Griffith UNIVERSITY
Queensland, Australia

Griffith Business School

Economics and business statistics

Understanding the Australian economy: a computable general equilibrium model with updated data and parameters

George Verikios, Kevin Hanslow, Marc Jim M. Mariano and Kenneth Clements

2021-06

Series editors Dr Nicholas Rohde and Dr Athula Naranpanawa **ISSN** 1837-7750

Department of Accounting, Finance and Economics

Understanding the Australian economy: a computable general equilibrium model with updated data and parameters

George Verikios[1], Kevin Hanslow[2], Marc Jim M. Mariano[3] and Kenneth Clements[4]

Keywords: computable general equilibrium, multi-sector, economic growth.

1. Introduction

This document describes the theory, data and parameters of a multi-sectoral model of the Australian economy. The model belongs to the computable general equilibrium (CGE) class of models; see Dixon and Jorgenson (2012) and Francois and Reinert (1997) for a broad survey of CGE models. The theory draws together special treatments for particular sectors of the Australian economy. These include the treatment of energy goods, tourism, public sector accounts and debt accumulation, and private sector debt and credit accumulation. The properties of the model are also consistent with the properties of dynamic macroeconomic models whereby the economy begins in a steady-state and moves along a balanced growth path to a new steady-state a experiencing a perturbation. Another novel feature of the model is the use of the latest data but also recently-estimated parameters in the area of import-domestic substitution and household demand.

The model described here is dynamic. That is, the theory of the model refers to how model variables relate to each other within a period or across time periods. A dynamic simulation of the effects of a policy change involves running the model twice to generate the baseline and project simulations. The baseline may be a plausible forecast of how the economy will evolve over time in the absence of the policy shock of interest. As such, the baseline may incorporate external forecasts for key macroeconomic variables in the short term with convergence to a balanced growth path in the long term. Alternatively, the baseline may represent the movement from a non-balanced to a balanced growth path via the application of balanced growth shocks to the model. With the exception of the project variables of interest (e.g., tax rates, technology, etc.), all exogenous variables in the project simulation are assigned the values they had in the baseline simulation. The differences in the values of variables in the baseline and project simulations quantify the effects of moving the variables of interest away from their baseline values, i.e., the deviations of variables from their baseline values caused by the project shock modelled.

The model distinguishes 117 sectors and commodities (see Table 7) based on the 2017-18 input-output (IO) tables published by the Australian Bureau of Statistics (2020). Primary factors are distinguished by 117 types of capital (one type per industry), 8 occupations, owner-operator labour (i.e., self-employed workers), two types of land, and natural resources.

A representative firm in each sector produces a single commodity. Each commodity is distinguished between a variety destined for export markets and a variety destined for domestic sales.

Some commodities produced for use in the domestic market are further divided into a margin and non-margin component. The margin component of a commodity is used to facilitate the movement and sale of both imported and domestic commodities within Australia, and of the exported commodities to the point of exportation. Margin commodities include such

[1] KPMG Economics and Department of Accounting, Finance and Economics, Griffith University. Email: g.verikios@griffith.edu.au.
[2] KPMG Economics
[3] KPMG Economics
[4] Business School, University of Western Australia

activities as the various modes of transportation, and wholesale and retail trade. The non-margin component is used as a direct input into industry activity, investment and government or private consumption, or as a change in inventories.

Production technology is represented by nested CRESH functions (Hanoch, 1971) allowing a high degree of flexibility in the parameterisation of substitution and technology parameters. Energy goods are treated separately to other intermediate goods and services in production and are complementary to primary factors.

The supply of labour is determined by working-age population and a labour-leisure trade-off that allows workers in each occupation to respond to changes in after-tax wage rates thus determining the hours of work they offer to the labour market. Working-age population typically moves with population.

Household consumption decisions are determined by a linear expenditure system (Stone, 1954) that distinguishes between subsistence (necessity) and discretionary (luxury) consumption.

The model represents detailed government fiscal accounts including the accumulation of public assets and liabilities. On the revenue side, detailed modelling of all direct and indirect taxes and income from government enterprises is included. On the expenditure side, government consumption, investment and payments of various types of transfers (such as pensions and unemployment benefits) are modelled.

Investment behaviour is industry specific and is positively related to the rate of return on capital. This rate takes into account company taxation and a variety of capital allowances, including the structure of the imputation system.

Foreign asset and liability accumulation is explicitly modelled, as are the cross-border income flows they generate and that contribute to the evolution of the current account. Along with other foreign income flows like labour payments and unrequited transfers, it takes account of primary and secondary income flows in Australia's current account. These are particularly important for Australia as they typically comprise a significant share of the balance on the current account.

2. Theory

The model is represented by equations specifying behavioural and definitional relationships. Formally, the model theory is represented by nonlinear equations specifying behavioural and definitional relationships as

$$F_i\left(\boldsymbol{N},\boldsymbol{X}\right)=\boldsymbol{0}, \tag{1}$$

where F_i are i (=1,...,m) continuous and differentiable functions, $\boldsymbol{N}$ is a $m \times 1$ vector of endogenous variables and $\boldsymbol{X}$ is a $n \times 1$ vector of exogenous variables. Typically, $\boldsymbol{X}$ describes changes in economic structure and policy (e.g., tariff rates, technology, etc.) and can be used to perturb the model to simulate changes in $\boldsymbol{N}$.[5]

3. Production of commodities

Each industry produces a single commodity that is allocated between an exported and local variety via a constant elasticity of transformation (CET) frontier. Letting *COM* be the set of commodities, transformation between exported and locally-used commodities is expressed as:

[5] The model is implemented and solved using the multistep algorithms available in the GEMPACK economic modelling software (Harrison and Pearson, 1996).

$$Q_j = B\left[\left(\chi_j Q_j^{DOM}\right)^{-\rho} + \left(1-\chi_j\right)\left(Q_j^{EXP}\right)^{-\rho}\right]^{-1/\rho},\ B>0, 0<\chi_{jr}<1, \rho \le -1; \qquad (2)$$

where Q_j is the activity level or output of industry j, Q_j^{DOM} is the quantity of the local commodity, Q_j^{EXP} is the quantity of the exported commodity, and χ_j and ρ are parameters. The CET elasticity of transformation is $\sigma_j^{DOMEXP} = 1/(1+\rho)$ and is typically set equal to a value of 20. An implication of (2) is that changes in domestic prices are not fully passed on to export prices via accommodating movements in Q_j^{EXP}. That is, for a given commodity the basic price for the domestic variety P_j^{LOC} and the exported variety P_j^{EXP} do not move together reflecting some heterogeneity between the variety produced for domestic markets and the variety produced for export markets. The degree of heterogeneity is controlled by σ_j^{DOMEXP}. The sales-share-weighted sum of P_j^{LOC} and P_j^{EXP} give the composite basic price received by the producer of good i P_i^{BAS} [6]. Note there is a one-to-one mapping of commodities to industries as all industries are assumed to be single-product industries and all commodities are assumed to be single-industry commodities.

Some of the local commodity may be added to inventories or may be supplemented by a drawdown of inventories. Any such adjustment in inventories is an exogenously imposed change under the normal model closures.

4. Purchasers' prices

The local commodity may be used for margin and non-margin purposes. The basic price of a domestic non-margin commodity is not necessarily the final price paid by a user of the commodity. This final price is called the purchasers' price and is constituted from the basic price, taxes levied on the basic value of the commodity, the cost of margins used to convey the commodity to the user and the GST levied as a rate on the total value of all other components of the purchasers' price. The purchasers' price P_{iu}^{PUR} is defined as

$$P_{iu}^{PUR} = P_{iu}^{PREGST}\left(1+T_{iu}^{GST}\right), \qquad i \in COM,\ u \in USR \qquad (3)$$

where P_{iu}^{PUR} is the purchasers' price of commodity i for user u, P_{iu}^{PREGST} is the pre-GST price of commodity i for user u, T_{iu}^{GST} is the GST rate applied to commodity i for user u. USR is a set made up of intermediate or investment usage by each industry, private consumption and government consumption.

The pre-GST price P_{iur}^{PREGST} is defined as

$$P_{iu}^{PREGST} = P_i^{LOC}\left(1+T_{iu}^{BAS}\right) + \sum_{m \in MAR} S_{ium}^{MAR}\left(P_i^{LOC} \cdot A_{im}^{MAR}\right)$$

$$i \in COM,\ u \in USR \qquad (4)$$

where T_{iu}^{BAS} is the tax rate applied to the basic value of commodity i for user u, P_m^{LOC} is the basic price of good m used as a margin,[7] A_{im}^{MAR} is the per unit input requirement for margin m

[6] The basic price is the price that is received by the supplier (or producer) of the commodity; hence it is also referred to as the supply price. This price covers the producer's costs including any taxes on production.

[7] There are no taxes on margins, or margins on margins, so there is no distinction between the basic price and purchasers' price of a margin.

conveying commodity i , and S_{ium}^{MAR} is the share of margin *m* used to convey commodity *i* to user u .

The expression $\left(P_m^{LOC} \cdot A_{im}^{MAR}\right)$ is the *effective* price of margin *m* for conveying commodity i . Note that ΔA_{im}^{MAR} < 0 means a fall in the per unit input requirement, that is, technical improvement or progress. This means that for a given P_m^{LOC}, $\Delta A_{im}^{MAR} < 0$ means $\Delta\left(P_m^{LOC} \cdot A_{im}^{MAR}\right)$ < 0, that is, a fall in the *effective* price. This is true for all per unit requirement variables presented below.

The tax levied on the basic value of a commodity T_{iu}^{BAS} may be constituted from many different taxes levied on the use of intermediate inputs to production, as described in section 5.

The demand for a margin is modelled as the quantity of commodity being conveyed times the per unit requirement for the margin, that is:

$$Q_{ium}^{MAR} = A_{im}^{MAR} Q_{iu} . \quad i \in COM,\, u \in USR,\, m \in MAR \qquad (5)$$

Equations of identical structure to (3) and (4) define the purchasers' price for each imported commodity in terms of taxes, margins and the basic price of the commodity. For an imported commodity the basic price is the landed duty-paid price, which is equal to the domestic currency CIF price[8] times the power of the import tariff rate, i.e., 1 + import tariff rate.

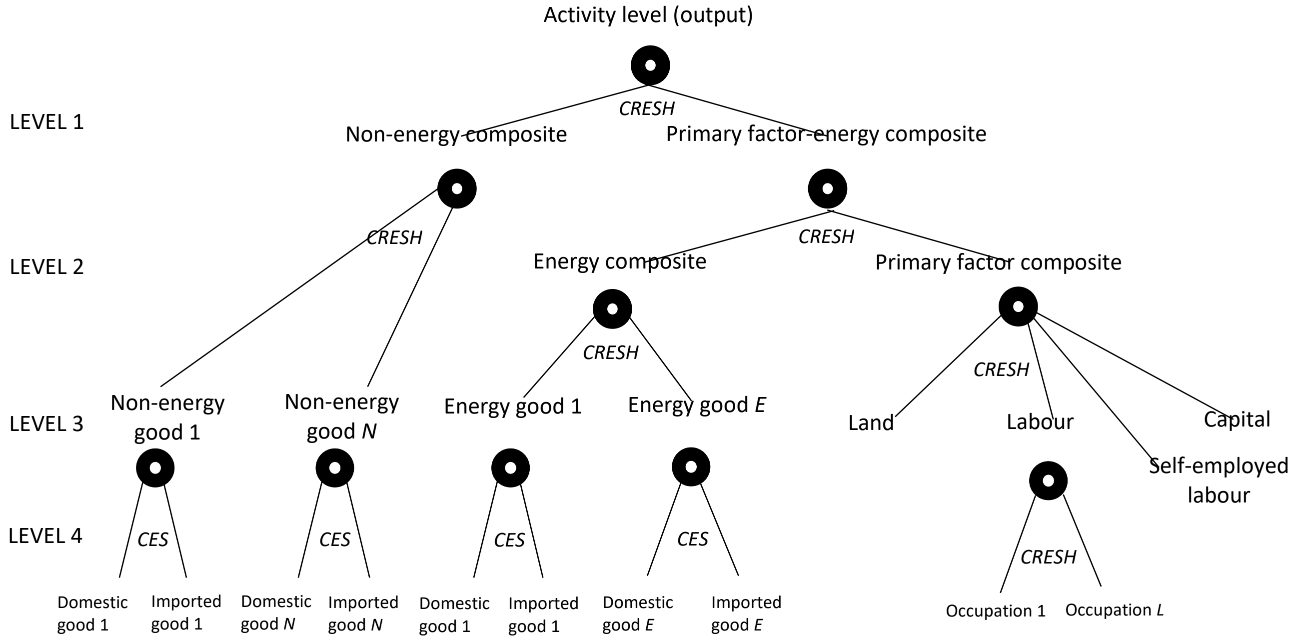
5. Input technology: current production

A representative firm in each sector produces a single commodity. The model recognises two broad categories of inputs: intermediate inputs and primary factors. Representative firms choose inputs of primary factors and intermediate inputs to minimise costs subject to a given production technology and given factor and commodity prices. Primary factors include land, nine types of labour (occupations),[9] owner-operator labour and physical capital. Intermediate inputs consist of 117 domestically-produced goods and services and 117 foreign substitutes. Demands for primary factors and intermediate inputs are modelled using nested production functions. As apparent from Figure 1, the nested production functions, which define the production technology available to the representative firm, have four tiers.

[8] The price inclusive of cost, insurance and freight.

[9] The occupational classification corresponds to 1-digit occupations in ONS (2010).

Figure 1. Input technology for current production



5.1. Level 1: Non-energy composite and primary factor-energy composite

At the top level firms determine optimal quantities of the non-energy composite (i.e., an aggregate of non-energy intermediate inputs) and the primary factor-energy composite (i.e., an aggregate of primary factors and energy intermediate inputs) subject to a CRESH (constant ratios of elasticities of substitution, homothetic) production technology. This formulation relaxes the assumption implied by CES functions that the elasticity of substitution across all pairs of inputs must be the same. CRESH production functions were introduced as a generalisation of CES by Hanoch (1974). The nested CRESH functional form is more desirable than alternative techniques such as fixed coefficients (Leontief) production technology since it allows us to take advantage of differences in econometrically-estimated values of the elasticities of substitution across individual factors.

The production technology distinguishes between primary and intermediate factors of production. Profit maximising producers are capable of choosing the optimal combination of primary factors independently of the prices of intermediate inputs. The nested CRESH functions allow different elasticities of substitution to exist between primary factors of production and goods. Thus, the optimal mix of the primary factor-energy composite (*PF-E*) and non-energy composite (*NE*) is represented as

$$\sum_i \left[\frac{Q_{ij}^F}{Q_j A_{ij}^F}\right]^{h_i} \frac{X_i}{h_i} = \alpha , \qquad 0 < h_i < 1, X_i > 0, \sum_i X_i = 1, \alpha > 0 ,$$

$$i \in PF\text{-}E,\ NE,\ j \in IND. \tag{6}$$

In (6) Q_{ij}^F is the demand for factor *i* by industry *j*, A_{ij}^F is factor-specific unit input requirements, and X_i, h_i and α are parameters. The elasticity of substitution between the primary factor-energy composite (*i*=*PF*-*E*) and non-energy composite (*j*=*NE*) is $\sigma_i\sigma_j \big/ \sum_{k=1}^{2} S_k\sigma_k$ where $\sigma_i = 1/1-h_i$ is the CRESH parameter associated with input *i* and S_k is the k-*th* input's cost share. In the special case when all σ_i have the same value, the CRESH system is equivalent to CES and all substitution elasticities are equal.

The CRESH parameter σ_i associated with non-energy inputs and primary factor-energy composites is 0.1 for all industries. Adopting a parameter of 0.1 at this level of the production nest assumes that firms' use of the non-energy composite and the primary factor-energy composite is close to a fixed share of output. This reflects the idea that the output share of these two composites is nearly invariant to changes in relative prices (i.e., they are complements) and reflects characteristics intrinsic to the production of each good. Note that these shares will vary if there is a change in production technology, e.g., innovation that allows less use of non-energy inputs per unit of output.

5.2. Level 2: Energy composite and primary factor composite

At the second level of the production nest, firms choose the optimal mix of the energy (*E*) and primary factor (*PF*) composites. The energy composite is an aggregation of energy intermediate inputs; the primary factor composite is an aggregation of all primary factors. These two composites are combined using CRESH production technology

$$\sum_i \left[\frac{Q_{ij}^{PF-E}}{Q_{kj}^{F} A_{ij}^{PF-E}} \right]^{m_i} \frac{Y_i}{m_i} = \varepsilon , \qquad 0 < m_i < 1, Y_i > 0, \sum_i Y_i = 1, \varepsilon > 0 ,$$

$$i=PF, E, k=PF\text{-}E, j \in IND. \tag{7}$$

where Q_{ij}^{PF-E} is demand for factor *i* (=*PF*, *E*) by industry *j*, A_{ij}^{PF-E} is factor-specific unit input requirements, and Y_i , m_i and ε are parameters. The elasticity of substitution between the energy composite (*i*=*E*) and primary factor composites (*j*=*NE*) is $\sigma_i \sigma_j \Big/ \sum_{k=1}^{2} S_k \sigma_k$ where $\sigma_i = 1/1 - m_i$ is the CRESH parameter associated with input *i* and S_k is the k-*th* input's cost share. The CRESH parameter is set equal to 0.1. This choice of parameters effectively makes the energy and primary factor composites near complements.

5.3. Level 3: Non-energy inputs, energy inputs and primary factors

At the third level of the production nest, firms choose cost-minimising combinations of constituents in each of the non-energy intermediate inputs composite (*NE*), energy intermediate inputs composite (*E*) and primary factor composite (*PF*).

The optimal mix of non-energy intermediate inputs is chosen subject to CRESH production technology

$$\sum_i \left[\frac{Q_{ij}^{NEI}}{Q_{kj}^{F} A_{ij}^{NEI}} \right]^{y_i} \frac{Z_i}{y_i} = \eta , \quad 0 < y_i < 1, Z_i > 0, \sum_i Z_i = 1, \eta > 0 ,$$

$$i \in NEI, k=NE, j \in IND, \tag{8}$$

where Q_{ij}^{NEI} is demand for non-energy input *i* ($\in NEI$) by industry *j*, Q_{kj}^{F} (*k*=*NE*) is demand for the non-energy composite, A_{ij}^{NEI} represent unit input requirements for non-energy inputs and Z_i , y_i and η are parameters. The elasticity of substitution across non-energy inputs is $\sigma_i \sigma_j \Big/ \sum_{k \in NEI} S_k \sigma_k$ where $\sigma_i = 1/1 - y_i$ is the CRESH parameter associated with input *i* and S_k is the k-*th* input's cost share. The CRESH parameter associated with all pairs of non-energy intermediate inputs is 0.25 for all industries based on estimates by Bruno (1984) and Atalay

(2017). These values imply that firms have some choice with respect to non-energy technology and will alter the pattern of non-energy usage in production if relative prices change.

Analogously, the optimal mix of energy intermediate inputs Q_{ij}^{EI} i ($\in EI$) is determined subject to CRESH production technology (viz. equation (8)) with CRESH parameter for all pairs of energy intermediate inputs of 0.25 for all industries. Thus firms also have some choice with respect to energy technology and will alter the pattern of energy usage in production if relative prices change.

At this level of the production nest firms also determine the optimal mix of capital and the land and labour composites subject to CRESH technology

$$\sum_i \left[\frac{Q_{ij}^{FAC}}{Q_{kj}^{PF-E} A_{ij}^{FAC}} \right]^{n_i} \frac{L_i}{n_i} = \pi \ , \quad 0 < n_i < 1, L_i > 0, \sum_i L_i = 1, \pi > 0 \ ,$$

$$i \in FAC,\ k{=}PF,\ j \in IND, \qquad (9)$$

where Q_{ij}^{FAC} is demand for primary factor i ($\in FAC$) by industry j, Q_{kj}^{PF-E} ($k{=}PF$) is demand for the primary factor composite, A_{ij}^{FAC} are unit input requirements for primary factor i, L_i, n_i and π are parameters The CRESH parameter associated with primary factors is set to 0.5 based on the survey by Chirinko (2008).

5.4. Level 4: Domestic inputs, imported inputs, labour and land types

At the lowest level of the production nest, firms decide on the optimal mix of domestic (*DOM*) and foreign (*IMP*) intermediate inputs subject to CES technology. For non-energy intermediate inputs this is represented as

$$Q_{ij}^{NEI} = \left[\sum_s \mu_s \left(\frac{Q_{isj}^{INT}}{A_{isj}^{INT}} \right)^{-\tau_i} \right]^{-1/\tau_i} , \quad 0 < \mu_s < 1, \sum_s \mu_s = 1, \tau_i \geq -1, \tau_i \neq 0 \ ,$$

$$i \in NEI,\ s \in SRC,\ j \in IND. \qquad (10)$$

In (10) Q_{ij}^{NEI} is demand for non-energy composite i by industry j, Q_{isj}^{INT} is demand for non-energy commodity i from source s ($\in SRC$, $SRC{=}DOM, IMP$) by industry j, and A_{isj}^{INT} are input-specific unit input requirements. μ_s and τ_i are parameters. The CES elasticity of substitution is $\sigma_i = 1/(1+\tau_i)$. There is an equivalent set of equations to (10) representing the combination of energy intermediate inputs ($i \in EI$) by source.

The values of σ_i are drawn from econometric estimates based on Australian data over the period 1995 to 2017. This work is described in Section 0. Our elasticity estimates imply low to medium responsiveness of firms to relative price changes between domestic and foreign goods. Thus, the elasticities of substitution range from 0.5 to 2 for primary goods, between 1.1 and 2 for processed food, 1 for textile, clothing and leather products, 0.8 for chemical products, and around 1 for most other manufactured goods. See section 0 for a complete listing of these values. The elasticities are zero for most services, the exceptions being water and air transport that use a value of 2.

At this level, firms also choose the optimal mix of the o ($\in OCC$, OCC=1,..,9) labour types (i.e., occupations) subject to CRESH technology

$$\sum_o \left[\frac{Q^{OCC}_{oj}}{Q^{F}_{kj} A^{OCC}_{oj}} \right]^{v_i} \frac{X_o}{v_o} = \lambda , \qquad 0 < v_i < 1, X_i > 0, \sum_o X_o = 1, \lambda > 0 ,$$

$$o \in OCC, k \in LAB, j \in IND, \tag{11}$$

where Q^{OCC}_{oj} is demand for occupation *o* by industry *j*, Q^{FAC}_{kj} (*k*=*LAB*) is demand for the labour composite, and A^{OCC}_{oj} represents unit input requirements. The elasticity of substitution across occupations is $\sigma_i \sigma_j \Big/ \sum_{o=1}^{9} S_o \sigma_o$ where $\sigma_i = 1/1 - v_i$ is the CRESH parameter associated with occupation *i* and S_o is the o-*th* occupation's cost share. The CRESH parameter is set to 0.25 representing limited possibilities for substitution across occupations.

At level 4 firms also decide on their use of two land types (primary production land and non-primary production land) using CRESH technology. At this stage, it is assumed that each industry uses only one type of land and that this cannot change. Thus, the elasticity of substitution between land types is set to zero for all industries and individual land usage moves with demand for the land composite (Q^{FAC}_{kj} , *k*=*LND*). Consistent with this assumption, although the model data can be aggregated (e.g., to reduce the size of the model or to reduce sectoral detail when it is not required) the primary production industries are never aggregated with the non-primary production industries.

6. Zero-pure-profits and market clearing

All firms are assumed to operate in competitive markets and thus take their output prices as given. Consistent with this we impose a zero-pure-profits condition that equates revenues with costs and determines each industry's activity level or output:

$$P^{BAS}_i Q_j = \left[\sum_{k \in COM} \sum_{s \in SRC} P^{INT}_{ksj} Q^{INT}_{ksj} + \sum_{f \in FAC} P^{FAC}_{fj} Q^{FAC}_{fj} \right] \left(1 + T^{BAS}_i\right), \quad i \in COM, j \in IND. \tag{12}$$

In (12), the left-hand side is revenue for the *j*-th industry comprising the product of the basic price of *i*-th commodity P^{BAS}_i and the output of the *j*-th industry Q_j. Note that there is a one-to-one mapping from the *i* commodities to the *j* industries as all industries produce only one product. The right-hand side of (12) represents the *j*-th industry's costs comprising intermediate input costs $\sum_{k \in COM} \sum_{s \in SRC} P^{INT}_{ksj} Q^{INT}_{ksj}$, primary factor costs $\sum_{f \in FAC} P^{FAC}_{fj} Q^{FAC}_{fj}$ and the production tax on industry *j* T^{BAS}_i .

Equation (12) requires that industry output adjust so that the left-hand side (industry revenue) is always equal to the right-hand side (industry costs) thus ensuring that an industry's revenue is always exhausted on the cost of its inputs. This requires that P^{BAS}_i is linked to Q_j . This is accomplished by a market-clearing condition.

Output prices are determined by a market-clearing condition for each commodity (i.e., total sales to all users equals output):

$$Q_j = \sum_{u \in ALLUSR} Q_{iu} + \sum_{u \in ALLUSR} \sum_{m \in MAR} Q^{MAR}_{ium} \qquad j \in IND, i \in COM. \tag{13}$$

The left-hand side of (13) is output for the *j*-th industry. The right-hand side of (13) is the sum of non-margin sales to all users $\sum_{u \in ALLUSR} Q_{iu}$ and margin sales to all users $\sum_{u \in ALLUSR} \sum_{m \in MAR} Q^{MAR}_{ium}$. Note that the set *ALLUSR* includes the set *USR* and exports sales and changes in stocks.

If demand for the *i*-th commodity rises at the initial output level, P_i^{BAS} will rise. A rise in P_i^{BAS} will increase revenue for the *j*-th industry via equation (12). At initial input quantities and prices this would normally lead to pure profits (i.e., revenues exceeding costs). But this is prevented by (12), which will cause output to rise thus driving up input quantities and prices until equality between revenue and costs is restored.

In a simple general equilibrium model, there are typically only two agents: households and firms. If the model represents a private ownership economy households will own all factors of production and thus firms, and profits by firms are transferred to households as income. The link between firm profits and household income determines that a general equilibrium exists (Starr, 1997). In a complex general equilibrium model with many agents as described here, factors of production are owned by households, foreigners and the governments. Despite this added complexity primary factor returns are assumed to accrue to the factor owner. This maintains the link between income for all agents and expenditure by all agents. This link determines the existence of a general equilibrium in the model described above.

7. Supply of factors of production

7.1. Land

Two types of land are distinguished: primary production and non-primary production land. Primary production land is used only by the agricultural and mining industries. Non-primary production land consists of commercial land and residential land. Non-primary production land used by the dwellings sector represents residential land; non-primary production land used by all other sectors represents commercial land. There is a fixed supply of each type of land. For a given supply of each land type intersectoral movements are governed by a less restrictive version of the CET known as CRETH (constant ratio of elasticities of transformation, homothetic) function. A summary of the properties of CRETH functions and an illustration of their use in commodity supply analysis is given in Vincent *et al*. (1980).

Thus the optimal supply of land is determined by the maximisation of after-tax land rentals subject to CRETH technology:

$$\sum_n \left[\frac{X_{nj}^{LND}}{X_n^{LND}}\right]^{b_i} \frac{W_n}{b_n} = \omega, \qquad b_n > 1, W_n > 0, \sum_n W_n = 1, \omega > 0\,,$$

$$n \in LND, j \in IND. \tag{14}$$

In (14) X_{nj}^{LND} is the supply of land type *n* to industry *j* and X_n^{LND} is total supply of land of type *n*. Note that the prices applied in maximising (14) are after income taxes have been applied as the allocation of land is made by the owner of land not the user (i.e., the industry). The elasticity of substitution across occupations is $\sigma_i \sigma_j \Big/ \sum_{n \in LND} S_n \sigma_n$ where $\sigma_i = 1/1 - b_i$ is the CRETH parameter associated with land type *n* and S_n is the n-*th* land type's revenue share. The CRETH parameter is set to -0.1 for primary production land making it relatively immobile across primary industries, and to -0.2 for land used by the non-dwellings sectors, and to -0.1 for land used by the dwellings sector. This means that non-primary production land is more mobile across the non-dwellings sectors than it is across the dwellings and non-dwellings sectors. The underlying assumption is that non-primary production land cannot be easily transferred between commercial and residential uses. For each type of land there is an industry-specific rental price that is determined by a market-clearing condition.

7.2. Labour

There is an infinitely-lived representative household that decides on the supply of each of the *o* (=1,..,9) labour types X_o^{LAB} based on a labour-leisure tradeoff that allows workers in each occupation to respond to changes in the real after-income-tax wage rate $\left(\frac{PWAGE_o}{CPI}\right)$, thus determining the hours of work they offer to the labour market. The labour-leisure tradeoff recognises the disutility of work. This gives upward-sloping labour supply curves for occupations as

$$\frac{X_o^{LAB}}{POP} = \left(\frac{PWAGE_o}{CPI}\right)^{\sigma_o^{LAB}}, \quad o \in OCC, \tag{15}$$

where POP is population, CPI is the consumer price index and σ_o^{LAB} is the uncompensated labour supply elasticity. The elasticity of labour supply is set at 0.15 reflecting econometric evidence on labour supply in Australia (Dandie and Mercante, 2007). For each occupation there is an occupation-specific wage rate that is determined by a market-clearing condition.

Unlike the supply of occupations, the supply of owner-operator labour is determined at the industry level recognising that the return to such labour varies by industry depending on many factors. Thus, the supply of owner-operator labour by industry j X_j^{OWN} is a positive function of population and the CPI-deflated real after-tax rental rate on owner-operator labour in industry j $POWN_j$:

$$\frac{X_j^{OWN}}{POP} = \left(\frac{POWN_j}{CPI}\right)^{\sigma^{OWN}}, \quad j \in IND. \tag{16}$$

The supply elasticity is defined as $\sigma^{OWN} = \sum_{o=1}^{9} \sigma_o^{LAB} / 9$. The rental rate on owner-operator labour is defined as the average of the rental rate on all non-labour factors of production. Note that the treatment applied in (16) combined with the definition of σ^{OWN} ensures that owner-operator labour has a similar supply elasticity as regular labour recognising that the wage and rental rates of the two labour types vary.

Note that in the above treatment of labour supply decisions are made by an infinitely-lived representative household. A limitation of this approach is that labour supply responses will not reflect the heterogeneity of preferences to supply labour across households. In tax policy analysis, this treatment will underestimate the marginal excess burden of the personal income tax system. This limitation is muted somewhat as labour supply responses can vary by occupation through occupation-specific wage rates and, thus, there will be some heterogeneity in labour supply responses across occupations depending on how relative wage rates respond to a tax policy change.

7.3. Capital

Each industry uses capital specific to its own production process. Thus, the supply of capital is specified separately for each industry. $K_{j,t}$ An industry's capital stock available for use in year t equals its capital at the start of year t-1 $K_{j,t-1}$ less any capital depreciation during year t-1 $\delta_j K_{j,t-1}$ plus any capital created (i.e., investment) during year t-1 $Q_{j,t-1}^{INV}$:[10]

$$K_{j,t} = \left(1-\delta_j\right) K_{j,t-1} + Q_{j,t-1}^{INV}, \quad j \in IND, \ \forall\, t. \tag{17}$$

[10] The determination of capital creation in each year is explained in section 9.1.

Note δ_j is the constant rate of depreciation per period; thus, capital is assumed to depreciate geometrically over time. The representation of capital accumulation in equation (17) assumes that there is a one year gestation lag between investment by firms and an increment to the capital available for use by firms. For each type of capital there is an industry-specific rental rate that is determined by a market-clearing condition.

8. Factor prices paid by industry

As described in the previous section, the supply of primary factors to industries is determined by the price received by the owner of the factor. This price usually differs from the price paid by an industry for the factor. The difference between the two prices is attributable to factor income taxes and industry-specific factor taxes, such as land and labour taxes.

The price paid by an industry for a factor is defined as

$$P_{if}^{FACIND} = P_{if}^{FAC}\left(1+T_{if}^{FAC}\right) \quad i \in IND, f \in FAC, \tag{18}$$

where P_{if}^{FACIND} is the price paid by industry *i* for factor *f*, P_{if}^{FAC} is the pre-income-tax price received by owners of factor *f* used in industry *i*, and T_{if}^{FAC} is the *ad valorem* rate of industry-specific tax on factor *f* used by industry *i*.

The price received by owners of a factor, net of income taxes, is

$$P_{if}^{FACNET} = P_{if}^{FAC}\left(1-T_{if}^{INC}\right) \quad i \in IND, f \in FAC, \tag{19}$$

where P_{if}^{FACNET} is the post-income-tax price received by owners of factor *f* used in industry *i*, T_{if}^{INC} is the *ad valorem* income tax rate on factor *f* used by industry *i*.

The different forms of the tax terms in equations (18) and (19) are attributable to the income tax rate T^{INC} being defined as a rate relative to *gross* income rather than as a rate relative to a net-of-tax value as is the case for the industry-specific factor tax rate .

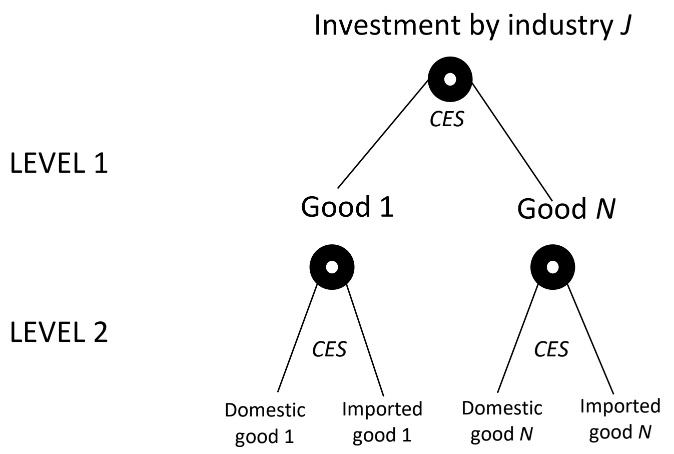
The provision of some examples helps tie down the more general notation of the current section to the factor-specific notation of the previous section:

- If factor *f* is land of type *n* then $P_{if}^{FACNET} = P_{in}^{LND}$; and
- If factor *f* is labour of occupation *o* then $P_{if}^{FACNET} = PWAGE_o$, $\forall i \in IND$.

9. Input technology: investment

Capital is assumed to be specific to each industry. Consistent with this investment (or capital creation) is also specific to each industry. As apparent from Figure 2 the creation of investment (or capital goods) for each industry is determined in a two-tiered hierarchical structure. Given a level of investment by industry, capital creators first determine composite inputs to investment (level 1) and then determine inputs to investment by source (level 2) using CES technology in both cases.

Figure 2. Input technology for investment (capital creation)



9.1. Investment by industry

Investment in each industry is determined as a positive function of the post-income-tax, net-of-depreciation rate of return on the industry's capital, ROR_j :

$$ROR_j = \frac{P_{jf}^{FACNET} K_j - \delta_j P_j^{INV} K_j}{P_j^{INV} K_j}, \quad i \in IND,\ f{=}capital, \qquad (20)$$

where P_j^{INV} is the purchasers' price of investment for industry j . Note that all variables in equation (20) are contemporaneous. Equation (20) defines ROR_j as post-income-tax rentals on capital $P_{jf}^{FACNET} K_j$ (*f=capital*) less capital depreciation $\delta_j P_j^{INV} K_j$ divided by the replacement cost of capital, $P_j^{INV} K_j$. The definition of ROR_j is equivalent to Tobin's Q adjusted for taxes and depreciation.

During a simulation ROR_j is able to fluctuate (i.e., it is endogenous) in the shortrun but will return to its initial value in the longrun. This is achieved by making investment Q_j^{INV} in year *t* a positive function of ROR_j in year *t*:

$$1 + \frac{Q_{jt}^{INV} - \delta_j K_{jt}}{K_{jt}} = \left[1 + ROR_{jt}\right]^{\gamma} F_{jt}^{INV}, \quad i \in IND,\ \forall\, t, \qquad (21)$$

where γ is the elasticity of the capital growth rate with respect to the rate of return, and F_j^{INV} is a positive constant. Equation (21) is written using transformed formed versions (i.e., by adding one) of the proportionate growth in industry *j*'s capital stock $\left(1 + \frac{Q_{jt}^{INV} - \delta_j K_{jt}}{K_{jt}}\right)$ and the rate of return $\left(1 + ROR_{jt}\right)$. That is, both are specified so that if either the rate of return or the proportionate growth in the capital stock pass through zero there will be no computational problems. With γ = 2, a higher rate of return will lead to higher investment and higher proportionate growth in an industry's capital stock.

9.2. Level 1: Composite inputs to investment

At level one, the capital creator determines the cost-minimising mix of effective composite inputs to capital creation Q_j^{INV} subject to CES production technology

$$Q_j^{INV} = \left[\sum_i \xi_i \left(\frac{Q_{ij}^{INV}}{A_{ij}^{INV}} \right)^{-\kappa} \right]^{-1/\kappa}, \quad 0 < \xi_i < 1, \sum_i \xi_i = 1, \kappa \geq -1, \kappa \neq 0,$$

$$i \in COM, j \in IND. \qquad (22)$$

In (22) Q_{ij}^{INV} is commodity composite *i* used by industry *j*, A_{ij}^{INV} are unit input requirements, and ξ_i and κ are parameters. The CES elasticity of substitution is $\sigma = 1/(1+\kappa)$ = 0.1. This makes inputs to capital creation close to fixed shares of industry investment levels and relatively unresponsive to changes in relative prices.

9.3. Level 2: Domestic and imported inputs to investment

At the second level of the hierarchical structure capital creators in industry *j* choose the optimal mix of domestic and foreign inputs to minimise the costs of producing units of capital subject to CES technology

$$Q_{ij}^{INV} = \left[\sum_s \varsigma_s \left(\frac{Q_{isj}^{INV}}{A_{isj}^{INV}} \right)^{-\psi_i} \right]^{-1/\psi_i}, \quad 0 < \varsigma_s < 1, \sum_s \varsigma_s = 1, \psi_i \geq -1, \psi_i \neq 0,$$

$$i \in COM, s \in SRC, j \in IND. \qquad (23)$$

Thus capital in each industry is produced with inputs of domestically-produced $\left(Q_{isjr}^{INV}, s = DOM\right)$ and imported commodities $\left(Q_{isjr}^{INV}, s = IMP\right)$. No primary factors are used directly as inputs to capital formation. Nevertheless, primary factors are used in the production of the commodity inputs to investment. The CES elasticity of substitution for the *i*-th input is $\sigma_i = 1/(1+\psi_i)$. These values are drawn from econometric estimates based on Australian data over the period 1995 to 2017. This work is described in section 0. The parameter values allow input demands to be responsive to relative price changes between domestic and foreign goods.

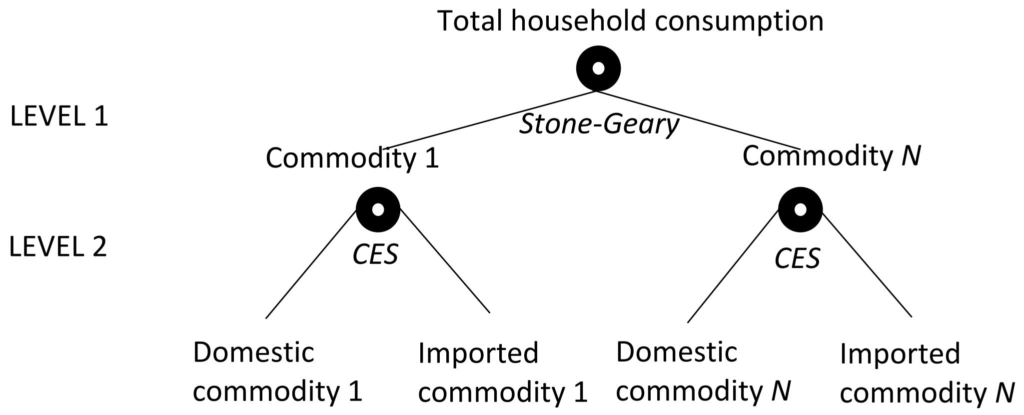
10. Household demands

The most common functional form in consumer theory is the Cobb-Douglas utility function, which displays constant average budget shares. Values for the price and income elasticities from maximisation of the Cobb-Douglas utility function equal unity. This is recognised as a drawback since unitary uncompensated own-price and income elasticities are not consistent with empirical evidence. Therefore, using the Cobb-Douglas functional form can give rise to biased estimates of behaviour for many general equilibrium simulations (Hertel and Tsigas, 1997).

Given the restrictive assumptions of Cobb-Douglas preferences, the CES utility function has become a popular functional form in the calibration process of CGE models. The CES function relaxes some of the assumptions of the Cobb-Douglas utility function by requiring that price elasticities are estimated rather than assumed; thus the CES's major strength is that it allows for the possibility of non-unitary price elasticities. Regardless, CES values for income elasticities still equal one. Theoretically, unitary income elasticities imply consumer preferences are homothetic in income, i.e., that budget shares for each commodity are entirely independent of the level of income. Homothetic preferences are unsupported by empirical work (Clements *et al*., 1995). This limitation can be overcome by using a Stone-Geary (Geary, 1950; Stone, 1954) or Klein-Rubin (Klein and Rubin, 1948) utility function to represent consumer preferences.

Here we assume that there is an infinitely-lived representative household that maximises nested utility functions subject to a budget constraint (see Figure 3). At the first level the representative household maximises a Stone-Geary utility function by consuming combinations of composite commodities. At the second level the representative household determines the optimal mix of domestic and imported varieties that combine to form composite commodities using CES technology.

Figure 3. Input technology for households (utility)



10.1. Level 1: Composite inputs to household consumption

The representative household determines the optimal mix of composite commodities by maximising a Stone-Geary utility function

$$U^H = \prod_i \left(Q_i^H - QSUB_i^H\right)^{\beta_i}, \quad 0 < \beta_i < 1, \ \sum_i \beta_i = 1, \quad i \in COM \qquad (24)$$

where Q_i^H and $QSUB_i^H$ are total household demand and subsistence household demand for the *i*-th commodity composite. A further constraint in (24) is $Q_i^H > QSUB_i^H$. With Stone-Geary utility the consumer first allocates an amount of income to the subsistence quantities; these are purchased regardless of price and income.

Maximisation of (24) subject to the income constraint $M = \sum_{i=1}^{n} P_i^H Q_i^H$, where M is total income (or expenditure) and P_i^H is the consumer price for the *i*-th good, yields the linear expenditure system (LES) Marshallian demand function

$$Q_i^H = QSUB_i^H + \frac{\beta_i}{P_i^H}\left(M - \sum_j P_j^H QSUB_j^H\right), \quad i, j \in COM. \qquad (25)$$

The name LES derives from the property that expenditure on each good is a linear function of prices and income (expenditure). The term in parentheses $\left(M - \sum_j P_j^H QSUB_j^H\right)$ refers to supernumerary (or luxury) income $\left(WLUX^H\right)$, representing the income available after the consumption of the subsistence bundle has been allocated. Thus, the LES divides total consumption of the i-th commodity composite into two components: a subsistence (or minimum) part $QSUB_i^H$ and a luxury (or supernumerary) part $\frac{\beta_i}{P_i^H}\left(M-\sum_j P_j^H QSUB_j^H\right)$.

Note that with $QSUB_i^H$ constant β_i represents the marginal budget share $\frac{\partial\left(P_i^H Q_i^H\right)}{\partial M}$, i.e., the change in expenditure on good i from a one-dollar change in income. Let $w_i = \frac{P_i^H Q_i^H}{M}$ represent the budget share for the i-th commodity. Then, $\eta_i = \frac{\beta_i}{w_i}$ is the i-th income elasticity with the constraint that $\sum_i w_i \eta_i = 1$. Clements *et al*. (2020) show that the (i,j)-th Marshallian price elasticity $\eta_{ij}^* = \delta_{ij}\left(\frac{s_i}{w_i}-1\right)-\frac{\beta_i}{w_i}s_j$ where δ_{ij} is the Kronecker delta and $s_i = \frac{P_i^H QSUB_i^H}{M}$, i.e., the subsistence budget share of good i.

The above definitions of the income and price elasticities show the importance of the marginal budget shares β_i and the subsistence parameters. As discussed in section 16, the β_i parameters are estimated from Australian household survey data; and the values of the subsistence parameters are obtained indirectly from the estimates of the Engel curves together with a specified value of the so-called Frisch parameter ω.

10.2. Level 2: Domestic and imported inputs to household consumption

At the second level of the utility nest household demand is characterised by the CES aggregation of domestically-produced goods Q_{is}^H (s=*DOM*) and imports Q_{is}^H (s=*IMP*) that are considered imperfect substitutes

$$Q_i^H = \left[\sum_s S_{is}\left(Q_{is}^H\right)^{-\zeta_i}\right]^{-1/\zeta_i}, \quad 0 < S_{is} < 1, \sum_s S_{is} = 1, \zeta_i \geq -1, \zeta_i \neq 0,$$
$$i \in COM,\ s \in SRC, \qquad (26)$$

where S_{is} and ζ_i are parameters. The CES elasticity of substitution for the i-th composite is $\sigma_i = 1/\left(1+\zeta_i\right)$. These values are drawn from econometric estimates based on Australian data over the period 1995 to 2017. This work is described in section 0.

11. Export demands

Export demands by foreigners are treated differently for tourism and non-tourism commodities. Export demands for non-tourism commodities (represented by the set *NONTOUR*) are determined by a constant elasticity of demand function

$$Q_i^{EXP} = F_i^{EXP} \cdot F^{EXP}\left(PFC_i^{EXP}\right)^{-\vartheta_i}, \quad \vartheta > 0, \quad i \in NONTOUR \qquad (27)$$

where Q_i^{EXP} is exports of commodity i, and F_i^{EXP} and F^{EXP} represent shifts in commodity and aggregate exports, and PFC_i^{EXP} is the foreign currency price of exports of commodity i. ϑ_i is the elasticity of demand for commodity i. It is assumed that Australia has little market power in its export markets, and so ϑ_i is set to 12 for all non-tourism commodities.

Export demands for tourism commodities (represented by the set *TOUR*) are treated as a bundle. The bundle represents purchases made by foreign tourists to Australia and includes expenditure on accommodation, restaurants, transport, the arts, recreation services, etc.[11] The tourism bundle is determined by a constant elasticity of demand function

$$Q_i^{EXP} = F_i^{EXP} \cdot F^{EXP}\left(PTOUR^{EXP}\right)^{-\varpi_i}, \qquad i \in TOUR \tag{28}$$

where $PTOUR^{EXP} = \sum_{i \in TOUR} S_i^{EXP} PFC_i^{EXP}$, i.e., the price of the tourism bundle faced by consumers. ϖ_i is set to 10 for all tourism commodities. This treatment of tourism commodities makes export demand very elastic for the tourism bundle, i.e., Australia has little market power as a tourism destination, but foreigners purchase units of these commodities in a fixed pattern.

The foreign currency price of exports is defined as

$$PFC_i^{EXP} = PFOB_i^{EXP} \cdot E, \qquad i \in COM, \tag{29}$$

where $PFOB_i^{EXP}$ is the FOB[12] domestic currency price of exports and E is the exchange rate defined as foreign currency price of a unit of domestic currency.

The FOB domestic currency price of exports is defined as

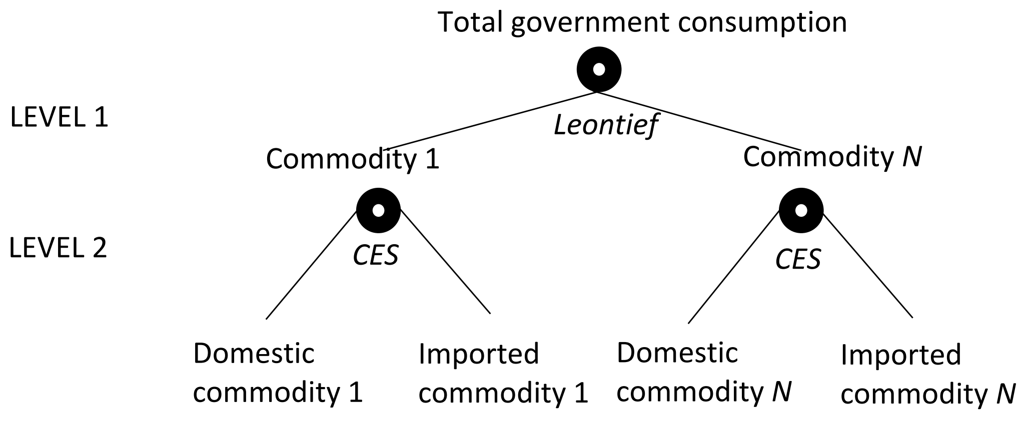
$$PFOB_i^{EXP} = P_{iu}^{PREGST}\left(1 + T_{iu}^{GST}\right). \qquad i \in COM,\ u{=}EXP. \tag{30}$$

In equation (30) P_{iu}^{PREGST} represents the pre-GST price of exports and T_{iu}^{GST} is the *ad valorem* GST rate applied to commodity *i* for export. The pre-GST price of exports is defined similarly to the pre-GST price of domestic goods, as described in section 4, but uses P_i^{EXP} in place of P_i^{LOC}.

12. Government consumption and expenditure

We represent governments as affecting the economy by purchasing goods and services, collecting taxes, receiving revenue from government-owned assets, and making transfer payments. The composite government sector demands commodities. There is a consistent structure of demand for all government consumption activities as shown in Figure 4. As apparent from the figure, at level 1 the government sector determines composite inputs by applying a Leontief utility function. At level 2, the government sector chooses an optimal mix of domestically-produced and imported and goods assuming CES preferences.

Figure 4. Input technology for governments



[11] A complete listing of tourism commodities appears in Table 8.
[12] Free On Board.

12.1. Level 1: Composite inputs to goverment consumption

The i composite inputs to consumption by government g Q_i^G are a Leontief function of total government consumption $Q_{\bullet}^G$

$$Q_i^{ACT} = \min\left[Q^G\right]\cdot\left(F^G\right), \quad i \in COM. \tag{31}$$

F^G is a shift term that allows for specific targeting of government demands in aggregate. For instance, in most simulations Q^G is exogenous in order to enforce zero change in total government demands, or a given change in total government demands.

12.2. Level 2: Domestic and imported inputs to goverment consumption

The optimal combination of domestic and imported inputs to the i composite inputs to government consumption Q_{is}^G ($s \in SRC$) are determined via CES technology. Thus, Q_{is}^G = Q_i^G (s=DOM) and Q_{is}^G = 0 (s=IMP).

12.3. Government transfer payments

A range of transfer payments are represented including unemployment benefits, benefits to the aged and a composite of other government benefits payments. These transfers move with an appropriate volume base (e.g., the number of unemployed persons, the aged population or population). The price component of government benefits is indexed to the national average nominal wage rate. Interest payments on government debt are made to households and these form part of government transfer payments. Interest payments are calculated as the product of the interest rate on government debt and the level of the debt.

The budget balance of all governments is typically exogenous (relative to GDP) in baseline and project simulations. This is accommodated by allowing a variable that would usually be exogenous, such as a tax rate, to vary. The usual tax rate is that applying to personal income.

12.4. Other government expenditure

For each level of government a range of other government expenditures are represented including other operating expenses, government investment expenditure and capital expenditure on existing assets. Other operating expenses are linked to aggregate government consumption. Government investment expenditure is determined as the product of the government investment demands by industry and the industry-specific investment price index. Government investment demands are typically held exogenous or imposed. Capital expenditure on existing assets typically moves with government consumption expenditure.

13. Asset and liability accumulation

13.1. Foreign assets and liabilities

The model specifies foreign assets and liabilities held by the representative household. Foreign assets comprise equity (FE) and credit (FC) instruments; foreign liabilities comprise foreign direct investment (FDI) and debt (FD) instruments. Foreign credit can be issued in domestic currency $\left(FC^{DC}\right)$ and foreign currency $\left(FC^{FC}\right)$, and similarly for foreign debt $\left(FD^{DC}, FD^{FC}\right)$, which means that revaluation effects caused by changes in prices and the exchange rate will influence the accumulation of net foreign liabilities. This is an important mechanism as changes in net foreign liabilities have real effects. We can write foreign assets (FA) and foreign liabilities (FL) in any year as

$$FA = FE + FC^{DC} + FC^{FC} . \tag{32}$$

$$FL = FDI + FD^{DC} + FD^{FC} . \tag{33}$$

It is helpful in the following discussion to introduce a time subscript. All gross foreign asset variables $\left(FA_t,\ FE_t,\ FC_t^{DC},\ FC_t^{FC}\right)$ and gross foreign liability variables $\left(FL_t,\ FDI_t,\ FD_t^{DC},\ FD_t^{FC}\right)$ are defined as averages of stocks of across year *t*. Nevertheless, the net foreign liability variable $\left(NFL_t\right)$ is defined as the value of net foreign liabilities at the beginning of year *t*. The change in net foreign liabilities from the beginning of year *t* to the beginning of year *t*+1 $\left(\Delta NFL_t\right)$ will equal minus the current account from year *t*:

$$\Delta NFL_t = NFL_{t+1} - NFL_t = -CA_t . \tag{34}$$

To link net foreign liabilities to foreign assets and liabilities we assume that net foreign liabilities grow linearly across each year, that is:

$$NFL_{t+\tau} = NFL_t - \tau CA_t . \quad 0 \le \tau \le 1 \tag{35}$$

Therefore, the average net foreign liabilities across year *t* $\left(NFL_t^{AVE}\right)$ are:

$$\begin{aligned} NFL_t^{AVE} &= \int_0^1 NFL_{t+\tau} d\tau \\ &= NFL_t - 0.5CA_t \end{aligned} \tag{36}$$

The average net foreign liabilities can be expressed as the difference of the foreign asset and liability variables (all these variables being average stocks across a year) as:

$$NFL_t^{AVE} = FL_t - FA_t . \tag{37}$$

The substitution of equation (36) into equation (37) yields, after rearrangement of terms:

$$NFL_t = FL_t - FA_t + 0.5CA_t . \tag{38}$$

The current account is defined as the value of net exports (exports minus imports) plus the value of net foreign income. Net foreign income is the sum of income earned on foreign assets $\left(FE + FC^{DC} + FC^{FC}\right)$ minus income paid on foreign liabilities $\left(FDI\ + FD^{DC} + FD^{FC}\right)$. In a typical baseline simulation foreign equity and foreign credit will grow at the same rate as nominal GDP. Foreign debt will grow as the same rate as foreign direct investment. Foreign direct investment is determined as a residual that allows equation (38) to be consistent with equation (34). This means that the composition of foreign assets and liabilities will be constant across time. Nevertheless, the driver of the accumulation of net foreign liabilities will be the accumulation of foreign direct investment. This is appropriate as relative to other components of net foreign liabilities, foreign direct investment is the only component that is determined based on optimising behaviour. All other components of net foreign liabilities are assumed to have a fixed rate of return. Given all of these assumptions, equation (38) ensures foreign direct investment changes so that the net capital inflow (i.e., the balance on the capital account) is consistent with the balance on the current account.

In baseline and project simulations the time path of net foreign liabilities relative to GDP can be treated in a range of ways. For example, the ratio can grow over time without stabilising in the final year, the ratio can grow over time but stabilise in the final year, or the ratio can be stable over time. Regardless of these choices, choosing a path for net foreign liabilities is achieved via an endogenous household saving rate that trades off household consumption and exports. For example, if the growth in net foreign liabilities must be slowed, this can be achieved by raising the saving rate. This will decrease the rate of growth in household consumption and increase the rate of growth in exports. This will improve the current account balance (i.e., reduce current account deficit or increase the surplus). An improvement in the current account balance will slow the rate of growth in net foreign liabilities.

13.2. Government debt

Government debt at the beginning of year *t*+1 $\left(GD_{t+1}\right)$ equals government debt at the beginning of year *t* $\left(GD_{t}\right)$ minus the government budget incurred during year *t* $\left(GB_{t}\right)$. This gives an accumulation equation similar to (34):

$$\Delta GD_{t} = -GB_{t-1} \qquad \forall\, t. \tag{39}$$

For all levels of government, the budget is defined as total revenue minus expenditure inclusive of interest on government debt.

Similar to net foreign liabilities, in baseline and project simulations the time path of government debt relative to GDP can be treated in a range of ways. Choosing a path for government debt is achieved by adjusting government saving (i.e., the budget balance) via changes in the rate of growth in tax revenues or government expenditure. Tax revenues will usually be adjusted by raising or lowering the personal income tax rate. Government expenditure will usually be adjusted by increasing or decreasing the rate of growth in government consumption expenditure.

14. Macroeconomic closure

The model described here is dynamic. That is, the theory of the model refers to how model variables relate to each other within a period or across time periods. A dynamic simulation of the effects of a policy change involves running the model twice to generate the baseline and policy simulations. The baseline may be designed to be a plausible forecast of how the economy will evolve over time in the absence of the policy shock of interest. The baseline may incorporate some external forecasts for key macroeconomic variables in the short term with convergence to a balanced growth path in the long term. Alternatively, the baseline may represent the movement from a non-balanced to a balanced growth path. The balanced growth path can be calibrated to reflect the 30-year annual growth rate in real GDP for Australia, i.e., 3.2%. This means that all quantity variables grow at this common rate. The balanced growth moves the economy from the initial steady-state to a new steady state. The new steady state is a point where the economy reaches a capital-labour ratio that can be sustained infinitely into the future.

Two aspects of the baseline apply budget constraints for the household and the government. Aggregate household consumption is determined by moving the ratio of the current account to GDP to a level that stabilises net foreign liabilities in the final year of the model time horizon (typically 30 years), the household saving rate adjusting to achieve this target. This ensures that in the longrun households consume at a rate that is sustainable relative to the growth in output. Similarly, the government budget as a ratio of GDP is slowly moved to a level that stabilises government debt in the final year of the model time horizon, the personal income tax rate adjusting to achieve this target. This ensures that in the longrun government spending is sustainable relative to the growth in output.

With the exception of the policy variables of interest (e.g., tax rates, technology, etc.), all exogenous variables in the policy simulation are assigned the values they had in the baseline simulation. The differences in the values of variables in the baseline and policy simulations quantify the effects of moving the variables of interest away from their baseline values, i.e., the deviations of variables from their baseline values caused by the policy shock modelled. The household and government budget constraints applied in the baseline also apply in the policy simulation. Note that the model time horizon must be long enough that the economy can reach a new steady-state given the policy shock of interest. For most shocks, 30 years is an adequate time horizon. Shocks that strongly perturb the rate of capital accumulation may require much longer time horizons to reach a new steady-state.

15. Model tests

Two types of tests are applied to check that the model has been properly specified and behaves as expected.

The first type of test checks for homogeneity with respect to prices and quantities in the model theory and data. Economic models, including general equilibrium models, have various homogeneity properties. Price homogeneity requires that all price variables are homogeneous of degree one in prices and homogeneous of degree zero in quantities. This means that one solution of the model is obtained by increasing all nominal variables (such as domestic prices, domestic dollar values and the exchange rate) by one per cent, while all volumes (such as physical quantities) remain unchanged. Quantity homogeneity requires that all quantity variables are homogeneous of degree one in quantities and homogeneous of degree zero in prices. This means that one solution of the model is obtained by increasing all quantity variables by one per cent, while all prices remain unchanged. Checking such homogeneity properties is one important way of verifying that the model has been implemented correctly.

The second type of test implements a realistic shock to the model that has a known solution. Typically this involves an exogenous increase in government consumption expenditures. Given the labour intensive nature of the majority of government consumption expenditures (e.g., education, health and public administration), in the shortrun such a shock will lead to increased employment in government-provided or government-dominated industries relative to other industries. With slowly-adjusting wage rates, it will also mean that employment will rise faster than labour supply. With no change in the capital stock this means a lower capital-labour ratio. GDP will increase and the current account will deteriorate mainly due to increased imports. As government consumption is generally untaxed or lightly taxed relative to other industries, the expansion in government consumption will increase the size of lightly-taxed industries (and commodities) and decrease the size of highly taxed industries (and commodities). Thus the tax base will contract. This reflects a reduction in allocative efficiency as the economy has moved further away from its optimal output level.

In the longrun this outcome is not sustainable. The movement of labour to government provided or funded activities will eventually bid up the real wage rate and employment will remain constant relative to labour supply. A higher real wage rate means that the real cost of labour is higher for all industries and the non-government industries will generally contract. For the reasons described earlier, the tax base will contract. The further contraction of the non-government industries will cause the capital stock to fall (i.e., a lower capital-labour ratio) and GDP will contract. Higher labour costs for domestic producers will mean lower exports and a further deterioration in the current account. If the current account is to return to sustainable levels, the household saving rate must rise to allow household consumption to fall and exports to rise. Thus increase in government consumption will be more than offset by a fall in household consumption.

Implementing an exogenous increase in government consumption and checking the model results against the behaviour described above is another important way of verifying that the model has been implemented correctly.

16. Household demand parameters

16.1. Theoretical background

Section 10 describes the demand system applied to represent household preferences: LES. This system requires the calibration of parameters that capture the response of consumers to changes in relative prices and to income, i.e., price and income elasticities. These responses will vary depending on the nature of the commodity. Here we describe how these parameter values were estimated.

For the purposes of this section only, we shall use a notation more generic than that employed elsewhere in the paper. The linear expenditure system (LES, Stone, 1954) expresses expenditure on good i $(p_i q_i, i = 1, \cdots, n)$ as a linear function of the prices (p_i) and income (M):

$$p_i q_i = p_i \gamma_i + \beta_i \left(M - \sum_{j=1}^{n} p_j \gamma_j\right), \quad i = 1, \cdots, n. \qquad (40)$$

Here, $\mathrm{M} = \sum_{i=1}^{n} p_i\, q_i$ is total expenditure, but is conventionally referred to as "income". As the first term on the right-hand side of equation (40), $p_i \gamma_i$, is expenditure on good *i* unrelated to income, it can be interpreted as the cost of subsistence consumption of the good (assumed to be positive). Thus, the consumer first spends $\sum_{j=1}^{n} p_j \gamma_j$ to satisfy all subsistence requirements and then a fraction β_i of supernumerary income, $M - \sum_{j=1}^{n} p_j \gamma_j$, is spent on good *i*. This β_i is the i^{th} marginal share, with $\sum_{i=1}^{n} \beta_i = 1,\ 0 < \beta_i < 1$, and answers the question, what fraction of a one-dollar rise in income is spent on the good? The utility function lying behind (40) is the Stone-Geary, $u(q_1, \cdots, q_n) = \sum_{i=1}^{n} \beta_i \log(q_i - \gamma_i)$, $q_i > \gamma_i$. This takes the Cobb-Douglas form if $\gamma_i = 0, i = 1, \cdots, n$.

Let $w_i = \frac{p_i q_i}{M}$ be the budget share of good i, $s_i = \frac{p_i \gamma_i}{M}$ be the fraction of income devoted to the cost of subsistence consumption of i and $r = 1 - \sum_{j=1}^{n} s_j = \frac{M - \sum_{j=1}^{n} p_j \gamma_j}{M}$ be the supernumerary ratio. Dividing both sides of equation (40) by *M*, the *i*-th budget share can be expressed as

$$w_i = (1 - r)\frac{p_i \gamma_i}{\boldsymbol{p}'\boldsymbol{\gamma}} + r\beta_i,$$

where $\boldsymbol{p}'\boldsymbol{\gamma} = \sum_{j=1}^{n} p_j \gamma_j$. This reveals the budget share is itself a weighted average of two other shares that are both constants (when prices remain unchanged). Thus, when the consumer is poor, most of income is absorbed by subsistence, the supernumerary ratio $r \approx 0$ and the budget share approximates $\frac{p_i \gamma_i}{\boldsymbol{p}'\boldsymbol{\gamma}}$. As income grows, r rises and w_i moves away from subsistence towards its marginal share β_i. If the good is a necessity, so its share falls with higher income, then $\frac{p_i \gamma_i}{\boldsymbol{p}'\boldsymbol{\gamma}} > \beta_i$, and vice versa for a luxury. This means that necessities have relatively large subsistence components, while those of luxuries are smaller.

The logarithmic differential of (40) is

$$d(\log q_i) = \frac{\beta_i}{w_i} d(\log M) + \sum_{j=1}^{n} \left[\delta_{ij}\left(\frac{s_i}{w_i} - 1\right) - \frac{\beta_i}{w_i} s_j\right] d(\log p_j),$$

where δ_{ij} is the Kronecker delta $(\delta_{ij} = 1 \text{ if } i = j, 0 \text{ otherwise})$. This shows that $\eta_i = \frac{\beta_i}{w_i}$ is the income elasticity of good *i*, while the $(i,j)^{th}$ Marshallian (or uncompensated) and Slutsky (compensated) price elasticities are

$$\eta_{ij}^{*} = \delta_{ij}\left(\frac{s_i}{w_i} - 1\right) - \frac{\beta_i}{w_i} s_j, \qquad \eta_{ij} = \delta_{ij}\left(\frac{s_i}{w_i} - 1\right) + \frac{\beta_i}{w_i}(w_j - s_j).$$

16.2. Idenfication of the model

We write (40) as

$$p_i q_i = \alpha_i + \beta_i M,\ i = 1, \cdots, n \tag{41}$$

where

$$\alpha_i = \sum_{j=1}^{n} \left(\delta_{ij} - \beta_i\right) p_j \gamma_j,\ i = 1, \cdots, n. \tag{42}$$

The coefficients of (41) satisfy $\sum_{i=1}^{n} \beta_i = 1$ and $\sum_{i=1}^{n} \alpha_i = 0$.

When households face the same prices, household survey data can be used with system (41) to estimate the n marginal shares, $\beta_1, \cdots, \beta_n$, as well as the *n* intercepts, $\alpha_1, \cdots, \alpha_n$. The question is, can we then recover from these estimates the n subsistence parameters, $\gamma_1, \cdots, \gamma_n$, by using the relationship (42)? Answer: No. As there are only $n - 1$ independent values of the intercepts (one is constrained by $\sum_{i=1}^{n} \alpha_i = 0$), there is insufficient information to determine the *n* subsistence expenditures, $p_1\gamma_1, \cdots, p_n\gamma_n$.[13]

Identification obviously requires the introduction of some additional information and there are several approaches. First, as established by Howe (1975), taking savings to be another "good" in LES setting its $\gamma = 0$ produces the extended linear expenditure system (Lluch, 1973). The zero restriction of this approach provides the one additional piece of information required for identification.

Second, a minimum-cost diet approach has been used to determine subsistence food expenditure, thereby allowing identification of all parameters (Howe, 1977). A third approach to identification is to exploit whatever cross-sectional variation in prices is available. For example, Betancourt (1971) used the variation in wages (the opportunity cost of leisure) across households; Lluch (1971) used regional price variation; and Kravis et al. (1982, Chap. 9) employed cross-country price variation. See also Pollak and Wales (1978).

We shall use a third approach of setting the total cost of subsistence as follows. It can be easily shown that Stone-Geary utility implies income elasticity of the marginal utility of income (λ) is the negative inverse of the supernumerary ratio, $\frac{\partial \lambda}{\partial M}\frac{M}{\lambda} = -\frac{M}{M - \boldsymbol{p}'\boldsymbol{\gamma}}$. This elasticity, to be denoted by ω, is known as the Frisch parameter:

$$\omega = -\frac{M}{M - \boldsymbol{p}'\boldsymbol{\gamma}} < 0. \tag{43}$$

A rise in income causes the supernumerary ratio and a decrease in $|\omega|$.[14] The Stone-Geary utility function is defined only when $M > \boldsymbol{p}'\boldsymbol{\gamma}$, which further implies $\omega < -1$. The Frisch parameter is a measure of the curvature of the indirect utility function and $-\frac{1}{\omega}$ is the average elasticity of substitution σ (Powell, 1992).

---

[13] See Howe (1975), Pollak and Wales (1978) and Powell (1973).

[14] As the disparate conventions used in the literature can be a source of confusion, a clarification of notation and nomenclature is useful. Frisch (1959) denotes the marginal utility of income by ω, and its income elasticity by $\breve{\omega}$, which he calls the "money flexibility". In the context of the differential approach, Theil (1975/76) calls $1/\omega$ the "income flexibility" and denotes it by ϕ. Below, ω denotes the income elasticity of the marginal utility of income, $(\partial \lambda / \partial M)(M/\lambda)$, and following Lluch et al. (1977), we refer to it as "the Frisch parameter", although this is not a constant parameter in LES. Lluch et al. (1977) denote the supernumerary ratio of LES, $(M - \boldsymbol{p}'\boldsymbol{\gamma})/M$, by $-\phi$, so in that context $\omega = \phi^{-1}$. Clearly, this ϕ and Theil's are both the reciprocal of the income elasticity of the marginal utility of income, the only difference being the former refers to LES, the latter to general differential demand equations.

Given ω, the total cost of subsistence is determined from (43) as $\boldsymbol{p}'\boldsymbol{\gamma} = \left(1+\frac{1}{\omega}\right)M$. Writing equation (42) as $\alpha_i = p_i\gamma_i - \beta_i\boldsymbol{p}'\boldsymbol{\gamma} = p_i\gamma_i - \beta_i\left(1+\frac{1}{\omega}\right)M$, the value of subsistence expenditure for each good can then be recovered from the estimated intercepts and marginal shares as

$$p_i\gamma_i = \alpha_i + \beta_i\left(1+\frac{1}{\omega}\right)M, \qquad i = 1,\cdots,n.$$

To summarise, once the value of the Frisch parameter ω is known, all the parameters of LES can be estimated from a single household expenditure survey.

Where do we obtain a value of ω from? Frisch (1959) conjectured about possible values associated with different values of income of consumers. But this seems too impressionistic for our purpose. A second source is Lluch et al. (1977) who used time-series data from the 1950s and 60s to estimate ω for 14 countries. They then regressed these estimates on GDP per capita to obtain an income elasticity of ω of -0.36. A stream of the older CGE literature has extrapolated the Lluch et al. equation to obtain a value of ω. But as the underlying data are now half a century or more old, further extrapolations would seem to be take things too far beyond the "relevant range" to what the equation could be expected to apply.

We shall set ω at -2. The basis for this is the accumulation of evidence mostly from estimates of the Rotterdam model (Barten, 1964, Theil, 1965) in which ω is treated parameterised as a constant. For summaries of this evidence, see Clements and Zhao (2009), Clements and Si (2017, 2018) and Clements et al. (2020a). Note also equation (44) implies that one-half of income is supernumerary when $\omega = -2$, which seems not unreasonable for a contemporary, high-income economy.

16.3. Data and elasticity estimates

The main source of data is the 2015-16 Household Expenditure Survey (HES), carried out by the Australian Bureau of Statistics (ABS) through interviews from the usual residents of private dwellings in urban and rural areas of Australia.[15] We use the 10,046 households from HES identified by the ABS as overlapping with the ABS Survey of Income and Housing.[16]

The HES provides spending on 693 disaggregated goods and services based on the Household Expenditure Classification (HEC). We aggregated the 693 into 114 commodities based on the Input-Output Product Group (IOPG) classification.[17] Then, we further aggregated the IOPG data to a more manageable 20 sectors, which is patterned on the 1-digit commodity classification used in the national accounts. To put households of different size on more or less the same basis, we use equivalised expenditures everywhere.[18] We also adjust the few cases of negative expenditure by replacing them with the corresponding mean expenditure of households belonging to the same income group. Table 1 presents a summary of the data. Overall, Housing is the biggest single item accounting for about a fifth of total expenditure (17.1%), followed by Insurance (10.6%), Food (9.9%), and Light Goods Manufactures (7.5%).

[15] Usual residents were residents who regarded the dwelling as their own or main home.

[16] For details of this overlap, see https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/6503.0~2015-16~Main%20Features~Sampling~13.

[17] The concordance between the HEC and IOPG classifications is available at ABS' website: cat. 5209.0.55.001, Table 40. Industry and product concordances.

[18] Equivalised expenditure is expenditure by the household divided by the number of 'equivalent adults', which takes into account household size and composition, and adjusts for economies of scale that arise from the sharing of dwellings.

Table 1. Data Summary of expenditure data, Australia 2015-16

	Mean expenditure ($)	Expenditure Shares (%)
1. Food	4,559	9.9
2. Beverages and Tobacco	1,477	3.2
3. Clothing and Footwear	1,430	3.1
4. Light Goods Manufacturing	3,448	7.5
5. Heavy Goods Manufacturing	2,531	5.5
6. Utilities	1,867	4.0
7. Housing	7,902	17.1
8. Hotels and Restaurants	3,012	6.5
9. Private Transportation	1,738	3.8
10. Public Transportation	1,190	2.6
11. Communications	1,770	3.8
12. Finance	2,865	6.2
13. Insurance	4,895	10.6
14. Professional Services	561	1.2
15. Admin and Support	1,016	2.2
16. Public Administration	491	1.1
17. Education	1,107	2.4
18. Health	1,147	2.5
19. Recreation	719	1.6
20. Other Services	2,495	5.4

Note: Dollar values are average annual equivalent household expenditures at 2015-16 prices.

Table 2 provides the LES estimates and the derived expenditure elasticities. All coefficients of the LES model are significant. The largest marginal share is for housing at 0.16, indicating that 16 cents of a one-dollar rise in income is spent on this good. As discussed above, to identify subsistence expenditures we set a value of the Frisch parameter $\omega = -2$, and columns 6 and 7 of Table 5 contain the resulting shares.

From section 16.2, the LES can be expressed in share form as $w_i = (1-r)\frac{p_i\gamma_i}{\boldsymbol{p}'\boldsymbol{\gamma}} + r\beta_i$, where $r = \frac{M-\boldsymbol{p}'\boldsymbol{\gamma}}{M}$ is the supernumerary ratio. When income changes by $d\log M$, the change in the budget share of good i is

$$dw_i = \left(\beta_i - \frac{p_i\gamma_i}{\boldsymbol{p}'\boldsymbol{\gamma}}\right)\frac{\boldsymbol{p}'\boldsymbol{\gamma}}{M}\,d\log M, \quad \sum_{i=1}^{n} dw_i = 0.$$

Table 2. LES estimates, consumption shares and elasticities, Australia

Commodity group	Coefficients of $p_i q_i = \alpha_i + \beta_i M$ (Standard errors)		Budget share	Marginal share	Subsistence budget share		Income elasticity	Own-price elasticities	
	Intercept α_i	Slope β_i			Proportion of income	Proportion of total subsistence		Marshallian	Slutsky
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Food	1,476 (29.24)	7.95 (0.13)	9.86	7.95	7.17	14.34	0.806	-0.408	-0.328
2. Beverages and tobacco	67 (23.03)	3.45 (0.10)	3.20	3.44	1.86	3.73	1.077	-0.498	-0.463
3. Clothing and Footwear	-179 (19.12)	3.63 (0.09)	3.09	3.62	1.43	2.85	1.171	-0.576	-0.539
4. Light Goods Manufactures	-349 (30.38)	8.36 (0.13)	7.46	8.36	3.43	6.85	1.120	-0.587	-0.504
5. Heavy Goods Manufactures	295 (19.62)	5.48 (0.09)	5.48	5.47	3.37	6.74	0.999	-0.478	-0.423
6. Utilities	1,252 (14.71)	1.51 (0.07)	4.04	1.51	3.46	6.92	0.373	-0.191	-0.176
7. Housing	-132 (67.93)	16.31 (0.29)	17.10	16.30	7.87	15.73	0.954	-0.589	-0.426
8. Hotels and Restaurants	-352 (23.3)	7.47 (0.10)	6.52	7.47	2.97	5.94	1.146	-0.590	-0.515
9. Private Transportation	-542 (31.14)	4.51 (0.14)	3.76	4.51	1.08	2.16	1.198	-0.690	-0.645
10. Public Transportation	-152 (17.73)	2.89 (0.08)	2.58	2.89	1.12	2.23	1.122	-0.576	-0.548
11. Communications	531 (13.14)	3.05 (0.06)	3.83	3.04	2.67	5.34	0.795	-0.383	-0.352
12. Finance	-795 (33.31)	7.85 (0.15)	6.20	7.84	2.20	4.41	1.266	-0.668	-0.590
13. Insurance	-39 (38.83)	9.62 (0.17)	10.59	9.61	4.72	9.45	0.908	-0.552	-0.456
14. Professional Services	-43 (15.6)	1.26 (0.07)	1.21	1.25	0.53	1.07	1.032	-0.545	-0.533
15. Admin and Support Services	-166 (22.64)	2.48 (0.10)	2.20	2.47	0.88	1.76	1.124	-0.595	-0.570
16. Public Administration	90 (8.9)	0.93 (0.04)	1.06	0.93	0.66	1.31	0.871	-0.419	-0.410
17. Education	-275 (21.23)	2.72 (0.10)	2.39	2.71	0.76	1.52	1.133	-0.650	-0.623
18. Health	-154 (19.9)	2.77 (0.09)	2.48	2.76	1.05	2.10	1.114	-0.580	-0.553
19. Recreation	-79 (12.91)	1.81 (0.06)	1.56	1.80	0.73	1.46	1.154	-0.560	-0.542
20. Other Services	-457 (31.99)	6.06 (0.14)	5.40	6.06	2.04	4.08	1.122	-0.622	-0.561
Sum	0	100	100	100	50	100			

Notes: (1) Columns 3 to 7 are × 100. (3) Column 6 is $p_i \gamma_i / M = \alpha_i / M + \beta_i (1 + 1/\omega)$, with $\omega = -2$.
(2) Column 5 = column 3. (4) Elasticities are at sample means.

This shows that the budget share rises (falls) with income when the marginal share β_i exceeds (is less than) the subsistence share $\frac{p_i \gamma_i}{\boldsymbol{p}'\boldsymbol{\gamma}}$; and in this situation, the good is a luxury (necessity). From columns 5 and 7 of Table 2, food, utilities and communications have a subsistence share substantially above their marginal share and are thus necessities, as is confirmed by their income elasticities in column 8. Higher elasticities are observed for finance, private vehicles, apparel, recreation and hotel and restaurants. Columns 9 and 10 of Table 5 give the own-price elasticities. These are all less than one in absolute value, as is to be expected for these fairly broad categories. The Marshallian elasticities are all larger than the Slutsky versions, but the differences are not substantial. As the difference between the two is $\eta_{ii} - \eta_{ii}^* = \beta_i$, the reason for the similarity is that many of the marginal shares necessarily tend to be modest when there are 20 goods.

17. Import-domestic elasticities of substitution

17.1. Theoretical background

In the model described above, domestically produced and imported goods are assumed to be imperfectly substitutable due to their heterogeneous nature. This assumption applies for all users of these commodities: households, firms and the government. This treatment of domestically produced and imported goods has been adopted in the literature to incorporate the cross-hauling observed in international trade data. That is, the phenomenon that countries simultaneously import and export the same commodities. The degree of heterogeneity will vary by commodity and country and is reflected by the elasticity of substitution: higher elasticity values imply less heterogeneity, lower values imply greater heterogeneity. Here we describe the elasticity values estimated.

Each commodity available to users is a constant-elasticity-of-substitution (CES) aggregate of the domestically produced and imported varieties. The utility-maximising problem of the representative consumer for a given level of total expenditure for good *i* (Y_i) is

$$Max\ U_i = \left[\alpha_i D_i^{\frac{\sigma_i - 1}{\sigma_i}} + (1-\alpha_i) M_i^{\frac{\sigma_i - 1}{\sigma_i}} \right]^{\frac{\sigma_i}{\sigma_i - 1}}$$

$$\text{subject to } \ Y_i = p_i^D D_i + p_i^M M_i \qquad \forall\, i,$$

where

U_i is the utility of the representative consumer,

D_i and M_i is demand for domestic and imported goods,

σ_i is the elasticity of substitution between domestic and imported good *i*,

α_i is a distribution parameter, and

p_i^D and p_i^M are the prices of domestic and imported good *i*.

Using the objective function and budget constraint above we can derive the first-order conditions for the least-cost combination of domestic and imported good *i*

$$\frac{M_i}{D_i} = \left(\frac{1-\alpha_i}{\alpha_i} \right)^{\sigma_i} \left(\frac{P_i^D}{P_i^M} \right)^{\sigma_i}. \qquad (44)$$

Equations (44) are the demand functions for the problem specified by the objective function and budget constraint; they say that a one per cent increase in the price ratio of domestic and imported good *i* will cause a σ_i per cent increase in the ratio of imported and domestic good *i*. These demand functions are applied to estimate σ_i .

17.2. Specification of the model

Here we describe the statistical model and its constraints that lead to the most direct and popular way of estimating the elasticity of substitution between domestic and imported goods. We apply a log-linear functional form because it results in estimated elasticities that are constant and therefore allows direct estimation of the desired elasticities. The following two log-linear equations represent the demand for domestic and imported goods:

$$\ln D_i = \alpha_{0i} + \alpha_{1i} \ln \overline{Y} + \alpha_{2i} \ln P_i^D + \alpha_{3i} P_i^M + \alpha_{4i} \ln \overline{P}, \qquad (45)$$

$$\ln M_i = \beta_{0i} + \beta_{1i} \ln \overline{Y} + \beta_{2i} \ln P_i^D + \beta_{3i} P_i^M + \beta_{4i} \ln \overline{P}, \qquad (46)$$

where $\overline{Y}$ and $\overline{P}$ are nominal GNP and aggregate price of all goods. The parameters to be estimated are α_{0i} - α_{4i} and β_{0i} - β_{4i}.

Subtracting (46) from (45) gives the demand functions in relative form

$$\ln\left(\frac{D_i}{M_i}\right) = \theta_{0i} + \theta_{1i} \ln \overline{Y} + \theta_{2i} \ln P_i^D + \theta_{3i} P_i^M + \theta_{4i} \ln \overline{P}, \qquad (47)$$

where $\theta_i \left(= a_i - \beta_i\right)$ is the parameter to be estimated. The disadvantage of this relative functional form is that the parameters α_i and β_i cannot be identified from θ_i . But the advantage is that the relationship between D_i and M_i is more stable than individual demand equations (Leamer and Stern, 1970).

Imposing homogeneity, i.e., $\sum_{i=1}^{4} \alpha_i = \sum_{i=1}^{4} \beta_i = \sum_{i=1}^{4} \theta_i = 0$, on (47) gives

$$\ln\left(\frac{D_i}{M_i}\right) = \theta_{0i} + \theta_{1i} \ln\left(\frac{\overline{Y}}{\overline{\overline{P}}}\right) + \theta_{2i} \ln\left(\frac{P_i^D}{\overline{\overline{P}}}\right) + \theta_{3i} \ln\left(\frac{P_i^M}{\overline{\overline{P}}}\right). \qquad (48)$$

Applying the assumption of a constant elasticity of substitution for each good *i*, i.e., $\alpha_{2i} = -\alpha_{3i}$, $\beta_{2i} = -\beta_{3i}$, $\theta_{2i} = -\theta_{3i}$, to (48) gives

$$\ln\left(\frac{D_i}{M_i}\right) = \theta_{0i} + \theta_{1i} \ln \overline{Y} + \theta_{3i} \ln\left(\frac{P_i^M}{P_i^D}\right) + \theta_{4i} \ln \overline{P}.$$

Applying the restriction that the income expansion path for domestic and imported good *i* is identical, i.e., $\theta_{1i} = 0$ or $\alpha_{1i} = \beta_{1i}$, gives

$$\ln\left(\frac{D_i}{M_i}\right) = \theta_{0i} + \theta_{3i} \ln\left(\frac{P_i^M}{P_i^D}\right). \qquad (49)$$

Equation (49) is the most common form used to estimate the elasticity of substitution between domestic and imported goods. In (49) θ_{3i} is the elasticity of substitution and is expected to be positive. Note that equation (49) is the log form of equation (44) and is thus derived from the same CES utility function.

17.3. Data and elasticity estimates

The data used in this study were assembled from the supply-use tables (SUT), international trade statistics (ITS) and national accounts produced by the Australian Bureau of

Statistics (ABS). The supply-use tables provide annual data on the value of imported and domestic goods by product and industry disaggregation. The producer price indices of domestically produced goods are published quarterly in the national accounts. The international trade statistics provide quarterly data on the value and price indexes of exported and imported goods. A number of transformations were applied to the ABS data to produce a data set of $n = 20$ goods in $T = 23$ years.

1. Commodity aggregation. The SUT data has 114 commodities and these include both merchandise and non-merchandise goods. We only consider merchandise goods since non-merchandise goods mostly do not have an import component, and domestic services are mostly complimentary rather than substitutable with imported services. The values of the 60 merchandise goods in the SUT were aggregated into 20 broad commodity groups. Although the data on price indices have a slightly different classification to that of the values data, the majority of the sectors are similar and were matched accordingly.
2. Time aggregation. The price indices are quarterly whereas the value data are published on an annual basis. We converted the quarterly prices into annual data using value-share-weighted average prices. The data span from 1995 to 2017.
3. Domestic sales. The differences between domestic production and export sales were used to define domestic sales of a given product.
4. Scale deflation. All values were placed on a per capita basis by deflating by population.
5. Quantities. Domestic and import quantities were derived by dividing nominal values by the corresponding prices.

Table 6 gives the means and standard deviations of the domestic shares, and log-changes in the relative price and quantity. This table shows that the domestic shares of agricultural-related products is higher compared to other commodities, with about 90% of total consumption domestically-produced. In particular, Australia imports only 4% of the total demand for Meat products (item 1 of Table 6), while less than 10% of Dairy and eggs (item 2) is imported. The import shares of other agri-forest products [e.g., Fish (3), Wood (11), Paper (12) and Furniture (13)] and mining products [Non-metals (14), Iron and steel (15) and Non-ferrous metals (16)] are higher, roughly ranging between 10% and 20%. Australia does not manufacture its own cars but produces vehicle parts and transport equipment, so that there are high import shares for the relevant products (items 17-19). The import share of Clothing and footwear (10) is also higher than most others at about 30%.

Table 3. Summary statistics

	Commodity	Domestic sales shares		Relative prices (Pd/Pf) (Log-changes)		Relative quantities (Qd/Qf) (Log-changes)	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Meat Products	95.61	1.290	-0.126	13.541	-4.037	16.641
2	Dairy Products and Egg	92.70	1.523	-0.526	12.182	-2.370	15.079
3	Fish Products	78.96	3.421	-1.361	10.938	-0.582	13.469
4	Other Food Products	85.72	4.013	-0.363	7.547	-3.988	6.901
5	Beverage and Tobacco	93.06	2.527	3.002	5.365	-7.975	8.858
6	Coal, Petroleum and Gas	74.16	8.420	0.257	26.578	-4.964	20.668
7	Basic Chemicals	66.53	3.680	0.040	10.005	-1.988	8.852
8	Pharmaceutical Products	60.76	5.762	1.739	4.091	-4.728	8.878
9	Textile and Leather	69.12	3.129	0.917	8.889	-2.050	10.411
10	Clothing and Footwear	71.00	7.076	-0.229	8.541	-5.185	9.143
11	Wood and Products	88.82	1.143	-1.183	6.052	0.696	10.290
12	Paper Products	83.98	2.561	0.761	8.218	-2.527	9.100
13	Furniture	80.72	7.413	-0.865	9.018	-6.343	10.111
14	Non Metals	79.34	2.325	0.608	9.212	-2.787	6.742
15	Iron Steel	80.47	2.122	-2.188	10.566	0.672	10.049
16	Non Ferrous Metals	80.84	5.732	-1.551	14.142	-4.217	30.868
17	Machinery Equipment	49.08	3.902	0.275	7.620	-2.978	7.907
18	Motor Vehicles and Parts	56.94	8.719	0.501	3.422	-5.617	8.046
19	Transport Equipment	55.00	6.146	-1.984	8.226	0.799	29.586
20	Other Manufactures	66.94	5.920	2.259	9.502	-6.991	10.402
	Average	75.49	13.310	-0.001	1.356	-3.358	2.257

Note: All entries are x 100

Figure 5 contains histograms for the relative price and quantity log-changes. In most cases, the quantity changes fall within the range [-5% to 0%], while price changes fall within [0% to 5%]. However, quantities are more volatile than prices as the standard deviations are 14.2% and 10.6%, respectively. This larger dispersion of quantities is also evident from Figure 6, which is a plot of the changes for each good in each year. Additionally, there are substantial "spikes" in the quantities for (a) Non-ferrous metals and (b) Transport equipment; the higher dispersion for these sectors is also clear from the last column of Table 3.

Three sets of import-domestic substitution elasticities were derived from three estimation methods: an OLS approach, a panel approach, and a restricted panel approach, with the results in broad agreement with each other. The first set involves single-equation OLS estimates for each of the 20 goods. Table 7 (columns 2-3) presents the estimated elasticities. Most of the substitution elasticities are significant and positive, where they range from 0.14 for Motor Vehicles to 2.06 for Transport Equipment, and the majority of the significant estimates are either less than unity or very close to it. From the last row of Table 7, on the basis of a Wald test, we fail to reject a common σ for changes.

Figure 5. Distribution of log-changes in relative prices and quantities

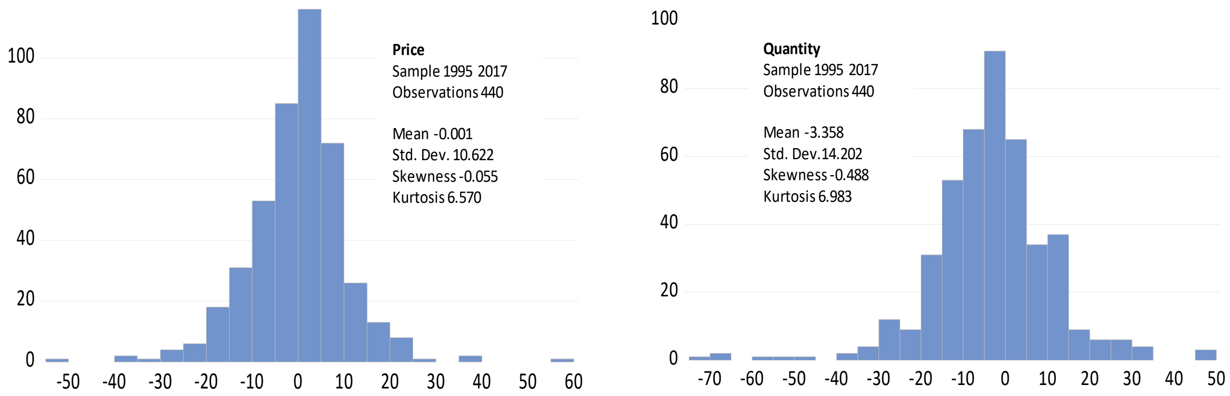
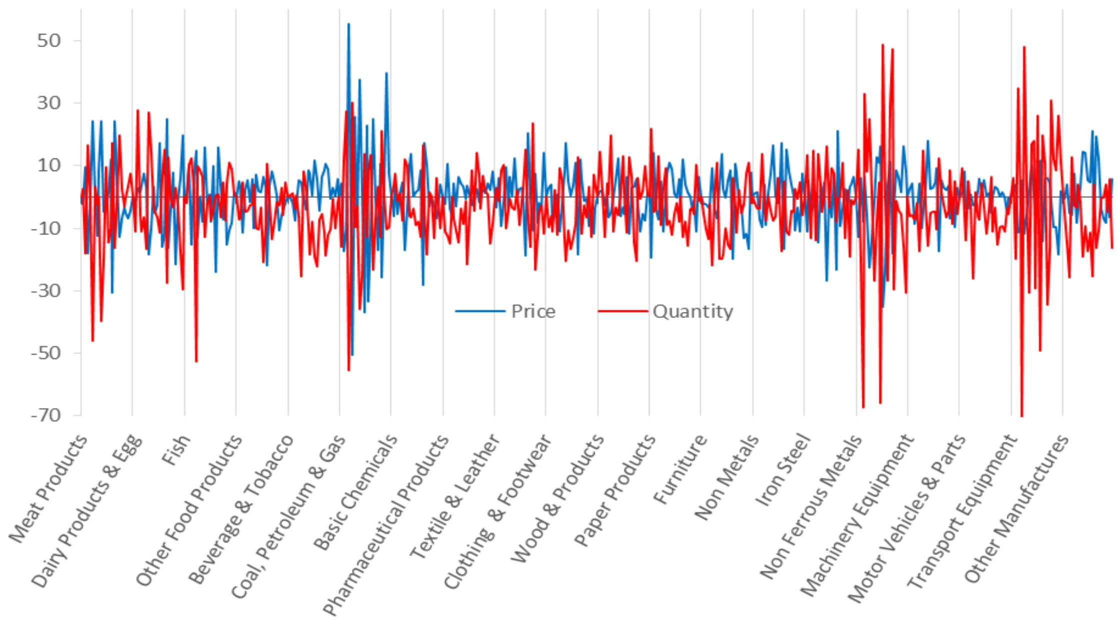


Figure 6. Time-series plot of price and quantity log-changes for all goods



Note: All entries are x 100

Table 4. Single-equation OLS and Panel estimates of substitution elasticities

	Commodity	Single OLS estimates			Panel estimates		
		Elasticity of substitution σ		Standard error	Elasticity of substitution σ		Standard error
	(1)	(2)		(3)	(4)		(5)
1	Meat Products	1.000	***	0.160	1.133	***	0.185
2	Dairy Products and Egg	0.906	***	0.189	1.051	***	0.203
3	Fish Products	0.608	**	0.239	0.839	***	0.230
4	Other Food Products	0.710	***	0.129	1.013	***	0.331
5	Beverage and Tobacco	1.009	***	0.292	1.268	***	0.462
6	Coal, Petroleum and Gas	0.642	***	0.098	0.747	***	0.093
7	Basic Chemicals	0.637	***	0.137	0.849	***	0.251
8	Pharmaceutical Products	0.523		0.471	0.730		0.603
9	Textile and Leather	0.682	***	0.213	1.004	***	0.282
10	Clothing and Footwear	0.775	***	0.165	1.033	***	0.295
11	Wood and Products	0.823	**	0.333	1.210	***	0.413
12	Paper Products	0.858	***	0.157	1.009	***	0.303
13	Furniture	0.826	***	0.170	0.991	***	0.279
14	Non Metals	0.552	***	0.107	0.777	***	0.273
15	Iron Steel	0.301		0.202	0.494	**	0.235
16	Non Ferrous Metals	1.002	**	0.434	1.048	***	0.174
17	Machinery Equipment	0.742	***	0.162	0.978	***	0.330
18	Motor Vehicles and Parts	0.143		0.525	0.355		0.728
19	Transport Equipment	2.056	***	0.660	2.246	***	0.306
20	Other Manufactures	0.742	***	0.180	0.905	***	0.264
Test for common sigma		Value		df	Value		df
	Chi-square	20.305		20.305	31.45		18

***, **, *significant at 1%, 5% and 10% levels

Our second pass uses a panel approach, which has two advantages. First, it allows for the easy incorporation of a time effect for each year that affects all goods simultaneously such as a transport disruption that delays the delivery of all imported goods. A second advantage is that the panel approach facilitates the testing of hypotheses covering multiple sectors, as will be demonstrated. Table 4 (columns 4-5) contains the results. Now, the elasticities tend to be more significant than before; they are also larger, ranging from 0.355 to 2.246. The Wald test rejects a common σ for both levels and changes.

Next, we test if groups of commodities share the same elasticity, rather than it being the same for every commodity individually. If true, this could represent a considerable simplification. Table 5 presents the results for when the 20 commodities form 7 broad groups. Results show that only within the 'Transport, machinery and equipment' group are the elasticities statistically different. Table 6 presents the estimates with the group-pattern restrictions imposed. All the substitution elasticities are positive and are mostly significant. The average elasticity is 1.046.

Table 5. Test for common sigma for seven commodity groups

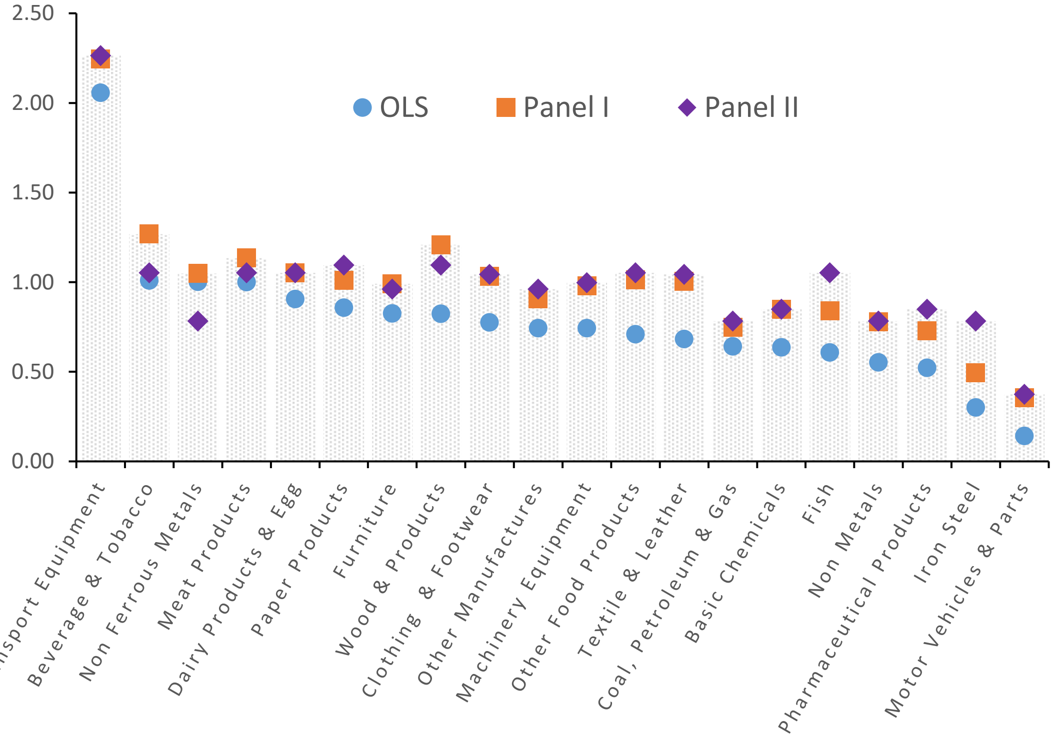
	Group name	Commodities	Null hypothesis	Test statistic	Value	df	Probability
1	Food and agricultural commodities	1. Meat Products 2. Dairy Products and Egg 3. Fish Products 4. Other Food Products 5. Beverage and Tobacco	$\sigma_i = \sigma_I$, $i = 1, \cdots, 5$	F-statistic	0.341	(4, 379)	0.851
				Chi-square	1.362	4	0.851
2	Energy and minerals	6. Coal, Petroleum and Gas 14. Non-metals 15. Iron Steel 16. Non-Ferrous Metal	$\sigma_i = \sigma_{II}$, $i = 6,14,15,16$	F-statistic	1.344	(3, 379)	0.260
				Chi-square	4.031	3	0.258
3	Chemical	7. Basic Chemicals 8. Pharmaceutical Products	$\sigma_i = \sigma_{III}$, $i = 7,8$	F-statistic	0.147	(1, 379)	0.702
				Chi-square	0.147	1	0.702
4	Textile, leather, clothing and footwear	9. Textile and Leather 10. Clothing and Footwear	$\sigma_i = \sigma_{IV}$, $i = 9,10$	F-statistic	0.005	(1, 379)	0.942
				Chi-square	0.005	1	0.942
5	Wood and paper products	11. Wood and Products 12. Paper Products	$\sigma_i = \sigma_V$, $i = 11,12$	F-statistic	0.161	(1, 379)	0.688
				Chi-square	0.161	1	0.688
6	Miscellaneous Manufacture goods	13. Furniture 20. Other Manufactures	$\sigma_i = \sigma_{VI}$, $i = 13,20$	F-statistic	0.054	(1, 379)	0.816
				Chi-square	0.054	1	0.816
7	Transport, machinery and equipment	17. Machinery Equipment 18. Motor Vehicles and Parts 19. Transport Equipment	$\sigma_i = \sigma_{VII}$, $i = 17,18,19$	F-statistic	5.867	(2, 379)	0.003
				Chi-square	11.734	2	0.003

Table 6. Panel estimates for 9-sector model

Commodity (1)	Elasticity of substitution σ	Standard Error

		(2)		(3)
1	Food and Agricultural Commodities	1.051	***	0.114
2	Energy and Minerals	0.782	***	0.075
3	Chemicals and Pharmaceuticals	0.848	***	0.232
4	Textile, Leather and Wearing Apparel	1.043	***	0.214
5	Wood and Paper Products	1.095	***	0.247
6	Miscellaneous Manufactured Goods	0.961	***	0.196
7	Machinery Equipment	0.997	***	0.327
8	Motor Vehicles and Parts	0.374		0.722
9	Transport Equipment	2.264	***	0.302
Fixed effects		Cross-section, Time		
	R-squared	0.47		
	Durbin-Watson stat	2.52		

Figure 7. Three sets of substitutions elasticities



A summary of the three sets of elasticities is presented in Figure 7, where the name 'Panel I' ('Panel II') refers to the case in which 20 (9) sectors are distinguished. As can be seen, on average, the substitution elasticities in Panel II are the highest, closely followed by Panel I. At the same time, however, the panel estimates are not too different to the unrestricted OLS counterparts.

18. Data sources and methods

Here we describe the process of developing the data used to calibrate the model. Table 7 provides a brief description of each block of data and summarises the source. Table 8 lists the 117 commodities in the model database. As all commodities are produced by a single representative industry, this is also the number of industries in the model. The listing of commodities and industries comprises the 114 commodities and industries in the product-by-industry tables provided by the Australian Bureau of Statistics (ABS) plus three transport freight industries that have been disaggregated in the original data. The industries represented align with the Australian and New Zealand Standard Industrial Classification (ANZSIC) at the 2-digit level.[19] Table 9 presents a stylised description of the recursive process applied to covert raw data in a format compatible with the model theory. The structure of the core database is illustrated in Figure 5 with the definition of the database components (i.e., sets, coefficients and parameters). Figure 6 summarises the division of gross value-added across primary factors of production.

[19] See https://www.abs.gov.au/ANZSIC.

Table 7. Data description and sources

Item	Description	Source
Input-output (IO) tables: domestic use, basic prices, product by product	This is the core data of the model. The table is simplified to produce the 'make' or production matrix by assuming each product is produced by a single representative industry. **IO Table 1.** Australian Production by Product Group by Industry **IO Table 2.** Input by Industry and Final Use Category and Australian Production and Imports by Product Group	Australian National Accounts: Input-Output Tables, Cat. no. 5209.0.55.001. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5209.0.55.0012015-16?OpenDocument*
Imports use table: basic prices, product by product	This supplements the IO table by detailing the import values by product and user. **IO Table 3.** Imports - Supply by Product Group and Inputs by Industry and Final Use Category	Australian National Accounts: Input-Output Tables, Cat. no. 5209.0.55.001. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5209.0.55.0012015-16?OpenDocument*
Margins tables	Margins (along with taxes and subsidies) determine the difference between producer prices and user prices for products. These data appear in the following IO tables: **IO Table 23.** Wholesale Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 24.** Retail Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 25.** Restaurants, Hotels and Clubs Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 26.** Road Transport Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 27.** Rail Transport Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 28.** Pipeline Transport Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 29.** Water Transport Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 30.** Air Transport Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 31.** Port Handling Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 32.** Marine Insurance Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 33.** Gas Margin on Supply by Product Group by Using Industry and Final Use Category **IO Table 34.** Electricity Margin on Supply by Product Group by Using Industry and Final Use Category	Australian National Accounts: Input-Output Tables, Cat. no. 5209.0.55.001. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5209.0.55.0012015-16?OpenDocument*
Taxes and subsidies tables on production and products	This data is provided in the IO tables as the values of taxes (subsidies) by product and user. **IO Table 35.** Net Taxes on Products by Product Group by Using Industry and Final Use Category **IO Table 36.** Goods and Services Tax on Products by Product Group by Using Industry and Final Use Category	Australian National Accounts: Input-Output Tables, Cat. no. 5209.0.55.001. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5209.0.55.0012015-16?OpenDocument*

Item	Description	Source
	IO Table 37. Duty on Products by Product Group by Using Industry and Final Use Category **IO Table 38.** Taxes on Products NEI by Product Group by Using Industry and Final Use Category **IO Table 39.** Subsidies on Products by Product Group by Using Industry and Final Use Category	
Gross fixed capital formation (GFCF) by industry	The GCFC data in Australia specifies only the capital formation by industry but it doesn't tell the commodity inputs used by an industry to form the capital.	ABS website under 'Input-output supply and use table # 2, Cat. no. 5209.0.55.001. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5209.0.55.0012015-16?OpenDocument*
Broad GFCF by 20 broad sector and 15 broad capital products	ABS has aggregated data on GCFC that specifies 15 broad commodity inputs to capital formation by 20 broad industries.	ABS website under 'Australian System of National Accounts' Table 64, Cat. no. 5204064. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02017-18?OpenDocument*
UK GFCF by industry and product	UK has a detailed level of GCFC data that specify the 'commodity' inputs to capital formation by industry. We use the cost structure in the UK data to split the Australian GFCF data across commodities but still preserving the industry totals. The commodity totals are then adjusted to match the broad commodity totals in the broad GFCF data.	ONS website under 'Input-output supply and use tables' (no reference number). *https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables*
Capital stocks by industry	Capital stock data represents initial quantities of capital used by firms. ABS publishes this data by 20 broad industries and 15 broad capital types.	ABS website under 'Australian System of National Accounts' Table 64-69, Cat. no. 5204. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02017-18?OpenDocument*
Unincorporated GOS by broad industries	These data are used to separate the component of GOS that is paid directly to workers who are self-employed. These data were only available for the 20 major industry groups.	ABS website under 'Business Indicators' statistics Table 13 and 15, Cat. no. 5676. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5676.0Dec%202018?OpenDocument*
Employment by industry	Data on employment by industry at the 4-digit level was mapped to the SUT categories. These then provided row totals for a RAS process that gave a balanced matrix of employment by industry and occupation.	Table builder at ABS website: *https://www.abs.gov.au/census*
Occupation by industry	The occupation by industry matrix is taken from the 2016 census. This data provides a relationship between occupations of workers and the industry.	Table builder at ABS website: *https://www.abs.gov.au/census*
Labour cost by industry	Data on wages and salaries, employer's contributions to superannuation, workers' compensation premiums, fringe benefit tax and payroll tax by 66 industry divisions.	ABS website under: 'Australian Industry' statistics, Table 2, Cat. no. 8115.0. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8155.02016-17?OpenDocument*
Superannuation funds	Value of superannuation funds in Australia	ABS website under: 'Managed Funds' statistics, Table 4, Cat. no. 5655. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5655.0Dec%202018?OpenDocument*
Government accounts data	Data on government revenues by type of tax collections, public sector debt and net interest, capital expenditure, total expenses, and current transfers.	ABS website under: - 'Taxation Revenue' Tables 1-18, Cat. no. 5506.0. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5506.02016-17?OpenDocument*
	Data on government benefits (age pensions, unemployment benefits)	- Budget Strategy and Outlook Budget Paper # 1

Item	Description	Source
	Data on government lending/borrowing and net worth	- 'Government Finance Statistics' Table 001 and 069, Cat. no. 55120. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5512.02017-18?OpenDocument*
Company income taxes by industry	Data on capital gains taxes, company dividends, and franking credits	ATO website *https://data.gov.au/dataset/ds-dga-5c99cfed-254d-40a6-af1c-47412b7de6fe/distribution/dist-dga-cbdd520b-0f61-4191-aabc-ede0a2f6ce14/details?q=taxation%20statistics*
Balance of payments (BOP) and international investment position (IIP)	Data on the following: - foreign assets, credits, debts, equity, liability and interests - foreign payments to AUS workers and payments to foreign workers in AUS	ABS website under: 'BOP and IIP, Cat. no. 5302.0.
Land values by type	Data on the value of land used in residential, commercial, and rural. These values are used to split the value of land across agriculture, dwelling and other industries.	ABS website under 'Australian System of National Accounts' Table 61, Cat. no. 5204. *http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02017-18?OpenDocument*

Note: The model data is specified in AUD millions. Initial data is for the IO year 2017-18 and then macro data were updated to the most recent national accounts. The hyperlinks provide the exact sources for the data.

Table 8. Commodities and industries

ABS IO industry		Industry description
1.	ShpGrnBefDry	Sheep, Grains, Beef and Dairy Cattle
2.	PoulOthLive	Poultry and Other Livestock
3.	OthAg	Other Agriculture
4.	Aquacult	Aquaculture
5.	ForLog	Forestry and Logging
6.	FishHuntTrap	Fishing, hunting and trapping
7.	AgForFishSrv	Agriculture, Forestry and Fishing Support Services
8.	Coal	Coal mining
9.	OilGas	Oil and gas extraction
10.	IrnOre	Iron Ore Mining
11.	NonFerMetOre	Non Ferrous Metal Ore Mining
12.	NonMetMiner	Non Metallic Mineral Mining
13.	ExpMinSrv	Exploration and Mining Support Services
14.	Meat	Meat and Meat product Manufacturing
15.	Seafood	Processed Seafood Manufacturing
16.	Dairy	Dairy Product Manufacturing
17.	FruVeg	Fruit and Vegetable Product Manufacturing
18.	OilFat	Oils and Fats Manufacturing
19.	GrainCer	Grain Mill and Cereal Product Manufacturing
20.	Bake	Bakery Product Manufacturing
21.	SugConf	Sugar and Confectionery Manufacturing
22.	OthFood	Other Food Product Manufacturing
23.	SoftDrink	Soft Drinks, Cordials and Syrup Manufacturing
24.	Beer	Beer Manufacturing
25.	WinSpirTob	Wine, Spirits and Tobacco
26.	Text	Textile Manufacturing
27.	Leath	Tanned Leather, Dressed Fur and Leather Product Manufacturing
28.	TextPrd	Textile Product Manufacturing
29.	Knitt	Knitted Product Manufacturing
30.	Cloth	Clothing Manufacturing
31.	Foot	Footwear Manufacturing
32.	Sawmill	Sawmill Product Manufacturing
33.	OthWood	Other Wood Product Manufacturing
34.	PulpPaper	Pulp, Paper and Paperboard Manufacturing
35.	PaperStat	Paper Stationery and Other Converted Paper Product Manufacturing
36.	Print	Printing (including the reproduction of recorded media)
37.	PetCoal	Petroleum and Coal Product Manufacturing
38.	HumPharm	Human Pharmaceutical and Medicinal Product Manufacturing
39.	VetPharm	Veterinary Pharmaceutical and Medicinal Product Manufacturing
40.	BasChem	Basic Chemical Manufacturing
41.	CleanComp	Cleaning Compounds and Toiletry Preparation Manufacturing
42.	Polymers	Polymer Product Manufacturing
43.	NatRubber	Natural Rubber Product Manufacturing
44.	Glass	Glass and Glass Product Manufacturing
45.	Ceramics	Ceramic Product Manufacturing

ABS IO industry		Industry description
46.	CemLime	Cement, Lime and Ready-Mixed Concrete Manufacturing
47.	PlasterConc	Plaster and Concrete Product Manufacturing
48.	OthNonMetMin	Other Non-Metallic Mineral Product Manufacturing
49.	IrnSteel	Iron and Steel Manufacturing
50.	BasNonFerMet	Basic Non-Ferrous Metal Manufacturing
51.	ForgIrnSteel	Forged Iron and Steel Product Manufacturing
52.	StrucMetPrd	Structural Metal Product Manufacturing
53.	MetContSheet	Metal Containers and Other Sheet Metal Product manufacturing
54.	OthFabMetal	Other Fabricated Metal Product manufacturing
55.	MotVeh	Motor Vehicles and Parts; Other Transport Equipment manufacturing
56.	ShipsBoats	Ships and Boat Manufacturing
57.	RailRollStck	Railway Rolling Stock Manufacturing
58.	Aircraft	Aircraft Manufacturing
59.	PrSciComElEq	Professional, Scientific, Computer and Electronic Equipment Manuf.
60.	ElecEq	Electrical Equipment Manufacturing
61.	DomApplian	Domestic Appliance Manufacturing
62.	SpecMachEq	Specialised and other Machinery and Equipment Manufacturing
63.	Furniture	Furniture Manufacturing
64.	OthMan	Other Manufactured Products
65.	ElecGen	Electricity Generation
66.	ElecTranDist	Electricity Transmission and Distribution
67.	GasSupply	Gas Supply
68.	WatSewDrnSrv	Water Supply, Sewerage and Drainage Services
69.	WasteSrv	Waste Collection, Treatment and Disposal Services
70.	ResCon	Residential Building Construction
71.	NonResCon	Non-Residential Building Construction
72.	HvyCvlCon	Heavy and Civil Engineering Construction
73.	ConSrv	Construction Services
74.	WholTrd	Wholesale Trade
75.	RetTrd	Retail Trade
76.	Accom	Accommodation
77.	FoodBevSrv	Food and Beverage Services
78.	RoadTrn	Road Passenger Transport
79.	RoadFreight	Road Freight Transport
80.	RailPass	Rail Passenger Transport
81.	RailFreight	Rail Freight Transport
82.	WatPipOthTrn	Water, Pipeline and Other Transport
83.	AirPass	Air and Space Passenger Transport
84.	AirFreight	Air Freight Transport
85.	PostCourSrv	Postal and Courier Pick-up and Delivery Service
86.	TrnSrvStor	Transport Support services and storage
87.	Publishing	Publishing (except Internet and Music Publishing)
88.	FilmAudioRec	Motion Picture and Sound Recording
89.	Broadcast	Broadcasting (except Internet)
90.	ISPIntPubWeb	Internet Service Providers, Internet Publishing and Broadcasting
91.	Telecom	Telecommunication Services

ABS IO industry		Industry description
92.	LibOthInfSrv	Library and Other Information Services
93.	Finance	Finance
94.	InsSupFunds	Insurance and Superannuation Funds
95.	AuxFinInsSrv	Auxiliary Finance and Insurance Services
96.	RentHireSrv	Rental and Hiring Services (except Real Estate)
97.	Dwell	Ownership of Dwellings
98.	NResPrpReEst	Non-Residential Property Operators and Real Estate Services
99.	PrfSciTecSrv	Professional, Scientific and Technical Services
100.	ComSysDesSrv	Computer Systems Design and Related Services
101.	EmpTrvAdmSrv	Employment, Travel Agency and Other Administrative Services
102.	BuildSupSrv	Building Cleaning, Pest Control and Other Support Services
103.	PubAdmRegSrv	Public Administration and Regulatory Services
104.	Defence	Defence
105.	PubOrderSafe	Public Order and Safety
106.	PrimSecEdu	Primary and Secondary Education Services
107.	TertVocEdu	Technical, Vocational and Tertiary Education Services
108.	ArtSporAdEdu	Arts, Sports, Adult and Other Education Services
109.	HealthCar	Health Care Services
110.	ResCarSocial	Residential Care and Social Assistance Services
111.	HerCrePerArt	Heritage, Creative and Performing Arts
112.	SportRec	Sports and Recreation
113.	Gambling	Gambling
114.	AutoRep	Automotive Repair and Maintenance
115.	OthRepMnt	Other Repair and Maintenance
116.	PersSrv	Personal Services
117.	OthSrv	Other Services

Note: Tourism commodities are shaded green.

Table 9. Steps to convert raw data in model compatible form

Step 1	• Raw IO data are converted from Excel to header array format. • IO tables are labelled with brief labels of commodity/industry, value added components, and final demand users.
Step 2	• Any missing values are replaced by informed guesses consistent with other data. • Any values with no economic meaning (e.g., negative imports) are set to zero or small positive values. • Data is reformatted into model form. • Margin commodities are determined. • Data is checked for balance.
Step 3	• Data is relabelled with brief names. • Imports are checked so that they do not exceed total domestic consumption. • A variety of diagnostic checks are performed (e.g., commodity sales check, industry cost check, tax check)
Step 4	• Margins are scaled so that they do not exceed total domestic consumption.
Step 5	• Margins and taxes are allocated across domestic and imported flows. • Basic flows of commodities are split into imported and domestic uses.
Step 6	• Gross operating surplus is divided across non-labour factors of production. • Wages are divided across occupational categories using labour hours data. • Employment and labour supply data by occupation is added.
Step 7	• Investment inputs by industry are introduced. • Import-domestic elasticities of substitution are introduced.
Step 8	• Investment inputs are divided across imported and domestic flows. • First version of model data files is created.
Step 9	• Stamp duties are divided into residential and commercial duties. • Taxes on production are determined (e.g., payroll and land taxes). • Gross Value Added is split across factors of production (i.e., wages, imputed wages, capital rents, land rents, and natural resource rents) • Income taxes are determined (non-factor income taxes – capital gains tax and dividend imputation tax credits, labour and owner operator income tax, taxes of GOS – company income tax and withholding tax, natural resource and land income taxes) • Investment-capital ratios and rates of return on capital are determined.
Step 10	• Government expenditure on non-consumption items are determined. • Stocks are adjusted. • Balance of payments data are determined. • Parameters file is created. • Supplementary data is created • Data imbalances are removed. • Second version of model data files is created.

Step 11	• Remove other costs via proportional adjustments in production cost items. • Data diagnostic checks are performed (e.g., sales and cost imbalances, GDP expenditure and income imbalances). • Model diagnostic checks are performed (e.g., homogeneity test)
Step 12	• Update database to the latest national accounts by informing the model with values of key economic indicators. • Model data is adjusted (if necessary) to remove imbalances caused by the updating procedure. • Split transport sectors (road, rail, airspace) into transport margins and transport services. • Re-run diagnostics to check data balances and model homogeneity after the margins split. • Run project simulation to check the theoretical validity of model results.
Step 13	• Database is aggregated to facilitate faster simulations for particular applications. • Diagnostic checks are performed to the aggregated database.

Figure 8. Structure of KPMG-CGE database

			Absorption Matrix					
			1	2	3	4	5	8
			Producers	Investors	Household	Export	Government	Change in Inventories
		Size	I	I	1	1	1	1
1	Basic Flows	CxS	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V8BAS
2	Margins	CxSxM	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	n/a
3	Sales Tax	CxSxT1	V1STAX	V2STAX	V3STAX	V4STAX	n/a	n/a
4	GST	CxS	V1GST	V2GST	V3GST	V4GST	n/a	n/a
5	Labour	O	V1LAB					
6	Imputed Wages	1	V1OWN					
7	Capital	U	V1CAPU					
8	Land	N	V1WAGE					
9	Natural Resource	1	V1RES					
10	Production Taxes	T2	V0ZTAX					
11	Payroll Tax	1	V0PRT					
12	Land Tax	T3	V0NTAX					
13	Other costs	1	V1OCT					

	Production
Size	I
C	V0MAKE

	Tariffs
Size	1
C	V7TAR

	Income Taxes
Size	I
OxT4	V1LTAX
UxT5	V1KTAX
1	V1WTAX
1	V1NTAX
1	V1MTAX
UxT6	V0TAX

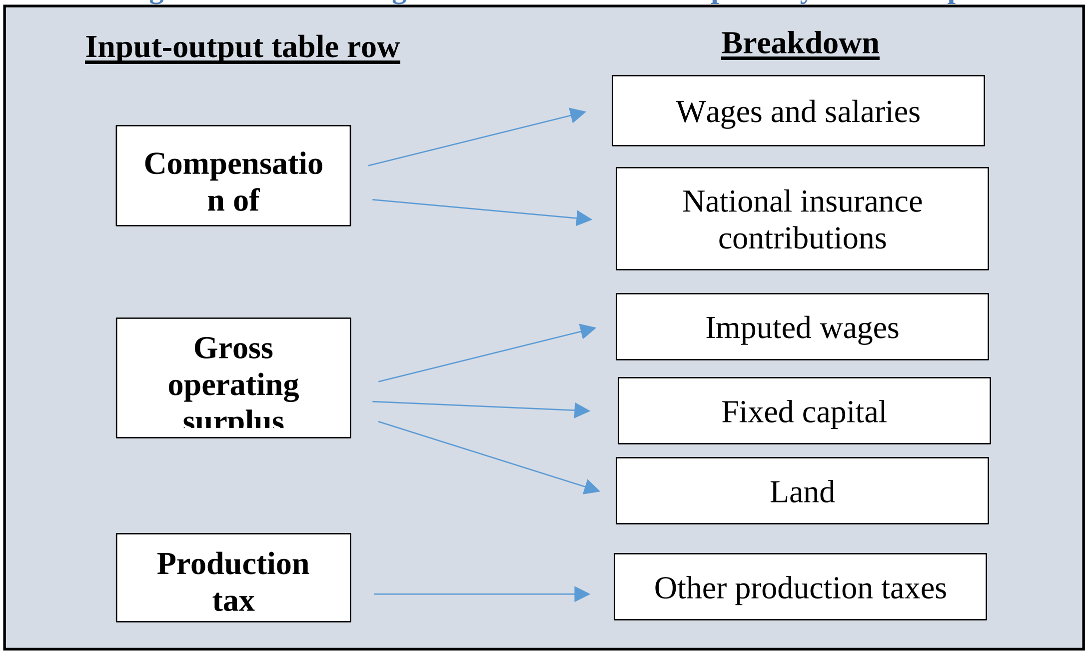
C = Commodities
I = Industries
S = {domestic, imported}
M = Margin commodities
O = Occupational types
U = {Domestic capital owners, Foreign capital owners, Superannuation funds, Unincorporated business owners}
N = {Primary land, Non-primary land}

T1 = {Sales tax, Carbon tax, Conveyance tax}
T2 = {Production tax, Carbon Tax}
T3 = {Agricultural land tax, Other taxes on immovable property}
T4 = {Labour Income Tax, Fringe Benefits Tax}
T5 = {Capital Income Tax, Withholding Tax}
T6 = {Capital Gains Tax, Dividend Income Tax, Individual Income Tax}

Code	Description	Dimension
Sets		
COM	Commodities	117 Commodities
IND	Industries	117 Industries
SRC	Commodity sources	2 Sources = (DOM, IMP)
MAR	Margin commodities	12 Margins
OCC	Occupational types	8 Broad Occupations
LAND	Land types	2 = (PPLND, NPPLND)
STAX	Sales tax types	3 = (STX, CO2C, CNV)
PTAX	Production tax types	2 = (PDT, CO2P)
TAXL	Personal income tax types	2 = (PIT, FBT)
TAXO	All other income tax types	3 = (CGT, DIT, IIT)
TAXK	Capital income tax types	2 = (CIT,WHT)
OWNER	Capital owner types	4 = (DOMCORP, FORCORP, SUPER, UNINCORP)
Coefficients		

Code	Description	Dimension
Flows of commodities at basic values		
V1BAS	Intermediate inputs at basic values	COM*SRC*IND
V2BAS	Investment at basic values	COM*SRC*IND
V3BAS	Household demands at basic values	COM*SRC
V4BAS	Export demands at basic values	COM
V5BAS	Government demands at basic values	COM*SRC
V8BAS	Inventory changes at basic values	COM*SRC
Flows of margin commodities		
V1MAR	*Basic values of margins on intermediate inputs*	COM*SRC*IND*MAR
V2MAR	*Margins on inputs to investment*	COM*SRC*IND*MAR
V3MAR	*Margins on household consumption at basic values*	COM*SRC*MAR
V4MAR	*Margins on exports*	COM*MAR
V5MAR	*Margins on government consumption*	COM*SRC*MAR
Indirect taxes on commodity flows		
V1STAX	*Sales tax on intermediate inputs*	COM*SRC*IND*STAX
V2STAX	*Sales taxes on investment*	COM*SRC*IND*STAX
V3STAX	*Sales taxes on household consumption*	COM*SRC*IND*STAX
V4STAX	*Sales taxes on exports*	COM*SRC*IND*STAX
V1GST	*GST on intermediate inputs*	COM*SRC*IND
V2GST	*GST on investment*	COM*SRC*IND
V3GST	*GST on household consumption*	COM*SRC
V4GST	*GST on exports*	COM
V7TAR	*Tariff on imports*	COM
Flows of primary factors		
V1WAGE	*Wages (market prices)*	IND*OCC
V1OWN	*Imputed wages*	IND
V1CAPU	*Capital rentals*	IND*OWNER
V1LND	*Land rentals (market prices)*	IND*LAND
V1RES	*Natural resource rents*	IND
Other operating costs		
V1OCT	*Other operating costs*	IND
Production taxes		
V0ZTAX	*Value of production tax collection*	IND*PTAX
V0PRT	*Payroll taxes*	IND
V0NTAXL	*Land tax*	IND
V0NTAXM	*Municipal rates & other taxes on fixed property*	IND
Direct (income) taxes		
V1LTAX	*Tax on labour income*	IND*OCC*TAXL
V1KTAX	*Capital income tax*	IND*OWNDER*TAXK
V1WTAX	*Imputed wages income tax*	IND
V1NTAX	*Land income tax*	IND
V1MTAX	*Natural resources income tax*	IND
V1OTAX	*Tax on other income*	IND*OWNER*TAXO

Figure 9. Division of gross value-added across primary factors of production



References

Atalay, E. (2017), 'How important are sectoral shocks', *American Economic Journal: Macroeconomics*, vol. 9, no. 4, pp. 254–80.

Australian Bureau of Statistics (2020), *Australian National Accounts: Input-Output Tables, 2017-18*, Cat. No. 5209.0, Australian Bureau of Statistics, Canberra.

Barten, A. P. (1964), 'Consumer demand functions under conditions of almost additive preferences', *Econometrica*, vol. 32, pp. 1-38.

Betancourt, R. R. (1971). 'The estimation of price elasticities from cross-section data under additive preferences', *International Economic Review*, vol. 12, pp. 283-92.

Bruno, M. (1984), 'Raw materials, profits, and the productivity slowdown', *The Quarterly Journal of Economics*, vol. 99, no. 1, pp. 1–30.

Chirinko, R.S. (2008), 'σ: The long and short of it', *Journal of Macroeconomics*, vol. 30, issue 2, pp. 671–86.

Clements, K.W., Mariano, M. and Verikios, G. (2020), 'Estimating the linear expenditure system using cross-sectional data', *Department of Economics Discussion Paper 20.18*, The University of Western Australia.

Clements, K.W., Selvanathan, S. and Selvanathan, E.A. (1995), 'The economic theory of the consumer', in Selvanathan, E.A. and Clements, K.W. (eds), *Recent Developments in Applied Demand Analysis: Alcohol, Advertising and Global Consumption*, Spinger Verlag, Berlin, pp. 1–72.

Clements, K. W. and Si, J. (2017), 'Notes on the pattern of OECD consumption', Unpublished working paper, UWA Business School.

Clements, K. W. and Si, J. (2018), 'Engel's law, diet diversity and the quality of food consumption', *American Journal of Agricultural Economics,* vol. 100, pp. 1–22.

Clements, K. W. and Zhao, X. (2009), *Economics and Marijuana: Consumption, Pricing and Legalisation,* Cambridge University Press, Cambridge.

Dandie, S. and Mercante, J. (2007), 'Australian labour supply elasticities: comparison and critical review', Treasury Working Paper 2007-04, Australian Government, Canberra.

Dixon, P. and Jorgenson, D. (2012), *Handbook of Computable General Equilibrium Modeling*, Elsevier, Amsterdam.

Francois, J.F. and Reinert, K.A. (1997), *Applied Methods for Trade Policy Analysis: A Handbook*, Cambridge University Press, New York.

Frisch, R. (1959), 'A complete scheme for computing all direct and cross demand elasticities in a model with many sectors', *Econometrica*, vol. 27, pp. 177-96.

Geary, R.C. (1950), 'A note on 'a constant-utility index of the cost of living'', *Review of Economic Studies*, vol. 18, no. 2, pp. 65–66.

Hanoch, G. (1971), 'CRESH production functions', *Econometrica*, vol. 39, no. 5, pp. 695–712.

Harrison, W.J. and Pearson, K.R. (1996), 'Computing solutions for large general equilibrium models using GEMPACK', *Computational Economics,* vol. 9, no. 2, pp. 83–127.

Howe, H. (1975), 'Development of the extended linear expenditure system from simple saving assumptions', *European Economic Review*, 6, pp. 305-10.

Howe, H. (1977), 'Cross-section application of linear expenditure systems: responses to sociodemographic effects', *American Journal of Agricultural Economics*, vol. 59, pp. 141-48

Klein, L.R. and Rubin, H. (1948), 'A constant-utility index of the cost of living', *Review of Economic Studies*, vol. 15, no. 2, pp. 84–87.

Kravis, I. B., Heston, A., and Summers, R. (1982), *World Product and Income: International Comparisons of Real Gross Product*, Baltimore, Johns Hopkins University Press.

Leamer, E.E. and Stern, R.M. (1970), *Quantitative International Economics*, Allyn and Bacon, Boston.

Lluch, C. (1971), 'Consumer Demand Functions, Spain', 1958-1964." *European Economic Review*, vol. 2, pp. 277-302.

Lluch, C., A. Powell ,A. and Williams, R. A. (1977), *Patterns in Household Demand and Saving*, Oxford University Press, Oxford.

Pollak, R. A., and Wales, T. J. (1969), "Estimation of the linear expenditure system." *Econometrica*, vol. 37, pp. 611-28.

Pollak, R. A., and Wales, T. J. (1978), 'Estimation of complete demand systems from household budget data: the linear and quadratic expenditure systems', *American Economic Review*, vol. 68, pp. 348-59.

Powell, A. A. (1973), "Estimation of Lluch's extended linear expenditure system from cross-sectional data." *Australian Journal of Statistics*, vol. 15, pp. 111-17.

Powell, A. A. (1992), "Sato's insight on the relation between the Frisch 'parameter' and the average elasticity of substitution". *Economics Letters*, vol. 40, pp. 173-75.

Starr, R.M. (1997), *General Equilibrium Theory*, *An Introduction*, Cambridge University Press, Cambridge, UK.

Stone, R. (1954), 'Linear expenditure systems and demand analysis: an application to the pattern of British demand', *The Economic Journal*, vol. 64, no. 255, pp. 511–527.

Theil, H. (1975/76), *Theory and Measurement of Consumer Demand*, Volumes 1 and 2, North-Holland Publishing Company, Amsterdam.

Theil, H. (1980), *The System-Wide Approach to Microeconomics*, The University of Chicago Press, Chicago.

Theil, H. (1965), 'The Information Approach to Demand Analysis', *Econometrica*, vol. 33, pp. 67-87.

Tulpule, A. and Powell, A.A. (1978), *Estimates of Household Demand Elasticities for the ORANI Model*, Preliminary Working Paper OP-22, Industries Assistance Commission, Canberra.

Vincent, D.P., Dixon, P.B. and Powell, A.A. (1980), 'The estimation of supply response in Australian agriculture: The CRESH/CRETH production system', *International Economic Review*, vol. 21, no. 1, pp. 221–42.