE(x,g,q) >= 0 and PARTRATE(x,g,q) <= 100;
Update (all,x,WORKINGAGE)(all,g,GENDER)(all,q,REGDST)
PARTRATE(x,g,q) = prATE(x,g,q);

Coefficient (all,q,REGDST)(all,o,OCC)
LABSUP_RD(q,o)
# State labour supply by occupation (persons) (new demographic module) #;
Formula (all,q,REGDST)(all,o,OCC)
LABSUP_RD(q,o) = EMPLOY_I(q,o)/sum{k,OCC,EMPLOY_I(q,k)}*
    sum{x,WORKINGAGE,sum{g,GENDER, [PARTRATE(x,g,q)/100]*COHORT(x,g,q)}};

Equation E_natlab_o_rd # % change in national labour supply from cohort-
based demographic module #
natlab_o_rd = 100/sum{q,REGDST, C_WPOP_RD(q)}*
    sum{y,WORKINGAGE,sum{g,GENDER,sum{q,REGDST,
        popchange(y,g,q) + COHORT(y,g,q)/100*prate(y,g,q)}}};

Equation E_f_natlab_o_rd # Link national labour supply in model core to
cohort-based demographic module #
natlab_o = natlab_o_rd + f_natlab_o_rd;

Equation E_natlab_o # National supply of labour in model #
natlab_o = natpartrate + natwpop;
```

Figure 7.2: Modelling of labour supply using age and gender cohorts



7.2 Linking government consumption to the cohort-based demographic module

With the inclusion of a cohort-based demographic module (discussed in section 7.1), government consumption expenditure can, if desired, be endogenously linked to sources of demographic change, such as the level or composition of the population (by age, gender or region).

As a proof of concept, the modelling of regional and federal government consumption expenditure discussed in sections 3.7 and 3.8 (equations *E_x5a* and *E_x6a*) has also been linked to ageing of the population for those commodities in the set AGECOM. The set AGECOM currently contains a single element, health services. In addition to the drivers of regional and federal government consumption contained in the basic model, equations *E_x5aB2* and *E_x6aB2* also link regional and federal government consumption expenditure to the percentage change in the population in region q aged 65 years and over as a share of the initial population (the variable ageshare(q)). The coefficient ISDEMMOD takes on a value of 1 when the cohort-based demographic module is operational and 0 otherwise. The equations can be turned on or off by swapping the shift variables f5a(c,s,q) and f6a(c,s,q) with f_x5a(c,s,q) and f_x6a(c,s,q).

Equations *E_x5aB1* and *E_x6aB1* determine regional and federal government consumption expenditure for all non-age-related commodities (i.e., the set NONAGECOM). These equations mirror equations *E_x5a* and *E_x6a*, which are discussed in sections 3.7 and 3.8.

This 'proof of concept' approach could be extended to, among other things, include:

- additional commodities in the set AGECOM (such as pharmaceuticals, community services and education);
- more plausible linking of government expenditure to sources of demographic change (such as linking health and education expenditure to particular ages or age groups); and
- more realistic modelling of the actual costs incurred by government.

These changes could be integrated more widely into VURM. To illustrate this, the modelling of aged-pension payments by the Australian Government in the government finance module (discussed in chapter 6) is linked to changes in the share of population in each region aged 65 years and over, thereby extending the approach outlined in section 5.2.

```
! Regional government consumption !
 Equation E_x5aB1 # Regional government consumption of commodities not
associated with ageing #
(all,c,NONAGECOM)(all,s,ALLSRC)(all,q,REGDST)
x5a(c,s,q) = x3tot(q) + f5tot(q) + natf5tot + f_x5a(c,s,q);

Equation E_x5aB2
# Regional government consumption of commodities associated with ageing #
(all,c,AGECOM)(all,s,ALLSRC)(all,q,REGDST)
x5a(c,s,q) =
    x3tot(q) + f5tot(q) + natf5tot + ISCOHORT*ageshare(q) + f_x5a(c,s,q);
```

```
! Federal government consumption !
Equation E_x6aB1 # Federal government consumption of commodities not
associated with ageing #
(all,c,NONAGECOM)(all,s,ALLSRC)(all,q,REGDST)
x6a(c,s,q) = natx3tot + f_x6a(c,s,q) + f6tot(q) + natf6tot;

Equation E_x6aB2
# Federal government consumption of commodities associated with ageing #
(all,c,AGECOM)(all,s,ALLSRC)(all,q,REGDST)
x6a(c,s,q) =
    natx3tot + f6tot(q) + natf6tot + ISCOHORT*ageshare(q) + f_x6a(c,s,q);
```

7.3 Labour supply by occupations

Changes in wage relativities provide existing workers with an incentive to reskill and may influence the career choices of those leaving school or entering the labour market. Over time, changes in these wage relativities may give rise to ‘occupational transformations’ in which the occupational composition of the labour force changes (e.g., reducing the supply of labourers and increasing the supply of professionals).

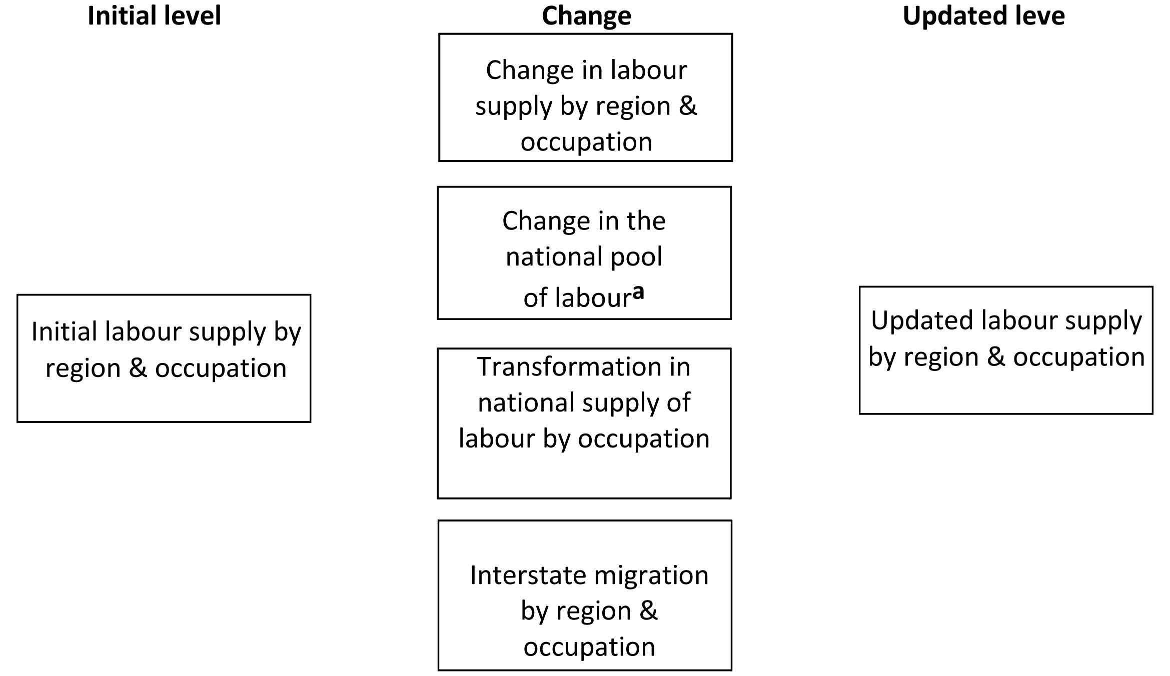
Occupational transformation has been added to VURM5 to enable the national supply of labour by occupation to change over time (equation *E_natlab*). The national supply of labour in each occupation is assumed to move in-line with aggregate labour supply (natlab_o). In addition, the national supply of labour in each occupation also responds positively to the change in the wage relativity for that occupation relative to other occupations (natpwage_i(o) – natpwage_io).[43] This adjustment is based on a constant elasticity of transformation (the parameter SIGMALABO). SIGMALABO is set to 0.1 in the model database (implying that, in the absence of any exogenous shock, the supply of labour by occupation adjusts gradually). The resource costs associated with this transformation are assumed to be embodied in the cost structure of the economy and are not explicitly modelled in the current implementation.

The regional supply of labour by occupation is determined by equation *E_lab*. For a given occupation, the regional supply of labour is assumed to move in-line with national supply of labour (natlab). The regional supply of labour in each occupation also responds positively to the change in the wage relativity for that region relative to the national average for that occupation (pwage_i(o) – natpwage_i(o)). This adjustment is based on a constant elasticity of transformation (the parameter SIGMALABS). SIGMALABS is set to 1 in the model database (implying that, in the absence of any exogenous shock, the supply of labour by occupation in each region adjusts proportionally to the difference in wage relativities). Like the modelling of occupational transformation, the resource costs associated with this interstate migration of labour supply are assumed to be embodied in the cost structure of the economy and are not explicitly modelled in the current implementation.

Changes in the supply of labour by region and occupation in the updated model are shown schematically in figure 7.3.

[43] Occupational substitution in the demand for labour is discussed in section 3.1.

Figure 7.3: Schematic representation of labour market arrangements



[a] Change in the national working-age population arising through demographic change (mortality, overseas migration and ageing of the population).

```
Equation E_natlab # National supply of labour by occupation #
(all,o,OCC)
natlab(o) = natlab_o + SIGMALABO*[natpwage_i(o) - natpwage_io];

Equation E_lab # Labour supply by state and occupation #
(all,q,REGDST)(all,o,OCC)
lab(q,o) = natlab(o) + SIGMALABS*[pwage_i(q,o) - natpwage_i(o)];
```

7.4 Export supply

The description of VURM in chapters 2, 3 and 6 assumes that producers can instantaneously adjust their pattern of sales to ensure that the same basic price is received across all categories of demand — production, investment, household consumption, exports, regional and federal government consumption, inventories and the National Electricity Market.

However, the presence of contractual arrangements and other short-term rigidities may mean that producers cannot instantaneously adjust the pattern of their sales in response to any differences in price across different categories of demand in the short term. This less than instantaneous adjustment may give rise to 'price wedges' between sales to certain markets. As contracts are re-negotiated and other adjustments occur (including to the level of production), producers would vary production levels and sales mixes to reduce or eliminate any price differences. The combination of physically distinct products in aggregative classifications, such as used in VURM, also complicates the modelling of adjustment between export and domestic use.

The problem of modelling export supplies in general equilibrium models has been recognised for some time,[44] and extensions using the constant elasticity of transformation (CET) aggregation function have been included in precursors of VURM. Gretton (1998) introduced transformation possibilities across all categories of demand in the ORANI model. The export component of the ORANI transformation was added to the Monash model for use in replicating structural and other economic change over time (PC, 2000) and Horridge (2003, 2011) introduced export transformation as an option into the ORANI-G model.

The current version of the VURM has been extended to include the CET function to model supplies as gradually switching between the domestic and export markets in response to any difference in the basic price (termed 'export transformation').[45] This enables VURM to handle existing contractual arrangements and other real world factors that may impede the rate at which producers can switch sales between categories of demand in the short term in response to any price differentials.

The modelling of export supplies in VURM5 extends these earlier implementations in three ways:

- implementation of export transformation is at the regional, rather than national, level;
- explicitly accounting for the additional returns to export sales (termed here 'additional returns') separately from those available from the domestic market; and
- quarantining the decision on primary factor use in production from the additional return on export sales.[46]

7.4.1 Volume of export sales

Export supply (E_x4r_supply)

As described in section 3.6.1, equations *E_x4rA* to *E_x4rF* determine world *demand* for Australian exports. To operationalise the export transformation theory, a shift term, f_x4r1, is added to each equation to enable the export demand schedules to be turned on or off.

The supply of these export sales can be determined by the export transformation function, equation *E_x4r_supply*, which, if desired, allows the supply of export sales to vary positively in response to the gap between basic price of export sales (p4) and the weighted-average basic price across all categories of sales (p0com). The export transformation function can be turned on by setting the shift term exogenous (f_x4r2) and swapping it with the markup on export sales (d_p4markup).[47]

If equation *E_x4r_supply* is made operational, the supply of export sales will increase if the percentage change in the basic price of export sales exceeds that of domestic sales (and, hence, is above that of the average basic price). The converse will occur if the percentage change in the basic price of domestic sales (and, hence, the average basic price) exceeds that of export sales.

The CET export transformation parameter, EXP_TRAN, governs the rate at which switching between domestic and export sales can occur. A parameter value of 0 ensures that no substitution is possible and that export volumes move with domestic sale volumes. Sensitivity testing by Gretton (1988)

---

[44] See Dervise, DeMelo and Robinson (1982) for an early example.

[45] References in this section to exports relate to foreign exports and not to interstate trade.

[46] The use of the term 'normal rate of return' in this chapter denotes the return to capital earned from sales to the domestic market. It does not include the additional return from export sales. The use of the term 'normal rate of return' does not imply that the model database is in equilibrium.

[47] If both f_x4r1(c,s) and f_x4r2(c,s) are exogenous and p4markup(c,s) is endogenous, the export demand schedule effectively determines the foreign currency price of exports.

indicated that a value of 300 approximates perfect transformation, so that the basic price of export sales moves in line with the basic price of domestic sales. In keeping with the earlier implementations of the theory, the export transformation parameter in VURM is set to value of 0.5 for all commodities and source region combinations.

The twist term locsaletwist is included to enable exogenous shifts in the composition of sales of domestic production between the domestic and export markets. If locsaletwist>0, the shift term induces a switch away from export sales to domestic sales. If locsaletwist<0, the shift term induces a switch away from domestic sales to export sales.

```
! Export transformation !
Equation E_x4r_supply # Supply of commodities to the export market #
(all,c,COM)(all,s,REGSRC)
x4r(c,s) = x0com_i(c,s) + IF[V4BAS(c,s) ne 0,
    EXP_TRAN(c,s)*[p4(c,s) - p0com(c,s)]] -
        [SALES(c,s) - V4BAS(c,s)]/ID01[SALES(c,s)]*locsaletwist(c,s) +
            f_x4r2(c,s);
```

7.4.2 Export and domestic prices

The transformation behaviour that underpins the exports supply equation is driven by the wedge between the return to producers from domestic sales (termed 'the basic price of domestic sales') and that received from export sales (termed 'the basic price of export sales').

The price wedge can be conceived of, and modelled as, a 'phantom tax' in the vein of Dixon & Rimmer (2002, pp. 28, 53 & 181-184). Under this treatment however, the return is not allocated to producers.

VURM extends this theory to allocate the 'phantom tax' to producers. Under this treatment, the price wedge means that producers can earn an additional per unit return (either positive or negative) from export sales. As a result, the ‘basic price’ of export sales can differ from the basic price of domestic sales.

The relationships between the purchasers’ price and the basic price of domestic sales and export sales for non-margin commodities are set out in figure 7.4.

It is assumed that the basic price received by producers on domestic sales (often called the ex-farm/mine/factory price) (the variable p0a in VURM) reflects the cost of production, including a return on capital. Taxes and margins that differ across categories of demand are added to the basic price give the purchasers’ price for each category of demand (upper panel of figure 7.4). These relationships are the same as existed in earlier versions of VURM.

Figure 7.4: Schematic representation of key price relationships in VURM

Domestic sales

Export sales

An export price wedge is introduced on top of the basic price of domestic sales to represent the *additional* return that producers receive on export sales.[48] The overall per unit return to producers from export sales is referred to as 'the basic price of export sales' to distinguish it from the basic price on domestic sales (lower panel of figure 7.1). Taxes and margins on export sales that differ across categories of demand are levied on top of the basic price of export sales to give the purchasers' price of export sales (lower panel of figure 7.1).

The price wedge is assumed to apply only to exports of non-margin commodities. The basic price of exports of margin commodities (such as wholesale trade, retail trade and air transport) is assumed to remain unchanged and is the same as that from domestic sales.

To simplify the analysis, the additional return from export sales is separated from the returns to capital described in chapter 3. This disaggregation enables the additional return to export sales to be accounted for separately and, so as to not distort the capital-labour ratio, to be quarantined from decisions by producers on primary factor use in production.

Basic price of export sales (E_p4_A to E_d_natp4_c)

The presence of additional returns in the price that producers receive from export sales can be conceived of as being equivalent to them receiving a different ex-farm/mine/factory price for those sales.

In the absence of data on prices and activity levels in the model database, the additional return from export sales is expressed on a proportional basis in VURM. Under this approach, a 'power of the markup' $(1 + \mathrm{M})$ relates the basic price of export sales to the basic price of domestic sales (P0A):

$$\mathrm{P4} = (1 + \mathrm{M}) \times +\mathrm{M})\mathrm{omestic\ sa} \qquad \text{(E7.1)}$$

The per unit return from export sales in the absence of the markup is given by $\mathrm{P0A}$ and the per unit additional return is given by $\mathrm{M} \times \mathrm{P0A}$. If $\mathrm{M} = 0$, there is no additional per unit return from export sales. If $\mathrm{M} > 0$, the additional per unit return from export sales is positive. If $\mathrm{M} < 0$, the additional per unit return from export sales is negative.

Let m denote the percentage change in the 'power of the markup' on export sales such that:

$$\mathrm{m} = \frac{\mathrm{d}(1 + \mathrm{M})}{(1 + \mathrm{M})} \times 100$$

The use of the power of the markup $(1 + \mathrm{M})$ enables the percentage change to be calculated when there is initially no markup on export sales (i.e., M=0).

[48] Negative returns may arise where export prices are set independently of the contractual arrangements that restrict the switching of sales and where producers do not hedge against price changes (including exchange rate changes).

The percentage change form of equation (E7.1) is:

$$p4 = p0a + m \qquad (E7.2)$$

The variable p4(c,s) denotes the percentage change in the basic price of export sales by commodity and source in the TABLO implementation. The coefficient POWERP4MARK represents the corresponding level of the markup on export sales and corresponds to $1 + M$ in the stylised presentation above. The variable p4markup represents the percentage change in the markup on export sales and corresponds to m above. It represents the percentage change in the additional per unit return from export sales.

Equation *E_p4_A* specifies the relationship between the basic price of export sales and domestic sales set out in equation (E7.2) for non-margin commodities. As it is assumed that there is no markup on export sales of margin commodities, equation *E_p4_B*, which applies to margin commodities.

In standard applications, the percentage change in the markup on export sales (p4markup) is exogenous, and the percentage change in the basic price of export sales (p4) is endogenous (and equal to p0a if the markup is not shocked).

Equation *E_d_p4markup* determines the ordinary change in the power of the markup on export sales, which is used to calculate the additional return from export sales (the variable. d_p4markup, which corresponds to $d(1 + M)$ in the stylised presentation above). The ordinary change in the power of the markup on export sales (d_p4markup) is:

$$d(1 + M) = 0.01 \times (1 + M) \times m$$

The model also includes a number of related export basic-price aggregates:

- the national basic price of export sales by commodity ($A) (equation *E_natp4*), which is defined as the share weighted-sum of the basic price of export sales across regions (p4) using the basic value of export sales as weights (V4BAS);
- the basic price of export sales by region ($A) (equation *E_p4_c*), which is defined as the share weighted-sum of the basic price of export sales across commodities and regions (p4) using the basic value of export sales as weights (V4BAS); and
- the national basic price of export sales ($A) (equation *E_natp4_c*), which is defined as the share weighted-sum of the basic price of export sales across commodities and regions (p4) using the basic value of export sales as weights (V4BAS).

```
Equation E_p4_A # Basic price of export sales (incl additional return) -
non-margin commodities #
(all,c,NONMARGCOM)(all,s,REGSRC)
p4(c,s) = p0a(c,s) + p4markup(c,s);

Equation E_p4_B # Basic price of export sales (incl additional return) -
margin commodities#
(all,r,MARGCOM)(all,s,REGSRC)
p4(r,s) = p0a(r,s);
```

```
Equation E_d_p4markup # Ordinary change in the power of markup on export
sales by commodity & region #
(all,c,COM)(all,s,REGSRC)
d_p4markup(c,s) = 0.01*POWERP4MARK(c,s)*p4markup(c,s);

! National basic price of export sales by commodity ($A) !
Equation E_natp4 # National basic price of export sales by commodity ($A) #
(all,c,COM)
ID01[sum{s,REGSRC, V4BAS(c,s)]*natp4(c) =
        sum{s,REGSRC, V4BAS(c,s)*p4(c,s)}};

! Basic price of export sales by region ($A) !
Equation E_p4_c # Basic price of export sales by region (A$) #
(all,s,REGSRC)
sum{c,COM, V4BAS(c,s)}*p4_c(s) = sum{c,COM, V4BAS(c,s)*p4(c,s)};

! National basic price of export sales ($A) !
Equation E_natp4_c # National basic price of export sales ($A) #
sum{c,COM,sum{s,REGSRC, V4BAS(c,s)}}*natp4_c =
        sum{c,COM,sum{s,REGSRC, V4BAS(c,s)*p4(c,s)}};
```

Purchasers' price of export sales in Australian dollars (E_p4a to E_natp4a_c)

Federal government taxes and the GST on exports (there are no regional taxes on exports in VURM) and margins are assumed to be levied on the export basic price in the same manner as in chapter 3.

Equation *E_p4a* links the percentage change in the purchasers' price of export sales expressed in Australian dollars (the variable p4a) to the percentage change in the basic price of export sales (p4). It takes into account the margins and federal taxes levied on top of the basic price of exports.

It is assumed that any federal government taxes on export sales are levied on the basic price of those exports.

Equation *E_natp4a* calculates the national percentage change in the purchasers' price of exports by commodity ($A), using as the value of export sales as weights (V4PURR). Equation *E_natp4a_c* calculates the corresponding national percentage change sales across commodities.

```
Equation E_p4a # Purchasers' prices - User 4 ($A) #
(all,c,COM)(all,s,REGSRC)
ID01[V4PURR(c,s)]*p4a(c,s) = (1 + T4GST(c,s)/100)*{
    [V4BAS(c,s) + V4TAXF(c,s)]*p4(c,s) +
    V4BAS(c,s)*d_t4f(c,s) +
    sum{r,MARGCOM,V4MAR(c,s,r)*
            [p4(r,s) + a4marg(s,r) + acom(r,s) + natacom(r)]}} +
    V4GSTBASE(c,s)*d_t4GST(c,s);

Equation E_natp4a
# National purchasers' price of export sales by commodity ($A) #
(all,c,COM)
ID01[NATV4R(c)]*natp4a(c) = sum{s,REGSRC, V4PURR(c,s)*p4a(c,s)};
```

```
Equation E_natp4a_c
# National purchasers' price of export sales by commodity ($A) #
ID01[sum{c,COM, NATV4R(c)}]*natp4a_c =
            sum{c,COM,sum{s,REGSRC, V4PURR(c,s)*p4a(c,s)}};
```

Purchasers' price of export sales in foreign currency units (E_p4r to E_natp4r)

The purchasers' price of Australian exports expressed in Australian dollars is linked to the foreign currency price and the nominal exchange rate in the same manner as in chapter 3.

Equation *E_p4r* converts the percentage change in the Australian dollar purchasers' price of exports (p4a) to the percentage change in the foreign currency price of exports (the variable p4r) using the nominal exchange rate (phi).[49]

Equation *E_natp4r* calculates the national foreign currency price of export sales by commodity, using the foreign currency unit price of export sales as weights (V4PURR).

```
Equation E_p4r # Purchasers' price - User 4 (foreign currency) #
(all,c,COM)(all,s,REGSRC)
p4r(c,s) + phi = p4a(c,s);

Equation E_natp4r # National foreign currency (fob) price of export sales #
(all,c,COM)
ID01[NATV4R(c)]*natp4r(c) = sum{q,REGDST, V4PURR(c,q)*p4r(c,q)};
```

Weighted-average basic price of domestic production (E_p0com to E_natp0com)

Equation *E_p0com* determines the weighted-average basic price of all domestic production for each commodity by region. It is equal to the basic domestic price sales plus the markup on export sales averaged over all sales.

Equation *E_natp0com* determines the national weighted-average basic price of all domestic production. It weights up the percentage change in the basic price of all domestic production for each commodity in each region (p0com) by its share of national sales for that commodity.

```
! Weighted-average basic price of domestically produced goods !
Equation E_p0com
# Weighted-average basic price of production (inc any additional return) #
(all,c,COM)(all,s,REGSRC)
ID01[SALES(c,s)]*p0com(c,s) =
    [SALES(c,s) - V4BAS(c,s)]*p0a(c,s) + V4BAS(c,s)*p4(c,s);

Equation E_natp0com # National weighted-average basic price of production
(inc additional return) #
(all,c,COM)
ID01[sum{q,REGDST, SALES(c,q)}]*natp0com(c) =
        sum{q,REGDST, SALES(c,q)*p0com(c,q)};
```

[49] The nominal exchange rate in VURM is expressed as the number of Australian dollars per unit of foreign currency.

Weighted-average price received by industries (E_x1tot to E_natp1tot)

Equation *E_x1tot* is updated to link the weighted-average output price for each regional industry (p1tot) to the basic price of the commodities produces by that industry. The basic price of domestic sales (p0a) is mapped to industry on the basis of sales excluding any additional return from export sales [MAKE(c,i,q) - COM2IND(i,c)*ADDEXPINC(c,q)]. The coefficient COM2IND(i,c) maps the additional return from commodity to industry, and takes on a value of 1 when the industry and commodity are the same (i.e., i=c) and 0 otherwise.[50] The markup on export sales is mapped to industry on the basis of the additional return from export sales.

Equation *E_natp1tot* calculates the basic price of output by national industry (natp1tot), using the MAKE matrix as weights (MAKE_C).

```
Equation E_x1tot # Average basic price received by industry & region (inc
additional return) #
(all,i,IND)(all,q,REGDST)
ID01[MAKE_C(i,q)]*p1tot(i,q) = sum{c,COM, MAKE(c,i,q)*p0com(c,q)};

Equation E_natp1tot
# Basic price of national industry output (including additional return) #;
 (all,i,IND)
sum{q,REGDST, MAKE_C(i,q)}*natp1tot(i) =
        sum{q,REGDST, MAKE_C(i,q)*p1tot(i,q)};
```

The basic price of domestic sales by industry (E_p1cost to E_p0a)

Equation *E_p1cost* relates the basic price of domestic sales to the cost of producing those sales. The percentage change in per unit revenue, net of any additional return from export sales, that producers in each regional industry receive (p1cost) is equal to the prices paid for the inputs used in production (intermediate inputs, primary factors and other costs), taking into account any change in the average efficiency with which these inputs are used in production (a). The coefficient PRODCOSTS is equivalent to the total cost of production (COSTS) less the additional return from export sales (ADDRETURN).

Equation *E_p0a* links the percentage change in per unit revenue, net of any additional return from export sales, received by each regional industry to the basic price of domestic sales of each commodity (p0a). The basic price of domestic sales (p0a) is mapped to industry on the basis of sales excluding any additional return from export sales [MAKE(c,i,q) - COM2IND(i,c)*ADDEXPINC(c,q)]. Given this, equation *E_p1cost* determines the return to capital excluding any additional return accruing through export sales (p1cap).

---

[50] As described in chapter 3, the coefficient MAKE was previously used to map the weighted-average output price for each regional industry from the commodity to industry dimension, but it includes the additional return from export sales which does not form part of the basic price of domestic sales.

```
Equation E_p1cost # Cost of production by industry & region (excluding
markup on export sales) #
(all,i,IND)(all,q,REGDST)
ID01[PRODCOSTS(i,q)]*{p1cost(i,q) - a(i,q)} =
   sum{c,COM,sum{s,ALLSRC, V1PURA(c,s,i,q)*p1a(c,s,i,q)}} +
                V1LAB_O(i,q)*p1lab_o(i,q) +
                V1CAP(i,q)*p1cap(i,q) +
                V1LND(i,q)*p1lnd(i,q) +
                V1OCT(i,q)*p1oct(i,q) +
                ISSUPPLY(i)*V1NEM(q)*p8tot;

Equation E_p0a
# Average cost of industry production (excluding markup on export sales) #
(all,i,IND)(all,q,REGDST)
p1cost(i,q) =
    1/ID01[sum{c,COM, MAKE(c,i,q) - COM2IND(i,c)*ADDEXPINC(c,q)}]*
        sum{c,COM, [MAKE(c,i,q) - COM2IND (i,c)*ADDEXPINC(c,q)]*p0a(c,q)};
```

7.4.3 Commodity supply by industry

Volume of supply (E_x0com)

Equation *E_x0com* is updated to link the percentage change in the supply of each commodity produced by each industry (x0com) to the percentage change in the per unit revenue from domestic sales (p1cost).

As a result, the percentage change in the supply of each commodity produced by a regional industry is linked to the percentage change in the gross output of that industry (x1tot) and to a transformation term based on the basic price of domestic sales of that commodity (p0a) relative to the average per unit revenue for that industry from domestic sales (p1cost). Thus, regional industries will produce more of those commodities whose price rises relative to the industry average and less of those that fall.

```
Equation E_x0com # Supplies of commodities by regional industry #
(all,c,COM)(all,i,IND)(all,q,REGDST)
x0com(c,i,q) = x1tot(i,q) + SIGMA1OUT(i)*[p0a(c,q) - p1cost(i,q)];
```

Value of export sales (E_d_w4bas)

With the introduction of the markup on export sales, the nominal basic value of export sales is:

$$W4 = (1 + M) \times +\text{Mh the introd} \qquad \text{(E7.3)}$$

In ordinary change terms:

$$d\_W4 = 0.01 \times W4 \times (p4 + x4r) \qquad \text{(E7.4)}$$

Equation *E_d_w4bas* determines the percentage change in the nominal basic value of export sales evaluated at the export basic price, which is inclusive of the markup on export sales.

```
Equation E_d_w4bas
# Change in export sales (valued at export basic price)(A$m) #
(all,c,COM)(all,s,REGSRC)
d_w4bas(c,s) = 0.01*V4BAS(c,s)*(p4(c,s) + x4r(c,s));
```

Updating the MAKE matrix

The MAKE matrix (or the 'supply table' in ABS terminology) denotes the value of sales of each commodity by each industry in each region. The MAKE matrix implicitly includes any additional returns from export sales in the initial model database.

Disaggregating the returns to capital to separate the additional returns from export sales from those on domestic sales does not affect the value of export sales and, hence, the MAKE matrix.

Accordingly, the MAKE matrix is updated using the weighted-average return to producers across *all* sales (i.e., domestic and export sales). With the separation of the additional return from export sales, the variables p0com and x0com are used to update the MAKE matrix, rather than p0a and x0com used previously, as p0a is the basic price of domestic sales (i.e., it excludes the additional return on export sales).

7.4.4 Accounting for the income from the markup on export sales

To avoid distorting the mix of primary factors used in production (primarily the capital-labour ratio), the additional income from export sales is accounted for separately. This 'sterilisation' to quarantine the rental price of capital, which plays a key role in driving primary factor use in VURM, from the additional return on export sales requires some additional terms to be added to the relationships outlined in chapters 2, 3 and 4.

This approach results in two streams of capital income:

- income from the domestic basic price on all sales; and
- additional income arising from the markup on export sales.[51]

Both streams of capital income continue to accrue to the owners of capital used in production (domestic and foreign), and to governments in the form of tax revenue. The transmission mechanisms are described in chapters 3 and 6.

With the introduction of the additional returns, the coefficients V1CAP and V1CAPINC now represent the streams of capital income that are consistent with the return on all sales valued at the basic price of domestic sales (but excluding the additional return) before and after production taxes, respectively. This income is used to derive the rental price of capital that flows through into the primary factor input decisions for current production.

The additional stream of income arising from the markup on export sales is assumed to flow directly to the owners of capital (domestic and foreign) and to the federal government (in the form of tax revenue). This additional income stream provides producers in VURM with an incentive to:

[51] In the standard model, changes in the basic price of export and domestic sales are aligned and any all returns are subsumed in the single basic prices. The accounting of the extended model therefore disaggregates measures in the standard model according to destination of supply.

- switch sales of existing production between the domestic and export markets, thereby increasing average returns; and
- vary the level of total production.

Income from the markup on export sales (E_d_addexpinc to E_d_nataddret_i)

Any markup on export sales over domestic sales will generate additional income (positive or negative) on export sales.

In level terms, the before tax additional return from export sale can be calculated as:

$$A = P4 \times X4R - P0A \times X4R$$

$$A = (1 + M) \times (P0A \times X4R) - P0A \times X4R$$

$$A = MA(P0AA \times X4) \qquad \text{(E7.5)}$$

where: A is the additional return from export sales; M is the per unit markup on export sales; and $P0A \times X4R$ is the value of exports in the absence of the markup on export sales.

The value of exports in the absence of the markup on export sales is:

$$P0A \times X4R = \frac{W4}{(1 + M)} = Alt\_W4$$

Substituting this in (E7.5) gives:

$$A = M \times Alt\_W4 = M \times \frac{W4}{(1 + M)}$$

In ordinary change terms this becomes:

$$d\_A = M \ \times d\_Alt\_W4 + Alt\_W4 \times d\_M$$

But as:

$d\_Alt\_W4 = 0.01 \times \frac{W4}{1+M} \times \{p0a \ + \ x4r\}$ and $Alt\_W4 = \frac{W4}{(1+M)}$

Substituting these in give:

$$d\_A = M \ \times 0.01 \times \frac{W4}{1 + M} \times \{p0a \ + \ x4r\} + \frac{W4}{1 + M} \times d\_M$$

$$d\_A = 0.01 \times M \ \times \frac{W4}{1 + M} \times \{p0a \ + \ x4r\} + \frac{W4}{1 + M} \times d\_M$$

$$d\_A = 0.01rA \times \{p0a \ + \ x4r\} + \frac{W4}{1+M} \times d\_M \qquad \text{(E7.6)}$$

In VURM, the average technical change term ‘a’ applies to the total value of *all* production, including any additional return. Consequently, any change in the average rate of technical change will also impact on the additional return from export sales. To account for this, the following term is also included in the additional return from export sales equation:

sum{i,IND, 0.01*COM2IND(i,c)*[COSTS(i,s) - PRODCOSTS(i,s)]*a(i,s)}

The additional returns from the markup on export sales are recorded in two ways in VURM:

- by the commodity and source region, denoted by the coefficient ADDEXPINC and its change variable d_addexpinc; and

- by industry and destination region, denoted the coefficient ADDRETURN and its change variable d_addreturn.

Equation *E_d_addexpinc* determines the ordinary change in the additional return on export sales of each commodity from each region (in A$ million). The additional return can be made exogenous by setting d_addexpinc exogenous and swapping it with the shift term f_addreturn. This closure change could be undertaken in conjunction with those to turn the export transformation function off, which involves:

- setting the markup on export sales exogenous (p4markup); and
- making the shift term f_x4r2 exogenous (chapter 9).

Equation E_d_addreturn maps the ordinary change in the additional return on export sales by commodity and source region to producing industry and region. As the distribution of the additional returns from export sales across regions may differ from the value of sales in the MAKE matrix, the coefficient COM2IND is used to the additional return to the corresponding industry in the same region.

```
Equation E_d_addexpinc # Change in the additional return on export sales by
commodity & region #
(all,c,COM)(all,s,REGSRC)
d_addexpinc(c,s) =
  0.01*ADDEXPINC(c,s)*{p0a(c,s) + x4r(c,s)} +
    [V4BAS(c,s)/POWERP4MARK(c,s)]*d_p4markup(c,s) +
      sum{i,IND, 0.01*COM2IND(i,c)*[COSTS(i,s) - PRODCOSTS(i,s)]*a(i,s)};

Equation E_d_addreturn
# Change in the additional return on export sales by industry & region #
(all,i,IND)(all,q,REGDST)
d_addreturn(i,q) = sum{c,COM, COM2IND(i,c)*d_addexpinc(c,q)};

Equation E_d_addreturn_i
# Change in the additional return on export sales by state #
(all,q,REGDST)
d_addreturn_i(q) = sum{i,IND, d_addreturn(i,q)};

Equation E_d_nataddret
# Change in the additional return on export sales by national industry #
(all,i,IND)
d_nataddret(i) = sum{q,REGDST, d_addreturn(i,q)};

Equation E_d_nataddret_i
# National change in the additional return on export sales #
d_nataddret_i = sum{q,REGDST,sum{i,IND, d_addreturn(i,q)}};
```

Taxation of the income from the markup on export sales (natw1gos_i)

It is assumed in VURM that both Australian and foreign owners of the domestic capital stock pay income tax on the additional return on export sales. The modelling of taxation occurs in the *Government Finance Statistics module* (described in chapter 5).

In the *Government Finance Statistics* module, federal government income tax is levied on *all* capital income, including from the additional return on export sales. In keeping with the convention adopted in the ABS *Government Finance Statistics* and consistent with the way other primary factor income (including capital income) is taxed in VURM, it is assumed that the additional return from export sales is taxed in the hands of the companies that initially receive the returns, rather than in the hands of the domestic and foreign households that ultimately receive that income. In this way, the additional return is taxed in the same way as other income accruing to the owners of capital. The additional return from export sales is added to equation *E_natw1gos_i* which calculates the national change in gross operating surplus. The percentage change in income taxes paid by enterprises is calculated from the variable natw1gos_i in equation *E_d_wgfsi_132B*. As a result, the additional return feeds through into the coefficient VGFSI_132. It also feeds through indirectly into the formula that calculates the effective company tax rate in VURM (TGOSINC).

```
Equation E_natw1gos_i # National value for w1gos_i #
sum{q,REGDST, V1GOSINC_I(q)}*natw1gos_i =
sum{q,REGDST, [V1CAPINC_I(q)*w1capinc_i(q) + 100*d_addreturn_i(q)] +
    V1LNDINC_I(q)*w1lndinc_i(q) + V1OCTINC_I(q)*w1octinc_i(q)};
```

Distribution of the income from the markup on export sales (E_w1ncapinc)

It is assumed that the additional return on export sales is distributed to the owners of capital in the same way as the capital income from domestic sales, which was described in chapter 6.

The additional return is added to equation *E_w1ncapinc* to feed into capital income net of depreciation and any federal and state taxes on the use of capital in production (the coefficient V1NCAPINC and the variable w1ncapinc).

The additional return also feeds through into any federal and regional taxes on the use of that capital in production (the coefficients V1CAPTXF and V1CAPTXS, and the variables d_w1captxf and d_w1captxs).

In level terms, the level of after-tax capital income net of depreciation becomes:

V1NCAPINC(i,q) = [1 - DEPR(i)]*V1CAP(i,q) + ADDRETURN(i,q) - V1CAPTXF(i,q) - V1CAPTXS(i,q)

The percentage change in net after-tax capital income net of depreciation is:

ID01[V1NCAPINC(i,q)]*w1ncapinc(i,q) = [1 - DEPR(i)]*V1CAP(i,q)*(p1cap(i,q) + x1cap(i,q)) + 100*d_addreturn(i,q) - 100*(d_w1captxF(i,q) + d_w1captxS(i,q))

Capital income net of depreciation and production taxes is distributed to the owners of non-labour primary factors according to their relevant factor ownership shares. The existing equations handle this and do not need to be updated to accommodate the additional return. This means that the additional return flowing to:

- foreign investors is determined on the basis of the foreign ownership share of the Australian capital stock (the coefficient FORSHR, which is defined as 1 – the domestic ownership share, the coefficient DOMSHR);
- Australian households is determined on the basis of the domestic ownership share (the coefficient DOMSHR); and

- Australian households in each region is determined on the basis of domestic ownership share (the coefficient DOMSHR) multiplied by the local ownership share (the coefficient LOCSHR).[52]

These ownership shares vary by industry and state.

It is assumed that DOMSHR and LOCSHR are the same as they are for domestic sales. The additional return to export sales ultimately feed through to:

- regional household non-labour income through equation *E_whinc_120* (along with the after production-tax income flows arising from the ownership of capital, land and other costs); and
- foreign owners of the domestic capital stock via the equation *E_d_FORCAPINCA*.

```
Equation E_w1ncapinc # Capital income net of depreciation #
(all,i,IND)(all,q,REGDST)
ID01[V1NCAPINC(i,q)]*w1ncapinc(i,q) =
[{1 - DEPR(i)}*V1CAP(i,q)*(p1cap(i,q) + x1cap(i,q)) + 100*d_addreturn(i,q)]
- 100*(d_w1captxF(i,q) + d_w1captxS(i,q));
```

Effect of the additional return on investment (E_d_r1cap to E_d_r1cap_i)

Given the assumption of static expectations, the additional return to export sales provides producers with an incentive to switch the pattern of existing sales and, through increased investment, to increase output.

The drivers of investment by regional industry in VURM are described in detail in chapter 4. Central to this is the signalling role played by deviations in the rate of return on capital from its long-run trend.

These transmission mechanisms are adapted to accommodate the income stream associated with the additional return on export sales. The additional return on export sales is assumed to feed into the investment decisions of producers by altering the actual rate of return on capital (and, hence, the deviation from its long-run trend that drive investment), as in standard VURM. Gradually, changes in the rate of return on capital and will feed through into the capital stock available for use in production.[53]

The rate of return on capital in VURM is expressed on an after-tax basis. It is assumed that the additional return on export sales is taxed in the same way as all other non-labour primary factor income at the proportional rate of TGOSINC.[54] This makes the after-tax additional return from export sales by industry and region [1 – TGOSINC]*ADDRETURN(i,q).

---

[52] For most commodities, the local ownership share used in VURM is effectively the regional share of national population. The share of Australian non-labour primary factor income flowing to households in other states is 1 - LOCSHR.

[53] As described in chapter 2 and 3, investment behaviour in VURM is governed by the assumption of adaptive expectations, in which changes in the disequilibrium rate of return that drive investment decisions are set equal to the change in the after-tax rate of return to capital.

[54] The tax rate on capital in VURM is calculated as *Taxes on income – enterprises* in the GFS database (VGFSI_132("Federal")) divided by the national total of non-labour primary factor income available for consumption (which is equal to sum{q,REGDST, V1GOSINC_I(q)}). The implied tax rate in 2005-06 is about 0.16 (i.e., 16 per cent).

The change in the after-tax additional return on export sales consists of two parts:

- the effect of the existing tax rate on any change in the additional return

[1 - TGOSINC]*d_addreturn(i,q); and

- the effect of any change in the tax rate on any pre-existing additional return

- ADDRETURN_I(q)*d_tgosinc.

Combining these gives the overall change in the after-tax additional return from export sales:

[1 - TGOSINC]*d_addreturn(i,q) - ADDRETURN_I(q)*d_tgosinc

The resulting percentage point change in the after-tax rate of return by industry and region (d_r1cap) arising from the additional return on export sales is:

100*IF[VCAP(i,q) ne 0.0, [1 - TGOSINC]/VCAP(i,q)*d_addreturn(i,q) - ADDRETURN_I(q)/VCAP_I(q)*d_tgosinc];

This term has been added to equation *E_d_r1cap*, which was described in chapters 2 and 4 and 3, which determines the percentage point change in the after-tax rate of return by industry and region. Equation *E_d_r1cap_i* similarly determines the percentage point change in the after-tax rate of return by region.

```
Equation E_d_r1cap
# Definition of after-tax rates of return to capital by industry & region #
(all,i,IND)(all,q,REGDST)
d_r1cap(i,q) = {1 + IF[VCAP(i,q) ne 0.0,
     (-1 + {(1 - TGOSINC)*V1CAPINC(i,q)/VCAP(i,q)})]}*
         [p1capinc(i,q) - p2tot(i,q)] -
  100*IF[VCAP(i,q) ne 0.0, (V1CAPINC(i,q)/VCAP(i,q) - DEPR(i))]*d_tgosinc +
  100*IF[VCAP(i,q) ne 0.0,
         [1 - TGOSINC]/VCAP(i,q)*d_addreturn(i,q) -
         ADDRETURN_I(q)/VCAP_I(q)*d_tgosinc];

Equation E_d_r1cap_i # Region-wide after-tax rate of return #
(all,q,REGDST)
d_r1cap_i(q) =
    IF(VCAP_I(q) ne 0.0, {[1 - TGOSINC]*V1CAPINC_I(q)/VCAP_I(q)})*
         [p1capinc_i(q) - p2tot_i(q)] -
    100*IF[VCAP_I(q) ne 0.0, {V1CAPINC_I(q)/VCAP_I(q) - DEPR_I(q)}]*
         d_tgosinc +
    100*IF[VCAP_I(q) ne 0.0,
         [1 - TGOSINC]/VCAP_I(q)*d_addreturn_i(q) -
         ADDRETURN_I(q)/VCAP_I(q)*d_tgosinc];
```

7.4.5 Other miscellaneous changes

Regional real GSP on the income side and at factor cost (E_x0gspinc to E_x0gspfc)

The right hand side of equation *E_x0gspinc*, described in chapter 3, which determines the percentage change in regional real GSP on the income side, is modified to include the effect of changes in export sales on the pre-existing additional return on export sales (ADDEXPINC) that have accrued in previous periods:

sum{c,COM, ADDEXPINC(c,q)*x4r(c,q)}

The equation for real GSP at factor cost, equation *E_x0gspfc*, is modified in a similar manner.

```
Equation E_x0gspinc # Real GSP from the income side #
(all,q,REGDST)
V0GSPINC(q)*x0gspinc(q) =
    V1LND_I(q)*x1lnd_i(q) + V1CAP_I(q)*x1cap_i(q) +
    sum{c,COM, ADDEXPINC(c,q)*x4r(c,q)} +
    V1LAB_IO(q)*x1lab_io(q) + V1OCT_I(q)*x1oct_i(q) +
    sum{c,COM,sum{s,ALLSRC,sum{i,IND,
        (V1TAXF(c,s,i,q) + V1TAXS(c,s,i,q))*x1a(c,s,i,q) +
        T1GST(c,s,i,q)/100 * {
            V1BAS(c,s,i,q)*x1a(c,s,i,q) +
            (V1TAXF(c,s,i,q) + V1TAXS(c,s,i,q))*x1a(c,s,i,q) +
            sum{r,MARGCOM, V1MAR(c,s,i,q,r)*x1marg(c,s,i,q,r)}} +
        (V2TAXF(c,s,i,q) + V2TAXS(c,s,i,q))*x2a(c,s,i,q) +
        T2GST(c,s,i,q)/100 * {
            V2BAS(c,s,i,q)*x2a(c,s,i,q) +
            (V2TAXF(c,s,i,q) + V2TAXS(c,s,i,q))*x2a(c,s,i,q) +
            sum{r,MARGCOM, V2MAR(c,s,i,q,r)*x2marg(c,s,i,q,r)}} } +
        (V3TAXF(c,s,q) + V3TAXS(c,s,q))*x3a(c,s,q) +
        T3GST(c,s,q)/100 * {
            V3BAS(c,s,q)*x3a(c,s,q) +
            (V3TAXF(c,s,q) + V3TAXS(c,s,q))*x3a(c,s,q) +
            sum{r,MARGCOM, V3MAR(c,s,q,r)*x3marg(c,s,q,r)}} } +
        V4TAXF(c,q)*x4r(c,q) + V0TAR(c,q)*x0imp(c,q) +
        T4GST(c,q)/100 * {
            V4BAS(c,q)*x4r(c,q) +
            V4TAXF(c,q)*x4r(c,q) +
            sum{r,MARGCOM, V4MAR(c,q,r)*x4marg(c,q,r)}}} -
    sum{k,IND, [COSTS(k,q)]*a(k,q)} -
    sum{c,COM,sum{i,IND, V2PURO(c,i,q)*[a2(q) + acom(c,q) + natacom(c)]}} -
    V0MAR(q)*a0mar(q);

Equation E_x0gspfc # Real GSP at factor cost #
(all,q,REGDST)
V0GSPFC(q)*x0gspfc(q) =
    V1LNDINC_I(q)*x1lnd_i(q)  + V1CAPINC_I(q)*x1cap_i(q) +
    sum{c,COM, ADDEXPINC(c,q)*x4r(c,q)} +
    sum{o,OCC, V1LABINC_I(q,o)*x1lab_i(q,o)} + V1OCTINC_I(q)*x1oct_i(q) -
    sum{k,IND, COSTS(k,q)*a(k,q)} -
    sum{c,COM,sum{i,IND, V2PURO(c,i,q)*[a2(q) + acom(c,q) + natacom(c)]}} -
    V0MAR(q)*a0mar(q);
```

Regional GSP deflator on the income side and at factor cost (E_p0gspinc to E_p0gspfc)

Equation *E_p0gspinc*, described in chapter 3, which determines the percentage change in the regional GSP deflator on the income side is modified to include the price effect of the additional return on export sales:

sum{c,COM, ADDEXPINC(c,q)*p0a(c,q) + 100*V4BAS(c,q)/POWERP4MARK(c,s)*p4markup(c,q)}

The equation for real GSP at factor cost, equation *E_p0gspfc*, is modified in a similar manner.

```
Equation E_p0gspinc # State GSP deflator from the income side #
(all,q,REGDST)
V0GSPINC(q)*p0gspinc(q) =
    V1LND_I(q)*p1lnd_i(q)    + V1CAP_I(q)*p1cap_i(q) +
    sum{c,COM, ADDEXPINC(c,q)*p0a(c,q) +
        100*[V4BAS(c,q)/POWERP4MARK(c,q)]*d_p4markup(c,q)} +
    V1LAB_IO(q)*p1lab_io(q) + V1OCT_I(q)*p1oct_i(q) +
sum{c,COM,sum{s,ALLSRC,sum{i,IND,
(1 + T1GST(c,s,i,q)/100)*[
    [V1TAXF(c,s,i,q)*p0a(c,s) + V1BAS(c,s,i,q)*d_t1F(c,s,i,q)] +
    [V1TAXS(c,s,i,q)*p0a(c,s) + V1BAS(c,s,i,q)*d_t1S(c,s,i,q)] ] +
    V1GSTBASE(c,s,i,q)*d_t1GST(c,s,i,q) + T1GST(c,s,i,q)/100* {
    V1BAS(c,s,i,q)*p0a(c,s) + sum{r,MARGCOM, V1MAR(c,s,i,q,r)*p0a(r,q)}} +
(1 + T2GST(c,s,i,q)/100)*[
    [V2TAXF(c,s,i,q)*p0a(c,s) + V2BAS(c,s,i,q)*d_t2F(c,s,i,q)] +
    [V2TAXS(c,s,i,q)*p0a(c,s) + V2BAS(c,s,i,q)*d_t2S(c,s,i,q)] ] +
    V2GSTBASE(c,s,i,q)*d_t2GST(c,s,i,q) + T2GST(c,s,i,q)/100* {
    V2BAS(c,s,i,q)*p0a(c,s) + sum{r,MARGCOM, V2MAR(c,s,i,q,r)*p0a(r,q)}}} +
(1 + T3GST(c,s,q)/100)*[
    [V3TAXF(c,s,q)*p0a(c,s) + V3BAS(c,s,q)*d_t3F(c,s,q)] +
    [V3TAXS(c,s,q)*p0a(c,s) + V3BAS(c,s,q)*d_t3S(c,s,q)] ] +
    V3GSTBASE(c,s,q)*d_t3GST(c,s,q) + T3GST(c,s,q)/100* {
    V3BAS(c,s,q)*p0a(c,s) + sum{r,MARGCOM, V3MAR(c,s,q,r)*p0a(r,q)}} } +
(1 + T4GST(c,q)/100)*[
    [V4TAXF(c,q)*p4(c,q) + V4BAS(c,q)*d_t4f(c,q)] ] +
    V4GSTBASE(c,q)*d_t4GST(c,q) + T4GST(c,q)/100* {
    V4BAS(c,q)*p4(c,q) +
    sum{r,MARGCOM, V4MAR(c,q,r)*p4(r,q)}} +
    [V0TAR(c,q)*(natp0cif(c) + phi) + V0IMP(c,q)*powtar(c)] } +
sum{k,IND, COSTS(k,q)*a(k,q)} +
sum{c,COM,sum{i,IND, V2PURO(c,i,q)*(a2(q) + acom(c,q))}} +
V0MAR(q)*a0mar(q);
```

```
Equation E_p0gspfc # State GSP deflator at factor cost #
(all,q,REGDST)
V0GSPFC(q)*p0gspfc(q) =
    V1LNDINC_I(q)*p1lndinc_i(q)    + V1CAPINC_I(q)*p1capinc_i(q) +
    sum{c,COM, ADDEXPINC(c,q)*p0a(c,q) +
        100*[V4BAS(c,q)/POWERP4MARK(c,q)]*d_p4markup(c,q)} +
    sum{o,OCC, V1LABINC_I(q,o)}*pwage_io(q) + V1OCTINC_I(q)*p1octinc_i(q) +
sum{k,IND, COSTS(k,q)*a(k,q)} +
sum{c,COM,sum{i,IND, V2PURO(c,i,q)*(a2(q) + acom(c,q) + natacom(c))}} +
V0MAR(q)*a0mar(q);
```

7.4.6 Key coefficients and formulas to operationalize the export supply theory

To complete the documentation of the module the final box in this section lists the key coefficients and formulas used to implement the export transformation theory described above.

```
! CET export transformation parameter !
Coefficient (parameter)(all,c,COM)(all,s,REGSRC)
EXP_TRAN(c,s)
# CET transformation elasticity between domestic and export sales #;

Read EXP_TRAN from file EXPTRANSDATA header "EXPT";

! Additional returns from export sales by commodity !
Coefficient (all,c,COM)(all,s,REGSRC)
ADDEXPINC(c,s)
# Additional return on export sales by commodity & region (A$m) #;
Read ADDEXPINC from file MDATA header "REXP";
Update (change)(all,c,COM)(all,s,REGSRC)
ADDEXPINC(c,s) = d_addexpinc(c,s);

! Additional returns from export sales by industry !
Coefficient (all,i,IND)(all,q,REGDST)
ADDRETURN(i,q)
# Additional return on export sales by industry & region #;
Read ADDRETURN from file MDATA header "RSUP";
Update (change)(all,i,IND)(all,q,REGDST)
ADDRETURN(i,q) = d_addreturn(i,q);

Coefficient (parameter)
(all,i,IND)(all,c,COM)
COM2IND(i,c) # Mapping of commodities to industries #;
Read COM2IND from file EXPTRANSDATA header "MAP";
```

```
Coefficient (all,c,COM)(all,i,IND)(all,q,REGDST)
MAKE(c,i,q) # Sales of commodity c by industry i in state q (including any
additional return) #;
Read MAKE from file MDATA header "MAKE";
Assertion (all,c,COM)(all,i,IND)(all,q,REGDST)
MAKE(c,i,q) >= 0;
Update (all,c,COM)(all,i,IND)(all,q,REGDST)
MAKE(c,i,q) = x0com(c,i,q)*p0com(c,q);

Formula (all,i,IND)(all,q,REGDST)
COSTS(i,q) = sum{c,COM,sum{s,ALLSRC, V1BAS(c,s,i,q)}} +
    sum{c,COM,sum{s,ALLSRC,sum{r,MARGCOM, V1MAR(c,s,i,q,r)}}} +
sum{c,COM,sum{s,ALLSRC, [V1TAXF(c,s,i,q) + V1TAXS(c,s,i,q) +
V1GST(c,s,i,q)]}} + V1LAB_O(i,q) + [V1CAP(i,q) + ADDRETURN(i,q)] +
V1LND(i,q) + V1OCT(i,q) + ISSUPPLY(i)*V1NEM(q);

Formula # Cost of production (excluding additional return) #
(all,i,IND)(all,q,REGDST)
PRODCOSTS(i,q) = sum{c,COM,sum{s,ALLSRC, V1PURA(c,s,i,q)}} +
V1LAB_O(i,q) + V1CAP(i,q) + V1LND(i,q) + V1OCT(i,q) + ISSUPPLY(i)*V1NEM(q);

Formula (all,i,IND)(all,q,REGDST)
V1NCAPINC(i,q) = [{1 - DEPR(i)}*V1CAP(i,q) + ADDRETURN(i,q)] -
        V1CAPTXF(i,q) - V1CAPTXS(i,q);

Formula (all,i,IND)(all,q,REGDST)
V1GOS(i,q) = [V1CAP(i,q) + ADDRETURN(i,q)] + V1LND(i,q) + V1OCT(i,q);

Formula (all,i,IND)(all,q,REGDST)
V1GOSINC(i,q) =
    [V1CAPINC(i,q) + ADDRETURN(i,q)] + V1LNDINC(i,q) + V1OCTINC(i,q);

Formula (all,i,IND)(all,q,REGDST)
R1CAP(i,q) = 0.0 + IF(VCAP(i,q) ne 0.0,
        100*{[1 - TGOSINC]*V1CAPINC(i,q)/VCAP(i,q) - DEPR(i)}) +
        100*[1 - TGOSINC]*ADDRETURN(i,q)/VCAP(i,q));
```

8 Greenhouse gas module

8.1 Introduction

This chapter describes the greenhouse gas emissions module included in VURM5.[55] Additional supporting material can be found in Adams and Parmenter (2012).

This module includes:

- an accounting of Australian greenhouse gas emissions that is consistent with the Kyoto-reporting protocol (at the higher level);
- differential approaches to modelling emissions arising from the burning of fossil fuels (combustion emissions) and non-combustion emissions arising from undertaking particular activities;[56]
- mechanisms to tax or restrict the quantity of emissions by source occurring in Australia;
- the ability to link an Australian emissions trading scheme to an international scheme and the ability to undertake international trade in emissions permits;
- full or partial shielding of particular industries or activities from the pricing of emissions through a range of measures, such as differential emission tax rates or through the grandfathering of permits;
- different ways of using the revenue raised by government from the taxation of emissions or the issuing of permits, including through directing it into consolidated revenue (and thereby into existing government revenue and expenditure accounting), or returning it to households through lump-sum transfers, a change in the rate of taxation on labour income, or consumer subsidies; and
- endogenous modelling of technological change in response to a tax or price on emissions.

While providing substantial functionality, the module could be further developed in a number of respects to better meet the requirements of particular applications. Such developments could include:

- introducing capital-energy bundling which recognises that, in certain activities, the use of physical capital and energy is complementary, and that price-based substitution can occur between different source of energy;[57] and
- adding additional sectoral detail for key emissions sectors producing electricity and transportation services; and

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[55] As different versions of VURM have greenhouse gas modelling capabilities, the discussion in this chapter refers to the capability included in VURM5. This capability is suited to a basic level of analysis of carbon emissions and emissions-related policies. Additional sectoral detail can be added for key sectors, such as electricity generation, transport and household demand, to enable more rigorous analysis of such policies (such as that reported in Australian Government 2008 and Treasury 2011).

[56] This chapter uses the term non-combustion emissions to cover all emissions other than those arising from the combustion of fossil fuels. It includes fugitive and activity emissions.

[57] Capital-energy bundling could, for example, recognise the complementary nature of car use and energy, while allowing substitution between fuel sources based on relative price.

The remainder of the chapter is organised as follows. Following this introduction, section 8.2 outlines the modelling of greenhouse gas emissions. The discussion then precedes to the modelling of emissions abatement policies, starting with the modelling of independent action by Australia to price or restrict the quantity of emissions (section 8.3) before moving on to the modelling of Australian involvement in a notional international emissions trading scheme (section 8.4). Section 8.5 describes the modelling of other greenhouse gas-related government policies, such as alternative ways of dealing with the revenue raised from the pricing of emissions or the sale of permits. The chapter concludes with a discussion of the modelling of technical change relating to the intensity of greenhouse gas emissions (section 8.6). Annexes to this chapter provide additional supporting detail.

Each section generally commences with the rationale underpinning the approach adopted in VURM5 (discussed in the subsection labelled 'Conceptual model'). The remainder of each section discusses the key formulae and equations implemented in the module and the mechanisms in operation to aid understanding (discussed in the subsection labelled 'TABLO implementation'). The TABLO code also includes a range of additional formulae and equations, many of which deal with the updating of the coefficients and various accounting identities needed to operationalise the model in a dynamic framework. These features are documented in the comments in the model code.

8.2 Modelling of greenhouse emissions

8.2.1 Coverage

VURM5 covers emissions from the key greenhouse gases in the Australian *National Greenhouse Gas Inventory* (DIICCSRTE 2011) emitted during each simulation year (which corresponds to a financial year).[58] Rather than modelling each gaseous emission separately, VURM5 adopts the convention of modelling emissions in terms of a composite 'carbon dioxide equivalent' measure (CO_2-e), in which emissions from each gas is aggregated using its global-warming potential as a weight.

While model reporting covers the main sources of *domestic* emissions (box 8.1) and is consistent with Kyoto reporting protocols, certain emissions are not covered. These relate to activities not covered in the official ABS economic statistics on which VURM5 is based, and relate to: agricultural soils; and some land use change, including the prescribed burning of savannahs.

It also does not include emissions that occur outside Australia, such as those arising from:

- the combustion overseas of Australian exports of coal, oil and gas;
- international air transport and shipping; or
- international bunkering of fuels.

Australian combustion and non-combustion emissions in the 2005-06 model database amount to 500.2 Mt (figure 8.1). This represents 95 per cent of actual Australian emissions in 2005-06 (DIICCSRTE 2011). These emissions can be broken down by Kyoto reporting category (figure 8.1). The main Kyoto reporting emission categories in the 2005-06 database are: energy (407 Mt) and agriculture (74 Mt). Energy emissions can be further decomposed into those arising from the combustion of fossil fuels (377 Mt) and those from fugitive emissions (30 Mt). Electricity generation

---

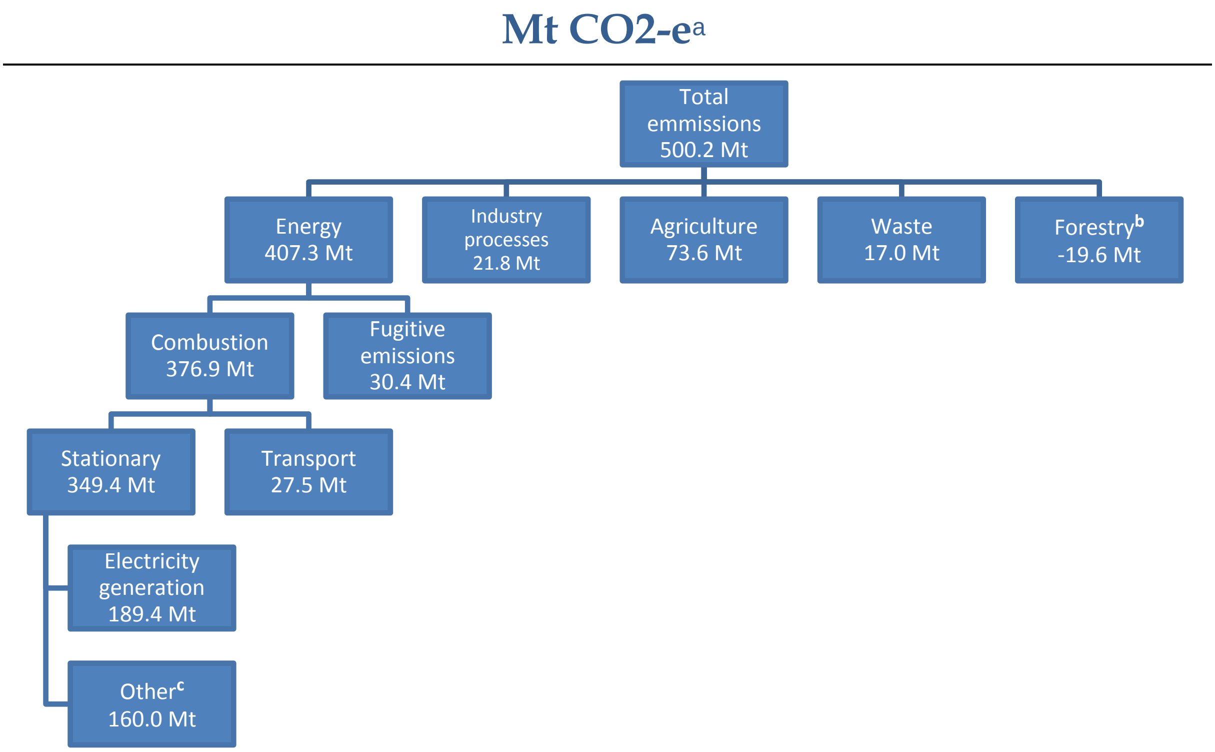
[58] The main greenhouse gases included in the Australian *National Greenhouse Gas Inventory* (DIICCSRTE 2011) are: carbon dioxide (CO_2); methane (CH_4); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulphur hexafluoride (SF_6).

accounts for 189 Mt of combustion emissions in the model database (amounting to nearly 40 per cent of total emissions). Greenhouse gas emissions by source (fuel/activity) and emitting sector are detailed in annex 8A.1 at the end of this chapter.

As noted, these different categories of emissions emanate from:

- the combustion of fossil fuels — the burning of carbon-based fuels derived from coal, oil (burnt in its processed form as petroleum products and other refinery products) and gas; or
- as a consequence or by-product of undertaking specific activities, such as certain agricultural activities and industry processes (box 8.1).

Figure 8.5 Greenhouse gas emissions in the VURM5 database by broad Kyoto reporting category, 2005-06



[a] Million tonnes of carbon dioxide equivalent. [b] Negative emissions from forestry result from the sequestration of greenhouse gases through vegetation growth. [c] Other stationary emissions covers **emissions from, among other things, the combustion of fossil fuels used in refining petroleum, by the manufacturing, construction and commercial sectors, and that used in domestic heating**.

8.2.2 Policy capabilities

The greenhouse gas module has been developed with assessment of greenhouse gas emissions abatement policies in mind. As indicated above, it is capable of modelling policies that:

- levy a tax on some, or all, greenhouse gas emissions; or
- restrict the quantity of some, or all, greenhouse gas emissions (such as through an emissions trading scheme).

Both policies, either directly or indirectly, infer a 'price' on greenhouse gas emissions.

Box 8.1 Sources of greenhouse gas emissions modelled in VURM5

Greenhouse gas emissions occur from a range of sources.

Combustion emissions

- *Stationary energy*, which includes emissions from the combustion of fossil fuels used in:
  - generating electricity and refining petroleum;
  - manufacturing, construction and commercial sectors; and
  - other sources, such as domestic heating;
- *Transport*, which includes emissions from the combustion of fossil fuels used directly by road and rail transport, domestic air transport and domestic shipping;

Non-combustion emissions

- *Fugitive emissions*, which includes methane, carbon dioxide and nitrous oxide emitted in extracting, processing, transporting, storing and distributing raw fossil fuels (coal, oil and gas);
- *Industry processes*, which includes non-energy emissions from mineral processing, chemicals and metal production that usually arise from chemical reactions during manufacture (e.g. calcification during cement manufacture releases carbon dioxide);
- *Agriculture*, which includes methane and nitrous oxide emissions from soil, manure management, rice cultivation and livestock;
- *Waste*, which includes methane emissions from solid waste disposed in landfill and the treatment of domestic, commercial and industry wastewater; and
- *Land-use*, land-use change and forestry (LULUCF), which includes:
  - emissions from burning forests and the decaying of unburnt vegetation, and from soil disturbed during land clearing; and
  - reductions in emissions from the sequestration of greenhouse gases through vegetation growth.

The current implementation of VURM5 does not include emissions arising from:

- land use and land-use change (VURM5 includes emissions sequestered through forestry);
- agricultural soils; and
- the prescribed burning of savannahs.

Source: Adapted from Australian Government (2008, p. 8).

A tax on emissions or a tax equivalent arising from restricting the quantity of emissions can be easily introduced (or changed, if one already exists in the model database). Any pricing of emissions will drive economic behaviour in the model by altering costs of activities that produce greenhouse gases relative to those that do not. The cost minimising behaviour of producers and the utility maximising behaviour of consumers in the model give rise to behavioural responses that will affect the level and composition of economic activity and emissions. The introduction of a tax on emissions, for example, will increase the price of electricity generated from emissions-intensive fuels (such as the burning black or brown coal) relative to electricity generated from lower (or zero) emissions-intensive sources (such as hydroelectricity), thereby inducing a switch in demand towards electricity generated from the now relatively cheaper fuels.

If desired, industries can be modelled as being exempt from any tax on emissions or as receiving full or partial compensation. This may be done to 'shield' some producers from the full or partial effect of the tax (typically trade-exposed, emissions-intensive industries that compete internationally). Shielding or compensation can be modelled as cutting out after a pre-determined period of time or as being phased out over time.

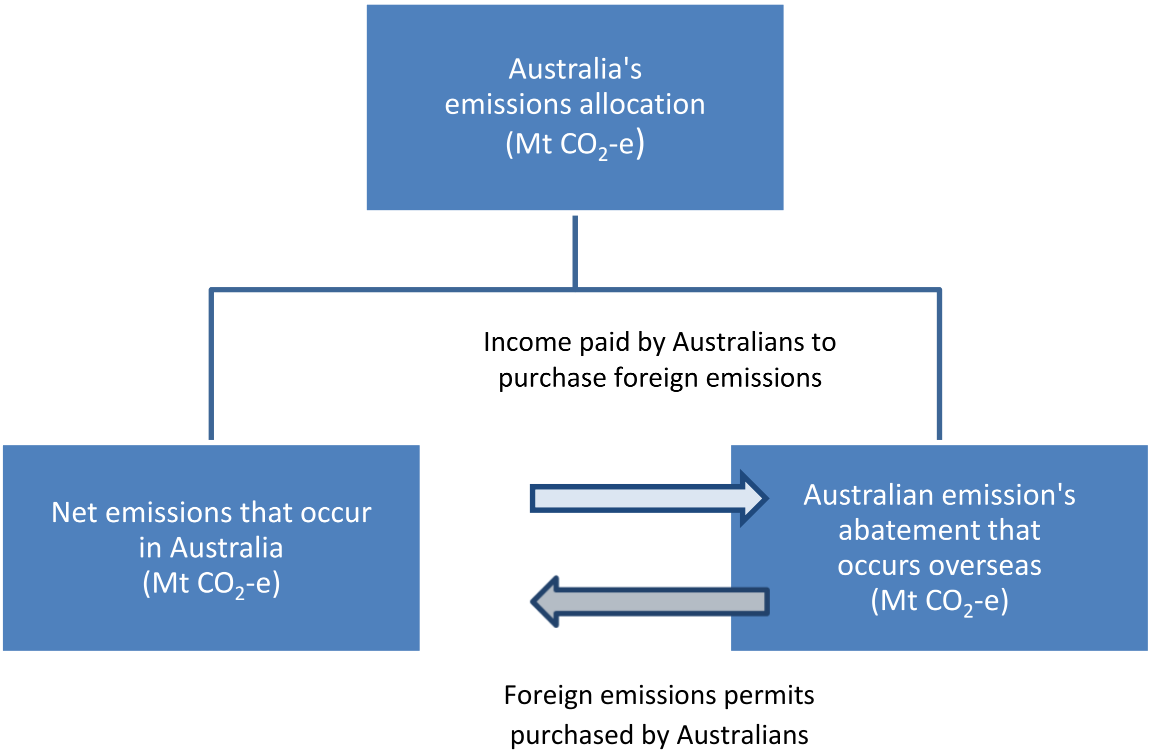
The pricing of emissions also provides producers and consumers with the economic incentive to switch towards less emissions-intensive technologies, thereby reducing the level of emissions per unit of production or consumption (that is, their emissions intensity).

The option exists to allow VURM5 to endogenously reduce the emissions intensity of economic activity in response to changes in the price of emissions through the use of 'marginal abatement curves' (often called 'MAC curves') (discussed in section 8.6.1). As the development, deployment and use of low-emissions technologies may not be costless, a resource cost to support the new technology can be imposed in VURM5. Such resource costs are modelled as a one-off cost increase.

VURM5 does allow for the possibility that an Australian emissions trading scheme may be linked into an international abatement scheme (discussed in section 8.4). This may mean that it could be cheaper for Australians to pay other countries to reduce their emissions rather than to reduce emissions in Australia, or for other countries to pay Australia to reduce its emissions if the converse occurs (figure 8.2). The resulting international trade in emissions permits is allowed to occur, up to a specified cap, in response to the relative cost of abatement in Australia (the price on emissions in Australia) compared to that overseas, where the cost of abatement overseas is represented by an 'international' price on emissions.

A wide range of other policies that target or impact on the abatement of greenhouse gas emissions can also be modelled in VURM5 by utilising and, if necessary, adapting the theory discussed in chapters 3 and 4. Such policies include mandatory renewable energy targets and specific taxes on the use of certain fuels or activities. The modelling of such policies may require changes to the model closure and, in some instances, the model code.

Figure 8.2 Modelling Australian involvement in an international emissions trading scheme[a]



[a] Assuming that Australia is a net purchaser of emissions permits overseas. If Australia is a net seller of emissions permits, the flows are in the opposite direction to that indicated. Whether Australia is a net buyer or seller of emissions permits in VURM5 depends on the price of Australian permits relative to the Australian dollar price of foreign permits.

8.2.3 Conceptual model

Emissions can be modelled from the quantity of each fossil fuel used (for combustion emissions) and the level of each relevant activity (for non-combustion emissions) by applying the appropriate emissions coefficient.[59] If Q denotes the physical quantity of a particular fossil fuel burnt (such as tonnes or litres) or activity undertaken (such as cubic metres of gas extracted or the number of sheep) and the corresponding emissions coefficient is C (tonnes of CO_2-e per tonne or litre of that fuel burnt or per unit of activity undertaken), CO_2-e emissions are:

$$E = C \times Q \qquad \text{(E8.1)}$$

A strength of this approach is that, in a stylised manner, it reflects the underlying chemistry giving rise to the emissions. This is a highly stylised version of the approach that all countries, including Australia, use in their reporting obligations under the Kyoto Protocol.

The percentage change form of equation (E8.1) is:

$$e = c + q \qquad \text{(E8.2)}$$

8.2.4 TABLO Implementation

The variable and coefficient names used in the TABLO implementation are also outlined in annex 8A.2 at the end of this chapter. These variable and coefficients generally span multiple dimensions, such as the fuels and activities giving rise to the emissions.

The main energy and greenhouse gas emission sets used in the TABLO implementation are set out in annex 8A.3 at the end of this chapter. As implemented in the model database:

- the set FUEL represents the fossil fuels that give rise to combustion emissions: coal; gas; petrol; and other refinery products; and
- the element “Activity” represents non-combustion emissions.

Together they cover all sources of greenhouse gas emissions in VURM5 (denoted by the set FUELX).

The industries, activities and sectors that give rise to these emissions are represented by the set FUELUSER. In the model database, the set consists of all 64 industries and households (termed “residential”). It is assumed that no fuels are used in investment and that no emissions arise from investment. As a result, there are 65 emitters in the VURM5 model database.

These sets are used in the TABLO implementation to give the coefficients and variables a high degree of dimensionality. For example, the coefficients for the level of emissions and *specific* emission tax rates (QGAS and ETAXRATE, respectively) have the dimensions source of greenhouse gas emissions (the set FUELX) by emitting sectors (the set FUELUSER) by region (the set REGDST). This means that

[59] The notation used in the conceptual models detailed in this and subsequent sections is set out in annex 4.2 at the end of this chapter. While not presented in the conceptual model, each variable discussed below can be thought of as representing a more detailed matrix (such as emissions by fuel type and industry). The additional dimensions that accompany each variable are included in the Tablo implementation.

each ‘coefficient’ corresponds to 2 600 different coefficients in the TABLO implementation (= 5 × 65 × 8).

All of the greenhouse-specific data for the emission module are contained on the physical file that corresponds to the file with the logical name GDATA (annex 8A.4 at the end of this chapter). The three main data items read are:

- the quantity of greenhouse gas emissions (the coefficient QGAS);
- the *specific* Australian tax rates on emissions (if any) (the coefficient ETAXRATE); and
- the price to which the *specific* tax rates are indexed, which is a scalar used to convert the tax rates into the price level prevailing in the current simulation year (the coefficient ENERINDEX).

The data items read in are discussed in the relevant sections to which they relate.

Equations

The first six equations determine the percentage change in CO_2-e emissions (the variable xgas):

- equations *E_xgasA*, *E_xgasB*, *E_xgasC* and *E_xgasD* cover industry emissions; and
- equations *E_xgasE* and *E_xgasF* cover household emissions.

Each equation determines elements of the variable xgas. xgas is also used to update the coefficient QGAS, which records the *level* of emissions expressed in kilo-tonnes (kt). The coefficient is read from header “QGAS” in the file GDATA.[60]

Percentage change in industry emissions (E_xgasA to E_actdriveC)

Emissions by industry and region are determined by four equations:

- Equation *E_xgasA* determines combustion emissions arising from the burning of coal;
- Equation *E_xgasB* determines combustion emissions arising from the burning of gas;
- Equation *E_xgasC* determines combustion emissions arising from the burning of petroleum products; and
- Equation *E_xgasD* determines non-combustion emissions.

The basic form of each equation is the same.

- The left-hand side denotes the percentage change by industry and region in emissions from that source (emissions from the burning of coal in the case of equation *E_xgasA*).
- The first term on the right-hand side denotes the percentage change in the corresponding quantity term that gives rise to those emissions (the driver of those emissions). In the case of equation *E_xgasA*, for example, the relevant quantity term is the percentage change in primary energy sourced from coal (the variable xprimen). This is equivalent to the variable q in equation (E8.2).
- The second term on the right-hand side denotes the percentage in per unit emissions (emissions intensity) and is equivalent to the variable c in equation (E8.2). The emissions-intensity term for coal, for example is agas(“Coal”,i,q). The emissions-intensity term is generally exogenous and can be shocked to introduce technical change

[60] In this chapter, GDATA refers to the file associated with the logical filename GDATA in the Tablo code. The physical file that corresponding to GDATA for VURM5 is gdatnew6pc2.har.

that affects the intensity of industry emissions. Note that the marginal abatement curves discussed in section 8.6.1 feed through into emissions via this emission-intensity term.

The details on each of these four equations are set out in table 8.1.

Emissions sequestered through forestry are modelled as being proportional to changes in output of the VURM5 industry forestry, which, in turn, is based on the ABS input-output industry of the same name. This approach uses the change in the value of forestry output as a proxy for the change in the quantity of logs harvested and, assuming that forestry is in a steady state, that the quantity of logs harvested proxies CO_2 sequestration.[61]

[61] Alternatively, as the amount of CO_2 sequestered from forestry in any given year is a function of tree growth occurring in plantations in that year, emissions sequestration could instead be modelled by treating forestry as an investment activity and by making emissions a function of the stock of investment in forestry. Pant (2010) implemented a version of this in the GTEM model after splitting the forestry industry into separate activities, including an investment component.

Table 8.1: Summary of the equations for determining emission by industry and region

Equation	*Purpose*	*Activity driver of emissions*	*Emissions intensity term*
E_xgasA	Percentage change in combustion emissions from the burning of coal by industry and region	***Initially:*** Percentage change in primary energy use [xprimen("Coal",i,q)] ***Ultimately:*** Percentage change in input use in current production [x1o("Coal",i,q)]	agas("Coal",i,q)
E_xgasB	Percentage change in combustion emissions from the burning of gas by industry and region	***Initially:*** Percentage change in primary energy use [xprimen("Gas",i,q)] ***Ultimately:*** Percentage change in input use in current production [x1o("Gas",i,q)]	agas("Gas",i,q)
E_xgasC	Percentage change in combustion emissions from the burning of each petroleum product[a] by industry and region	***Initially:*** Percentage change in final energy use [xfinalen(PETPROD,i,q)] ***Ultimately:*** Percentage change in input use in current production [x1o(PPETPROD,i,q)]	agas(PETPROD,i,q)
E_xgasD	Percentage change in non-combustion emissions by industry and region	***Initially:*** Percentage change in the activity variable driving non-combustion emissions [actdrive(,i,q)] ***Ultimately:*** Percentage change in: *Forestry* — land used in forestry in that region (the variable x1lnd in *E_actdriveA*) *Waste disposal*[b] — regional population (the variable pop in *E_actdriveB*) *All other industries* — the output of the emitting industry in that region (the variable x1tot in *E_actdriveC*)	agasact(i,q)

[a] The equation is defined over the set petroleum products (PETPROD in the TABLO code). In the model database, the set petroleum products consists of the elements: "Petrol" (Petroleum products); and "OthRefine" (Other refinery products). [b] The activity waste disposal is part of the VURM5 industry "Other services".

```
Coefficient (all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
QGAS(f,u,q) # Quantity of gas by fuel, user and use-state (kt) #;
Read QGAS from file GDATA header "QGAS";
Update (all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
QGAS(f,u,q) = xgas(f,u,q);

Equation E_xgasA # Percentage change in combustion emissions - coal #
(all,i,IND)(all,q,REGDST)
xgas("Coal",i,q) = xprimen("Coal",i,q) + agas("Coal",i,q);
```

```
Equation E_xgasB # Percentage change in combustion emissions - gas #
(all,i,IND)(all,q,REGDST)
xgas("Gas",i,q) = xprimen("Gas",i,q) + agas("Gas",i,q);

Equation E_xgasC
# Percentage change in combustion emissions - petrol products #
(all,p,PETPROD)(all,i,IND)(all,q,REGDST)
xgas(p,i,q) = xfinalen(p,i,q) + agas(p,i,q);

Equation E_actdriveA
# Activity variable driving non-combustion emissions - forestry #
(all,q,REGDST)
actdrive("Forestry",q) = x1lnd("Forestry",q);

Equation E_actdriveB
# Activity variable driving non-combustion emissions - waste disposal #
(all,q,REGDST)
actdrive("Other",q) = pop(q);

Equation E_actdriveC
# Activity variable driving non-combustion emissions - all other industries
#
(all,i,NOFORWASTE)(all,q,REGDST)
actdrive(i,q) = x1tot(i,q);

Equation E_xgasD
# Percentage change in non-combustion emissions - industry #
(all,i,IND)(all,q,REGDST)
xgas("Activity",i,q) = [actdrive(i,q) + agasact(i,q)];
```

Percentage change in household emissions (E_xgasE to E_xgasF)

Household emissions (labelled "residential" in the TABLO code) by region are determined by two equations:

- Equation *E_xgasE* determines the percentage change in household combustion emissions by region and fuel type. The quantity driver of household combustion emissions is the demand for each fuel by households from the core of the model (denoted by the variable x3o). The variable agas denotes the technical change in the intensity of household combustion emissions.

Equation *E_xgasF* determines the percentage change in household non-combustion emissions by region. The quantity driver of household non-combustion emissions is real household consumption spending in that region from the core of the model (denoted by the variable x3o).

The basic form of each household emissions equation is essentially the same as for industry emissions discussed previously. The left-hand side denotes the percentage change in emissions. The right-hand side contains the quantity driver of emissions and, in one of the two equations, technical change in the intensity of emissions.

```
Equation E_xgasE
# Percentage change in combustion emissions - households #
(all,f,FUEL)(all,q,REGDST)
xgas(f,"Residential",q) =
  x3o(f,q) + agas(f,"Residential",q);

Equation E_xgasF
# Percentage change in non-combustion emissions - households #
(all,q,REGDST)
xgas("Activity","Residential",q) = x3tot(q);
```

Changes in greenhouse gas emissions aggregates (E_xgas_q to E_d_xgas_fuq)

The key equations modelling the changes in greenhouse gas emissions aggregates are set out in table 8.2. At each level of aggregation, there are two equations:

- one determining the percentage change in emissions; and
- one determining the ordinary change in emissions (expressed in kt).

Each equation aggregates the percentage change in emissions by fuel, fueluser and region (the variable xgas) using the *level* of CO_2-e emissions as weights (the coefficient QGAS).

The suffix in each variable and equation name indicates the elements of xgas(f,u,q) that have been eliminated in aggregation. For example, the variable xgas_fuq denotes the percentage change in total emissions (that is, after eliminating the dimensions f, u and q).

Table 8.2: Summary of the key greenhouse gas emissions aggregates

Level of emissions	*Nature of aggregation*	*Percentage change equation*	*Ordinary change equation*
By fuel, fueluser and region	No aggregation	Discussed in previous section	E_d_xgas
By fuel and fueluser	Aggregated over region (q)	E_xgas_q	E_d_xgas_q
By region	Aggregated over fuel (f) and fueluser (u)	E_xgas_fu	E_d_xgas_fu
By fueluser	Aggregated over fuel (f) and region (q)	E_xgas_fq	E_d_xgas_fq
Total Australian emissions	Aggregated over fuel (f), fueluser (u) and region (q)	E_xgas_fuq	E_d_xgas_fuq

```
! Percentage change in emissions !
Equation E_xgas_q
# % Change in emissions by fuel and fueluser; that is, aggregated over q #
(all,f,FUELX)(all,u,FUELUSER)
ID01[sum{q,REGDST, QGAS(f,u,q)}]*xgas_q(f,u) =
  sum{q,REGDST, QGAS(f,u,q)*xgas(f,u,q)};
```

```
Equation E_xgas_fu
# % Change in emissions for each region; that is, aggregated over f and u #
(all,q,REGDST)
ID01[sum{f,FUELX,sum{u,FUELUSER, QGAS(f,u,q)}}]*xgas_fu(q) =
  sum{f,FUELX,sum{u,FUELUSER, QGAS(f,u,q)*xgas(f,u,q)}};

Equation E_xgas_fq
# % Change in emissions by fueluser; that is, aggregated over f and q #
(all,u,FUELUSER)
ID01[sum{f,FUELX,sum{q,REGDST, QGAS(f,u,q)}}]*xgas_fq(u) =
  sum{f,FUELX,sum{q,REGDST, QGAS(f,u,q)*xgas(f,u,q)}};

Equation E_xgas_fuq
# % Change in emissions for Australia; that is, aggregated over f, u and q
#
sum{f,FUELX,sum{u,FUELUSER,sum{q,REGDST, QGAS(f,u,q)}}}*xgas_fuq =
  sum{f,FUELX,sum{u,FUELUSER,sum{q,REGDST, QGAS(f,u,q)*xgas(f,u,q)}}};

! Ordinary change in emissions !
Equation E_d_xgas
# Change in emissions (kt) #
(all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
100*d_xgas(f,u,q) = QGAS(f,u,q)*xgas(f,u,q);

Equation E_d_xgas_q
# Change in emissions by fuel and fueluser (kt); that is, aggregated over q
#
(all,f,FUELX)(all,u,FUELUSER)
100*d_xgas_q(f,u) = sum{q,REGDST, QGAS(f,u,q)}*xgas_q(f,u);

Equation E_d_xgas_fu
# Change in emissions for each region (kt); that is, aggregated over f and
u #
(all,q,REGDST)
100*d_xgas_fu(q) = sum{f,FUELX,sum{u,FUELUSER, QGAS(f,u,q)}}*xgas_fu(q);

Equation E_d_xgas_fq
# Change in emissions by fueluser (kt); that is, aggregated over f and q #
(all,u,FUELUSER)
100*d_xgas_fq(u) = sum{f,FUELX,sum{q,REGDST, QGAS(f,u,q)}}*xgas_fq(u);

Equation E_d_xgas_fuq
# Change in emissions for Australia (kt); that is, aggregated over f, u and
q #
100*d_xgas_fuq =
  sum{f,FUELX,sum{u,FUELUSER,sum{q,REGDST, QGAS(f,u,q)}}}*xgas_fuq;
```

8.3 Modelling policies for mitigation

Policies that tax or restrict the quantity of greenhouse gas emissions, either directly or indirectly, infer a 'price' on greenhouse gas emissions.

8.3.1 Conceptual model

It is initially assumed that Australia independently puts a price on domestic emissions of CO_2-e and, if an emissions trading scheme being modelled, that there is no international trade in emissions permits. These assumptions will be relaxed later.

Although the price of emissions in VURM5 can vary across greenhouse gas emitting activities, greenhouse gas emitters and regions, the remainder of this chapter is couched in terms of a single price on greenhouse gas emissions. The discussion can easily be generalised to include differential emission prices (or no price).

The price on CO_2-e emissions added to VURM5 is defined as a *specific* tax (T) expressed in terms of \$000 per tonne of CO_2-e.[62] Such a tax would raise revenue equal to:

$$R = T \times E \qquad \text{(E8.3)}$$

The *specific* tax rate (T) in VURM5 is expressed in terms of some base year dollars (say 2009-10 dollars). To allow for changes in prices over time, the specific tax rate is re-indexed to the prices prevailing in the current simulation year by multiplying it by an index of prices in the current year relative to the base year of the tax (I). This effectively makes the *specific* tax rate in the current simulation year T × I.

Thus, the *specific* tax on a given quantum of emissions in the current simulation year (E) would raise revenue (R) equal to:

$$R = T \times I \times E \qquad \text{(E8.4)}$$

The ordinary change in the revenue raised from the *specific* tax on emissions, corresponding to equation (E8.4), is:

$$dR = T \times E \times I \times (t + e + i) / 100$$

$$= T \times E \times I \times t / 100 + T \times E \times I \times (e + i) / 100$$

$$= E \times I \times dT + R / 100 \times (e + i) \qquad \text{(E8.5)}$$

Rather than modelling the *specific* tax directly, VURM5 models the tax on emissions in terms of an *ad valorem* equivalent tax that can be linked to the value of economic activity to align with the economic data on the structure of the Australian economy in the ABS *Input-Output Tables* and contained in the model database. The *ad valorem* equivalent tax (V) is defined as a proportional tax on the value of economic activity that raises the same amount of revenue as the *specific* tax T.

While superficially appearing quite different, this approach of linking into the underlying value of economic activity is equivalent to the conceptual model outlined above.

[62] The *specific* tax is expressed in terms of \$000 per tonne of CO_2-e to align with the price and quantity data in the model database. Nominal values are expressed in A\$ million and the quantity of emissions in kt CO_2-e. Dividing the former by the latter gives A\$000 per tonne of CO_2-e.

First, the level of emissions can be recast so that it is a function of the underlying value of economic activity. This involves introducing the nominal value of output (Y) into equation (E8.1):

$$E = C \times Q \times \frac{Y}{Y} = \frac{C \times Q}{Y} \times Y = \varepsilon \times Y \qquad \text{(E8.6)}$$

where:

$\varepsilon = \frac{C \times Q}{Y}$ is the emissions intensity of the value of output with respect to the fossil fuel giving rise to those emissions.

The value of economic activity is equal to:

$$Y = P \times Q \qquad \text{(E8.7)}$$

where:

P is the unit price of output from the relevant economic activity in the model core; and

Q is the quantity of output from the relevant economic activity in the model core.

The *ad valorem* equivalent tax rate is calculated as:

$$V = R / Y \times 100 \qquad \text{(E8.8)}$$

Re-arranging equation (E8.8) gives:

$$R = V / 100 \times Y \qquad \text{(E8.9)}$$

Substituting equation (E8.7) in equation (E8.9) gives:

$$R = V / 100 \times P \times Q \qquad \text{(E8.10)}$$

Setting equation (E8.10) equal to equation (E8.4) gives:

$$V / 100 \times P \times Q = T \times E \times I$$

Re-arranging this gives the ratio of the *ad valorem* equivalent tax rate to its *specific tax* counterpart:

$$\frac{V}{T} = \frac{E \times I}{P \times Q} \times 100 \qquad \text{(E8.11)}$$

VURM5 makes frequent use of the propensity to emit CO_2-e, the ratio $\frac{E \times I}{P \times Q}$, to convert from a *specific* to an *ad valorem* equivalent tax on emissions. It is the indexed value of emissions as a share of the *ad valorem* tax base.

Re-arranging equation (E8.11) gives:

$$V = T \times \frac{E \times I}{P \times Q} \times 100 \qquad \text{(E8.12)}$$

The ordinary change in the *ad valorem* equivalent tax rate on emissions is:

$$dV = \left\{T \times d\,\frac{E \times I}{P \times Q} + \frac{E \times I}{P \times Q} \times dT\right\} \times 100$$

$$dV = \left\{T \times \frac{E \times I}{P \times Q} \times \frac{[e + i - p - q]}{100} + \frac{E \times I}{P \times Q} \times dT\right\} \times 100$$

$$dV = \frac{E \times I}{P \times Q} \times \{T \times [e + i - p - q] + 100 \times dT\} \qquad \text{(E8.13)}$$

In this framework, a tax on emissions can be modelled by specifying the *specific* tax rate T (setting it exogenous and shocking it) and allowing the quantity of emissions E to be determined. Alternatively, an emissions trading scheme can be modelled by determining the quantity of emissions E (setting it exogenous and shocking it) and allowing the *specific* tax rate T to be determined.

8.3.2 TABLO implementation

The modelling expresses the *specific* and *ad valorem* equivalent tax rates in ordinary change form to avoid problems when the initial value is zero (dT and dV in the notation above).

The price to which the emissions tax is indexed (the variable I in section 8.3.1) is denoted by the coefficient ENERINDEX in the TABLO implementation. It the ratio of the level of prices in the current simulation year (say, 2011) to those in the year in which the tax is specified (say, 2006 in this example) and is included in the model to preserve homogeneity in prices. The coefficient is updated using the percentage change in the national consumer price index (natp3tot).

The core of VURM5 supplies the values for $P \times Q$, which are:

(1) for goods in the set FUEL, the basic value of use (the coefficient V1BAS); and

(2) for the element "Activity", the value of output for industries (the coefficient COSTS), or the total value of consumption for households (the coefficient V3TOT).

The model core also supplies the values for p and q.

Emissions tax rates

It is assumed that emission taxes in VURM5 are levied by the 'Federal' (Australian) Government.

Change in the specific tax rate on emissions (E_d_gastax)

Equation *E_d_gastax* determines the change in the *specific* tax rate on emissions. The change in the *specific* tax rate (d_gastax) has the dimensions:

- source of emissions (the set FUELX);
- emitting sector (the set FUELUSER); and
- region (the set REGDST).

As dimensioned in the model database, this gives rise to 2 600 different *specific* tax rates on emissions. This dimensionality allows considerable flexibility in tailoring emission abatement policies to particular source of emissions, emitting sectors and/or regions.

Equation *E_d_gastax* enables a single shock to the variable d_gastaxdom to be applied across all endogenous components of d_gastax. The equation can be turned on by making the shift term d_fgastax exogenous and setting it to zero, or turned off by making it endogenous.

Equation *E_d_gastax* also allows the level of the tax rates to be equalised across each category of FUELUSER by setting the relevant element of d_CrunchUSR to one. This sets the tax rate in each industry to the tax rate in the industry specified in the TABLO code, which is arbitrarily set to the printing industry. The choice of target industry can be changed by changing the element specified in the TABLO code and re-compiling the model.

The *specific* tax rate on emissions in the simulation year feeds, through the intermediate variables d_t1Fgas and d_t3Fgas, into the equations in the model core that specify the percentage point changes in the *ad valorem* tax rate on production and on household consumption (d_t1F and d_t3F, respectively).

The variable d_gastax updates the coefficient ETAXRATE, which denotes the *level* of the *specific* tax rate and corresponds to the variable T in the conceptual model outlined above.

```
Coefficient  (all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
ETAXRATE(f,u,q) # Specific tax rate on CO2-e emissions (A$000 per tonne) #;
Read ETAXRATE from file GDATA header "ETXR";
Update  (change)(all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
ETAXRATE(f,u,q) = d_gastax(f,u,q);

Equation E_d_gastax
# Change in the specific tax rate on CO2-e emissions (A$000 per tonne) #
(all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
d_gastax(f,u,q) = d_gastaxdom +
(ETAXRATE@1(f,"Printing",q) - ETAXRATE@1(f,u,q))*d_CrunchUSR(u) +
  d_fgastax(f,u,q);
```

Percentage point change in the ad valorem equivalent tax rate on fuels used in production (E_d_t1Fgas to E_p0a_s)

Equation *E_d_t1Fgas* converts the ordinary change in the *specific* tax rate (d_gastax) into the percentage point change in the *ad valorem* equivalent tax rate on production (d_t1Fgas). This conversion is needed to feed the tax on emissions into the existing taxes in the model core. This formulation of the equation is based on equation (E8.13) above.

The equation applies to the use of fossil fuels (designated by the set FUEL) in production. The percentage point change in the *ad valorem* equivalent tax rate is expressed in terms of the basic values of those fuels used in production.

Equation *E_p0a_s* maps the percentage change in the domestic basic price of each commodity paid by industry users (p0a) from source region to destination region and industry (p0a_s). It does so using purchasers' price values as weights (the coefficient V1PURA). This equation supports equation *E_d_t1Fgas*.

```
Equation E_d_t1Fgas
# Ad Valorem (%) equivalent of specific fuel tax rate, user 1 #
(all,c,FUEL)(all,i,IND)(all,q,REGDST)
d_t1Fgas(c,i,q) = EIoverPQ(c,i,q)*{
 ETAXRATE(c,i,q)*[xgas(c,i,q) + gastaxindex - p0a_s(c,i,q) - x1o(c,i,q)] +
             100*d_gastax(c,i,q)};

Equation E_p0a_s # Basic price of good c used by industry i in region q#
(all,c,COM)(all,i,IND)(all,q,REGDST)
ID01[sum{s,ALLSRC, V1PURA(c,s,i,q)}]*p0a_s(c,i,q) =
  sum{s,ALLSRC, V1PURA(c,s,i,q)*p0a(c,s)};
```

8.3.2.1.1 Percentage point change in the ad valorem equivalent tax rate on fuels used for consumption (E_d_t3Fgas to p3a_s)

Equation *E_d_t3Fgas*, which is analogous to equation *E_d_t1Fgas*, converts the ordinary change in the *specific* tax rate (d_gastax) into the percentage point change in the *ad valorem* equivalent tax rate on household consumption (d_t3Fgas). This conversion is needed to feed the tax on emissions into the existing taxes in the model core. This formulation of the equation is based on equation (E8.13) above.

The equation applies to the "residential" component of the set FUELUSER. The percentage point change in the *ad valorem* equivalent tax rate is expressed in terms of the basic values of those fuels used in production.

Equation *E_p3a_s* maps the percentage change in the domestic basic price of each commodity paid by household users (p3a) from source region to destination region (p3a_s). It does so using purchasers' price values as weights (the coefficient V3PURA). This equation supports equation *E_d_t3Fgas*.

```
Equation E_d_t3Fgas
# Ad Valorem (%) equivalent of specific fuel tax rate user 3 #
(all,c,FUEL)(all,q,REGDST)
d_t3Fgas(c,q) = EIoverPQ(c,"Residential",q)*{
 ETAXRATE(c,"Residential",q)*
    [xgas(c,"Residential",q) + gastaxindex - p3a_s(c,q) - x3o(c,q)] +
              100*d_gastax(c,"Residential",q)};

Equation E_p3a_s # Basic price of good c used by households in region q #
(all,c,COM)(all,q,REGDST)
ID01[sum{s,ALLSRC, V3PURA(c,s,q)}]*p3a_s(c,q) =
  sum{s,ALLSRC, V3PURA(c,s,q)*p0a(c,s)};
```

Percentage point change in the ad valorem equivalent tax rates on non-combustion emissions (E_d_indtax to E_d_tFgascs)

Two equations map the *specific* taxes on non-combustion emissions into the existing taxes in the model core.

- Equation *E_d_indtax* converts the ordinary change in the *specific* tax rate on non-combustion emissions (d_gastax("Activity",i,q)) by industry emitters (the set IND) into the percentage point change in the *ad valorem* equivalent tax rate for each regional industry. The structure of the equations is similar to that of *E_d_t1Fgas*, but where the percentage change in the *ad valorem* equivalent tax base is determined by the basic value of industry output, excluding any additional returns from export sales (p1cost and x1tot).
- Equation *E_d_tFgascs* converts the percentage point change in the *ad valorem* equivalent tax rate by regional industry (d_indtax) to a commodity and source-based tax (d_tFgascs). This ensures that the tax on commodity c is equivalent to the value of the tax on the output of industry i. This mapping is needed because all of the indirect taxes in the model core are taxes on the flows of commodities.

On the right-hand side of *E_d_tFgascs*, ISDOM(s) is a dummy coefficient that is equals to one when s is a domestic source, and zero otherwise. The mapping is based on the share of commodity c produced by industry i in the region corresponding to the value of the index s. The operator SOURCE2DEST(s) maps the value by domestic source region to destination region. It does not include the value of foreign imports, which is also an element of the set denoting all source regions

(ALLSRC). The percentage point change in the sales tax rate on imported commodities (d_tFgascs) is, consequently, zero.

```
Equation E_d_indtax # %-Point change in the ad valorem tax rate on all
sales by industry i & q #;
(all,i,IND)(all,q,REGDST)
d_indtax(i,q) = EIoverPZ(i,q)*{ETAXRATE("Activity",i,q)*
    [xgas("Activity",i,q) + gastaxindex - p1cost(i,q) - x1tot(i,q)] +
              100*d_gastax("Activity",i,q)};

Coefficient (all,s,ALLSRC)
ISDOM(s) # = 1 If source of input is domestic, =0 otherwise #;
Formula (all,s,REGSRC)
ISDOM(s) = 1;
ISDOM("imp") = 0;

Equation E_d_tFgascs
# %-Point change in sales tax rate, by commodity & source region #
(all,c,COM)(all,s,ALLSRC)
(TINY + MAKE_I(c,SOURCE2DEST(s)))*d_tFgascs(c,s) =
  ISDOM(s)*sum{i,IND, MAKE(c,i,SOURCE2DEST(s))*d_indtax(i,SOURCE2DEST(s))};
```

Emissions tax revenue

Change in federal government emissions tax revenue by region of collection (E_d_etaxrev)

Equation *E_d_etaxrev* calculates the change in federal government revenue from the taxation of emissions by source region. It is based the right-hand side of equation (E8.5), summed over the set of sources of greenhouse gases (FUELX) and the set of emitters that give rise to greenhouse gas emissions (FUELUSER). For an emissions trading scheme, the tax revenue collected represents the value of domestic permits issued.

The equivalent of variable d_etaxrev is used to update the coefficient ETAX, which denotes the *level* of revenue raised by the federal government from the taxation of greenhouse gas emissions.

```
Coefficient (all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
ETAX(f,u,q) # Revenue from the emissions tax (A$ million) #;
Read ETAX from file GDATA header "ETAX";
Update (change)(all,f,FUELX)(all,u,FUELUSER)(all,q,REGDST)
ETAX(f,u,q)= QGAS(f,u,q)*ENERINDEX*d_gastax(f,u,q) +
                  ETAX(f,u,q)/100*[xgas(f,u,q) + gastaxindex];

Equation E_d_etaxrev
# Change in revenue from the emissions tax by region (A$ million)#
(all,q,REGDST)
d_etaxrev(q) = sum{f,FUELX,sum {u,FUELUSER,
  QGAS(f,u,q)*ENERINDEX*d_gastax(f,u,q) +
      ETAX(f,u,q)/100*[xgas(f,u,q) + gastaxindex]}};
```

8.3.2.1.2 Change in total federal government emissions tax revenue (E_d_natetaxrev)

Equation *E_d_natetaxrev* calculates the total change in revenue from the taxation of greenhouse gas emissions. It is calculated as the sum of the changes in tax revenue by region of collection.

```
Equation E_d_natetaxrev
# Change in total revenue from the emissions tax (A$ million) #
d_natetaxrev = sum{q,REGDST, d_etaxrev(q)};
```

8.4 Modelling Australian involvement in an international emissions trading scheme

Now we allow Australian involvement in an international emissions trading scheme.[63] This module relaxes the assumptions that Australia independently taxes CO_2-e emissions and that there is no trade in emissions permits. Figure 8.2 provides a stylised representation of the way that Australian involvement in an international emissions trading scheme is modelled in VURM5.

As modelled, Australia is allocated a fixed quantity of emission permits in each simulation year under an international emissions trading scheme. Australian emitters can change the nature of their operations to avoid producing emissions and the need to purchase emissions permits. If they don't, Australian emitters are required to purchase an emissions permit for each unit of CO_2-e occurring in the simulation year. These emissions permits can be purchased from:

- within Australia at the Australian domestic permit price; or
- from overseas at the prevailing world price (up to some specified limit).

Australian permit holders can also sell Australian permits overseas at the prevailing world price (again up to some specified limit). The relative price of Australian and foreign permits (expressed in Australian dollars) determines whether Australia is a net buyer or seller of emissions permits in VURM5. Australia is assumed to be a net buyer of permits if the Australian dollar price of foreign permits is less than the domestic permit price, and a net seller if the converse occurs.

There will also be a flow of income in the opposite direction to the international flow of permits. There will be transfer of income out of Australia if Australia buys permits internationally and into Australia if the converse occurs. This income is assumed in VURM5 to come from, or feed into, the household income account. This flow, in turn, feeds into the income account of the balance of payments and into gross national product.

8.4.1 Conceptual model

Assume initially that there is no limit on the amount of abatement that Australians can purchase overseas or limit on the number of permits that Australians can sell overseas. Also assume that all permits must be used in the year in which they are issued, such that there is no inter-temporal banking or borrowing of permits.

Given the equivalence between an emissions trading scheme and a direct price on emissions, the *specific* emissions tax outlined in section 8.3.1 is equivalent to the cost of purchasing an Australian emissions permit for a given pre-determined level of emissions.

[63] An international emissions trading scheme is often referred to as a 'global ETS' in the Tablo code.

Let F denote the cost of a foreign emissions permit in foreign currency units. Indexing this price to adjust for price changes through time price index makes the effective foreign currency permit price $\mathrm{F} \times \mathrm{I}$.

The cost of a foreign emissions permit in Australian dollars (Υ) is:

$$\Upsilon = \mathrm{F} \times \mathrm{I} \times \Phi \qquad \text{(E8.14)}$$

where:

F is the foreign currency price of a foreign emissions permit (the foreign-equivalent of the *specific* price on domestic emissions) in the simulation year;

I is an index of prices in the current year relative to the base year of the tax; and

Φ is the nominal exchange rate (expressed as domestic currency per unit of foreign currency).

It will be rational for Australian emitters subject to the emissions trading scheme to reduce their emissions if their marginal cost of abating emission is less than the cost of purchasing an emissions permit. If not, it will be cheaper for the Australian emitter to purchase an emissions permit than to abate emissions. It will be rational to purchase an Australian permit if the Australian permit price is less than the overseas price in Australian dollars, or from overseas if the converse occurs. The absence of restrictions on international trade in permits means that arbitrage between permit buyers and sellers should ensure that the cost of Australian and overseas emissions permits (expressed in Australian dollars) are the same.

The change in the price of a foreign emissions permit in Australian dollars ($d\Upsilon$) is:

$$d\Upsilon = \mathrm{F} \times \mathrm{I} \times \Phi \times \{\mathrm{f} + \mathrm{i} + \varphi\} / 100$$

$$d\Upsilon = \mathrm{F} \times \mathrm{I} \times \Phi \times \frac{\mathrm{f}}{100} + \mathrm{F} \times \mathrm{I} \times \Phi \times \left\{\frac{\mathrm{i}}{100} + \frac{\varphi}{100}\right\}$$

$$d\Upsilon = \mathrm{I} \times \Phi \times \mathrm{dF} + \frac{\mathrm{F} \times \mathrm{I} \times \Phi}{100} \times \{\mathrm{i} + \varphi\} \qquad \text{(E8.15)}$$

where:

df is the change in the foreign currency price of a foreign emissions permit in the simulation year;

i is the percentage change in the price index; and

φ is the percentage change in the nominal exchange rate.

If Australia's allocation of permits under the emissions trading scheme is E^{T}, Australia will be a net seller of permits if the cost of abatement in Australia is less than that overseas (when $\mathrm{T} < \Upsilon$) and a net importer otherwise (when $\mathrm{T} > \Upsilon$).

The number of Australian emissions permits sold overseas (E^{F}) is equal to:

$$\mathrm{E}^{\mathrm{F}} = \mathrm{E}^{\mathrm{T}} - \mathrm{E} \qquad \text{(E8.16)}$$

where:

E^{T} is Australia's allocation of permits under the emissions trading scheme; and

E is the quantity of CO_2-e emissions occurring in Australia.

The income flow of this export of permits (Y) is equal to the number of Australian emissions permits sold overseas (E^{F}) multiplied by the Australian dollar price of those permits (Υ):

$$Y = E^F \times \Upsilon = E^F \times F \times I \times \Phi \qquad (E8.17)$$

The change in income flow of this export of permits (dY) is equal to:

$$dY = E^F \times F \times I \times \Phi \times \{e^f + f + i + \varphi\} / 100$$

$$dY = \left[E^F \times F \times I \times \Phi \times \frac{e^f}{100}\right] + \left[E^F \times F \times I \times \Phi \times \frac{f}{100}\right] + \left[E^F \times F \times I \times \Phi \times \frac{\{i + \varphi\}}{100}\right]$$

$$dY = [F \times I \times \Phi \times dE^f] + [E^F \times I \times \Phi \times dF] + \left[E^F \times F \times I \times \Phi \times \frac{\{i + \varphi\}}{100}\right] \qquad (E8.18)$$

where:

dE^f is the change in the number of Australian emissions permits sold overseas.

8.4.2 TABLO implementation

Linking the change in the domestic permit price to the change in the international permit price (E_d_gastaxdom)

Equation *E_d_gastaxdom* links the change in the domestic permit price (d_gastaxdom) to the change in the international permit price expressed in foreign currency units (d_gastaxfor), assuming that there is no restriction on international permit trade. The formulation of the equation implemented is based on equation (E8.15). The equation can be activated by making d_fgastaxdom exogenous and setting it to zero, and d_gastaxdom endogenous.

The change in the domestic price of an emissions permit is a function of:

- the level and ordinary change in the foreign currency permit price (GASTAXFOR and d_gastaxfor, respectively);
- the level and percentage change in the nominal exchange rate (LEVPHI and phi, respectively); and
- the level and percentage change in the price index (ENERINDEX and gastaxindex, respectively).

The equation also allows for the Australian dollar price of domestic and foreign permits (in *level* terms) to be equated in a simulation year by setting the variable d_CrunchETS equal to one.

```
Variable (levels, change, Linear_VAR = d_gastaxfor)
GASTAXFOR
# Foreign-currency global price of permits (per tonne of CO2-e) #;
Read GASTAXFOR from file GDATA header "GTXF";

Equation E_d_gastaxdom
# Change in foreign-currency global price of permits #
d_gastaxdom =
    ENERINDEX*LEVPHI*d_gastaxfor +
    GASTAXFOR*ENERINDEX*LEVPHI/100*{gastaxindex + phi} +
    (GASTAXFOR@1 - GASTAXDOM@1)*d_CrunchETS + d_fgastaxdom;
```

Restricting the amount of abatement that can be undertaken overseas and international permit trade (E_d_qgasfor to E_d_domemm)

Equation *E_d_qgasfor* determines the change in Australian exports of emissions permits under an international emissions trading scheme. It can be:

- turned on, by making d_fqgasfor exogenous and setting it to zero, and d_qgasfor endogenous, so that the model determines changes in international permit trade; and
- turned off, by making d_qgasfor exogenous and setting it to zero, and d_fqgasfor endogenous, so that the change in international permit trade is fixed, either at the initial level if d_qgasfor is not shocked or at the level implied by the shock if d_qgasfor is shocked.

The variable d_qgasfor is:

- positive when Australia exports additional emissions permits overseas (or imports less foreign permits); and
- negative when Australian imports additional foreign emissions permits (or exports less Australian permits).

Whether Australia exports or imports emissions permits will depend on:

- the number of emissions permits allocated to Australia under the international trading scheme (the levels variable FOREMM);
- CO_2-e emissions occurring in Australia (the levels variable DOMEMM); and
- the relative price of emissions permits in Australia and overseas (expressed in Australian dollars).

Initially, this will be determined by the respective values in the model database. Australia will export emissions permits if FOREMM > DOMEMM, and import them if the converse occurs.

If the price of an emissions permit in Australia is less than it is overseas (that is, if GASTAXDOM < GASTAXFOR), Australia is financially better exporting its permits overseas and reducing domestic emissions. Conversely, if the price of an emissions permit in Australia is higher than it is overseas (that is, if GASTAXDOM < GASTAXFOR), Australia is financially better off by importing foreign emissions permits (purchasing abatement overseas), as they cost less than reducing domestic emissions.

Assuming that Australian and foreign emissions permits are perfectly substitutable, arbitrage should ensure that the price of emissions permits in Australia equals the overseas (in Australian dollars) in the absence of any restrictions on permit trade. While international trade in emissions permits may be economically efficient, unrestricted trade may not be desirable. Similarly, the presence of transaction and other costs may mean that Australian and foreign emissions permits are imperfect substitutes.

VURM5 also allows trade in permits up to some pre-determined limit (specified by the levels variable LIMIMPMAX). If the constraint on trade is binding or Australian and foreign emissions permits are imperfect substitutes, the Australian permit price will differ from the foreign permit price.

The direction, quantity and price of international permits trade is a function of:

- the relative price of Australia and foreign emissions permits (both expressed in Australian dollars);
- whether there is a binding constraint on international permit trade; and
- the degree of substitutability between Australian and foreign emissions permits.

The parameter SIGMAGHGEXP controls the degree of substitutability between domestic and foreign permits. A value of 1 indicates that, if the price of Australian permits is one per cent higher than the foreign permit price (expressed in Australian dollars), Australia exports one per cent less foreign permits (or imports one per cent more foreign permits). A value of 0 indicates no substitutability between Australian and foreign permits and a value of 300 approximates perfect substitution.

The modelling of the relationships between the relative price of Australia and foreign emissions permits and whether the constraint, if any, on international permit trade is binding; are set out in table 8.#.

To allow for the possibility of constrained and unconstrained trade in emissions permits, Australian exports of emissions permits under an international emissions trading scheme will be:

- QGASFOR = FOREMM – DOMEMM, if the constraint on emissions permit trade is not binding [based on equation (E8.16)]; or
- QGASFOR = LIMIMPMAX, if the constraint on emissions permit trade is binding.

The conditionals in the formula that determines QGASFOR. If Australia exports emissions permits, this equates to:

QGASFOR = MIN(FOREMM – DOMEMM, LIMIMPMAX)

If Australia imports emissions permits, this equates to:

QGASFOR = MAX(FOREMM – DOMEMM, -LIMIMPMAX)

This can be simplified by introducing a coefficient, ISPERMITEXP, that takes on a value of +1 when Australia exports permits, -1 when Australia imports permits and 0 otherwise:

QGASFOR = MIN(FOREMM – DOMEMM, ISPERMITEXP*LIMIMPMAX)

and as all of these terms are levels variables in the Tablo implementation, the levels variable QGASFOR is determined by a formula (and not an equation).

Equation *E_gastaxfor* determines the change in the quantity of permits traded internationally (d_qgasfor). The change in the quantity of permits traded internationally is determined as:

- the change in Australia's net allocation of emission permits under the international trading scheme (d_foremm); less
- the change in the quantity of the CO_2-e emissions occurring in Australia (d_domemm); less
- the change in maximum number of imported emissions permits that Australia can use (d_LIMIMP); plus
- the change in the *maximum* number of imported emissions permits that Australia can use to achieve its emissions abatement target (d_LIMIMPMAX) are specified exogenously.

The level of Australian international permit trade (the levels variable QGASFOR) is derived using is derived using variables FOREMM is equivalent to E^{T} in the conceptual model outlined above. It is read in from header "QGSF" in the file GDATA and updated using the variable d_FOREMM.

Australia's net allocation of emission permits under the international trading scheme (FOREMM) and the quantity of the Australian emissions covered by the scheme (DOMEMM) are also read in from the file GDATA (headers "QGSF" and "QGSD", respectively) and updated using their corresponding ordinary change variables (d_FOREMM and d_DOMEMM, respectively). The quantity of net foreign permit sales (QGASFOR) is derived as the difference between these two measures at the start of the simulation year.

The linear variable LIMIMPMAX represents the *maximum* number of imported emissions permits that Australia can use to achieve its emissions abatement target (that is, the maximum amount of Australian emissions abatement that can be undertaken overseas). It is read in from the header "LMMM" on the file GDATA and updated using the corresponding exogenous ordinary change variable d_LIMIMPMAX. Changes in the *maximum* number of imported emissions permits that Australia can use to achieve its emissions abatement target can be introduced by shocking d_LIMIMPMAX.

Australia's net allocation of emission permits under the international trading scheme (FOREMM) and the quantity of the Australian emissions covered by the scheme (DOMEMM) are also read in from the file GDATA (headers "QGSF" and "QGSD", respectively) and updated using their corresponding ordinary change variables (d_FOREMM and d_DOMEMM, respectively). The quantity of net foreign permit sales (QGASFOR) is derived as the difference between these two measures at the start of the simulation year.

The limit on the number of imported emissions permits that Australia can use (emissions abatement that can occur overseas) is specified by the coefficient LIMIMP, which is calculated at the start of each simulation year as the difference between Australia's greenhouse gas emissions (QGAS) and its emissions net of the limit on international permit trade (DOMEMM).

All of these quantity measures are expressed in kt CO_2-e.

Equation *E_domemm* determines the change in the quantity of the emissions occurring in Australia under the international emissions trading scheme (d_domemm).

Equation *E_d_gastaxfor* determines the change in the net foreign sales of Australian emissions permits occurring in Australia under the international emissions trading scheme (d_domemm).

The changes in Australia's net allocation of emission permits under the international trading scheme (d_FOREMM), the limit on the number of imported emissions permits that Australia can use (d_LIMIMP) and the *maximum* number of imported emissions permits that Australia can use to achieve its emissions abatement target (d_LIMIMPMAX) are specified exogenously.

Given this and the change in Australian emissions (d_xgas):

- equation *E_d_domemm* determines the change in emissions that has to occur in Australia (d_domemm); and
- equation *E_d_gastaxfor* determines the change in international permit sales (d_qgasfor).

```
Variable (levels, change, Linear_VAR = d_foremm)
FOREMM # Australia's net allocation of emissions (kt of CO2-e) #;
Read FOREMM from file GDATA header "QGSF";

Formula (initial) # Quantity of net foreign sales of permits #
QGASFOR = FOREMM - DOMEMM;

Formula (initial) # Number of limited imported permits #
LIMIMP = sum{f,FUELX,sum{u,FUELUSER,sum{q,REGDST, QGAS(f,u,q)}}} - DOMEMM;

Variable (levels, change, Linear_VAR = d_LIMIMPMAX)
LIMIMPMAX # Maximum number of limited imported permits #;
Read LIMIMPMAX from file GDATA header "LMMM";

Equation E_d_domemm
# Change in Australia's emissions net of d_LIMIMP (kt CO2-e) #
d_domemm + d_LIMIMP =
  sum{f,FUELX,sum{u,FUELUSER,sum{q,REGDST, d_xgas(f,u,q)}}};

Equation E_d_qgasfor
# Change in quantity of net foreign sales of permits (kt) #
d_qgasfor = {d_foremm - d_domemm} - d_LIMIMP +
  !To remove an annoying warning!0*d_LIMIMPMAX;
```

Change in the income from net permit sales (E_d_gasincfor to E_d_foretsinc)

Equation *E_d_gasincfor* determines the change in the flow of income into (out of) Australia from the export (import) of emissions permits (d_gasincfor). The equation implemented is based on equation (E8.18).

The flow of income always occurs in the opposite direction to the flow of permits traded internationally. Therefore, d_gasincfor takes on a takes on:

- a positive value when Australia sells permits overseas (exports permits); and
- a negative value when Australia buys permits overseas (imports permits).

The equation is also a function of:

- the level and ordinary change in the quantity of Australian emission permits sold overseas (QGASTAXFOR and d_qgasfor, respectively);
- the level and ordinary change in the foreign currency permit price (GASTAXFOR and d_gastaxfor, respectively);
- the level and percentage change in the nominal exchange rate (LEVPHI and phi, respectively); and
- the level and percentage change in the price index (ENERINDEX and gastaxindex, respectively).

The variable d_gasincfor is used to update the linear levels variable GASINCFOR, which denotes the *level* income that Australia receives from the sale of emissions permits overseas.

```
Variable (levels, change, Linear_VAR = d_gasincfor)
GASINCFOR # Value of net foreign sales of permits #;
Read GASINCFOR from file GDATA header "GINF";
```

```
Equation E_d_gasincfor
# Change in income from Australian exports of emissions permits (A$
million) #
d_gasincfor =
    GASTAXFOR*d_qgasfor + QGASFOR*d_gastaxfor + d_fgasincfor;
```

Equation *E_d_whinc_400* determines the change in income accruing to Australian households (d_whinc_400) from changes in the sale of permits overseas (d_gasincfor). It is assumed that households sell/buy permits internationally in VURM5, after initially purchasing them from the federal government. This income is apportioned across regions based on their initial share of the population (C_POP(q)/C_NATPOP).

The two additional terms in equation *E_d_whinc_400* relate to the handing back of changes in government revenue from the issuing of permits — d_grandinc relates to grandfathering and d_lumpinc to lump-sum transfers to households). These are discussed in turn in section 8.5.1.

```
Equation E_d_whinc_400 # Change in permit income with grandfathering #
(all,q,REGDST)
d_whinc_400(q) =
    C_POP(q)/C_NATPOP*d_gasincfor + 0.8*d_grandinc(q) + 1.0*d_lumpinc(q);
```

Equation *E_d_forestinc* determines the change in the income flow into (out of) Australia from the sale of Australian permits overseas (import of foreign permits). d_FORESTINC will be positive if Australia sells permits overseas and negative if Australia purchases permits overseas. The change in this income flow feeds through into the change in the foreign income account of the balance of payments in VURM5 (d_IAB) and, ultimately, into the percentage change in the nominal value of gross national product (w0gnp). This income change is apportioned across regions based on their initial share of the population (C_POP(q)/C_NATPOP).

The two additional terms in equation *E_d_forestinc* relate to changes in international income flows associated with the handing back of government permit revenue — d_grandinc relates to grandfathering and d_lumpinc relates to lump-sum transfers to households. These are discussed in turn in section 8.5.1.

```
Equation E_d_foretsinc # Change (A$m) in net inflow ETS related income #
(all,q,REGDST)
d_FORETSINC(q) =
    C_POP(q)/C_NATPOP*d_gasincfor + 0.2*d_grandinc(q) + 0.0*d_lumpinc(q);
```

8.5 Modelling other aspects of greenhouse gas-related policies

8.5.1 Changes in government revenue from the pricing of emissions

Revenue raised by the federal government from the taxation of emissions or from the sale of emissions permits can be handled in VURM5 in one of two broad ways.

- The revenue raised can feed through into the finances of the federal government (consolidated revenue) to fund its other activities. In this case, the revenue from the emissions module feeds through into the existing federal government revenue equations in the model core and into the government finance module (outlined in chapter 6).

- The revenue raised can be handed back to:
  - domestic and foreign households, who are the ultimate owners of the emitting firms;
  - domestic households, through lump-sum transfers;
  - domestic households, through a consumer subsidy; or
  - domestic workers, through a reduction in taxes on labour income (PAYE).

Retaining the change in revenue as part of consolidated revenue

If the first approach is adopted, the revenue from the pricing of emissions would be modelled as feeding into consolidated revenue of the federal government in the model core. This is achieved by linking the price on emissions into the existing federal government tax variables for non-GST *ad valorem* taxes on:

- production (equation *E_d_t1Fgas*); and
- household consumption (equation *E_d_t3Fgas*).

These equations were discussed in section 8.3.1.2, which dealt with the change in the specific tax rate on emissions.

Returning the change in revenue to producers and consumers

To the owners of emitting firms (E_d_grandinc to d_wgfsi_600)

Equation *E_d_grandinc* determines the change in federal government revenue in each region from changes to the grandfathering arrangements. Grandfathering of emission permits involves the federal government issuing free permits (typically a one-off issue) to emitting firms (which is equivalent to providing them with a subsidy equal to the permit price). This equation can be activated by making the shift variable d_fgrandinc exogenous and setting it to zero, and d_grandinc endogenous. When the shift variable is exogenous, the change in the amount of revenue grandfathered (d_grandinc) is equal to the change in the revenue collected from the pricing of emissions (d_etaxrev).

```
Equation E_d_grandinc # Grandfathered emissions permit income #
(all,q,REGDST)
d_grandinc(q) = d_etaxrev(q) + d_fgrandinc(q);
```

Equation *E_d_whinc_400* models the change in permit income from grandfathering flowing to Australian households. Based on the domestic and foreign ownership shares in the model database, it is assumed that, as the ultimate owners of the emitting firms that receive the free permits, 80 per cent of the change in permit income accrues to Australian households and 20 per cent to non-residents. Changes in the permit income accruing to Australian households feeds through into change in gross household income in the household income accounts (whinc_000).

Equation *E_d_forestinc* models the change in permit income from grandfathering flowing to non-Australian resident owners of emitting firms. Given the foreign ownership shares in the VURM5 model database, it is assumed that 20 per cent of changes in income from grandfathering accrue to non-residents. This income feeds through into the change in the foreign income account (d_IAB) of the balance of payments in VURM5 and, ultimately, into the percentage change in the nominal value of gross national product (w0gnp). Equation *E_d_forestinc* was discussed in section 8.3.2 with regard to the receipt of income from the sale of permits overseas by Australian households.

Equation *E_d_wgfsi_600* models the change in the change in government revenue lost from grandfathering (denoted by the variable d_wgfsi_600). This loss in revenue is modelled in VURM5 on the income side of the government fiscal accounts (rather than as a notional outlay) to cancel out the increase in *ad valorem* tax revenue from the issuing of permits and to leave overall government revenue unchanged.

The d_lumpsum term in equation *E_d_wgfsi_600* relates to changes in government revenue from handing back revenue to households through lump-sum transfers. This term is discussed in the next section.

```
Equation E_d_wgfsi_600
# Loss in tax revenue from grandfathering of emissions permits #
d_wgfsi_600 = -sum{q,REGDST, d_grandinc(q)} - sum{q,REGDST, d_lumpinc(q)};
```

To domestic households through lump-sum transfers (E_d_lumpinc)

The modelling of handing back of changes in government revenue through lump-sum transfers is similar to that used for grandfathering, with the variable d_lumpinc playing a similar role to d_grandinc. As a result, many of the same equations used are also used.

Equation *E_d_lumpinc* determines the amount of revenue handed back to Australian households through lump-sum transfers. The equation can be activated by making the shift variable d_flumpinc exogenous and setting it to zero, and d_lumpinc endogenous. When the shift variable is exogenous, the lump-sum transfers (d_lumpinc) equal the revenue collected from the pricing of emissions (d_etaxrev).

```
Equation E_d_lumpinc # Lump-sum payment to household of permit income #
(all,q,REGDST)
d_lumpinc(q) = d_etaxrev(q) + d_flumpinc(q);
```

Equation *E_d_whinc_400* models the changes in lump-sum transfers received by Australian households. In VURM5, lump-sum transfers are assumed to flow to domestic (not foreign) households. Consequently, all permit-related lump-sum transfers feed directly into the domestic household income accounts (d_whinc_400), with no income flowing into the foreign income account of the balance of payments (equation *E_d_FORESTINC*). Equations *E_d_whinc_400* and *E_d_FORESTINC* were discussed previously in section 8.3.2 with regard to the receipt of income from the sale of permits overseas by Australian households.

Equation *E_d_wgfsi_600* deals with the loss in government revenue from lump-sum transfers. It was also discussed in the previous section on the grandfathering of permit income.

To domestic households through a consumer subsidy (E_d_fauction_GST to E_d_t3GST)

In VURM5, handing back the change in revenue from the sale of emissions permits back to domestic households through a consumer subsidy is modelled in terms of a reduction in the rate of GST paid by households.

Equation *E_d_faction_GST* calculates the percentage point change in the rate of GST on household purchases (d_t3Fcomp) needed to return the change in revenue from emissions pricing. This equation can be activated by making the shift variable d_faction_GST exogenous and setting it to zero, and d_t3Fcomp endogenous.

The required change in the rate of GST on household purchases needed to return the revenue from emissions pricing (d_t3Fcomp) feeds into equation *E_d_t3GST* in the model core which determines the overall change in the rate of GST paid by households.

```
Equation E_d_fauction_GST
# Handing back of revenue to households through a consumer subsidy #
d_natetaxrev = -sum{c,COM,sum{s,ALLSRC,sum{q,REGDST,
  V3BAS(c,s,q)*0.01*[d_t3Fcomp + TAX3FCOMP*[x3a(c,s,q) + p0a(c,s)]] }}} +
  d_fauction_GST;

Equation E_d_t3GST
# %-Point change in tax rate on commodity sales to 3: GST #
(all,c,COM)(all,s,ALLSRC)(all,q,REGDST)
d_t3GST(c,s,q) =
 {0 + IF(V3GST(c,s,q) gt 0,1)}*[d_tGST + d_tGSTq(q) + d_t0(q) + d_t3Fcomp];
```

8.5.1.1.1 To domestic workers through a reduction in taxes on labour income (E_d_fauction_PAYE)

In VURM5, the handing back of changes in revenue to domestic workers is modelled through a reduction in the tax rate on labour income.

Equation *E_d_fauction_PAYE* calculates the percentage point change in the tax rate on labour income needed to return the revenue from emissions pricing (d_tlabinc). This equation can be activated by making the shift variable d_fauction_PAYE exogenous and setting it to zero, and d_tlabinc endogenous.

```
Equation E_d_fauction_PAYE
# Handing back of revenue to households through a reduction in PAYE tax #
d_natetaxrev = -VGFSI_131@1*100/TLABINC*d_tlabinc + d_fauction_PAYE;
```

8.5.2 Other forms of compensation or shielding

If desired, VURM5 can be adapted to model other forms of compensation, such as the shielding arrangements that currently operate under the carbon pricing scheme that was introduced on 1 July 2012. As these policies are often sector- or year-specific and may change through time, the required changes to the model code may not be straightforward or easy to implement and, therefore, have not been included in VURM5.

8.6 Modelling changes in the intensity of carbon emissions

As discussed in chapter 3, fuels are modelled in VURM5 as intermediate inputs into production and household consumption. The pricing of carbon emissions is intended to reduce the emissions intensity of economic activity by encouraging producers and consumers to switch towards zero or lower carbon emission fuels and goods and services embodying zero or lower emission fuels.

Emissions pricing also provides investors with an incentive to invest in lower-emission fuel-using technologies or activities. Over time, this investment will change the technologies used in production.

In VURM5, relative prices play the central role in driving producer and consumer behaviour. The pricing of emissions will, in areas such as electricity generation and household demand, induce substitution away from CO_2-e intensive fuels, goods and services, thereby reducing the emissions intensity of production and consumption. For example, the inclusion of intermodal substitution in VURM5 enables users of road and rail freight transport to switch between modes based on relative prices.

While relative prices play an important role in driving producer behaviour in VURM5, the fixed nature of the highest level of the production nest (the Leontief assumption discussed in chapter 3) means that industry demand will not result in price-induced substitution between, say, intermediate inputs (such as energy) and primary factors (such as capital) or between different intermediate inputs (such as between gas and electricity).[64] This limits the extent to which endogenous price-based substitution can reduce the emissions-intensity of production in VURM5.

To overcome this limitation, VURM5 includes two optional mechanisms dealing with energy use and emissions intensity.

- First, it includes marginal abatement curves (often referred to as 'MAC curves') for combustion and non-combustion emissions to allow the emissions intensity of production or consumption to vary in response to the pricing of emissions (up to some pre-determined minimum emissions intensity). The marginal abatement curves (or MACs) represent the adoption of some unspecified technology, such as the introduction of carbon capture and storage, which reduces the emissions intensity of economic activity and are discussed in section 8.6.1.
- Second, it allows for possible substitution between effective units of intermediate inputs, especially energy intensive inputs. This is done to partially relax the Leontief assumption operating at the highest level of the production nest and is discussed in section 8.6.2.

Section 8.6.1 below outlines the modelling of the marginal abatement curves, while section 8.6.2 outlines the modelling of the resulting technological change, which is done in a 'cost-neutral' manner as a proxy for the resource costs associated with their development and deployment.

An alternative approach would be to model fuel use and the associated technological changes exogenously using the standard features of VURM5. Under this approach, technological change affecting the use of specific inputs, including primary factors, or the emissions intensity of production would be imposed on the model by shocking any one of the existing exogenous technical change terms in VURM5 (discussed in chapter 3).

8.6.1 Abatement of combustion and non-combustion emissions

The modelling of marginal abatement curves in VURM5 is based on Australian Government (2008, pp. 257–58) and Treasury (2011, pp. 178–79), which, in turn, adapt the implementation in Global Trade and Environment Model (GTEM) (Pant 2007) to VURM5.

The abatement of emissions is modelled in terms of marginal abatement curves. The curves derive changes in an index of emissions intensity by fuel type (each fossil fuel plus "Activity"), fuel user (each industry and residential) and region. That is, the change in CO_2-e emissions per unit of fossil

[64] The electricity supply industries in VURM5 switch between different fuel sources based on relative prices.

fuel used for combustion emissions or per unit of output for non-combustion emissions. These curves can be applied to most sources of emissions.

It is assumed that the emissions intensity falls in a nonlinear fashion as the price of emissions rises. More specifically, it is assumed that the emissions intensity is a negative monotonic convex function of the carbon price. The resulting reduction in emissions intensity is assumed to occur through the introduction of less emission-intensive technologies. The introduction of this new technology is assumed to occur gradually towards a target emissions intensity.[65]

The parameterisation in the model database is designed to operationalise the marginal abatement curves.[66] The parameters included in the current implementation are based on those used Treasury (2011, pp. 178–79). Because of the limited information available to assess the likely magnitude and veracity of the parameters, that should be treated as experimental.

In order to integrate them into the existing VURM5 theory, the marginal abatement curves are implemented in ordinary change form and the resulting indexes determine the percentage change in emissions intensity.

Conceptual model

The marginal abatement curves are specified in terms of changes in the *level* of a target index of emissions intensity ($d\Lambda^*_{i,q}$) that occur in response to changes in the price of CO_2-e emissions ($dT_{f,i,q}$). Within this framework, the target index of emissions intensity for fuel f, industry i in region q ($\Lambda^*_{i,q}$) can be expressed as a monotonic convex function of the price on emissions ($\mathrm{T_{f,i,q}}$):

$$\Lambda^*_{\mathrm{f,i,q}} = \begin{cases} e^{\alpha_{\mathrm{f,i}} - \alpha_{\mathrm{f,i}} \times (1+\mathrm{T_{f,i,q}})^{\gamma_{\mathrm{f,i}}}}, & \text{if } \Lambda^*_{\mathrm{i,q}} > \mathrm{MIN}\Lambda_{\mathrm{f,i}}, \\ \mathrm{MIN}\Lambda_{\mathrm{f,i}} \end{cases} \qquad \text{(E8.19)}$$

where:

$\mathrm{MIN}\Lambda_{\mathrm{f,i}}$ is the minimum possible emissions intensity for the use of fuel f by fuel user i;

$\mathrm{T_{f,i,q}}$ is the real price on emissions arising from the use of fuel f by fuel user i in region q ($ per tonne of CO_2-e in constant 2010 prices);

$\alpha_{f,i}$ is a positive coefficient, with a higher value indicating a larger reduction in emissions intensity in response to a given domestic price of carbon; and

$\gamma_{f,i}$ is a positive coefficient denoting the sensitivity of the target emissions intensity to the emissions price.

This approach assumes that the real tax rate is not negative (that is, $\mathrm{T_{f,i,q}} \geq 0$).

Equation (E8.19) defines $\Lambda^*_{\mathrm{f,i,q}}$ above $\mathrm{MIN}\Lambda_{\mathrm{i,q}}$ as a nonlinear monotonic decreasing function of $\mathrm{T_{f,i,q}}$. Typical values of $\alpha_{\mathrm{f,i}}$ and $\gamma_{\mathrm{f,i}}$ in the VURM5 database are around 0.03 and 0.7. With these settings, if

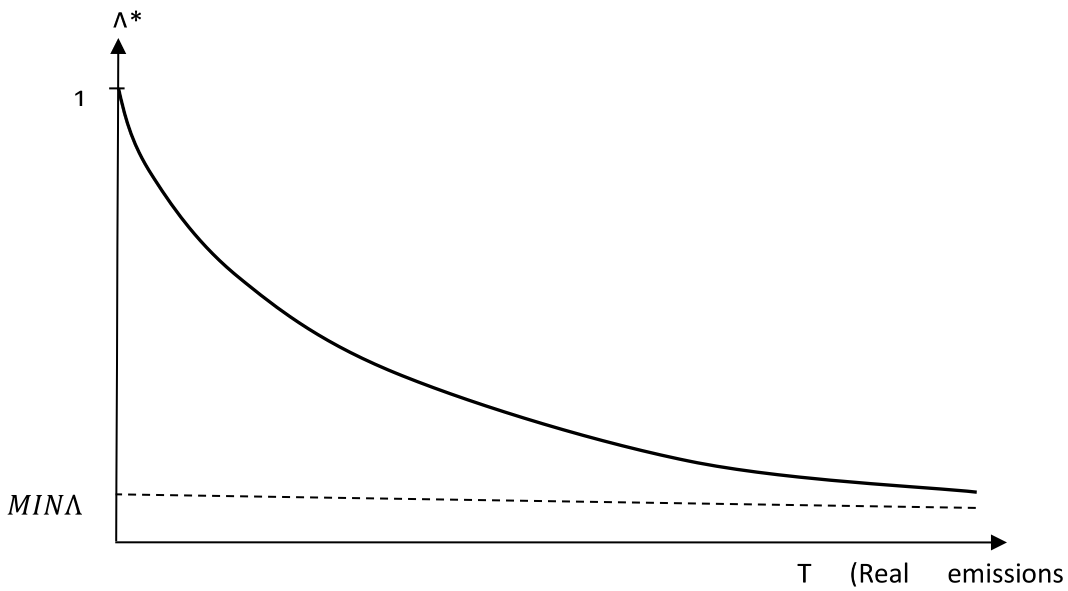
[65] This lagged response also ensures that the emissions intensities do not respond too vigorously to changes in emissions price, especially when a price on emissions rises immediately from zero.

[66] The parameterisation in the model database implies that, for a real tax of $100 (in 2005 06 dollars) per tonne CO_2-e, activity emissions from agriculture would drop by 60 per cent, emissions from black coal mining would drop by 70 per cent, emissions from crude oil extraction would drop by 40 per cent, emissions from alumina/aluminium smelting and refining would drop by 25 per cent, and natural gas, and emissions from chemicals (excluding petrol), cement and other services (waste disposal) would all drop by 10 per cent. These estimates are quite speculative, but are only really important in the case of agriculture, which makes a very large contribution to activity-related emissions.

the real emissions price is, say, \$50 per tonne, $\Lambda^*_{f,i,q}$=0.64. This compares to $\Lambda^*_{f,i,q} = 1$ if the price of CO_2-e is zero. Thus, the introduction of a \$50 per tonne price of emissions would reduce the target index of emissions intensity by 36 per cent.

The relationship between the target index of emissions intensity and the price on emissions is illustrated in figure 8.3 for a hypothetical industry. In this hypothetical example, the target index of emissions intensity is one when the real price of carbon is zero, and asymptotes to the minimum possible emissions intensity as the real price of emissions rises.

Figure 8.3 Target index of emissions intensity for the hypothetical industry



The current index of emissions intensity ($\Lambda^t_{f,i,q}$) is assumed to gradually adjust to the target index. This is implemented in VURM5 through a lagged adjustment mechanism:

$$\Lambda^t_{f,i,q} = \Lambda^{t-1}_{f,i,q} + \mathrm{ADJUSTMENT}_{f,i} \times \left(\Lambda^*_{f,i,q} - \Lambda^{t-1}_{f,i,q}\right) \qquad \text{(E8.20)}$$

where:

$\Lambda^t_{f,i,q}$ is the index of emissions intensity in year t;

$\Lambda^{t-1}_{f,i,q}$ is the index of emissions intensity lagged one year; and

$\mathrm{ADJUSTMENT}_{f,i}$ is a speed-of-adjustment parameter (with a typical value of 0.3).

The percentage change in emissions intensity is:

$$\lambda_{f,i,q} = \frac{d\Lambda_{f,i,q}}{\Lambda_{f,i,q}} \times 100 \qquad \text{(E8.21)}$$

TABLO implementation

As the TABLO implementation of VURM5 is a model linear in percentage changes, the implementation of the marginal abatement curves in the TABLO code is expressed in ordinary change form. These linearised forms of equations (E8.18) and (E8.19) that are implemented in the model code are derived in annex 8A.5.

Most of the coefficients in the TABLO implementation are read as parameters from the file GDATA — ADJUSTMENT(f,i), ALPHA(f,i), GAMMA(f,i), and MINLAMBDA(f,i) (headers "ADJM", "ALPH", "GAMA" and "MINL", respectively).

Change in the target index of emissions intensity (E_d_lambdat)

Equation *E_d_lambdat* determines the change in the target *level* of emissions that occurs in response to a change in the real domestic price of emissions. This change is constrained so that the target index of emissions intensity must exceed the minimum intensity index, denoted by the coefficient MINLAMBDA(f,i). The equation implemented is based on the linearised form of equation (E8.18) above, where d_lambdat(f,i,q) represents $d\Lambda^{*}_{f,i,q}$. As the price on emissions in VURM5 is expressed in $000/t, the emissions price and the change in the emissions price are both multiplied by 1000 to convert to the $ per tonne needed for the marginal abatement curve formula.

The change in the target *level* of emissions that occurs in response to a change in the real domestic price of emissions (d_lambdat) is used to update the coefficient L_LAMBDAT, which represents the *level* of the target emissions-intensity index in the current simulation year. L_LAMBDAT is equivalent to $\Lambda^{*}_{f,i,q}$ in the conceptual model outlined above. The coefficient is read at the start of each simulation year from header "LMBT" on the file GDATA.

```
Coefficient (parameter)(all,f,FUELX)(all,i,IND)
ALPHA(f,i) # Coefficient indicating response of emissions to carbon tax #;
Read ALPHA from file GDATA header "ALPH";

Coefficient (parameter)(all,f,FUELX)(all,i,IND)
GAMMA(f,i)  # Coefficient indicating power in emission response function #;
Read GAMMA from file GDATA header "GAMA";

Coefficient (parameter)(all,f,FUELX)(all,i,IND)
MINLAMBDA(f,i)  # Minimum emissions response #;
Read MINLAMBDA from file GDATA header "MINL";

Coefficient (all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDAT(f,i,q) # Target index of emissions intensity #;
Read L_LAMBDAT from file GDATA header "LMBT";
Update (change)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDAT(f,i,q) = d_lambdat(f,i,q);

Equation E_d_lambdat # Change in the target index of emissions intensity #
(all,f,FUELX)(all,i,IND)(all,q,REGDST)
d_lambdat(f,i,q) =
    IF{L_LAMBDAT(f,i,q) > MINLAMBDA(f,i),
        EXP(ALPHA(f,i))*[-ALPHA(f,i)*GAMMA(f,i)*(1+1000*ETAXRATE(f,i,q))
                ^(GAMMA(f,i)-1)*L_LAMBDAT(f,i,q)*1000*d_gastax(f,i,q)]};
```

Change in the index of emissions intensity in the previous year (E_d_lambda_L)

Equation *E_d_lambda_L* determines the change in the *level* of the index of emissions intensity in the previous simulation year ($\Lambda^{t-1}_{f,i,q}$). Its derivation is based on equation (E8.20) above, where d_lambda_L represents $d\Lambda^{t-1}_{f,i,q}$. d_lambda_L is calculated as the difference between the starting index of emissions intensity for the current simulation year ($\Lambda^{t-1}_{f,i,q}$) and the starting index from the previous year ($\Lambda^{t-2}_{f,i,q}$).

Equation *E_d_lambda_L* is expressed in terms of two intermediate working coefficients that are declared as parameters:

- L_LAMBDA@1 is used in place of rather than L_LAMBDA to represent the *level* of the index of emissions intensity at the start of the current simulation year. At the start of each simulation year, L_LAMBDA@1 is set equal to L_LAMBDA.
- L_LAMBDA@2 is used in place of rather than L_LAMBDA to represent the *level* of the index of emissions intensity at the start of the previous simulation year. At the start of each simulation year, L_LAMBDA@2 is set equal to L_LAMBDA_L.

In equation *E_d_lambda_L*, the change in the index of emissions intensity in the previous year is calculated as the difference in between L_LAMBDA@1 and L_LAMBDA@2 multiplied by a homotopy variable[67].

The change in the *level* of the index of emissions intensity in the previous simulation year (d_lambda_L) is used to update the coefficient L_LAMBDA_L, which) represents the *level* of the index of emissions intensity in the previous simulation year. L_LAMBDAT_L is equivalent to $\Lambda_{f,i,q}^{t-1}$ in the conceptual model outlined above. The coefficient is read at the start of each simulation year from header "LAML" on the file GDATA.

```
Coefficient (parameter)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA@1(f,i,q) # Initial index of emissions intensity #;
Formula (initial)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA@1(f,i,q) = L_LAMBDA(f,i,q);

Coefficient (parameter)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA_L(f,i,q) # Index of emissions intensity lagged one year #;
Read L_LAMBDA_L from file GDATA header "LAML";
Update (change)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA_L(f,i,q) = d_lambda_L(f,i,q);

Coefficient (parameter)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA@2(f,i,q) # Initial index of emissions intensity lagged one year #;
Formula (initial)(all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA@2(f,i,q) = L_LAMBDA_L(f,i,q);

Equation E_d_lambda_L # d_lambda lagged one year #
(all,f,FUELX)(all,i,IND)(all,q,REGDST)
d_lambda_L(f,i,q) = (L_LAMBDA@1(f,i,q) - L_LAMBDA@2(f,i,q))*d_unity;
```

Change in the index of emissions intensity in the current simulation year (E_d_lambda)

Equation *E_d_lambda* determines the change in the index of emissions intensity that occurs in the simulation year. The formulation implemented in the TABLO code is derived in annex 8A.5 from equation (E8.19) above, where d_lambda(f,i,q) represents $d\Lambda_{f,i,q}$. The coefficient ADJUSTMENT(i) determines the rate at which the current index of emissions intensity adjusts from the change in the

[67] Homotopy variables, which are set to one, are used in Tablo to enable an equation to consist of coefficients only (no variables).

level of emissions in the previous year (d_lambda_L) to the target index (d_lambdat). It is read from the file GDATA (header ("ADJM").

If the *level* of the index is higher than the minimum possible index, the change in the index of emissions intensity that occurs in the simulation year is used to update the coefficient L_LAMBDA(f,i,q)), which represents the *level* of the index of emissions intensity in the current simulation year ($\Lambda_{f,i,q}$). The coefficient is read from the file GDATA (header ("LAMB").

```
Coefficient (parameter)(all,f,FUELX)(all,i,IND)
ADJUSTMENT(f,i) # Emissions response adjustment rate #;
Read ADJUSTMENT from file GDATA header "ADJM";

Coefficient (all,f,FUELX)(all,i,IND)(all,q,REGDST)
L_LAMBDA(f,i,q) # Index of emissions intensity #;
Read L_LAMBDA from file GDATA header "LAMB";
Update
(change)(all,f,FUELX)(all,i,IND)(all,q,REGDST: L_LAMBDA(f,i,q) >
MINLAMBDA(f,i))
L_LAMBDA(f,i,q) = d_lambda(f,i,q);

Equation E_d_lambda # Change in the index of emissions intensity #
(all,f,FUELX)(all,i,IND)(all,q,REGDST)
d_lambda(f,i,q) =
 IF{L_LAMBDA(f,i,q) > MINLAMBDA(f,i),
        ADJUSTMENT(f,i)*d_lambdat(f,i,q) +
     (1-ADJUSTMENT(f,i))*d_lambda_L(f,i,q)
   };
```

Percentage change in emissions intensity (E_agas to E_agasact)

Equations *E_agas* and *E_agasAct* activate the modelling of endogenous emission-intensity reducing technological change (for combustion and non-combustion emissions, respectively).

The left-hand side variable of each equation denotes the percentage change in the index of emissions intensity — agas for emissions from fossil fuels (combustion fuels) and agasact for non-combustion emissions.

The right-hand side of each equation implements equation (E8.21) to detail the percentage change in the index of emissions intensity from the marginal abatement curve modelling, conditional on the index of emissions intensity exceeding the minimum level. The shift terms f_agas and f_agasact enable the equations to be turned on or off. These percentage changes in emissions intensity feed through into the equations that determine the percentage changes in the *level* of emissions (equations *E_xgasA* to *E_xgasE*, discussed in section 8.2.2).

```
Equation E_agas # Percentage change in combustion emissions #
(all,f,FUEL)(all,i,IND)(all,q,REGDST)
agas(f,i,q) =
    IF{L_LAMBDA(f,i,q) gt MINLAMBDA(f,i),
        100*[1/ID01[L_LAMBDA(f,i,q)]]*d_lambda(f,i,q)} + f_agas(f,i,q);
```

```
Equation E_agasact # Percentage change in non-combustion emissions #
(all,i,IND)(all,q,REGDST)
agasact(i,q) =
    IF{L_LAMBDA("Activity",i,q) gt MINLAMBDA("Activity",i),
        100*[1/ID01[L_LAMBDA("Activity",i,q)]]*d_lambda("Activity",i,q)} +
            f_agasact(i,q);
```

VURM5 can also model the costs of technological and organisational change needed to reduce the emissions intensity of production. Typically such changes involve a one off, up front fixed cost and cost savings extending over subsequent years. Section 8.6.3 discusses the modelling of these costs in VURM5 in a 'cost neutral' manner.[68]

The appendix to this chapter outlines the relationship between the marginal abatement curves in VURM5 and the marginal abatement cost curves used more frequently in the literature.

8.6.2 Substitution between effective units of intermediate inputs (E_agreen)

Equation *E_agreen* allows for price-induced substitution between effective units of intermediate inputs, especially those inputs that are energy intensive (e.g., gas and coal). When the shift variable f_agreen is exogenously set to zero, agreen equals the percentage change in the price paid by industry i in region q for input c (p1o) relative to the average basic price paid by industry i in region q for all intermediate inputs, excluding any additional returns from export sales (p1cost).

According to equation E_agreen, if the price paid by industry i in region q for input c increases relative to the average price paid by industry i in region q for intermediate inputs, then there will be a substitution in industry i away from effective inputs of commodity c. Conversely, if the price of effective inputs of c falls relative to the weighted average of all intermediate inputs, then there will be a substitution that favours the use of c by industry i. The extent of this substitution is governed by the constant price elasticity of substitution (the coefficient SIGMAGREENi), which has a typical value of 0.25.

```
Equation E_agreen
# Commodity-augmenting technical change in response to a change in price #
(all,c,COM)(all,i,IND)(all,q,REGDST)
agreen(c,i,q) = -SIGMAGREEN(c,i)*[p1o(c,i,q) - p1cost(i,q)] +
f_agreen(c,i,q);
```

8.6.3 Cost-neutral technical change

Changes in the mix of intermediate inputs used in production or the emissions intensity of output require changes in the technology of production (such as those discussed in sections 8.6.1 and 8.6.2).[69] Such changes impose financial costs on producers, typically a one off, up front fixed cost accompanied by ongoing cost savings. If operationalised, VURM5 models these additional costs to producers in a 'cost neutral' manner.

[68] Here, the treatment in VURM5 differs from that in GTEM, where it is assumed that the change in technology necessary to achieve the reduction in emission intensity is costless. In VURM5, the increase in cost is imposed as a contemporaneous all-input technological deterioration in production of the abating industry.
[69] The variables agreen, agas and agasact that achieve this in VURM5 are technical change variables.

All input-saving technological change to offset the cost effects (E_a1)

Equation *E_a1* makes all of the emissions-related and associated technical change terms — the variables agas(f,i,q), agasact(i,q), acom(c,q), acomind(c,i,q), agreen(c,i,q) and natacom(c) — cost neutral. This is achieved by introducing an all-input-using technological change (a1) to change the cost of production (COSTS) by an offsetting amount.

Without such an offset, positive values for, say, acom(c,q) would represent technological deterioration. To avoid such unrealistic implications, equation *E_a1* generates cost-neutralising reductions in all of industry j's inputs per unit of output. The equation is turned on by setting d_fa1 exogenous and setting it to zero, and a1 endogenous.

As the underlying source of the technical change is unknown, it is assumed that proportionally more of *all* resources are used in the year in which the technical change occurs. This imposes a one-off cost on producers, which is assumed to be equal to the cost reduction arising from the technical change. That is, in the year in which the technical change occurs, it is assumed that the technical change is 'cost neutral'. For example, if a reduction in emissions per unit of output achieves a cost saving to producers of $1, then all inputs per unit of activity are assumed to increase in that industry up to a point where, at a given level of scale, the cost increases by $1.

The variable a1 determines the percentage change in all inputs needed to make the relevant technical changes cost neutral. It enters demand equations *E_x1o* (intermediate inputs), *E_x1prim* (primary factor inputs) and *E_x1oct* (other cost inputs). The variable a1 also enters existing VURM5 equation *E_a*, which determines the average technical change by industry and region in current production.

```
Equation E_a1 # All input-augmenting technical change in production #
(all,i,IND)(all,q,REGDST)
-ID01[COSTS(i,q)]*a1(i,q) =
sum{f,FUEL, ETAX(f,i,q)*agas(i,q)} + ETAX("Activity",i,q)*agasact(i,q) +
sum{c,COM, V1PURO(c,i,q)*[acom(c,q) + natacom(c) + agreen(c,i,q) +
acomind(c,i,q)]} + 100*d_fa1(i,q);
```

Annex 8A.1 Greenhouse gas emissions in the model database

Table 8A.1:Greenhouse gas emissions by source of greenhouse gas emissions and emitting sector, 2005-06

Mt CO_2-e[a,b]

Fuel user	*Coal*	*Gas*	*Petrol*	*Other refinery products*	*Activity*[c]	*Total*
Livestock	0	1.1	135.1	1 029.2	6 5447.2	6 6612.6
Crops	0	0.6	162.3	1 088.6	2 349.7	3 601.3
Dairy	0	0.4	18.2	339.2	8 533.8	8 891.5
Other agriculture	0	2.5	262.8	1 490.5	5 821.8	7 577.6
Forestry	0	0.1	13.5	265.3	-19 610.0	-19 331.1
Fishing	0	0.1	126.9	865.4	13.2	1 005.5
Coal mining	0	0	18.3	2 615.4	21 371.0	24 004.7
Oil mining	0	0	1.9	293.9	782.3	1 078.1
Gas mining	0	8 974.4	1.6	295.9	6 126.6	15 398.5
Iron ore mining	125.4	516.0	9.0	1 437.7	0	2 088.0
Other metal ore mining	588.4	362.6	11.8	3 265.5	1 575.5	5 803.8
Other mining	0	49.0	10.2	2 014.1	0	2 073.3
Meat products	27.0	175.1	7.4	125.6	0	335.0
Dairy products	27.5	171.8	11.3	205.1	0	415.7
Other food, beverages & tobacco	722.5	1 218.7	407.0	321.5	0	2 669.6
Textiles, clothing & footwear	2.7	330.8	16.8	50.3	0	400.6
Wood products	164.2	135.9	18.8	39.9	0	358.6
Paper products	792.8	665.3	8.1	31.5	672.9	2 170.6
Printing	0	112.3	54.0	5.8	0	172.1
Petrol	0	495.4	16.6	3 754.4	0	4 266.4
Other petroleum & coal products	0	733.3	26.1	5 551.6	0	6 311.0
Chemical products	480.6	1 257.8	124.5	4 328.9	0	6 191.9
Rubber & plastic products	25.5	920.3	116.2	268.4	0	1 330.5
Other non-metal mineral products	420.7	1 861.5	13.9	161.0	1 539.8	3 996.8
Cement & lime	2 042.3	1 021.4	28.7	422.3	4 770.8	8 285.5
Iron & steel	3 256.1	1 189.4	3.2	204.4	8 254.0	12 907.1
Alumina	4 734.1	5 477.2	6.3	2 967.3	0	13 184.9
Aluminium	0	0	0	345.6	4 545.9	4 891.5
Other non-ferrous metals	354.2	699.6	0	374.8	0	1 428.7
Metal products	0	75.1	20.9	20.9	0	116.9
Motor vehicles & parts	10.6	57.5	11.2	25.1	0	104.4
Other equipment	45.9	93.1	34.6	34.4	0	208.0
Other manufacturing	37.6	126.1	21.8	21.0	662.2	868.5
Electricity generation: coal	175 401.0	0	62.9	0	0	175 463.9
Electricity generation: gas	0	13 809.1	7.0	0	0	13 816.1
Electricity generation: oil	0	0	0.3	80.3	0	80.6

Electricity generation: hydro	0	0	9.9	0	0	9.9

(Continued next page)

Table: (Continued

Fuel user	*Coal*	*Gas*	*Petrol*	*Other refinery products*	*Activity*[c]	*Total*
Electricity generation: other	0	0	3.1	0	0	3.1
Electricity supply	0	0	48.4	501.2	0	549.6
Gas supply	0	756.5	2.1	1.4	2 090.6	2 850.6
Water & sewerage services	0	0	7.1	504.5	0	511.6
Residential construction	0	0	116.1	642.5	0	758.6
Non-residential construction	0	160.0	233.2	3 306.3	0	3 699.5
Wholesale trade	0	214.6	437.8	909.2	358.8	1 920.4
Retail trade	0	213.7	285.4	542.2	0	1 041.3
Mechanical repairs	0	160.0	39.3	425.3	0	624.7
Hotels, cafes & accommodation	0	515.5	235.7	167.1	297.5	1 215.8
Road freight transport	0	65.9	332.2	5 070.5	0	5 468.5
Road passenger transport	0	10.9	61.3	936.1	712.6	1 720.9
Rail freight transport	0	0	365.2	750.6	0	1 115.9
Rail passenger transport	0	0	242.2	498.9	0	741.1
Pipeline transport	0	0.2	8.9	38.2	0	47.3
Water transport	0	0	1.9	194.7	0	196.6
Air transport	0	0	0	5 081.5	0	5 081.5
Services to transport	0	3.7	219.4	674.5	0	897.6
Communication services	0	278.9	347.6	352.8	0	979.2
Financial services	0	5.2	2.2	7.5	0	15.0
Ownership of dwellings	0	8.5	10.6	0	0	19.1
Business services	0	442.3	417.7	1 928.8	0	2 788.8
Government admin & defence	0	98.1	71.6	686.6	0	856.3
Education	0	93.4	3.8	50.6	0	147.7
Health	0	141.2	121.0	102.4	0	364.6
Community services	0	59.6	78.5	24.0	0	162.2
Other services	0	51.6	109.3	337.8	17 037.0	17 535.7
Residential	16.9	7 006.3	66 962.1	6 175.4	2 450.2	82 611.0
Total	**189 275.9**	**50 819.5**	**72 562.8**	**64 251.2**	**135 803.4**	**512 712.7**

[a] Million tonnes of carbon dioxide equivalent. [b] Data contained in header “QGAS”. [c] “Activity” in the header “QGAS” relates to non-combustion emissions.

Annex 8A.2 Summary of the notation used in this chapter

Table 8A.2: Notation used in the conceptual model and in the TABLO implementation

Algebraic representation	*Description*	*Corresponding TABLO coefficient/variable*	*Units*
E	Quantity of CO_2-e emissions	QGAS	kt of CO_2-e
C	Quantity of CO_2-e emissions per unit of fuel burnt or activity undertaken	Not applicable	kt of CO_2-e / physical unit
Q	Quantity of activity subject to the Australian price on CO_2-e emissions	Not applicable	Physical units (000) (such as tonnes)
e	Percentage change in the quantity of Australian CO_2-e emissions	xgas	Percentage change
c	Percentage change in quantity of CO_2-e emissions per unit of fuel burnt or activity undertaken	agas (for combustion emissions) agasact (for activity emissions)	Percentage change
q	Percentage change in the quantity of activity subject to the Australian price on CO_2-e emissions	x1o (for industry combustion emissions) x1tot (for industry non-combustion emissions) x3o (for residential combustion emissions)[a]	Percentage change
R	Revenue from taxation of CO_2-e emissions	ETAX	A$ million
T	Specific rate of taxation (or price) on CO_2-e emissions	ETAXRATE	A$000 / kt of CO_2-e
I	Price index to adjust the specific tax rate on CO_2-e emissions for price changes through time	ENERINDEX	Ratio of the price level in the simulation year to the reference year of the tax rate
dR	Ordinary change in revenue from Australian taxation of CO_2-e emissions	d_etaxrev	A$ million
t	Percentage change in the specific tax rate (or price) on Australian CO_2-e emissions	Not applicable[b]	Percentage change
i	Percentage change in the price index to adjust the specific price on CO_2-e emissions in the simulation year relative to the reference year of the tax rate	gastaxindex	Percentage change
dT	Ordinary change in specific tax rate (or price) on Australian CO_2-e emission	d_gastax	A$000 / kt of CO_2-e
ε	Level of Australian CO_2-e emissions per unit of nominal economic activity	Not applicable	tonnes of CO_2-e per A$000
P	Basic unit price of Australian activity subject to the CO_2-e emissions tax	Not applicable	A$000 per physical unit (such as A$000/t)

(Continued next page)

Table: (Continued)

Algebraic representation	*Description*	*Corresponding TABLO coefficient/variable*	*Units*
V	Australian ad valorem tax-rate equivalent to the specific tax rate (or price) T	Not applicable	Percentage
dV	Ordinary change in the ad valorem tax-rate equivalent to the specific tax rate (or price) T	d_t1Fgas (for industry combustion emissions) d_indtax and d_tFgascs (for industry non-combustion emissions) d_t3Fgas (for residential combustion emissions)**a**	Percentage points change
$\frac{E \times I}{P \times Q}$	Propensity to emit CO_2-e in Australia	EIoverPQ	kt of CO_2-e / A$000 of activity
p	Percentage change in the basic unit price of activity subject to the Australian price on CO_2-e emissions	p0a_s (for industry combustion emissions) p1cost (for industry non-combustion emissions) p3a_s (for residential combustion emissions)**a**	Percentage change
P × Q	Value of activity subject to the Australian price on CO_2-e emissions	V1BAS (for industry combustion emissions) COSTS (for industry non-combustion emissions) V3BAS (for residential combustion emissions) V3TOT (for residential non-combustion emissions)	A$ million
Y	Price of foreign CO_2-e emissions permits (expressed in Australian dollars)	None	A$ 000/t CO_2-e
F	Price of foreign CO_2-e emissions permits (expressed in foreign currency units)	ETAXRATE	Foreign currency units (000)/t CO_2-e
Φ	Nominal exchange rate (A$ per unit of foreign currency)	LEVPHI	A$/Unit of foreign currency
dY	Ordinary change in the price of foreign CO_2-e emissions permits (expressed in Australian dollars)	None	A$ 000/t CO_2-e
dF	Ordinary change in the price of foreign CO_2-e emissions permits (expressed in foreign currency units)	d_gastaxfor	Foreign currency units (000)/t CO_2-e
φ	Percentage change in the nominal exchange rate A$ per unit of foreign currency)	Phi	Percentage change
E^F	Quantity of Australian CO_2-e emissions permits sold overseas[70]	QGASFOR	kt of CO_2-e

(Continued next page)

[70] The level of emissions is, essentially, the quantum of that activity undertaken (such as fuel burnt or activity giving rise to the emissions) multiplied by the relevant emissions coefficient for that activity (which denotes the quantity of emissions per quantum of fuel burnt or activity undertaken).

Table: (Continued)

Algebraic representation	*Description*	*Corresponding TABLO coefficient/variable*	*Units*
E^T	Quantity of CO_2-equivalent emissions permits allocated to Australia	FOREMM	kt of CO_2-e
dE^f	Ordinary change in the quantity of Australian CO_2-e emissions permits sold overseas	d_qgasfor	kt of CO_2-e
$\alpha_{f,i}$	Positive coefficient in the marginal abatement curve that controls the speed of adjustment of the target emissions intensity to the real Australian price on CO_2-e emissions	ALPHA	Positive real number
$\gamma_{f,i}$	Positive coefficient in the marginal abatement curve that controls the speed of adjustment of the target emissions intensity to the real Australian price on CO_2-e emissions	GAMMA	Positive real number
None	Change in the price of Australian CO_2-e emission permits (scalar used to apply shocks)	d_gastaxdom	A$000 / kt of CO_2-e

a There are no residential non-combustion emissions. **b** Modelled in change form to allow for the introduction of a tax on emissions.

Annex 8A.3 Greenhouse sets used in the TABLO implementation

Table: Sets used in the Greenhouse module

Set	*Description*	*Coverage in the model database*	*No. of elements*	*Logical filename*	*Header*
FINALFUEL	Final energy fuels	Coal, gas, petrol, other refinery products and electricity supply	5	SET	FFUL
FORWASTE	The elements "Forestry" (sequestration) and "Other services" (Waste disposal) for driving technical change in non-combustion CO_2-e emissions	Forestry and other services	2	SETS	FRWS
FUEL	Fossil fuels that give rise to combustion emissions	Coal and gas plus the set PETPROD	4	SETS	FUEL
FUELUSER	Sectors emitting greenhouse gases	All 64 industries plus "Residential" (households)	65	SETS	IND (industries) FUSR (residential)
FUELX	All sources of greenhouse gases in VURM5	The set FUEL plus "Activity" (covering non-combustion emissions)	5	SETS	FULX
FUGITIVE	Fugitive activities	Coal, oil, gas and gas supply	4	SETS	FGTV
INDPROC	Activities treated as industry processes	All industries other than livestock, crops, dairy, other agriculture, forestry, fishing, coal, oil, gas, iron ore mining, non-iron ore mining, other mining, coal generation, gas generation, oil generation, hydro generation, other generation, electricity supply, gas supply and community services	44	SETS	INPR
PETPROD	Refinery products	Petrol and other refinery products	2	SETS	PPRD
PRIMFUEL	Primary fuels	Coal, oil and gas	3	SETS	PFUL
STATFINAL	Final fuels used by stationary processes	Petrol and other refinery products	2	STES	STFL
STATPRIM	Primary fuels used by stationary processes[a]	Coal and gas	2	SETS	STPM
STATFUEL	Primary and final fuels used by stationary processes[a]	The sets STATPRIM and STATFINAL	4	Defined in the TABLO code	
TABG	Kyoto emissions accounting reporting categories	G1 to G12[b]	12	Defined in the TABLO code	

[a] Stationary processes are defined as all processes involving the use of fuels (primary and secondary) other than for transport. [b] G1: Energy sector, total. G2: Fuel combustion. G3: Stationary. G4: Electricity generation. G5: Other. G6: Transport. G7: Fugitive emissions from fuels. G8: Industry processes. G9: Agriculture. G10: Waste. G11: LUCF (forestry). and G12: Total.

Annex 8A.4 Greenhouse data used in the TABLO implementation

Table: Data read in from GDATA

Coefficient	*Description*	*Units in model database*	*Dimensions*	*No. of elements*	*Header*
ADJUSTMENT	Rate of adjustment in emissions intensity towards the target intensity, with a higher value indicating faster adjustment	Parameter between 0 and 1	FUELX × IND	325	ADJM
ALPHA	Parameter in the emissions response function, with a higher value indicating a larger reduction in emissions intensity in response to a given domestic price of carbon	Non-negative parameter	FUELX × IND	325	ALPH
DOMEMM	Quantity of actual emissions occurring in Australia under an international emissions trading scheme	Kt	1	1	QGSD
ETAXRATE	Specific tax rate (or price) on Australian CO_2-e emissions	A$000 / tonne	FUELX × FUELUSER × REGDST	2 600	ETXR
FOREMM	Australia's net allocation of CO_2-e emission permits under an international trading scheme	kt	1	1	QGSF
GAMMA	Power in the emission response function, with a higher value indicating a larger reduction in emissions intensity in response to a given domestic price of carbon	Non-negative parameter	FUELX × IND	325	GAMA
GASTAXDOM	Australian price of CO_2-e emissions permits	A$000 / tonne	1	1	GTXD
GASTAXFOR	Foreign currency price of emissions permits	$FCU / tonne[a]	1	1	GTXF
L_LAMBDA	Index of emissions intensity in the current simulation year	Index (between 1 and MINLAMBDA)	FUELX × IND	325	LAMB
L_LAMBDAT	Target index of emissions intensity	Index (between 1 and MINLAMBDA)	FUELX × IND	325	LMBT
L_LAMBDA_L	Index of emissions intensity in the previous simulation year	Index (between 1 and MINLAMBDA)	FUELX × IND	325	LAML
LIMIMPMAX	Maximum number of imported emissions permits that Australia can use to achieve its emissions abatement target under an international emissions trading scheme	Kt	1	1	LMMM
MINLAMBDA	Minimum emissions intensity	Index (between 0 and 1)	FUELX × IND	325	MINL
QGAS	Level of Australian CO_2-e emissions	kt	FUELX × FUELUSER × REGDST	2 600	QGAS

[a] FCU: foreign currency units.

Annex 8A.5 Marginal abatement curves for emissions

This annex derives the time varying marginal abatement curve equations implemented in VURM5 from the underlying levels form.

The curves implemented into VURM5 are based on those used in Australian Government (2008, pp. 257-58) and Treasury (2011, pp. 178-79). The functional form used in these earlier studies has been modified slightly to re-index the indexes of emissions intensity to a value of 1 when there is no price on emissions (rather than to a value of 0.97).

Overview

The marginal abatement curves derive indexes of emissions intensity by fuel type (each fossil fuel and non-combustion emissions), fuel user (each industry and residential) and region. These indexes are expressed in ordinary change form. The indexes are used to derive the percentage changes in emissions intensity, which, along with the drivers of activity levels, are used to derive the various percentage changes in emissions reported in VURM5.

If operationalised through choosing the appropriate closure settings, the intensity of combustion and non-combustion emissions is allowed to endogenously fall in a nonlinear fashion as the price of CO_2-e emissions rises. This reduction in emissions intensity is assumed to occur through the introduction of less emission-intensive technologies and is assumed to be a monotonic convex function of the price on emissions. The adoption of this new technology is assumed to occur gradually towards a required (or target) emissions intensity (that is, the adjustment occurs with a lag). This abatement is modelled at the fossil fuel or activity level, with the parameterisation in the model database intended to operationalise the curves rather than to provide plausible values. Abatement is allowed to continue up to some minimum emissions intensity.

While the marginal abatement curves operate across each regional industry, their parameterisation in the current implementation is assumed to be uniform for a given fuel type and fuel user across all regions.

Underlying conceptual model

Let $\Lambda^{t}_{f,i,q}$ denote the index of the emissions intensity in year t from the use of fossil fuel f (or activity for non-combustion emissions) by fuel user i (an industry or residential) located in region q. Let $\Lambda^{t-1}_{f,i,q}$ denote that the value of that index in the preceding year (that is, the index lagged one year).

The index of emissions intensity is assumed to gradually transition from its value in the previous year towards a target index value (denoted by $\Lambda^{*}_{f,i,q}$). The parameter $\mathrm{ADJUSTMENT}_{f,i}$ controls the speed-of-adjustment (typically 0.3). Algebraically this can be expressed as:

$$\Lambda^{t}_{f,i,q} = \Lambda^{t-1}_{f,i,q} + \mathrm{ADJUSTMENT}_{f,i} \times \left(\Lambda^{*}_{f,i,q} - \Lambda^{t-1}_{f,i,q}\right)$$

Re-arranging gives:

$$\Lambda^{t}_{f,i,q} = \mathrm{ADJUSTMENT}_{f,i} \times \Lambda^{*}_{f,i,q} + \left(1 - \mathrm{ADJUSTMENT}_{f,i}\right) \times \Lambda^{t-1}_{f,i,q} \qquad \text{(E8.22)}$$

Above a pre-specified minimum value ($\mathrm{MIN}\Lambda_{f,i}$), the target index of emissions intensity is a nonlinear monotonic decreasing function of the real price on CO_2-e emissions ($1 + T_{f,i,q}$):

$$\Lambda^{*}_{\mathrm{f,i,q}} = \begin{cases} \mathrm{e}^{\alpha_{\mathrm{f,i}} - \alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}}, \text{ if } \Lambda^{*}_{\mathrm{f,i,q}} > \mathrm{MIN}\Lambda_{\mathrm{f,i}}, \\ \mathrm{MIN}\Lambda_{\mathrm{f,i}} \end{cases} \quad \text{(E8.23)}$$

where:

$\alpha_{f,i}$ is a positive coefficient, with a higher value indicating a larger reduction in emissions intensity in response to a given real domestic price on emissions;

$\mathrm{T_{f,i,q}}$ is the real price on emissions arising from the use of fuel f by fuel user i in region q ($ per tonne of CO_2-e in constant 2010 prices); and

$\gamma_{\mathrm{f,i}}$ is a positive coefficient denoting the speed of adjustment of the target emissions intensity to the price on emissions.

Note that this approach assumes that the real price on emissions is not negative (that is, $\mathrm{T_{f,i,q}} \geq 0$). Also note that the inclusion of the first $\alpha_{\mathrm{f,i}}$ in equation (E8.23) re-indexes the index of emissions intensity to 1 when the price on emissions is zero.

Linearisation of underlying conceptual model

The change form of equation (E8.22) is:

$$\mathrm{d}\Lambda^{\mathrm{t}}_{\mathrm{f,i,q}} = \mathrm{ADJUSTMENT_{f,i}} \times \mathrm{d}\Lambda^{*}_{\mathrm{f,i,q}} + \left(1 - \mathrm{ADJUSTMENT_{f,i}}\right) \times \mathrm{d}\Lambda^{\mathrm{t-1}}_{\mathrm{f,i,q}} \quad \text{(E8.24)}$$

$$\mathrm{d}\Lambda^{\mathrm{t-1}}_{\mathrm{f,i,q}} = \Lambda^{\mathrm{t-1}}_{\mathrm{f,i,q}} - \Lambda^{\mathrm{t-2}}_{\mathrm{f,i,q}} \quad \text{(E8.25)}$$

Above the minimum, the index of the emissions intensity in year t is:

$$\Lambda^{*}_{\mathrm{f,i,q}} = \mathrm{e}^{\alpha_{\mathrm{f,i}} - \alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}}$$

This can be re-specified as:

$$\Lambda^{*}_{\mathrm{f,i,q}} = \mathrm{e}^{\alpha_{\mathrm{f,i}}} \times \mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}}$$

$$\Lambda^{*}_{\mathrm{f,i,q}} = \mathrm{F_{f,i}} \times \mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}} \quad \text{(E8.26)}$$

where:

$$\mathrm{F_{f,i}} = \mathrm{e}^{\alpha_{\mathrm{f,i}}}$$

The change in the target emissions intensity index in response to a change in the real price on emissions given by equation (E8.26) is

$$\mathrm{d}\Lambda^{*}_{\mathrm{f,i,q}} = \mathrm{F_{f,i}} \times \frac{\mathrm{d}\mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+\mathrm{T})^{\gamma_{\mathrm{f,i}}}}}{\mathrm{d}T_{f,i,q}} \quad \text{(E8.27)}$$

$$\mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}} = -\alpha_{\mathrm{f,i}} \times \gamma_{\mathrm{f,i}} \times \left(1 + T_{f,i,q}\right)^{\gamma_{\mathrm{f,i}}-1} \times \mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}} \times \mathrm{d}T_{f,i,q}$$

$$\frac{\mathrm{d}\mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+\mathrm{T})^{\gamma_{\mathrm{f,i}}}}}{\mathrm{d}T_{f,i,q}} = -\alpha_{\mathrm{f,i}} \times \gamma_{\mathrm{f,i}} \times \left(1 + T_{f,i,q}\right)^{\gamma_{\mathrm{f,i}}-1} \times \mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i}}}} \quad \text{(E8.28)}$$

Substituting equation (E8.28) into equation (E8.27) gives:

$$\mathrm{d}\Lambda^{*}_{\mathrm{f,i,q}} = -\mathrm{F_{f,i}} \times \alpha_{\mathrm{f,i}} \times \gamma_{\mathrm{f,i}} \times \left(1 + T_{f,i,q}\right)^{\gamma_{\mathrm{f,i}}-1} \times \mathrm{e}^{-\alpha_{\mathrm{f,i}} \times (1+T_{f,i,q})^{\gamma_{\mathrm{f,i,q}}}} \times \mathrm{d}T_{f,i,q} \text{(E8.29)}$$

The resulting percentage change in emissions intensity is:

$$\lambda_{f,i,q} = \frac{d\Lambda_{f,i,q}}{\Lambda_{f,i,q}} \times 100 \quad \text{(E8.30)}$$

Implementation in VURM

In terms of the notation used in the TABLO implementation:

$$T_{f,i,q} = 1000 \times \text{ETAXRATE}(f,i,q)$$

$$dT_{f,i,q} = 1000 \times \text{d\_gastax}(f,i,q)$$

$$\Lambda_{f,i,q} = \text{L\_LAMBDA}(f,i,q)$$

$$\Lambda_{f,i,q}^{t-1} = \text{L\_LAMBDA@1}(f,i,q)$$

$$\Lambda_{f,i,q}^{t-2} = \text{L\_LAMBDA@2}(f,i,q)$$

$$\Lambda_{f,i,q}^{*} = \text{L\_LAMBDAT}(f,i,q)$$

$$\text{MIN}\Lambda_{f,i} = \text{MINLAMBDA}(f,i)$$

$$d\Lambda_{f,i,q} = \text{d\_lambda}(f,i,q)$$

$$d\Lambda_{f,i,q}^{*} = \text{d\_lambdat}(f,i,q)$$

$\lambda_{f,i,q} = \text{agas}(f,i,q)$ for combustion emissions

$\lambda_{\text{"Activity"},i,q} = \text{agasact}(i,q)$ for non-combustion emissions

$$\alpha_{f,i} = \text{ALPHA}(f,i)$$

$$\gamma_{f,i} = \text{GAMMA}(f,i)$$

$$\text{ADJUSTMENT}_{f,i} = \text{ADJUSTMENT}(f,i)$$

$$F_{f,i} = \text{EXP}(\text{ALPHA}(f,i))$$

The parameters $\text{ALPHA}(f,i)$, $\text{GAMMA}(f,i)$ and $\text{ADJUSTMENT}(f,i)$ are read in from the file GDATA (headers “ALPH”, “GAMA” and “ADJM”, respectively). $\text{MINLAMBDA}(f,i)$ is read in from the file GDATA (header “MINL”).

Annex 8A.6: Relationship between marginal abatement and marginal abatement cost curves

This appendix links the marginal abatement curves implemented in VURM5 with the more familiar marginal abatement cost curves discussed in the climate change modelling literature.

Based on the marginal abatement curves discussed in section 8.6.1, table 8A.1 below shows, for a hypothetical emitting industry and fuel type, the costs and benefits in a typical year associated with increasing values of the real price on emissions (T). It assumes that: $\alpha_{f,i} = 0.03$, $\gamma_{f,i} = 0.7$, $MIN\Lambda_{f,i} = 0.3$, and $ADJUSTMENT_{f,i} = 1$ (thus $\Lambda_{f,i,q} = \Lambda^*_{f,i,q}$). If the price of emissions in this example rises from \$0 per tonne to \$100 per tonne, $\Lambda_{f,i,q}$ falls from an initial level of 1.00 to 0.48 (still above $MIN\Lambda_{f,i}$).

Table 8A.1:Hypothetical annual accumulated costs and savings from emissions abatement

(1) Real CO2-e price ($ per tonne)	*(2) $\Lambda_{f,i}$ (Index[a])*	*(3) Production ($)*	*(4) Emissions (Index[b])*	*(5) Abatement (Index[c])*	*(6) Cost ($ of output)*	*(7) Saving ($ of output)*	*(8) Surplus ($ of output)*
0	1.00	1	1.00	0.00	0.0	0.0	0.0
10	0.88	1	0.88	0.12	1.2	1.2	0.0
20	0.80	1	0.80	0.20	2.8	4.0	1.2
30	0.74	1	0.74	0.26	4.6	7.8	3.2
40	0.69	1	0.69	0.31	6.6	12.5	5.8
50	0.64	1	0.64	0.36	8.9	17.8	8.9
60	0.60	1	0.60	0.40	11.2	23.7	12.5
70	0.57	1	0.57	0.43	13.7	30.1	16.5
80	0.54	1	0.54	0.46	16.2	37.0	20.8
90	0.51	1	0.51	0.49	18.8	44.2	25.4
100	0.48	1	0.48	0.52	21.5	51.8	30.3

[a] Index of emissions intensity (tonnes of CO_2-e per unit of \$ of output). [b] Index of emissions per dollar of output. [c] Index of emissions abatement per dollar of output.

Column (1) and (3) are assumed. Column (2) is calculated using equations (E8.26) with the parameter values given in the text. Column (4) is column (2) times column (3). Column (5) is the change in emissions relative to emissions with a zero price from column (4). Column (6) is the accumulated incremental cost {for price p, = Cost(p-10) + p × (Abatement(p) – Abatement(p-10)}. Column (7) is column (1) times column (5). Column (8) is column (7) less column (6).

The index of emissions intensity ($\Lambda_{f,i,q}$) is linked to emissions per dollar of output (as per equation (E8.26)) to demonstrate how it operates. With remaining unchanged, emissions (expressed as an index) fall in line with $\Lambda_{f,i,q}$. The column labelled 'Abatement' shows the reduction in the emissions index from an initial value of 1.00. For example, at an emissions price of \$100, the index of emissions falls from 1.00 to 0.48, implying abatement of 0.52.

The column labelled 'Cost' is the accumulated cost of that abatement per dollar of output. It is assumed that the increment in 'Cost' is the carbon price times the incremental abatement. For example, when the price on emissions goes from \$50 per tonne to \$60 per tonne, the incremental abatement is 0.04 (= 0.40 – 0.36), implying an additional production cost of $2.30 per dollar of output (= $11.20 – $8.90 per dollar of output). As the price on emissions rises, the cumulative annual cost of abatement measures falls short of the total tax saving. For example, at a price of $60, accumulated saving is $23.70 per dollar of output (= $60 per dollar of output × 0.40), and the surplus of accumulated saving over accumulated cost is $12.50 per dollar of output (= $23.70 – $11.20 per dollar of output).

To show how the concept of emissions intensity as a function of carbon price (equation (E8.26) is related to the better-known concept of marginal abatement cost, it is assumed that output continues to be fixed at 1, with initial emissions (with no abatement) = 1. Therefore,

$$\text{Abatement} = 1 - \text{Emissions} \qquad \text{(E8.31)}$$

Note that both Emissions and Abatement vary between 0 and 1, and that, with unit output, the index of emissions is also an index of emissions intensity.

Figure 8A.1 shows a typical marginal cost of abatement curve for an emitting industry. Abatement is costly and the marginal cost rises with each additional unit of abatement. If a price T* is paid for a unit of abatement, then the emitter will chose Abatement = A, where marginal cost M = T*. At this point, the emitter is indifferent to small variations in A, but reaps a surplus (profit) by undertaking the abatement, since initial abatement is cheaper than the current level. The producer surplus is indicated by the shaded area in the diagram.

Figure 8A.2 implies a relationship between T and abatement, or between T and emissions intensity ($\Lambda_{f,i,q}$), since according to equation (E8.19):

$$\Lambda_{f,i,q} = \text{Emissions} = 1 - \text{Abatement} \qquad \text{(E8.32)}$$

Figure 8A.2 is figure 8A.1 with the horizontal axis reversed to take account of equation (E8.32), the axes swapped and then re-labelled. As can be seen, based on the assumptions above, the relationship in figure 8A.2 is very similar to the relationship in figure 8.3. Indeed, if drawn carefully, the two would be the same. Note that the shaded portion showing producer surplus for T = T* is the same concept of surplus as calculated in the numerical example above.

Figure 8A.1: Marginal abatement cost curve for the hypothetical industry

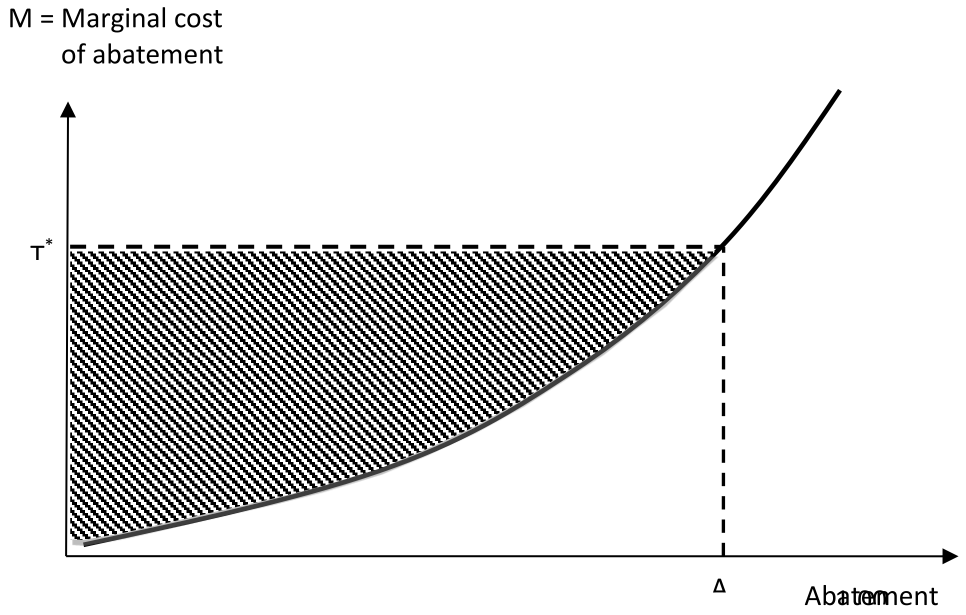
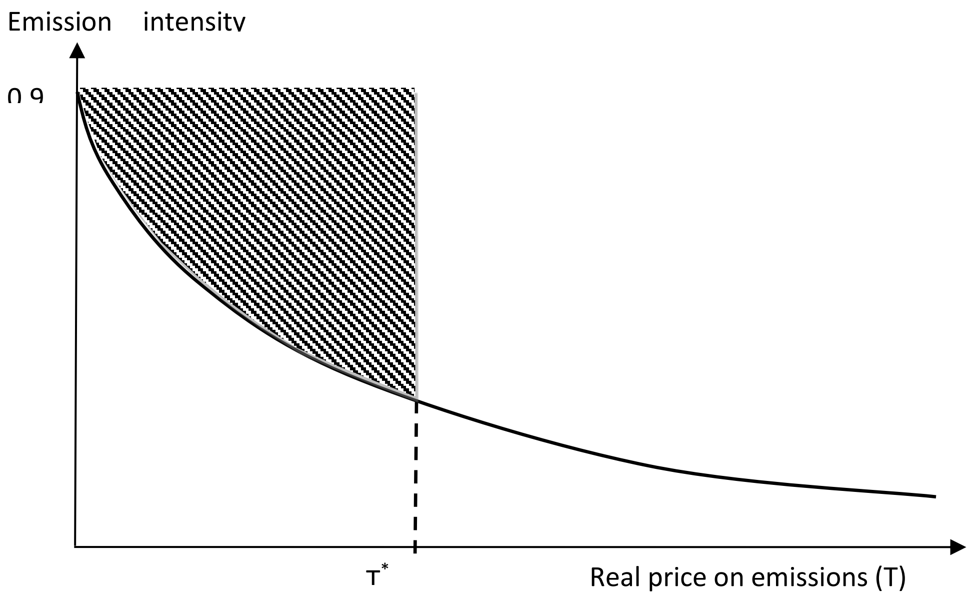


Figure 8A.2: Marginal abatement curve for the hypothetical industry



9 Closing the model

The number of variables (n) in the model exceeds the number of equations (m). Thus, to solve the model, (n-m) variables must be made exogenous. This choice of exogenous and endogenous variables is referred to as the model's closure.

As discussed in chapters 2 to 8, the model can be configured in many different ways. Many of these differences, such as whether capital stocks are able to adjust, reflect differences in economic environments being modelled (short run versus long run). Others relate to operationalising the cohort-based demographic module and/or export supply theory outlined in chapter 7. These different configurations give rise to many different closure permutations.

This chapter provides an overview of the main closures used in running VURM. It starts by documenting and describing the basic long-run, comparative-static closure that corresponds to the model described in chapter 3. It is 'long-run' in that it assumes that national aggregate employment is fixed and that national rates of return on capital determined by the BETA-mechanism (see Chapter 3). It is 'comparative-static' in that it does not allow full adjustment in capital and labour markets.

By swapping variables between exogenous and endogenous categories using the basic comparative-comparative-static long-run closure as a starting point, we develop a basic short-run, comparative-static closure. From this, a series of further closure swaps generates the closure used in running year-to-year simulations (referred to here as 'the year-to-year' closure), which forms the starting point for forecasting and policy closures.

The chapter then documents key extensions to each of these three basic closures.

9.1 Basic comparative-static closure

9.1.1 The basic long-run closure

Table 9.1 lists all of the exogenous variables in the benchmark model's standard basic long-run, comparative-static closure.

Model numeraire

We have to exogenously set a price. Section 1 of Table 9.1 sets the national CPI (natp3tot) as the model numeraire, the price that all other prices in the model are relative to. An obvious alternative is the nominal exchange rate (phi). Note that the results for real variables are unaffected by the choice of model numeraire.

Population, demography and labour supply (basic approach)

Section 2 of Table 9.1 covers the exogenous variables that relate to the supply of labour arising from demographic and labour supply changes. The supply of labour that results feeds through into regional labour markets.

The basic long-run, comparative-static closure holds regional populations (pop) and the ratio of working-age population to population in each region (r_wpop_pop) fixed. With the ratio of working-age population to total population in each region fixed, the working-age population is determined.

The three other exogenous variables, d_pop_g, d_pop_fm and d_pop_rm, in this section of the basic closure are used in the standard demographic module (chapter 6) that is run in year-to-year mode.[71]

The regional participation rate is also fixed by holding all shift terms (r_labsup_wpop) exogenous and equal to zero. Fixing regional working-age populations (wpop) therefore fixes regional labour supply (lab). Thus, under this approach, regional unemployment rates (d_unr) are determined endogenously.

The ratio of number of households to population (r_qhous_pop) is exogenous. Consequently, unless shocked, the number of households in each region moves in line with regional population in the default closure.

Variations of this basic closure are commonly used. In particular, regional population growth (pop) can be allowed to vary by setting regional participation rates (r_lab_wpop) exogenous. The adjustment in real wages across states, fpwage_io, can be fixed by allowing national employment to adjust, together with the ratio of the regional wage to the national wage. Furthermore, the national population, natpop, can be fixed and shocked by endogenising f_natpartrate so that the national participation rate adjusts.

Labour demand

Section 3 of Table 9.1 lists the exogenous variables that relate to the demand for labour by region. As discussed in chapter 3, the demand for labour in VURM is specified in terms of hours worked, which, in turn, is a function of the number of persons employed and average hours worked.

A key aspect of the long-run, comparative-static closure is that we assume that the exogenous shock under investigation does not affect aggregate employment in Australia, which is determined by demographic variables, participation rates and the natural rate of (national) unemployment. Consequently, the change in national employment (natx1lab_io) is exogenous in the long-run closure. It is also assumed that the national real wage rate (natrwage_c) varies to accommodate this assumption.[72] Note that, although the shock being analysed may not affect national employment, it does affect the regional distribution of employment (see below).

It is assumed that the ratio of total hours worked to total employment (r_ x1lab_x1emp) is fixed by industry, region and occupation. Given labour supply and unemployment, this fixes average hours worked by industry, region and occupation. With average hours worked (r_ x1lab_x1emp) fixed, determining employment (hours) also determines employment (persons) by industry, region and occupation.

It is assumed in the basic long-run, comparative-static closure that changes in unemployment rates by region and occupation (d_unro) are determined endogenously based on the interaction between the demand for, and supply of, labour.

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[71] These variables, respectively, enable the modelling of exogenous changes in natural growth (births less deaths), foreign migration and regional (interstate) migration.

[72] Wage rates by occupation, industry and region are related to the national CPI via equation *E_pwage*. In the basis closure, all of the shift terms on the RHS of *E_pwage* are exogenous except for the region-specific shifters, fpwage_io(q). The weighted average of fpwage_io(q) moves to achieve the change in national real wage rate necessary to accommodate the exogenous setting for national employment.

Wages

Section 4 of Table 9.1 covers the exogenous variables that relate to wages. In particular, they deal with the interaction between the demand for, and supply of, labour described above. With national employment (natx1lab_io) assumed fixed, the national real wage (natrwage_c) is determined endogenously.

We assume that interregional differentials in wages are exogenous. This is achieved by fixing exogenously the regional wage differentials r_wage_natwage1 for all but one state. Note that, fixing wage differentials in all but one state, effectively fixes the wage differential in the remaining state.

Capital markets and investment

Section 5 of Table 9.1 lists the exogenous variables that relate to the demand for capital and investment in regional industries. Because this closure is a long-run closure, we allow for capital accumulation and reallocation effects. For example, in simulating the effects of increased government expenditure in Victoria, we allow the capital stocks in Victorian industries to deviate from their basecase levels. We assume that, in the long run, the average rate of return on capital over all regional industries will be same with and without the shock under investigation. Thus, the variable d_natr1cap is exogenous. We do, however, allow increased rates of return to persist in regional industries experiencing relatively large stimuli to activity relative to those industries experiencing relatively small stimuli. Making exogenous the variable d_fr1cap, and thus activating equation *E_d_fr1cap*, achieves this. Alternatively, rates of return in regional industries can be held constant by making d_r1cap exogenous instead of d_fr1cap. While the former closure is shown in table 9.1, the alternative is also commonly implemented.

We assume that, investment in each regional industry in the long-run will deviate from the basecase in line with deviations in the industry's capital stock. Thus, the ratio variables, r_inv_cap_i, r_inv_cap_q, r_inv_cap_iq, and r_inv_cap are exogenous and typically set to zero. The implication of this assumption is that the rates of growth of industries' capital stocks do not deviate from basecase rates of growth.

The next three exogenous variables — twistlk, twistlk_i and nattwistlk_i — enable non-price-based changes to occur in the mix of labour and capital used in production. A positive value indicates an increase in demand for labour relative to capital (that is, an increase in the labour-capital ratio) and a negative value the converse.

Demand for other factors of production

Section 6 of Table 9.1 lists miscellaneous exogenous variables that are concerned with the demand for agricultural land and other costs used in production. It is assumed that the stock of land used in production (x1lnd) is fixed for each regional agricultural industry. Setting f1octinc exogenous links the change in the unit-income on other costs (p1octinc) to changes in the regional CPI (p3tot).

Technological change

Section 7 of Table 9.1 covers exogenous variables that relate to technological-change in the use of various inputs in production. Most of the variables are specified at the regional or national level. While VURM does not generally explain changes in technology, the inclusion of these terms allows the user to simulate the effects of a wide variety of exogenously given changes in technology. All of these variables are naturally exogenous.[73]

The first subsection of this block deals with technological-change in the use of labour in production. The second subsection deals with the use of the remaining primary factors — capital, agricultural land and other costs — in production (a1cap, a1lnd and a1oct, respectively). The third subsection deals with the use of all primary factors in production, including labour. The fourth subsection deals with the use of intermediate inputs used in production.

Domestic final absorption

Section 8 of Table 9.1 covers exogenous variables that relate to the size and composition of aggregate domestic absorption in each region.

The variables in the first subsection of this block deal with regional household consumption. The variable a3tot representing consumer tastes and is naturally exogenous. The variable apc (along with the national shifter natapc) is the average propensity to consume out of household disposable income. Setting this exogenously to zero activates equation *E_w3lux* that links changes in nominal private consumption (w3tot) to changes in household disposable income (whinc_dis) in each region.

The variables in the second subsection deal with regional government demand (final consumption expenditure). We assume that the ratio of real regional government consumption to real private consumption is fixed. Hence, f5tot appears in the exogenous list. The composition of regional consumption expenditure is fixed by the inclusion of f5a as an exogenous variable.

The variables in the third subsection deal with federal government demand and their treatment is analogous to those for regional government final consumption expenditure. Hence, f6tot and f6a are exogenous in the basic long-run, comparative-static closure.

The variable in the final subsection deals with changes in household inventories (stocks). The variable d_fx7r is set exogenous to force stocks to be indexed to domestic output via equation E_d_x7r.

International trade and foreign income accounts

Section 9 of Table 9.1 covers exogenous variables that relate to international trade and the foreign income accounts.

The variables in the first subsection of this block are all shift terms that enable exports to be determined by VURM's downward sloping export demand curves. As VURM contains no equations describing movements in foreign demand schedules and changes in foreign supply conditions, the various export demand shifters (for example, f4p and natf4p) are treated as exogenous variables.

The variable in the second subsection, natf4p_tot, is a shift-term to endogenously change the world demand for specific commodities linked to changes in the terms of trade. This enables exports of particular regional commodities specified in the coefficient TOT_DUMMY to adjust to accommodate any exogenously imposed change in the terms of trade.

The variable in the third subsection, natp0cif, makes the foreign currency prices of imports exogenous.

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[73] VURM can model technological change in the area of greenhouse gas emissions endogenously (discussed in chapter 8).

The exogenous variables in the fourth subsection enable non-price-based changes in the mix of domestic and imported inputs. A positive shock increases the ratio of imports to domestically-produced inputs, and a negative one has the converse effect.

The variables in the fifth subsection deal with the foreign income accounts of the Balance of Payments and are exogenous in the basic long-run, comparative-static closure.

Taxes (model core)

Section 10 of Table 9.1 cover exogenous variables that relate to tax rates on commodity sales and factor incomes in the model core (as opposed to those in the *Government Finance Statistics* module). These tax rates are exogenous in the basic long-run, comparative-static closure.

The variables in the first subsection of this block deal with product taxes, and those in the second with taxes on production.

Although tax rates are naturally exogenous to a model like VURM, one can imagine a simulation in which some tax rates are treated endogenously. For example, in many simulations, it is appropriate to assume that the federal government's budget balance is unaffected by the shock. To achieve this, we could fix the budget balance exogenously at zero change and allow income tax rates (on labour and capital) to be endogenous. The closure swap would be: budget balance exogenous, and the general shift in income tax rates d_tinc endogenous; d_tlabinc and d_tgosinc endogenous, and d_ftlabinc and d_ftgosinc exogenous (see equations *E_d_tla*binc and *E_d_tgosinc*). We could also achieve this by allowing lump sum transfers to households to be endogenous.

Government finance module

Section 11 of Table 9.1 covers exogenous variables that relate to the *Government Finance Statistics* module described in chapter 4. The section is divided into four subsections:

- shift-terms in the government revenue equations;
- shift-terms in the government expenditure equations;
- shift-terms for the average rates of personal benefit payments (unemployment benefits, disability support pensions, age pensions and other personal benefit payments); and
- Shift-terms in the personal benefit payment equations.

All of these variables are naturally exogenous.

Household income accounts

Section 12 of Table 9.1 consists of a single exogenous variable, d_whinc_500, which can be used to impose exogenous changes in household income.

Year-to-year simulation module

Section 13 of Table 9.1 cover exogenous variables that relate to the conducting year-to-year dynamic simulations (discussed in section 9.2). These exogenous terms (mostly exogenous shift terms) are included in the default long-run, comparative-static closure to turn off the relevant dynamic equations so that the model can solve in comparative-static mode.

Cohort-based demographic module

Section 14 of Table 9.1 covers exogenous variables that relate to the cohort-based demographic module described in chapter 7. These variables — covering age and region-specific fertility rates, age, gender and region-specific mortality rates and age and region-specific net overseas migration — are naturally exogenous.

Export transformation

Section 15 of Table 9.1 covers exogenous variables relating to the export transformation theory described in chapter 7. In the default long-run, comparative-static closure, the export transformation theory described in chapter 7 is not operational. Consequently, the markup on export sales (d_p4markup) is exogenous so that the export basic price (p4) moves in line with the domestic basic price (p0a). The twist term towards local sales away from export sales (locsaletwist) is also exogenous.

Greenhouse emissions module

The final section, section 16, in Table 9.1 covers exogenous variables that relate to the greenhouse module described in chapter 8. It is divided into three subsections covering variables relating to:

- linking an Australian emissions trading scheme to an international emissions trading scheme;
- the shielding of industries from the pricing of greenhouse emissions; and
- emissions-related cost-neutral and other technical change.

Table 9.1: Exogenous variables in the basic long-run, comparative-static closure of VURM

```
! (1) Model numeraire
!==================

    natp3tot            ! National CPI is the numeraire

! (2) Population, demography and labour supply (basic approach)
!=====================================================

! Population and demography
!--------------------------------------
! In this comparative-static structural closure, we fix population and its components
    pop                 ! Population
    d_pop_g             ! Change in regional population due to natural growth
    d_pop_fm            ! Change in regional population due to foreign migration
    d_pop_rm            ! Change in regional population due to regional migration

! We link changes to the working age population to changes in population
    r_wpop_pop          ! Ratio of working age population to changes in population

! We link changes in population to changes in the number of households
    r_qhous_pop         ! Ratio of number of households to population

! Labour supply
!--------------------
! We fix labour supply by region and occupation
    lab                 ! Labour supply by region and occupation

! (3) Labour demand
!================

! National employment assumed fixe din the long-run
    natx1lab_io         ! National employment (long-run assumption)

! At the regional level, with wage rates and hence unit costs of employment
! determined, employment (hours) is also set. The following determines
! employment (persons). It also determines unemployment rates by region, given
! that labour supply has been determined via the three exogenous settings shown
! above.
    r_x1lab_x1emp ! Ratio of hours worked to persons employed fixed by region
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
! (4) Wages
!=========

! The structural closure is a long-run, comparative-static closure. At the national
! level, employment (natx1lab_io) is fixed and the national real wage rate from
! the consumer point of view (natrwage_c) is endogenous. Given an outcome for
! natp3tot, natpwage_io is determined. The following rule allocates natpwage_io to
! regions by assuming that the wage differentials in regions 2-8 are exogenous
! (fixing the wage differential in the remaining region (region 1))
    r_wage_natwage1(ROSTATE)! Region wage differential

! Wage shift variables are naturally exogenous
    natfpwage_i     ! Occupation shift in pwage/P3TOT ratio
    natfpwage_io    ! National ratio of PWAGE to P3TOT
    fpwage          ! Ratio of PWAGE to NATP3TOT, specific to i,q & o

! (5) Capital markets and investment
!============================

! We put in place the BETA mechanism for allocating capital in a long-run
! comparative-static simulation
    d_fr1cap        ! Shifter in mechanism for distributing ROR in long-run CSS
    d_natr1cap      ! Shifter in rate of return beta mechanism

! With capital and rate of return reconciled, we determine investment at
! the industry level by fixing ratios of capital to investment
    r_inv_cap_i     ! Shifts in ratio of investment to capital, specific to q
    r_inv_cap_q     ! Shifts in ratio of investment to capital, specific to i
    r_inv_cap_iq    ! Shifts in ratio of investment to capital, specific to nothing
    r_inv_cap       ! Shifts in ratio of investment to capital, specific to i and q

! Exogenous changes in primary factor use
!-------------------------------------------------------
    twistlk         ! Twist in labour/capital ratio
    twistlk_i       ! Region specific general shift in labour/capital ratio
    nattwistlk_i    ! National twist in labour/capital ratio
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
! (6) Demand for other factors of production
!===================================

! Agricultural land
!-----------------------
    x1lnd            ! Quantity of agricultural land

! Other costs
!----------------
    f1octinc         ! Ratio of price of other costs to CPI

! (7) Technological change
!====================

! Primary factor saving technological change
!-------------------------------------------------------
    a1lab            ! Labour-saving technological change (- means improvement)
    a1lab_i          ! Labour-saving technological change (- means improvement)
    a1lab_o          ! Labour-saving technological change (- means improvement)
    a1lab_io         ! Labour-saving technological change (- means improvement)
    nata1lab_i       ! Labour-saving technological change (- means improvement)
    nata1lab_o       ! All occupation labour-saving, technological change (- means improvement)
    nata1lab_io      ! Labour-saving, all industry, all region technological change (- means
                     improvement)
    a1cap            ! Capital-saving technological change (- means improvement)
    a1lnd            ! Land-saving technological change (- means improvement)
    a1oct            ! Other-cost-saving technological change (- means improvement)

    a1prim           ! All-factor-saving technological change (- means improvement)
    a1prim_i         ! State-wide all-factor-saving technological change (- means improvement)
    nata1prim        ! National primary factor augmenting technical change by industry (- means
                     improvement)
    nata1prim_i      ! National equivalent of a1prim_i (- means improvement)

! Intermediate input saving technological change
!------------------------------------------------------------
    aind             ! All intermediate input-augmenting technical change
    a1o              ! Intermediate input-augmenting technical change

    acom             ! Commodity c-using technical change
    acomind          ! Commodity c-using, industry-specific technical change
    natacom          ! National commodity c-using technical change

    a8a              ! Generator-c augmenting technical change in NEM-market demand
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
! (8) Domestic final absorption
!========================

! Household consumption
!---------------------------------
   a3tot        ! Consumer tastes
   apc          ! Average propensity to consume (could be swapped with x3tot)
   natapc       ! National shift in average household propensity to consume

! Regional government demand (model core)
!-------------------------------------------------------------
   f5tot        ! Shift term for regional government consumption
   f5a          ! Shift term for regional government consumption by c
   natf5tot     ! Overall shift term for state government consumption

! Federal government demand (model core)
!----------------------------------------------------------
   f6tot        ! Shift term for federal government consumption
   f6a          ! Shift term for federal government consumption by c
   natf6tot     ! Overall shift term in federal government consumption

! Change in inventories
!------------------------------
   d_fx7r       ! Shift term for change in inventory accumulation

! (9) International trade and foreign income accounts
!==========================================

! Export demand
!----------------------
   f4p          ! Vertical (price) shift in individual export demand function
   f4q          ! Horizontal (quantity) shift in individual export demand function
   natf4p       ! Commodity-specific vertical (price) shift in export demand function
   natf4q       ! Commodity-specific horizontal (quantity) shift in export demand function
   natf4p_c     ! National vertical (price) shift in export demand
   natf4q_c     ! National horizontal (quantity) shift in export demand
   f4p_c        ! Region-specific vertical (price) shift in export demand
   f4q_c        ! Region-specific horizontal (quantity) shift in export demand
   f4q_ntrad    ! Horizontal (quantity) shift in non-traditional export function
   f4p_ntrad    ! Vertical (price) shift in non-traditional export function
   fntrad       ! Shift in composition of non-traditional bundle
   f4q_tour     ! Horizontal (quantity) shift in tourism export demand function
   f4p_tour     ! Vertical (price) shift in tourism export demand function
   ftour        ! Shifts in composition of tourism export bundle
   fcommunic    ! Shift in communications export function
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
    fothtrans       ! Shift in other transport export function
    fwattrans       ! Shift in water transport export function

! Exports of particular commodities can be allowed to adjust to accommodate exogenously imposed
changes in the terms of trade shocks
    natf4p_tot      ! World demand shift for specific commodities (linked to terms of trade)

! Import demand
!----------------------
    natp0cif        ! Foreign prices of imports

! Supply sourcing/taste changes
!-----------------------------------------
    twistsrc        ! Twist in import/domestic ratio
    twistsrc_c      ! Region specific general shift in import/domestic ratio
    nattwistsrc_c   ! National twist in ratio of imports/domestic-produced inputs

! Foreign income accounts
!----------------------------------
    d_FORINT        ! Foreign rate of interest on net stock of foreign liabilities
    d_FORSHR        ! Change in foreign share of capital in i,q (number like 0.05)
    d_NFE           ! Net stock of foreign equity
    d_NFD           ! Net stock of foreign debt
    d_FNCT          ! Exogenous shift in net current transfers from abroad
    d_FNATNCT       ! Exogenous shift in net current transfers - National
    d_VALD          ! Change in valuation effects for foreign debt income
    d_VALE          ! Change in valuation effects for foreign capital income

! (10) Taxes (model core)
!===================

! Product taxes
!-------------------
    d_t1F_csiq      ! %-point change in Federal sales tax rate(not GST)
    d_t2F_csiq      ! %-point change in Federal sales tax rate(not GST)
    d_t3F_csq       ! %-point change in Federal sales tax rate(not GST)
    d_t4f_cs        ! %-point change in Federal sales tax rate(not GST)
    d_tF            ! %-point change in Federal sales tax rate(not GST)
    d_tFq           ! %-point change in Federal sales tax rate(not GST), by region
    d_tSq           ! %-point change in State sales tax rate, by region
    d_tFc           ! %-point change in Federal sales tax rate(not GST), by commodity
    d_tSc           ! %-point change in State sales tax rate, by commodity
    d_tScq          ! %-point change in State sales tax rate, by commodity and region
    d_t1F_siq       ! %-point change in Federal sales tax rate(not GST), user 1, specific to c
    d_t1S_siq       ! %-point change in State sales tax rate, user 1, specific to c
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
    d_t1F_si      ! %-point change in Federal sales tax rate(not GST), user 1, specific to c
    d_t1S_si      ! %-point change in State sales tax rate, user 1, specific to c
    d_t2F_siq     ! %-point change in Federal sales tax rate(not GST), user 2, specific to c
    d_t2S_siq     ! %-point change in State sales tax rate, user 2, specific to c
    d_t2F_si      ! %-point change in Federal sales tax, user 2, specific to c
    d_t2S_si      ! %-point change in State sales tax rate, user 2, specific to c
    d_t3F_sq      ! %-point change in Federal sales tax rate(not GST), user 3, specific to c
    d_t3S_sq      ! %-point change in State sales tax rate, user 3, specific to c
    d_t3F_s       ! %-point change in Federal sales tax rate(not GST), user 3, specific to c
    d_t3S_s       ! %-point change in State sales tax rate, user 3, specific to c
    d_t4f_s       ! %-point change in Federal tax rate(not GST) on exports, specific to c
    d_tGST        ! %-point change in GST all regions
    d_tGSTq       ! %-point change in GST, specific to q
    powtar        ! Percentage change in the power of the tariff

! Taxes on production
!-----------------------------
    d_t1capF_i    ! %-point change in tax on capital input in region q - Federal
    d_t1capS_i    ! %-point change in tax on capital input in region q - State
    d_t1labS_i    ! %-point change in payroll tax in region q
    d_t1labF_i    ! %-point change in fringe-benefit tax in region q
    d_t1lndF_i    ! %-point change in tax on land input in region q - Federal
    d_t1lndS_i    ! %-point change in tax on land input in region q – State
    d_t1octF_i    ! %-point change in other-cost tax (Federal) in region q
    d_t1octS_i    ! %-point change in other-cost tax (state) in region q
    d_t1capF_iq   ! %-point change in tax rate on capital input – Federal
    d_t1capS_iq   ! %-point change in tax rate on capital input - State
    d_t1labS_iq   ! %-point change in payroll tax rate
    d_t1labF_iq   ! %-point change in fringe-benefit tax rate
    d_t1lndF_iq   ! %-point change in tax on land tax rate - Federal
    d_t1lndS_iq   ! %-point change in tax on land tax rate - State
    d_t1octF_iq   ! %-point change in other-cost tax rate (Federal)
    d_t1octS_iq   ! %-point change in other-cost tax rate (state)

    d_tlabinc     ! %-point change in tax on labour income
    d_tgosinc     ! %-point change in tax on non-labour income
    d_tinc        ! %-point uniform shift in tax on labour and non-labour income
    d_t0          ! Allows for fixing of payroll tax and income tax rates

    d_ft1capF     ! Allows for flexible handling of d_t1capF
    d_ft1capS     ! Allows for flexible handling of d_t1capS
    d_ft1labS     ! Allows for flexible handling of d_t1labS
    d_ft1labF     ! Allows for flexible handling of d_t1labF
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
    d_ft1lndF        ! Allows for flexible handling of d_t1lndF
    d_ft1lndS        ! Allows for flexible handling of d_t1lndS
    d_ft1octF        ! Allows for flexible handling of d_t1octF
    d_ft1octS        ! Allows for flexible handling of d_t1octS

! (11) Government finance module
!===========================

! Government revenue shift terms
!--------------------------------------------
    f_wgfsi_114      ! Shift-term: Tax on international trade
    f_wgfsi_118      ! Shift-term: Taxes on goods and services – other
    df_wgfsi_121     ! Shift-term: Payroll tax
    df_wgfsi_122     ! Shift-term: Property tax
    f_wgfsi_131      ! Shift-term: Income tax - individuals
    f_wgfsi_132      ! Shift-term: Income tax - enterprises
    f_wgfsi_133      ! Shift-term: Income tax - non-residents
    f_wgfsi_210(Rostate)! Shift-term: Federal grants to states - GST-tied
    f_wgfsi_220(Rostate)! Shift-term: Federal grants to states - Other current
    f_wgfsi_300      ! Shift-term: Sales of goods and services
    f_wgfsi_400      ! Shift-term: Interest received
    f_wgfsi_500      ! Shift-term: Other revenues

! Government expenditure shift terms
!------------------------------------------------
    f_wgfse_100      ! Shift-term: Gross operating expenses
    f_wgfse_312      ! Shift-term: Federal non-GST current grants to states
    f_wgfse_320      ! Shift-term: Federal grants to local governments
    f_wgfse_330      ! Shift-term: Grants to universities
    f_wgfse_340      ! Shift-term: Grants to private businesses
    f_wgfse_400      ! Shift-term: Property expenses
    f_wgfse_500      ! Shift-term: Subsidy expenses
    f_wgfse_600      ! Shift-term: Capital transfers
    f_wgfse_700      ! Shift-term: Other government expenditure
    d_wgfse_800      ! GFSE: Government handouts

! Rate of personal benefit payment shift terms
!----------------------------------------------------------
    benefitrate1     ! Average rate of unemployment benefit
    benefitrate2     ! Average rate of disability support pension
    benefitrate3     ! Average rate of age pension
    benefitrate4     ! Average rate of other personal benefit
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
! Personal benefit payment shift terms
!--------------------------------------------------
    f_whinc_210     ! Shift-term: Unemployed-benefit payments
    f_whinc_220     ! Shift-term: Disability support pension payments
    f_whinc_230     ! Shift-term: Age pension payments
    f_whinc_240     ! Shift-term: Other personal benefit payments

! (12) Household income accounts
!===========================

    d_whinc_500     ! Exogenous change in household income

! (13) Year-to-year simulation module
!================================

    d_unity         ! Dummy (homotopy) variable set to one for year-to-year simulations

! Capital growth between start and end of solution year exogenous
    d_k_gr          ! d_k_gr mechanism turned off for comparative-static simulations

! Expected equilibrium rate of return linked to exogenous capital growth
    d_feeqror_iq    ! Shift term in EROR/K_GR trade-off equation, specific to nothing
    d_feeqror_i     ! Shift term in EROR/K_GR trade-off equation, specific to q

! Exogenous variables relating to the labour supply schedule. These allow
! us to transfer results from forecast simulations to policy simulations
! when the model operates in year-to-year mode.
    f_emp           ! Ratio of forecast value of natl to deviation value of natl
    f_rw            ! Ratio of forecast value of rwage to deviation value of rwage
    a1              ! All input-augmenting technical change in production
    a2              ! All input technological change in investment - neutralises acom

! (14) Cohort-based demographic module
!================================

    d_projection    ! Turn PROJECTION year on and off

! Fertility
!----------
    nextpopalpha    ! Sex ratio (POPALPHA) in the next simulation year
    nexttfr         ! Total fertility rate in the next simulation year
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
! Mortality
!----------
   f_mort_a       ! Gender-specific change in mortality rate - common to age
   f_mort_g       ! Age-specific change in mortality rate - common to gender
   f_mort1        ! Shift term to turn on/off mortality rate improvement factor
   f_mrtb1        ! Shift term to turn on/off mortality rate improvement - newborn babies
   f_natmort      ! National change in mortality rate - all ages
   f_natmortb     ! National change in mortality rate - newborn babies
   mortimprove    ! Percentage change in mortality rate by state

! Net overseas migration
!--------------------------------
   f_natnom       ! National net overseas migration shift term (000)
   f_nom          ! Net overseas migration shift term by age, gender & state (000)
   f_nom_s        ! Net overseas migration shift term by state (000)

! Labour supply
!-------------------
   f_natlab_o_rd  ! Links national labour supply to demographic module

! Participation rates
!-------------------------
   f_natpartrate  ! Shift term - National participation rate (% change)
   f_partrate_q   ! Shift term - Participation rate by age & gender (% change)
   f_partrate     ! Shift term - Participation rate by age, gender & state (% change)

! (15) Export transformation
!======================

   d_p4markup     ! Markup on exporting (additional profit margin)
   locsaletwist   ! Twist towards local sales and away from export sales!
   f_x4r1         ! Shift-term to turn on/off conventional export demand

! (16) Greenhouse emissions module
!=============================

! Linking an Australian ETS to an international emissions trading scheme
!------------------------------------------------------------------------------------------
   d_CrunchETS    ! Forces domestic ETS price to foreign ETS price when 1
   d_CrunchUSR    ! Forces domestic ETS price onto user u when 1
   d_gasincfor    ! Change in value of net foreign sales of permits
   d_gastax       ! Change in Australian specific tax on emissions ($ per tonne)
   d_gastaxdom    ! Change in domestic price of emissions permits (scalar)
   d_gastaxfor    ! Change in foreign-currency global price of permits
```

Table continued on next page

Table 9.1 (continued): Exogenous variables in the basic long-run, comparative-static closure

```
    d_limimpmax   ! Maximum change (kt) in limited imported permits
    d_qgasfor     ! Change in quantity of net foreign sales of permits (kt)

! Shielding
!------------
    d_fgrandinc   ! Exogenous means that permit revenue is grandfathered
    d_lumpinc     ! Endogenous means that permit revenue is handed 100 per cent to households
    d_t3Fcomp     ! Permit-revenue compensation for deltax3

! Cost-neutral technical change
!----------------------------------------
    agas          ! Technological change in combustion emissions
    atrans        ! Allows for changes in distribution and transmission losses
    agreen        ! Commodity-augmenting technical change in response to price
    agasact       ! Non-fuel burning emissions per unit of activity
;
rest endogenous ;
```

9.1.2 The basic short-run closure

The basic long-run, comparative-static closure can be easily adapted to model a short-run modelling environment in which there is limited scope for capital and labour markets to adjust. The two key assumptions that are needed to produce a short-run, comparative-comparative-static closure are that:

- there is no growth in the capital stock (x1cap) by allowing the rate of return (d_fr1cap) to be endogenous and adjust in response to changes in the demand for capital; and
- the national wage (natrwage_c) is fixed by allowing national employment (natx1lab_io) to be endogenous and adjust in response to changes in the demand for labour.

The short-run closure is typically taken as representing the effects over one year of the policy under consideration.

The required changes to turn the basic long-run, comparative-static closure into the basic short-run closure are set out in table 9.2.

Table 9.2: Variable swaps from the basic long-run, comparative-static closure to obtain the basic short-run, comparative-static closure

Exogenous	*Endogenous*	*Purpose*
x1cap	d_fr1cap	Capital fixed and rates of return endogenous
natrwage_c	natx1lab_io	National employment endogenous and national real wage rate fixed

9.2 The basic year-to-year (dynamic) closure

9.2.1 The basic closure

The basic year-to-year (dynamic) closure builds on the basic short-run, comparative-static closure to introduce dynamic adjustment to the changes in population, labour force, capital stock and foreign liabilities in each simulation year. The resulting dynamic simulations represent a series of interlinked one-year simulations.

The changes to the benchmark long-run, comparative-static closure to introduce the basic year-to-year (dynamic) closure are specified in table 9.3.

Population, demography and labour market

Regional populations are modelled endogenously in the basic year-to-year (dynamic) closure by endogenising regional population growth (pop) and by exogenising the dynamic population switch (f_pop). This means that the regional populations are determined by the basic demographic module described in chapter 4. Changes in regional populations feed through into labour supply through the exogenous ratios of working-age population to population (r_wpop_pop) and labour supply to working-age population (r_lab_wpop) (the regional participation rate). National employment (natx1lab_io) is allowed to adjust in response to changes in the demand for labour, with the national wage (natrwage_c) fixed.

This basic approach to the dynamic modelling demographic and labour market change can be extended by using the cohort-based demographic module that forms part of VURM. The required closure changes are discussed in sections 9.3.1 and 9.3.2.

Capital stock and investment

The capital available for production (x1cap) is linked to the capital in the previous year by making it endogenous and making f_x1cap exogenous. Furthermore, investment in each year is linked to the expected rate of return. This is done by first exogenising the shift in investment (d_feeqror) in place of the ratio of investment to capital (r_inv_cap). Secondly, we endogenise the change in capital between the start and the end of the year (d_k_gr) and exogenise the investment dynamic switch variable (d_fk_gr).

Foreign liabilities

The growth in the net stock of foreign equity (d_NFE) and in the net stock of foreign debt (d_NFD) are both endogenous in the year-to-year closure, linking them to the dynamic foreign liability mechanisms by exogenising the switch variables, d_FNFE and d_FNFD, respectively.

Table 9.3: Variable swaps from the basic short-run, comparative-static closure to obtain the basic year-to-year closure

Exogenous	*Endogenous*	*Purpose*
! Regional population		
!---------------------------		
f_pop	pop	Regional population growth linked to year-to-year variable pop_t
! Capital in year t determined by capital and investment in year t-1		
!--		
f_x1cap	x1cap	Capital in year t determined by capital and investment in year t-1
! Investment in year t determined by expected rate of return		
!--		
d_feeqror	r_inv_cap	Investment in year t determined by expected rate of return
d_fk_gr	d_k_gr	Investment in year t determined by expected rate of return
! Net stock of foreign equity and debt		
!--		
d_FNFE	d_NFE	Net stock of foreign equity
d_FNFD	d_NFD	Net stock of foreign debt

9.2.2 Other year-to-year closure changes

The year-to-year closure outlined above can be extended to include the greenhouse emissions-related cost-neutral and other technical changes described in chapter 8 by making the closure changes outline din table 9.4.

Table 9.4: Variable swaps to introduce the greenhouse module-related technical changes into the basic year-to-year long-run, comparative-static closure

Exogenous	*Endogenous*	*Purpose*
f_agreen	agreen	Switch on the agreen mechanism (commodity augmenting tech change in response to price)
f_agasact	agasact	Allow for endogenous change in non-fuel burning emissions per unit of activity
d_fa1	a1	Allows for production input-saving technological change to offset changes in acom, natacom, acomin and agreen
d_fa2	a2	Allows for investment input-saving technological change to offset changes in acom and natacom

9.3 Extensions to the basic closure

9.3.1 Extensions to the basic long-run, comparative-comparative-static closure

Introduce flexible regional labour supply and population

Additional labour market flexibility can be introduced into the basic long-run, comparative-static closure assumptions by allowing the supply of labour by occupation in each region (lab) to respond positively, or negatively, to the differences between the nominal occupational wage in that region (pwage_i) and the national average nominal wage for that occupation (natpwage_i). This is achieved by endogenising the occupational supply of labour in each region (lab) and exoegnising the change in the occupational unemployment rate in each region (d_unr). Given that the regional working-age population (wpop) is fixed, the labour force participation rate by region (r_lab_wpop) is determined endogenously.

This approach can be extended by assuming that those not in the labour force move with changes in the supply of labour in that region, such that the working-age population (wpop) and population (pop) in each region also moves in the same proportions. This is achieved by exoegnising the labour force participation rate by region (r_lab_wpop) and the regional population (pop). This approach has been used by the Productivity Commission on a number of occasions (PC 2006, 2012).

The required closure changes to introduce flexible regional labour supply and population into the basic long-run, comparative-static closure are detailed in table 9.5.

Table 9.5: Variable swaps to introduce flexible regional labour supply and population into the basic long-run, comparative-static closure

Exogenous	*Endogenous*	*Purpose*
! Introduce labour mobility		
!------------------------------------		
d_unro	lab	Allow the regional supply of labour by occupation to move by holding regional unemployment rates by occupation fixed
! Fix regional wage differentials		
!---		
fpwage_io(State)	natx1lab_io	Fix real wage adjustments across regions by fixing the wage shift term for one arbitrary state (the set STATE) and allowing national employment to vary
fpwage_io(RoState)	r_wage_natwage1(RoState)	Fix real wage adjustments across states by fixing the wage shift term for all remaining states by allowing the ratio of regional wages to the national wage to vary
! Allow regional populations to vary		
!---		
r_lab_wpop	pop	Allow regional population growth to be determined endogenously by fixing regional participation rates

Fixed national population

Building on the closure changes outlined in the preceding section, that national population (natpop) can be held fixed in comparative-static simulations by drawing on part of the labour market extensions outlined in chapter 7. This can be achieved by setting the national population (natpop) exogenous and the change in the national labour force participation rate (f_natpartrate) endogenous. The required closure change is detailed in table 9.6.

Table 9.6: Variable swaps to introduce a fixed national population into the basic long-run, comparative-static closure with flexible labour supply and regional populations

Exogenous	*Endogenous*	*Purpose*
! Hold the national population fixed		
natpop	f_natpartrate	Hold the national population fixed by allowing the economy-wide participation rate to vary

Export supplies

The closure changes to the basic long-run, comparative-comparative-static closure that are needed to activate the export supply theory described in chapter 7 are specified in table 9.7. These changes can be made at the industry level and do not need to apply to all industries.

Table 9.7: Variable swaps from the basic long-run, comparative-static closure to activate the export supply theory

Exogenous	*Endogenous*	*Purpose*
f_x4r2	d_p4markup	Markup adjusts to accommodate any shocks to export price
p4a	f4p	Allows A$ purchasers' price of exports to be specified by allowing for an exogenous shift in world demand

9.3.2 Extensions to the basic year-to-year closure

The cohort-based demographic module described in chapter 7 is made operational by setting the coefficient ISDEMOD=1. This links the coefficients for regional population (C_POP), regional working-age population (C_WPOP) and regional labour supply (LABSUP) to the levels in the cohort-based demographic module.

Linking the cohort-based demographic module involves three steps.

First, the percentage change in regional population in each region in the model core (pop) is linked to the percentage change in regional population in each region (pop_rd) in the cohort-based demographic module, by activating equation *E_pop*. The required closure change involves setting the shift term f_pop_rd exogenous and setting f_pop endogenous to turn the year-to-year equation *E_f_pop*.

Second, the percentage change in regional working-age population in each region in the model core (wpop) is linked to the percentage change in regional working-age population in each region (wpop_rd) in the cohort-based demographic module, by activating equation *E_wpop*. The required closure change involves setting the shift term f_wpop_rd exogenous and setting the ratio of working-age population to population (r_wpop_pop) endogenous.

Third, the percentage change in national labour supply in the model core (natlab_o) is linked to the percentage change in the national labour supply implied by: (a) the regional working-age population in the cohort-based demographic module; and (b) the age, gender and region-based labour force participation rates in the cohort-based demographic module. This involves activating equation *E_f_natlab_o_rd*. The required closure change involves setting the shift term f_natlab_o_rd exogenous and setting the national supply of labour (natlab_o) endogenous.

The accompanying closure changes that are also required are set out in table 9.8.

Table 9.8: Variable swaps from the basic year-to-year closure to introduce the cohort-based demographic module in the year-to-year closure

Exogenous	*Endogenous*	*Purpose*
! Year-to-year simulations		
!----------------------------------		
! Link regional population to cohort-based demographic module		
f_pop_rd	f_pop	Regional population growth determined by cohort-based demographic module
! Link working-age population to cohort-based demographic module		
f_wpop_rd	r_wpop_pop	Working age population growth determined by cohort-based demographic module
! Link national labour supply to cohort-based demographic module		
f_natlab_o_rd	natlab_o	National labour supply growth determined by cohort-based demographic module

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Appendix A Computational method, interpretation of solutions

A.1 Overview

The levels form of many of the equations expressed in MMRF are non-linear, which presents computational difficulties. However, following Johansen (1960), the model is solved by representing it as a system of linear equations relating changes in the model's variables. Results are deviations from an initial solution of the underlying non-linear model.

The system of linear equations in MMRF is solved using GEMPACK. GEMPACK is a suite of general-purpose programs for implementing and solving large economic models. The linear version of MMRF is specified in the TABLO syntax, which is similar to ordinary algebra. GEMPACK solves the system by converting it to an Initial Value problem and then using a standard solution algorithm specified by the user, such as the Euler method. GEMPACK uses multi-step processes to generate accurate solutions of the underlying, non-linear, equations, as well as to compute linear approximations to those solutions.[74]

Writing down the equation system of the model in a linear (change) form has advantages from computational and economic standpoints. Linear systems are easy for computers to solve. This allows for the specification of detailed models, consisting of many thousands of equations, without incurring computational constraints. Further, the size of the system can be reduced by using model equations to substitute out those variables that may be of secondary importance for any given experiment. In a linear system, it is easy to rearrange the equations to obtain explicit formulae for those variables; hence the process of substitution is straightforward.

Compared to their levels counterparts, the economic intuition of the change versions of many of the model's equations is relatively transparent. In addition, when interpreting the results of the linear system, simple share-weighted relationships between variables can be exploited to perform back-of the-envelope calculations designed to reveal the key cause-effect relationships responsible for the results of a particular experiment.×

A.2 Nature of dynamic solution

Algebraically, dynamic models like MMRF take the form:

$$F(X(t)) = 0 \tag{A.1}$$

where X(t) is a vector of length *n* referring to variables for year t, and F() is an *m*-length vector of differentiable functions of n variables. In simulations with (A.1), given an initial solution for the *n* variables that satisfies (A.1), GEMPACK computes the movements in *m* variables (the endogenous variables) away from their values in the initial solution caused by movements in the remaining *n* – *m* variables (the exogenous variables). In year-to-year simulations, the movements in the exogenous variables are from one year to the next. If the initial solution is for year t then our first computation

[74] For details of the algorithms available in GEMPACK, see Harrison and Pearson (1996). For introductions to the Johansen/Euler solution method, see Dixon and Rimmer (2002, Section 11) and Horridge et al. (1993).

creates a solution for year t+1. This solution can in turn become an initial solution for a computation that creates a solution for year t+2. In such a sequence of annual computations, links between one year and the next are recognised by ensuring, for example, that the quantities of opening capital stocks in the year t computation are the quantities of closing stocks in the year t-1 computation.

A.3 Deriving the linear form of the underlying non-linear equations

In deriving the linear equations from the non-linear equations, we use the three basic rules of logarithmic differentiation:

1. ***the product rule***: $X = \beta YZ \Rightarrow x = y + z$, where β is a constant,
2. ***the power rule***: $X = \beta Y^{\alpha} \Rightarrow x = \alpha y$, where α and β are constants, and
3. ***the sum rule***: $X = Y + Z \Rightarrow Xx = Yy + Zz$.[75]

In the equations above, x, y and z represent the *percentage* change deviations in the levels values X, Y and Z, respectively. The levels values (X, Y and Z) are solutions to the model's underlying levels equations.

Inaccuracy, or linearization error, is inherent in the linear equations, particularly for the product rule and the power rule. These errors can be reduced by the use of multi-step procedures, and further by extrapolation.

Using the product-rule equation as an example, suppose the initial solution is given by $\beta = 2$, $X_0 = 100$, $Y_0 = 10$ and $Z_0 = 5$ (where the 0 subscript indicates the initial value), and we wish to perturb Y and Z by 3 per cent and 2 per cent respectively, and solve for X.

In the linear representation, y = 3 and z = 2. Therefore

$x = y + z = 3 + 2 = 5$.

We interpret this to mean that X has increased by 5 per cent, i.e. from $X_0 = 100$ to $X_1 = 105$ (where the 1 subscript indicates the perturbed value).

The exact, non-linear solution for X_1 is calculated as:

$X_1 = \beta Y_1 Z_1 = 2 \times (10 \times (103\%)) \times (5 \times (102\%)) = 105.06$

Comparing the levels solution to the percentage change solution shows there is a linearization error of 0.06 (i.e., 0.06 = 105.06 - 105). We can reduce this linearization error by the application of a multistep procedure which exploits a positive relationship between the size of the perturbation from the initial solution and the size of the linearization error. The principle of the Euler version of the multistep solution method can be illustrated using our above example. Instead of increasing the values of Y and Z by 3 per cent and 2 per cent, let us break the perturbation into two steps of half the desired amount. Thus (with notation $x_{1,2}$ indicating the solution for x for step 1 of 2),

$x_{1,2} = y_{1,2} + z_{1,2} = 1.5 + 1 = 2.5$

[75] Another common representation of the sum rule is $x = S_Y\, y + S_Z\, z$ where $S_Y = Y/X$ and $S_Z = Z/X$. In this case the S coefficients are interpreted as shares.

The new solutions to the levels equations are

$X_{1,2}$ = X_0 × (100 +
$x_{1,2}$)% = 100 ×
(102.5%) = 102.5

$Y_{1,2}$ = Y_0 × (100 + $y_{1,2}$)% = 10 × (101.5%) = 10.15

$Z_{1,2}$ = Z_0 × (100 + $z_{1,2}$)% = 5 × (101%) = 5.05

Now apply the remainder of our desired perturbation to Y and Z. The values for $y_{2,2}$ and $z_{2,2}$ are:

$y_{2,2}$ = 100 × (103/101.5 – 1) = 1.4778

and

$z_{2,2}$ = 100 × (102/101 – 1) = 0.9901

Therefore

$x_{2,2}$ = 1.4778+0.9901 = 2.4679

The final solution for X is

$X_{2,2}$ = $X_{1,2}$ × (100 + $x_{2,2}$)% = 102.5 × (102.4679%) = 105.0296

Recalling that the true solution is X_1 = 105.06, the two step procedure produces a solution that is clearly more accurate than the one step procedure. The reader may have noticed that the size of the linearization error in the two step procedure is approximately half of that in the one step procedure. In general, by doubling the number of steps, the linearization error may be halved. This is the basis of an *extrapolation* procedure, which can further reduce linearization error without adding to the computational load.

Further improvements are gained by increasing the number of steps, for example by calculating 4-step and 2-step solutions and doing a similar extrapolation. However, the increase in steps comes at a computational cost, e.g. a 4-step 2-step extrapolation requires solving the model 6 times, which takes approximately 6 times the computational effort of a Johansen (single step) solution.