Griffith UNIVERSITY
Queensland, Australia

Griffith Business School

Economics and business statistics

Macroeconomic shocks and income distribution: the case of coronavirus in Australia

George Verikios and Marc Jim M. Mariano

2022-02

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

Department of Accounting, Finance and Economics

Macroeconomic shocks and income distribution: the case of coronavirus in Australia

by

George Verikios* and Marc Jim Mariano[#]

Abstract

The coronavirus (COVID-19) pandemic brought economic recession that affected nations, businesses, and households globally. The severity of this global economic crisis is large and the impact has been asymmetric across socioeconomic groups. We examine distributional effects of the COVID-19 pandemic across household types using a specially-designed model that combines macro (computable general equilibrium) and micro (heterogenous households) approaches. Computable general equilibrium models are able to capture behavioural changes in macroeconomic and sectoral variables but they often lack the rich distributional detail found in microsimulation models. In this paper we address this limitation by incorporating 10,046 actual households into a computable general equilibrium model to capture the heterogeneity through which the pandemic may influence household behaviour. We find that the income effects are asymmetric across income groups leading to a slight increase in income inequality. The distributional effects are more progressive for non-wage income sources and uniform for wage income. For younger cohorts income changes are dominated by employment effects whereas income changes for older cohorts are dominated by changes in capital rentals and government transfers. Spatially, the income effects follow a similar pattern for city and non-city dwellers.

Keywords: COVID-19, computable general equilibrium, distributional analysis, microsimulation.

JEL classifications: C68, D31, D58, E32, I14

* Department of Accounting, Finance and Economics, Griffith University. [#] KPMG Economics.

We thank Kevin Hanslow for assistance and helpful advice on this paper.

Table of Contents

1. Introduction

The outbreak of infectious diseases is a threat not only to human health but also to economic stability. This has been observed in past outbreaks such as HIV, H1N1, H5N1 and SARS (e.g., Chou et al., 2004; Fan, 2003; Hai et al., 2004; Keogh-Brown et al., 2010; Verikios et al., 2012). More recently, another pandemic - human coronavirus (COVID-19) - has brought economic recession that has affected nations, businesses and households globally. The severity of this global economic crisis is large and the impact has been asymmetric across socioeconomic groups. Much economic analysis of COVID-19 has focussed on the macroeconomic effects and less on the effects across socioeconomic groups:[1] in this work we contribute to the literature on the latter effects.

The coronavirus pandemic began in Australia around February 2020 and led to the slowest period of average GDP growth over the next two years since the recession of the early 1990s. Before the pandemic the economy was growing at 2.43% per annum on average over the period 2016-17 to 2018-19. Over 2019-20 to 2020-21 real GDP growth averaged only 0.74%; this included zero growth and a 4% contraction in employment in 2019-20. The pandemic led to a strong contraction in trade, household consumption and investment. These effects were mainly related to the draconian social distancing measures (lockdowns) implemented in response to the uncertain nature of the pandemic. Countervailing fiscal policy responses included a large expansion in government consumption (6%) due to increased expenditure on medical spending, the enforcement costs of wide-ranging and compulsory social distancing measures, and a wide array of COVID-19 payments to households and businesses, e.g., JobKeeper, JobSeeker, etc. Unprecedented monetary policy responses were also implemented in the form of close to zero nominal interest rates and quantitative easing.

There is a variety of previous studies analysing the economic effects of global pandemics. The ideal approach to analysing public health emergencies, such as pandemics, is one that has a comprehensive representation of the economy: that is, either a macroeconomic or computable general equilibrium (CGE) approach. Partial equilibrium analysis mostly focuses on the health sector and forgone incomes resulting from disease-related morbidity and mortality while ignoring effects in other parts of the economy (Sander et al., 2009); such an analytical framework is limiting. Illness and death due to public health emergencies raise perceptions of risk leading to risk-modifying behaviour (such as prophylactic absenteeism from work and public gatherings) in an effort to reduce the risk of contracting illness. Risk-modifying behaviour affects consumption and reduces labour productivity. Deaths due to illness reduce the supply of workers. The effects of risk-modifying behaviour and deaths will affect all parts of the economy to a greater or lesser extent.

A general equilibrium approach provides a comprehensive analytical framework for analysing public health emergencies as it captures the interdependency between seemingly unrelated sectors (e.g., medical services and international tourism) and the behaviour of various agents (e.g., households, investors, government and foreigners) in the economy (Verikios, 2020). Nonetheless, most CGE models have a single household sector and thus, in standard form, are incapable of capturing distributional effects across household types. To address this limitation some studies have complemented the CGE approach with the features of microsimulation models (e.g., Cockburn, 2006; Robilliard et al., 2008; Corong and Horridge,

[1] Examples of studies with a macroeconomic focus include Jawad et al. (2021), Maliszewska et al. (2020), Malliet et al. (2021) and McKibbin and Fernando (2021). Chitiga-Mabugu et al. (2021) is an example of a study with a distributional focus.

2012; Verikios and Zhang, 2016). This is sometimes referred to as the macro-micro approach; a similar approach is taken in this paper.

For this analysis we develop a dynamic CGE model of the Australian economy that represents five broad categories of representative agents – producers, investors, households, governments and foreigners (Verikios et al., 2021). These agents exhibit optimising behaviour while operating in commodity and factor markets that are market-clearing in the medium-to-long run. We extend this model by replacing the aggregate representative household with 10,046 actual households based on household surveys of expenditure and income produced by the Australian Bureau of Statistics (ABS). This provides an extremely rich representation of household characteristics such as demographic status, income and expenditure patterns, and location. The macro and micro parts of the model are linked via top-down and bottom-up connections that ensure consistency in behaviour at the aggregate and individual household levels.

We apply this framework to understand how the macroeconomic and industry outcomes of the pandemic affected economic welfare of different household groups. We analyse the effects on households when grouped by income levels, age brackets, and capital city and non-capital city locations. Our findings show that the distributional effects across deciles are more regressive for non-wage income sources than wage income. For younger cohorts income changes are dominated by employment effects whereas income changes for older cohorts are dominated by changes in capital rentals and government transfers. Across locations, the income effects follow a similar pattern for city and non-city dwellers.

The contribution of the paper is twofold. First, it contributes to the growing literature on macro-micro distributional analysis by embedding a large dataset of households with behavioural microsimulation capability within a CGE framework. Second, the distributional analysis undertaken here provides valuable insights for policymakers in formulating effectively-designed government responses to alleviate the effects of coronavirus and future pandemics, particularly for the most vulnerable groups in society.

2. The macro-micro approach

Macroeconomic models like CGE models are popular for quantifying the economywide effects of policies and other changes via estimates of macroeconomic and industry indicators such as GDP, employment and industry output. Although such macroeconomic and industry results are commonly used in policy decision-making, the analysis of policy reforms or economic events is not limited to the assessment of these effects. Rather, there are also effects that can and should be investigated at the individual household level. This is because just as economic shocks affect different industries in asymmetric ways, different households or household groups are affected in asymmetric ways. This is because (i) households are directly affected by disease outbreaks, and (ii) the effects of disease outbreaks on household types (e.g., poor and rich, young and old, urban and rural residents) will be a function of their socioeconomic characteristics. Evaluating the distributional effects on households of disease outbreaks thus adds an important strand to the total information available to policy makers when assessing how to respond to disease outbreaks. To account for distributional effects, economists have integrated CGE models with household survey-based models, i.e., microsimulation models.

Microsimulation models are popular for conducting distributional analysis. However, these models generally lack the ability to quantify sophisticated behavioural responses at the broad level - a feature intrinsic to CGE models - such as (1) price and wage adjustments driven by resource constraints, and (2) household spending, government spending and taxing adjustments driven by budget constraints. In contrast, CGE models often lack the rich distributional detail found in microsimulation models. This compels the analyst to combine the two approaches if they wish to avoid the limitations of each approach. Such complementarity makes it possible to evaluate the trade-offs between the efficiency and equity impacts of a policy or other change in the economy.

The literature provides different approaches to combining macro and micro approaches. Davies (2004, 2009) summarises these approaches in two groups: the 'layered' approach and the 'integrated' approach. In the layered approach, the CGE model is linked to an independent microsimulation model that captures heterogeneity in income sources, expenditure patterns and the sociodemographic composition of households. The two models are solved sequentially in a top-down fashion where the CGE model is solved first and then provides required inputs to the microsimulation model; these inputs are typically in the form of computed changes in commodity prices, wage rates, employment levels, and income from non-wage sources. This approach was employed by Robilliard et al. (2008) who analysed the effects of the 1997 financial crisis on poverty and inequality in Indonesia.

The integrated approach incorporates multiple households directly into the CGE model. This is traditionally done by replacing the standard single representative household in a CGE model with many representative households based on socioeconomic characteristics such as income level, geographical area, gender, household size, age, among others. The aim of the disaggregation is to capture as much household heterogeneity as possible as this influences the level of detail of the distributional results. The representative households approach can capture the distributional effects of policy changes *across* household groups but not *within* groups as intra-household distribution is assumed to be fixed. Other limitations of this approach are discussed by Kirman (1992) and summarised by Cockburn et al. (2010) as follows: (1) there is no theoretical justification to affirm that the aggregation of individual choices necessarily leads to the same solution as the choice of a representative individual; (2) there is no guarantee that the reaction of the representative household will be the same as the aggregated reaction of the individuals it represents; and (3) the representative household approach may interfere with the weak principle of individual preferences.

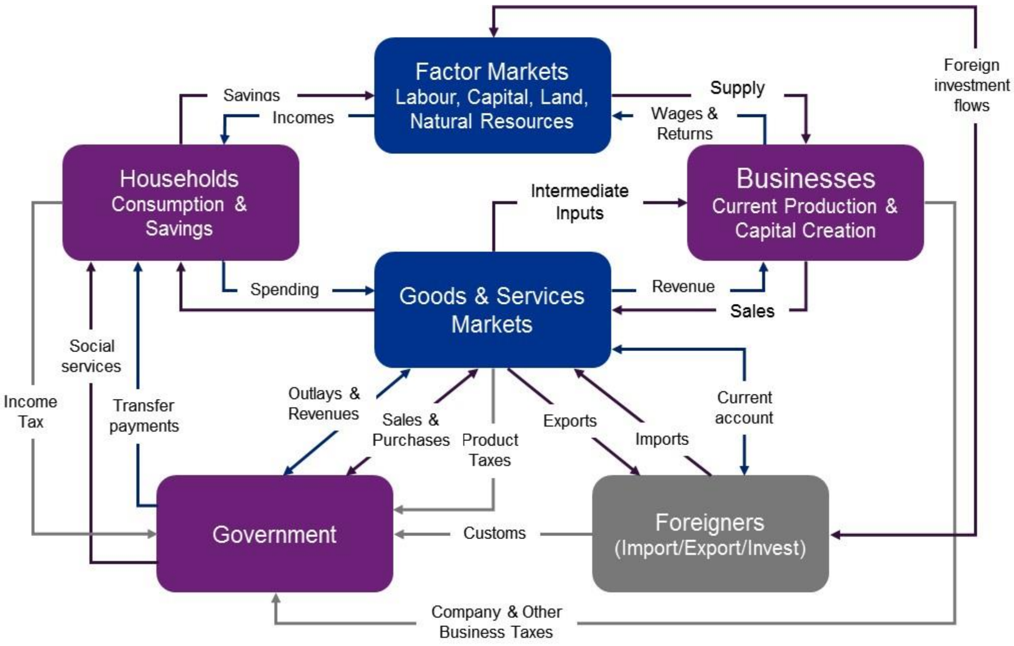
An alternative approach that overcomes the limitations of the representative households approach is to directly integrate all individual (i.e., real) households from a household survey into a CGE model. This is the most comprehensive approach, but, it is data intensive and computationally demanding. A key advantage of integrating real households within a CGE framework rather than using representative households is the greater flexibility it provides in stratifying household heterogeneity; this is possible since the sociodemographic characteristics of individual households are directly captured within the model. Examples of this approach include the work of Corong and Horridge (2012) for the Philippines with 38,400 households, Cockburn (2006) for Nepal with 3,373 households, and Cogneau and Robillard (2001) for Madagascar with 4,508 households. For Australia, Verikios and Zhang (2013, 2015, 2016) integrated a microsimulation model into a CGE model but used 10 representative households. For this paper we incorporate 10,046 actual households into a CGE model. To our knowledge, this is the first CGE-microsimulation model for Australia with a representation of thousands of actual households.

3. The macro model

3.1. Introduction

The macro model is a dynamic CGE model of the Australian economy.[2] The model represents five broad categories of representative agents – producers, investors, households, governments and foreigners. These agents make decentralised decisions in their economic activities but are interdependent via their concurrent participation in markets for commodities and primary factors and the interaction of saving and investment decisions. A graphical representation of the linkages between economic agents is presented in Figure 1.

Figure 1. Interaction of economic agents in the CGE model



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 $\boldsymbol{N}$.[3]

3.2. 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

[2] The model is formally documented in Verikios et al. (2021). Here we present a somewhat briefer description of the model.

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

of commodities, transformation between exported and locally-used commodities is expressed as:

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

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 (or supply) 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} [4]. 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.

3.3. 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 comprising intermediate or investment usage by each industry, private consumption and government consumption.

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

$$P_{iu}^{PREGST} = P_i^{LOC}\left(1+T_{iu}^{BAS}\right) + \sum_{m \in MAR} S_{ium}^{MAR}\left(P_i^{LOC} \cdot A_{im}^{MAR}\right)$$
$$i \in COM, u \in USR \qquad (4)$$

[4] 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.

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,[5] A_{im}^{MAR} is the per unit input requirement for margin m 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 $\Delta A_{im}^{MAR} < 0$ 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 3.4.

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

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

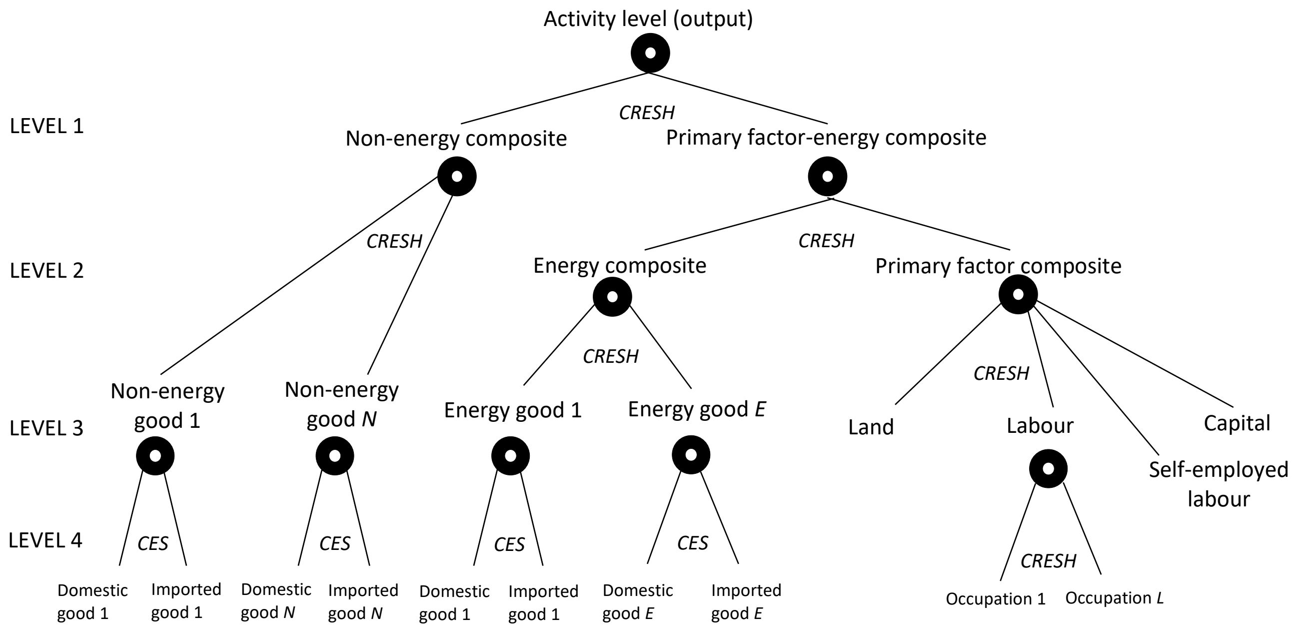
Equations of identical structure to (3) and (4) define the purchasers' price for each imported commodity in terms of taxes, margins and the basic price of the commodity. For an imported commodity the basic price is the landed duty-paid price, which is equal to the domestic currency CIF price[6] times the power of the import tariff rate, i.e., 1 + the import tariff rate.

3.4. 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 two types of land, 43 types of labour (occupations),[7] owner-operator labour, physical capital and natural resources. 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 2, the nested production functions, which define the production technology available to the representative firm, have four tiers.

[5] 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.
[6] The price inclusive of cost, insurance and freight.
[7] The occupational classification corresponds to 2-digit occupations in ABS (2019).

Figure 2. Input technology for current production



3.4.1. 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 inputs.

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.

3.4.2. 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

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

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

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.

3.4.3. 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

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

$$i \in NEI,\ k{=}NE,\ j \in IND, \qquad (8)$$

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

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

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

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).

3.4.4. 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

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

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

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 (see Clements et al., 2021). The 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. 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,..,43) labour types (i.e., occupations) subject to CRESH technology

$$\sum_o \left[\frac{Q_{oj}^{OCC}}{Q_{kj}^{FAC} A_{oj}^{OCC}} \right]^{v_i} \frac{X_o}{v_o} = \lambda \,, \qquad 0 < v_i < 1, X_i > 0, \sum_o X_o = 1, \lambda > 0 \,,$$

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

where Q_{oj}^{OCC} is demand for occupation o by industry j, Q_{kj}^{FAC} (k=LAB) is demand for the labour composite, and A_{oj}^{OCC} 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_{kj}^{FAC} , k=LND).

3.5. 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:

$$P_i^{BAS} Q_j = \left[\sum_{k \in COM} \sum_{s \in SRC} P_{ksj}^{INT} Q_{ksj}^{INT} + \sum_{f \in FAC} P_{fj}^{FAC} Q_{fj}^{FAC} \right] \left(1 + T_i^{BAS}\right), \quad i \in COM, j \in IND. \tag{12}$$

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_i^{BAS} 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 commodity. The right-hand side of (12) represents the j-th industry's costs comprising intermediate input costs $\sum_{k \in COM} \sum_{s \in SRC} P_{ksj}^{INT} Q_{ksj}^{INT}$, primary factor costs $\sum_{f \in FAC} P_{fj}^{FAC} Q_{fj}^{FAC}$ and the production tax on industry j T_i^{BAS} .

Equation (12) requires that industry output adjusts 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_i^{BAS} 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):

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

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 $\sum_{u \in ALLUSR} \sum_{m \in MAR} Q_{ium}^{MAR}$. 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 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.

3.6. Supply of factors of production

3.6.1. 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 function known as CRETH (constant ratio of elasticities of transformation, homothetic) function (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.

3.6.2. Labour

There is an infinitely-lived representative household that decides on the supply of each of the *o* (=1,..,43) labour types X_o^{OCC} 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

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

where POP is population, CPI is the consumer price index and σ_o^{OCC} 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 $\sigma^{OWN} = \sum_{o=1}^{43} \sigma_o^{LAB} \big/ 43$. 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. This limitation is addressed in Section 4 where the micro model is described.

3.6.3. Capital

Each industry uses physical capital specific to its own production process. Thus, the supply of capital is specified separately for each industry. An industry's capital stock available for use in year *t* $K_{j,t}$ 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 $Q_{j,t-1}^{INV}$:

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

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 physical 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.

3.7. 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 .

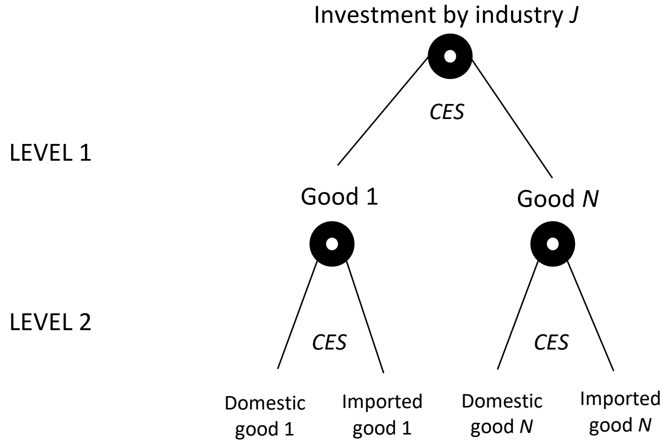
The provision of some examples helps tie down the more general notation of the current section to the factor-specific notation of the previous section:

- 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 $P_{if}^{FACNET} = PWAGE_o$, $\forall i \in IND$.

3.8. Input technology: investment

Physical 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 3 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 3. Input technology for investment (capital creation)



3.8.1. 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:

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

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.[8]

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*:

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

[8] Note that we ignore capital gains in defining the rate of return to the capital owner.

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.

3.8.2. 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

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

$$i\in COM, j\in IND. \tag{22}$$

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 $\sigma=1/\left(1+\kappa\right)$ = 0.1. This makes inputs to capital creation close to fixed shares of industry investment levels and relatively unresponsive to changes in relative prices.

3.8.3. 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

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

$$i\in COM, s\in SRC, j\in IND. \tag{23}$$

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 $\sigma_i=1/\left(1+\psi_i\right)$. These values are drawn from econometric estimates based on Australian data over the period 1995 to 2017 (see Clements et al., 2021). The parameter values allow input demands to be responsive to relative price changes between domestic and foreign goods.

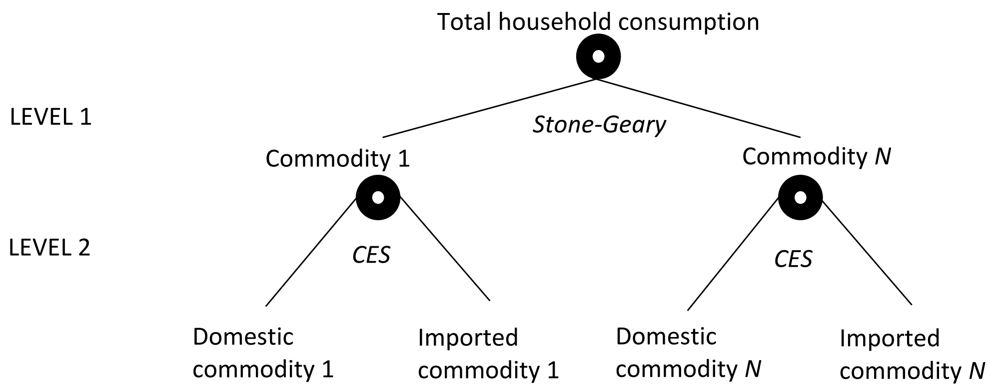
3.9. Household demands

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 4). 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 4. Input technology for households (utility)



3.9.1. 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

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

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) expenditure $\left(VLUX^H \right)$, 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. 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 (see Clements et al., 2022).

3.9.2. 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 $\sigma_i = 1/(1+\zeta_i)$. These values are drawn from econometric estimates based on Australian data over the period 1995 to 2017 (see Clements et al., 2021).

3.10. 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

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

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, and recreation services. The tourism bundle is determined by a constant elasticity of demand function

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

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

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

where $PFOB_i^{EXP}$ is the FOB[9] 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

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

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

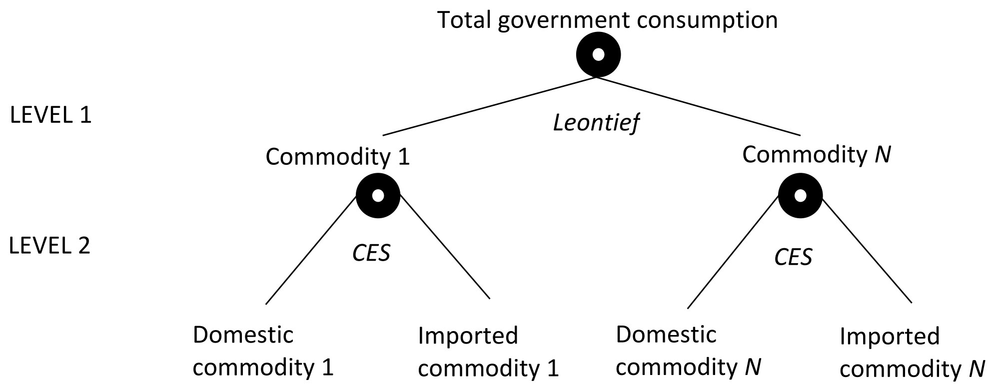
[9] Free On Board.

to the pre-GST price of domestic goods, as described in section 3.3, but uses P_i^{EXP} in place of P_i^{LOC}.

3.11. 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 5. 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 5. Input technology for governments



3.11.1. Level 1: Composite inputs to goverment consumption

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

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

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.

3.11.2. 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 with the elasticities of substitution based on the values estimated by Clements et al. (2021).

3.11.3. 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.

3.11.4. 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.

3.12. Asset and liability accumulation

3.12.1. 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 (FC^{DC}) and foreign currency (FC^{FC}), and similarly for foreign debt (FD^{DC}, FD^{FC}), 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 $(FA_r,\ FE_t,\ FC_t^{DC},\ FC_t^{FC})$ and gross foreign liability variables $(FL_t,\ FDI_t,\ FD_t^{DC},\ FD_t^{FC})$ are defined as averages of stocks of across year *t*. Nevertheless, the net foreign liability variable (NFL_t) 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.

3.12.2. 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.

4. The micro model

Analysing the distributional dynamics of the coronavirus pandemic requires a model capable of tracing the socioeconomic impacts across multiple dimensions of household characteristics. We extend the single household representation of the macro model by incorporating 10,046 actual households. This is done by constructing a micro household database with a detailed representation of household income and expenditure. The micro database is constructed using the 2015-16 Household Expenditure Survey (HES) and Survey of Income and Housing (SIH) conducted by the Australian Bureau of Statistics (ABS, 2018). These surveys contain a wealth of information on sociodemographic variables, income sources and expenditure patterns.

The raw survey data is transformed in three ways. First, we map the 10,046 households in the HES that also appear in the SIH to give expenditure and income accounts for all households to be represented in the micro model.[10] Second, we extract household data from the HES-SIH using a classification of income sources and commodity expenditure that is consistent with the structure of the CGE database as summarised in Table 1. Third, we reconcile the HES-SIH and the CGE database (which is calibrated using the national accounts) so that the household income and expenditure totals from the household surveys are equal to the aggregated income and expenditure values from the national accounts. This preserves the macro values of income and expenditure items from the national accounts while at the same time capturing the micro distribution from the survey.

The macro and micro models are connected via many top-down links and three bottom-up links: employment, labour supply and commodity demand. This means that the behavioural responses of workers and consumers are determined at the individual household level. The aggregated (across households) responses for employment, labour supply and commodity demand are each forced to match the responses at the macro level. Thus, the macro responses are determined by the macro model and the household responses are determined by the micro model and the results are consistent when compared at the same level of aggregation.

[10] The HES has information on 10,046 households and the SIH has information on 17,768 households. There are 10,046 households that are common to both surveys. We represent these common households in the micro model.

In the following sections we describe in detail the links between the macro and micro models. Sections 4.1-4.3 reiterate the specification of household income, labour supply and household consumption, respectively, in the macro model. Sections 4.4.1-4.4.2 then show how the micro model contains similar representations of household income, labour supply and household consumption but distinguished by individual household, with behaviour driven by household level data rather than by aggregate level data. Finally, section 4.4.3 describes how aggregate employment changes are allocated across households.

Table 1. Structure of the micro household database

Data	Size	Components
Expenditure	117 commodities	2-digit IOPG commodity classification
Income	43 wage income sources	2-digit ANZSCO occupational classification
	4 non-wage factor income sources	1. Owner-operator income 2. Capital rentals 3. Land rentals 4. Natural resource rentals
	12 government benefits	1. Age pension 2. Abstudy 3. Carer allowance 4. Disability pension 5. Family allowance 6. Overseas pension 7. Sick benefits 8. Supplementary partner benefits 9. Unemployment benefits 10. Veteran's pension 11. Widow pension 12. Wife pension
	5 other private income types	1. Accident compensation and sickness insurance 2. Child support/maintenance 3. Regular workers' compensation 4. Other regular sources 5. Scholarships

4.1. Household income

The representative household earns income from the supply of domestic factor endowments (labour, capital, land, and natural resources), receives government benefits (allowances and pensions), and income from foreign sources. Pre-tax household income *HY* is defined as

$$HY = \begin{array}{l} \sum_{j \in IND} \sum_{o \in OCC} Q_{oj}^{OCC} \cdot P_{o}^{OCC} + \sum_{j \in IND} \sum_{k=CAP} SD_{kj}^{FAC} \cdot Q_{kj}^{FAC} \cdot P_{kj}^{FAC} + \\ \sum_{j \in IND} \sum_{l \in LAND} Q_{lj}^{FAC} \cdot P_{lj}^{FAC} + \sum_{j \in IND} \sum_{p=OWN} Q_{pj}^{FAC} \cdot P_{pj}^{FAC} + \\ \sum_{j \in IND} \sum_{n=NR} Q_{nj}^{FAC} \cdot P_{nj}^{FAC} + \sum_{b} GB_{b} + \sum_{m} FT_{m} \end{array}$$

$$j \in IND,\ b \in BEN,\ m \in FTR. \qquad (40)$$

In equation (40) the factor income sources are labour (indexed by $o \in OCC$), capital (indexed by $k = CAP$), land (indexed by $l \in LAND$), owner-operator income (indexed by $p = OWN$) and natural resources (indexed by $n = NR$). The other income sources are government benefits GB_b (indexed by b) and foreign income transfers FT_m (indexed by m). Factor income is determined as a function of factor prices (P) and quantities (Q). Besides capital all factor income accrues to the household. Some capital income accrues to foreign capital owners; the proportion accruing to the household is represented by the share SD_{kj}^{FAC}.

The linearised version of (40) is

$$\begin{aligned} HY \cdot hy = \\ &\sum_{j\in IND}\sum_{o\in OCC} Y_{oj}^{FAC}\left(q_{oj}^{OCC}+p_{o}^{OCC}\right)+\sum_{j\in IND}\sum_{k=CAP} YD_{kj}^{FAC}\left(sd_{kj}^{FAC}+q_{kj}^{FAC}+p_{kj}^{FAC}\right)+ \\ &\sum_{j\in IND}\sum_{l\in LAND} Y_{lj}^{FAC}\left(q_{lj}^{FAC}+p_{lj}^{FAC}\right)+\sum_{j\in IND}\sum_{p=OWN} Y_{pj}^{FAC}\left(q_{pj}^{FAC}+p_{pj}^{FAC}\right)+ \\ &\sum_{j\in IND}\sum_{n=NR} Y_{nj}^{FAC}\left(q_{nj}^{FAC}+p_{nj}^{FAC}\right)+\sum_{b} GB_{b}\cdot gb_{b}+\sum_{m} FT_{m}\cdot ft_{m} \end{aligned} \quad ,(41)$$

where all variables in lower case are the percentage-change equivalents of levels variables in (40) and the Y coefficients represent income for the relevant primary factor. Equation (41) demonstrates the link between household income and production as the percentage-change in household factor income is driven by the percentage-changes in factor prices and quantities.

4.2. Labour supply

Section 3.6.2 derived labour supply by occupation o (=1,..,43) X_{o}^{OCC}. The linearised form of the labour supply function is

$$x_{o}^{OCC} = pop + \sigma_{o}^{OCC}\cdot rwage_{o}, \quad o\in OCC, \tag{42}$$

where pop is population, $rwage_{o}$ is the post-income-tax real wage rate and σ_{o}^{OCC} is the uncompensated labour supply elasticity.

4.3. Household consumption

Section 3.9.1 showed that consumption choices for commodity composites by the representative household being governed by a Stone-Geary utility function implies the (LES) Marshallian demand function in equation (25). The linearised version of (25) is

$$q_{i}^{H} = BLUX_{i}^{H}\cdot qlux_{i}^{H} + \left(1-BLUX_{i}^{H}\right)qsub_{i}^{H}, \quad i\in COM, \tag{43}$$

where $BLUX_{i}^{H}$ is the ratio of supernumerary (or luxury) expenditure to total expenditure defined as $\frac{\beta_i}{\omega}$: the ratio of the marginal budget shares β_i and the so-called Frisch parameter ω (see Clements et al., 2022). Subsistence demands $qsub_{i}^{H}$ are determined as

$$qsub_{i}^{H} = qhou + asub_{i}^{H}, \quad i\in COM, \tag{44}$$

where $qhou$ is the number of households and $asub_{i}^{H}$ represents (exogenous) household tastes for subsistence expenditure. Luxury demands $qlux_{i}^{H}$ are determined as

$$qlux_{i}^{H} = wlux^{H} - p_{i}^{H} + alux_{i}^{H}, \quad i\in COM, \tag{45}$$

where $wlux^{H}$ is total luxury expenditure, p_{i}^{H} is the consumer price for the i-th good, and $alux_{i}^{H}$ represents (exogenous) household tastes for luxury expenditure.

Given (43)-(45), the percentage-change in total household consumption is defined as

$$v^H = W_i^H \left(q_i^H + p_i^H \right), \quad i \in COM, \tag{46}$$

where W_i^H represents the budget share for the i-th good.

4.4. Defining household-specific behaviour

The micro-model follows the same specification of household activities as described above except that it has h (= 10,046) households (forming the set HOU) rather than a single representative household. This detailed representation of households captures the heterogeneity of household behaviour implicit in the multi-household database. The linearised equations defined above for household income, labour supply and consumption now include a household-specific dimension. For example, household income in the micro-model is defined as

$$\begin{aligned} HY_h = & \sum_{j \in IND} \sum_{o \in OCC} S_{ojh}^{FAC} \cdot Q_{oj}^{OCC} \cdot P_o^{OCC} + \sum_{j \in IND} \sum_{k = CAP} S_{kjh}^{FAC} \cdot SD_{kj}^{FAC} \cdot Q_{kj}^{FAC} \cdot P_{kj}^{FAC} + \\ & \sum_{j \in IND} \sum_{l \in LAND} S_{ljh}^{FAC} \cdot Q_{lj}^{FAC} \cdot P_{lj}^{FAC} + \sum_{j \in IND} \sum_{p = OWN} S_{pjh}^{FAC} \cdot Q_{pj}^{FAC} \cdot P_{pj}^{FAC} + \\ & \sum_{j \in IND} \sum_{n = NR} S_{njh}^{FAC} \cdot Q_{nj}^{FAC} \cdot P_{nj}^{FAC} + \sum_b S_{bh}^{GB} \cdot GB_b + \sum_m S_{mh}^{FT} \cdot FT_m \\ & h \in HOU. \end{aligned} \tag{47}$$

The S coefficients above allocate each income source across the h households using shares derived from the SIH-HES. The pattern of broad income sources across income deciles is presented in Table 2. This shows that for most households the dominant source of income is wages. Government benefits are more important for lower income households and non-labour income is more important for higher income households.

Table 2. Structure of household disposable income

Income decile	Share of income source in total household income (%)			Direct tax rate (%)
	Labour income	*Non-labour income*	*Government benefits*	
Lowest	11	28	62	2.85
Second	17	42	41	3.37
Third	36	39	25	6.85
Fourth	55	29	16	10.57
Fifth	58	27	15	12.58
Sixth	58	26	17	13.03
Seventh	58	26	16	13.76
Eighth	53	33	14	13.77
Ninth	55	38	7	15.95
Highest	35	63	2	19.68

Source: 2015-16 Household Expenditure Survey and Survey of Income and Housing (ABS, 2018).

4.4.1. Household-specific labour supply

The linearised equation defined above for labour supply now includes a household dimension

$$x_{oh}^{OCC} = x_o^{OCC} + \sigma_o^{OCC} \cdot \left(rwage_{oh} - rwage_o \right), \quad o \in OCC, h \in HOU. \tag{48}$$

In (48) household-specific labour supply for the *o*-th occupation x_{oh}^{OCC} moves with aggregate labour supply for the *o*-th occupation x_{o}^{OCC} unless there is a divergence in the relative household-specific post-income-tax real wage rate $\left(rwage_{oh} - rwage_{o}\right)$. That is, households experiencing higher relative wage rates will supply more labour at the expense of households experiencing lower relative wage rates; the size of this effect is controlled by σ_{o}^{OCC}. The household-specific post-income-tax real wage rate is defined in levels as

$$RWAGE_{oh} = \frac{P_{oh}^{OCC}}{CPI_{h}}\left(1 - TR_{oh}^{OCC}\right), \quad o \in OCC,\, h \in HOU, \tag{49}$$

where P_{oh}^{OCC} is the market wage received by occupation *o* in household *h* and CPI_{h} is the household-specific consumer price index. TR_{oh}^{OCC} is the labour tax rate paid by the (*o*, *h*)-th worker. The labour tax rate is defined as the ratio of labour income taxes to labour income. In defining the values applied to define TR_{oh}^{OCC} the allocation across households reflects the distribution across households of total income tax paid as reported in the SIH; that is, the SIH does not report income tax paid by income source only total income tax. We use the distribution of these values in SIH to allocate labour income tax from the macro model across households. A similar method is applied in defining income tax rates on income from other sources.

The determination of P_{oh}^{OCC} is explained in section 4.4.3 below. The linearised equation for CPI_{h} is

$$cpi_{h} = \sum\nolimits_{h} S_{ih}^{H} \cdot p_{i}^{H}, \quad i \in COM,\, h \in HOU, \tag{50}$$

where S_{ih}^{H} represent budget shares based on expenditure reported in the HES.

4.4.2. Household-specific demand for commodity composites

The linearised version of the equation defined above for consumption demands now includes a household dimension

$$q_{ih}^{H} = BLUX_{ih}^{H}\left[wlux^{H} - p_{i}^{H} + alux_{i}^{H}\right] + \left(1 - BLUX_{ih}^{H}\right)qsub_{i}^{H}, \quad i \in COM,\, h \in HOU. \tag{51}$$

To determine household-specific consumption demands q_{ih}^{H} requires only one new household-specific coefficient to be defined: $BLUX_{ih}^{H}$, the ratio of supernumerary (or luxury) expenditure to total expenditure. This is the product of the aggregate household ratio of supernumerary (or luxury) expenditure to total expenditure and household-specific marginal budget shares β_{ih}

$$BLUX_{ih} = BLUX_{i} \cdot \beta_{ih}, \quad i \in COM,\, h \in HOU. \tag{52}$$

β_{ih} is based on values estimated by Clements et al. (2022) for income quintiles. These values are mapped to the *h* households after they have been stratified by quintiles based on equivalised household disposable income.[11] More specifically, the marginal budget shares β_{ih} are estimated for 21 broad commodities and five income groups. These values are then mapped to the 117 commodities and 10,046 households in the micro model.

4.4.3. Allocating aggregate employment changes across households

Table 2 shows that for most households the dominant source of income is wages. Therefore, the treatment of wage income is crucial in a model that purports to explain how macroeconomic changes are distributed across households and the effect on income distribution. When there is a macroeconomic shock the percentage-change in wage rates p_o^{OCC} and employment q_{oj}^{OCC} will diverge from zero. The question is how to allocate these changes across households. The simplest (but not very satisfactory) approach is to scale household-specific wage income by wage income at the macro level as implied by the term $\sum_{j\in IND}\sum_{o\in OCC} S_{ojh}^{OCC}\cdot Q_{oj}^{OCC}\cdot P_o^{OCC}$ in equation (47) if the S_{ojh}^{OCC} were all constant. The ideal approach is to base changes in employment on household characteristics such as income level, married status, homeowner or renter status, government benefits recipient, etc. This can be done by estimating employment probabilities based on household characteristics by applying a probit model as in Liyanaarachchi (2015). In the absence of employment probabilities we assume the percentage-change in employment by occupation q_{oh}^{OCC} moves as follows[12]

$$q_{oh}^{OCC} = \sum_{j\in IND} S_{oj}^{OCC}\cdot q_{oj}^{OCC}\left(\frac{E_{oh}^{OCC}}{\sum_o E_{oh}^{OCC}}\right) + f_o\,,\quad o\in OCC,\, h\in HOU. \tag{53}$$

In (53) the term $\sum_{j\in IND} S_{oj}^{OCC}\cdot q_{oj}^{OCC}$ is the percentage-change in total employment for occupation *o*. This is distributed across households by the term $\frac{E_{oh}^{OCC}}{\sum_o E_{oh}^{OCC}}$, which represents the importance of each occupation in total employment for each of the *h* households. Thus, the more important an occupation is to a household (as represented by a higher value for the term $\frac{E_{oh}^{OCC}}{\sum_o E_{oh}^{OCC}}$) the greater will be the impact of changes in that occupation.

Equation (53) requires the inclusion of the adjustment factor f_o to ensure data balance between employment at the micro and macro level: $\sum_{h\in HOU} S_{oh}^{OCC}\cdot q_{oh}^{OCC} = \sum_{j\in IND} S_{oj}^{OCC}\cdot q_{oj}^{OCC}$.

An implicit assumption in (53) is that wage rates must be household-specific otherwise it would not be possible for q_{oh}^{OCC} to move differentially across households for a given occupation unless there existed some other type of difference between labour provided by different households (e.g., distance from the location of work). Household-specific wage rates P_{oh}^{OCC} are imposed by assuming a wage premium is earned by those households whose (*o*, *h*)-

[11] Equivalised disposable household income equals disposable household income adjusted by equivalence factors to standardise them for variations in household size and composition. This is necessary because "As household size increases, consumption needs also increase but there are economies of scale. An equivalence scale is used to adjust household incomes to take account of the economies that flow from sharing resources and enable more meaningful comparisons between different types of households." (ABS, 2022).

[12] This approach was suggested and developed by Kevin Hanslow and we gratefully acknowledge his assistance.

th unemployment rate is lower than for the *o*-th occupation in aggregate. The maximum premium that can be earnt is 10%. This premium represents productivity differentials across households. The linearised equation for the annual percent changes in household-specific wage rates is:

$$p_{oh}^{OCC} = p_{o}^{OCC} + 10 \cdot \left(U_{o}^{OCC} - U_{oh}^{OCC} \right) + fp_{o}, \quad o \in OCC, h \in HOU. \tag{54}$$

where U is the level of the unemployment rate and the adjustment factor fp_o ensures that the household-specific wage rates are consistent with the aggregate (macro-model) wage rate for each occupation.

5. Simulating the coronavirus pandemic

To generate an appropriate and consistent starting point for the macro and micro parts of the model database, we implement a simulation that covers 14 years. Starting with a database representing an observed equilibrium in 2015-16, the economy evolves in the long run via a three-part forecast that covers: the historical period 2016-17 to 2018-19, the pandemic period 2019-20 to 2020-21 and a future (or forecast) period from 2021-22 to 2029-30. The details of the three-part forecast are presented in Table 3. The historical and pandemic periods incorporate historical data from the Australian national accounts. These historical shocks include annual growth rates of expenditure- and income-side components of GDP, price deflators (consumer goods and labour), and consumption across 13 broad sectors – see Table 3 for an exhaustive list. Note that with this approach the effects of the pandemic on the macroeconomy are revealed in the actual data over the period rather than the difference between actual and projected forecasts starting from the pre-pandemic equilibrium. Thus we are implicitly assuming that the pandemic and policies related to the pandemic were the overwhelming determinant of macroeconomic outcomes over the pandemic period (2019-20 to 2020-21).

Table 3. Exogenous changes applied to the macro-micro model

Variables	**Historical period** *Source:* national accounts	**Pandemic period** *Source:* national accounts, budget papers	**Future period** *Source:* global macro-econometric model
Real GDP	√	√	√
Real household consumption	√	√	√
Real investment	√	√	√
Real government consumption	√	√	√
Real exports	√	√	√
Real imports	√	√	√
Employment	√	√	√
Labour supply	√	√	√
Population	√	√	√
Number of households	√	√	√
Consumer price index	√	√	√
Real wage rate	√	√	√
Real consumption across 13 broad commodity types	√		
Job seeker support		√	
Income support for the unemployed		√	

The future period incorporates forecasts for Australia from a global macroeconometric model.[13] These macroeconomic projections incorporate the latest information on policy and other changes that are relevant for the global and Australian economies, including the recovery path from the pandemic recession.[14] The variables that are shocked over the future period are macroeconomic in nature and operate under two long-run constraints. First, the household saving rate adjusts so that net foreign liabilities as a share of GDP stabilise over the forecast period, which in turn imposes a budget constraint on household behaviour in the long run. Second, the personal income tax rate adjusts so that government debt as a share of GDP stabilises over the forecast period, which in turn imposes a budget constraint on government behaviour in the long run. Under these conditions the macro-micro model will show the evolution of structural (industry) change and household distribution as the economy converges to a steady-state.

6. Results

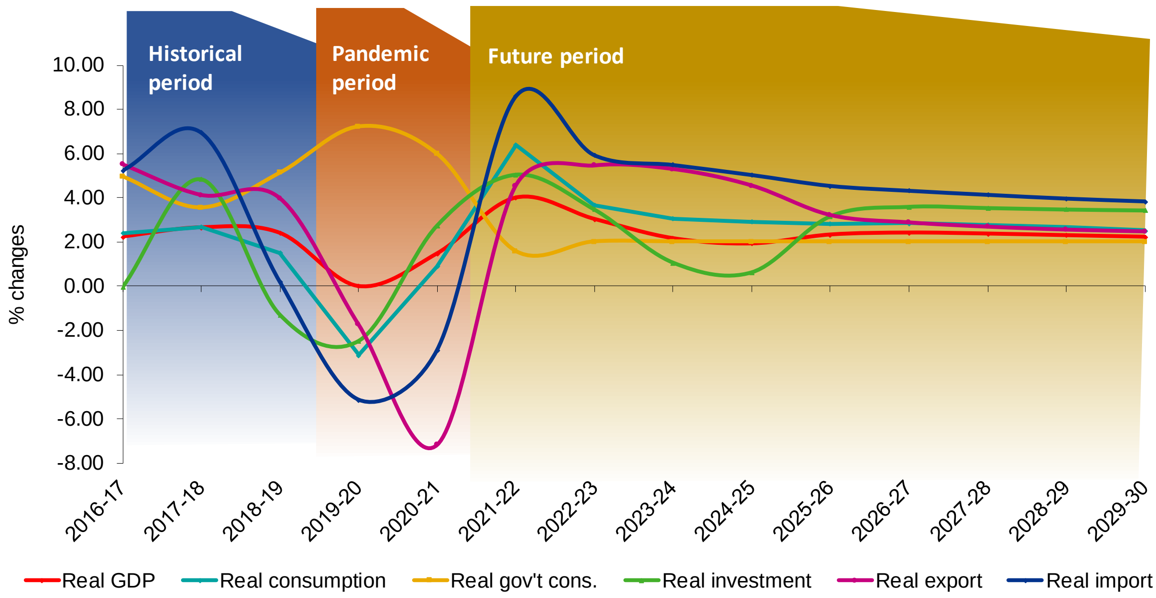
6.1. Macroeconomic effects

Figure 6 presents the macroeconomic effects of the pandemic in terms of real GDP and the expenditure-side components. Before the pandemic the economy was growing at 2.43% per annum on average over the historical period 2016-17 to 2018-19. This GDP growth was mainly driven by growth in exports (4.53% p.a.), imports (4.14% p.a.) and government consumption (4.54% p.a.). Lower growth is observed for household consumption (2.21% p.a.) and investment (1.17% p.a.). The onset of the pandemic shows a fall in all expenditure components of GDP except government consumption over the period 2019-20 to 2020-21. Average annual GDP growth falls to 0.74% over the two pandemic years. This is the lowest rate of annual GDP growth since the early 1990s recession in Australia. The trade sector is significantly affected with imports contracting by 5.13% in the first year of the pandemic and then exports falling significantly in the following year by 7.19%. There is also a reduction in household consumption (-3.13%) and investment (-2.47%) during the first year of the pandemic and then slightly recovering in the second year. Conversely, government spending increases significantly by over 6% over the pandemic period. This effect is related to the government's increased expenditure on medical spending, the enforcement costs of wide-ranging and compulsory social distancing measures, and a wide array of COVID-19 payments to households and businesses.

[13] This is based on the NiGEM model developed and maintained by the National Institute of Economic and Social Research (Hantzsche et al., 2018).

[14] Assumptions made in the economic forecast are broadly consistent with other contemporaneous forecasts such as those by the Commonwealth Treasury in the 2020-21 MYEFO economic outlook. These assumptions include: (1) localised outbreaks of COVID-19 that are largely contained; (2) a population-wide vaccine program in place by the end of 2021; (3) general social distancing in place until the end of 2021; (4) GDP growth returns to long-term trend in 2022-23; and (5) a steady rollout of vaccines globally and international trade continues with Australia.

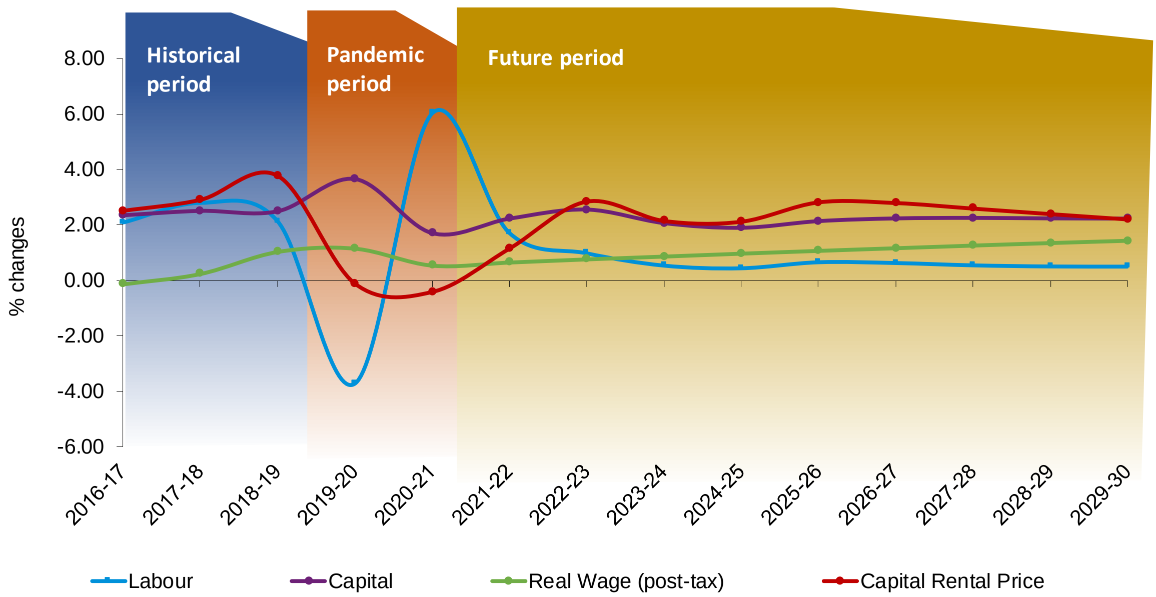
Figure 6. GDP and expenditure-side effects



In the post pandemic period economic activity recovers with imports growing by 5.10% p.a. and exports by 3.75% p.a. on average. There is also a positive investment response with average annual growth rate of 3.05% while household consumption is projected to recover to 3.30% p.a. on average. The economy eventually moves towards a balanced growth path as it approaches the end of the simulation period in 2029-30 with GDP growing by 2.5%.

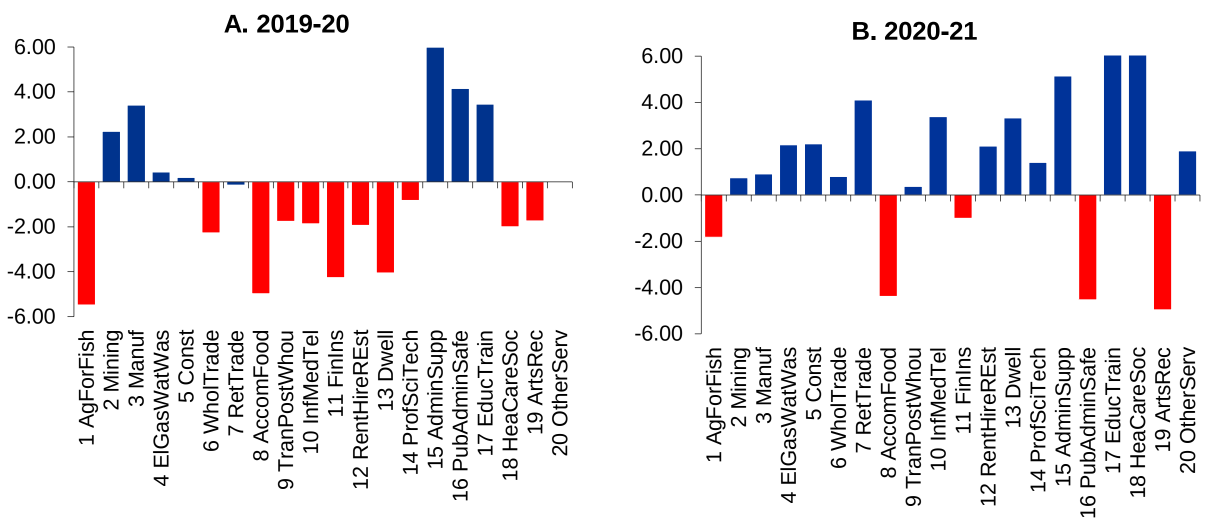
Figure 7 shows the effects on employment, capital and factor prices. Large swings in these variables are observed over the pandemic period. In 2019-20 we observe a rise in the post-tax real wage (1.15%) and a big fall in employment (-3.70%) as many workers were laid off due to the closures of many businesses and increased absence from the workplace due to illness or prophylaxis.

Figure 7. Employment, capital and price effects



The contractionary effect of the pandemic reduces demand for labour by firms. Industries that contract are mostly labour-intensive and tourism-related such as *Agriculture*, *Accommodation and food*, *Wholesale and retail trade*, *Transport, postal and warehousing* (air transport in particular), *Information, media and telecommunications*, *Finance and insurance*, *Rental, hiring and real estate services*, and *Arts and recreation* (see Figure 8, Panel A). During the pandemic there is also a contraction in *Health care and social assistance* as many medical services were halted to focus on COVID-19 cases. In contrast there is an expansion in *Public administration*, *Education and training*, and *Administration and support*. This mainly reflects the increase in government services to mitigate the effects of the pandemic. Capital-intensive industries such as *Mining* and *Manufacturing* also expand. The expansion of the manufacturing sector is most likely driven by the increased demand for work-from-home office equipment.

Figure 8. Percentage change in sectoral outputs during the pandemic periods



In the second year of the pandemic, employment recovers while the capital rental price falls (see Figure 7). Most of the industries that initially contracted during the onset of the pandemic have recovered except for *Accommodation and food*, *Agriculture*, *Finance and insurance*, and *Arts and recreation* (see Figure 8, Panel B). The tourism-related sectors (*Accommodation and food*, *Arts and recreation*) still show the largest contractions due to continued restrictions on international and interstate travel. There is also a contraction in *Public administration* as some government COVID-19 interventions were ended (e.g., JobSeeker payments) as were the requirement for policing lockdowns. In contrast, the *Ownership of dwellings* sector expands as many home buyers took advantage of low interest rates on housing loans. There is also an increased demand for *Information, media and telecommunication* due to the increase in working from home, online selling, home delivery services, and virtual meetings. *Health care and social assistance* increased as the number of COVID-19 infections continue to rise during the second year of the pandemic. The retail trade sector also expands due to the resumption of operations for some retail businesses. While the government withdrew its JobSeeker Payment for individuals in 2021 it continued to provide support for businesses and employers such as the COVID-19 financial support, JobKeeper Payment, JobMaker Hiring Credit and Rent concessions among others. These interventions contribute to the recovery of businesses especially small and medium size enterprises.

6.2. Household effects

We analyse the distributional effects on households of the pandemic by decomposing the effects along three household dimensions: income group, location and age group. The heterogeneity of results across household groups are driven by the variation in the composition of household expenditure and income as affected by pandemic-induced changes in commodity and factor prices and factor usage (capital and labour).

Figure 9 presents the percentage changes in household nominal disposable income across deciles (Panel A) and its decomposition into broad income sources: wage income (Panel B), non-wage factor income (Panel C) and government transfers (Panel D). Panel A shows that the effect of the pandemic on income distribution is asymmetric across deciles. In 2019-20 income rises for all deciles but rises much more for the first three deciles. This pattern is reversed in 2020-21 as income rises for all deciles except for the first three. However, the dispersion of the income effects is much greater in 2019-20 compared with 2020-21 as reflected by the standard deviation of 5.66 cf. 2.98. Thus, overall we observe a progressive pattern of effects (i.e., the income gain is smaller as we go up the income distribution) in 2019-20 and a regressive pattern in 2020-21.

The distributional effects can be understood by decomposing disposable income into income sources. We see in Panel B to D of Figure 9 that the asymmetry of income effects across deciles is more apparent for non-wage income sources as compared to wage income. In 2019-20 the income effects are dominated by non-wage factor income and other income. Both of these sources rise strongly in 2020-21 whereas wage income falls slightly. More specifically, Panel C shows that non-wage factor income increases for all households in 2019-20 but with a progressive pattern. The opposite happens in 2020-21 where non-wage income falls for the first four deciles and increases slightly for the subsequent deciles. Non-wage factor income of the first four deciles is negatively affected by the fall in the rental price of capital in 2020-21 as observed earlier in the macro effects. Panel D shows that other sources of income such as government transfers follow a similar pattern of distributional effects to that of non-wage factor income but with a lower degree of asymmetry across income deciles. In 2019-20 there is a larger increase in other income at the lower end of the income distribution for two reasons: (i) low-income households are the main recipients of COVID-19 payments from the government, and (ii) many low-income earners have withdrawn a lump-sum portion of their superannuation. In the following year there is a fall in other income for the lower deciles as government benefits such as JobSeeker ended in the first quarter of 2020-21. Conversely, Panel B shows that the effect of the pandemic on wage income is almost uniform across deciles in 2019-20 and 2020-21. Wage income is slightly lower for all households in the first year of the pandemic and then rebounds significantly in the following year.

Figure 10 summarises the distributional effects by age cohort. In the first year of the pandemic (Figure 10, Panel A), disposable income is higher for most deciles aged 36 and above. The largest increase in income is observed for the oldest group (i.e., aged over 65). We have seen in Figure 9 that both non-wage factor income (Panel C) and other income (Panel D) have increased for all deciles in the first year of the pandemic. The deciles aged over 65 benefit from this as this cohort includes many retired persons who receive income from dwelling rentals and government payments. In contrast, the income of younger households (i.e., 35 or less) is either unaffected or falls. This age cohort is dominated by households who rely most on wage income and who suffer a loss in employment or wages in 2019-20.

Figure 9. Percentage change in household nominal disposable income and sources by decile

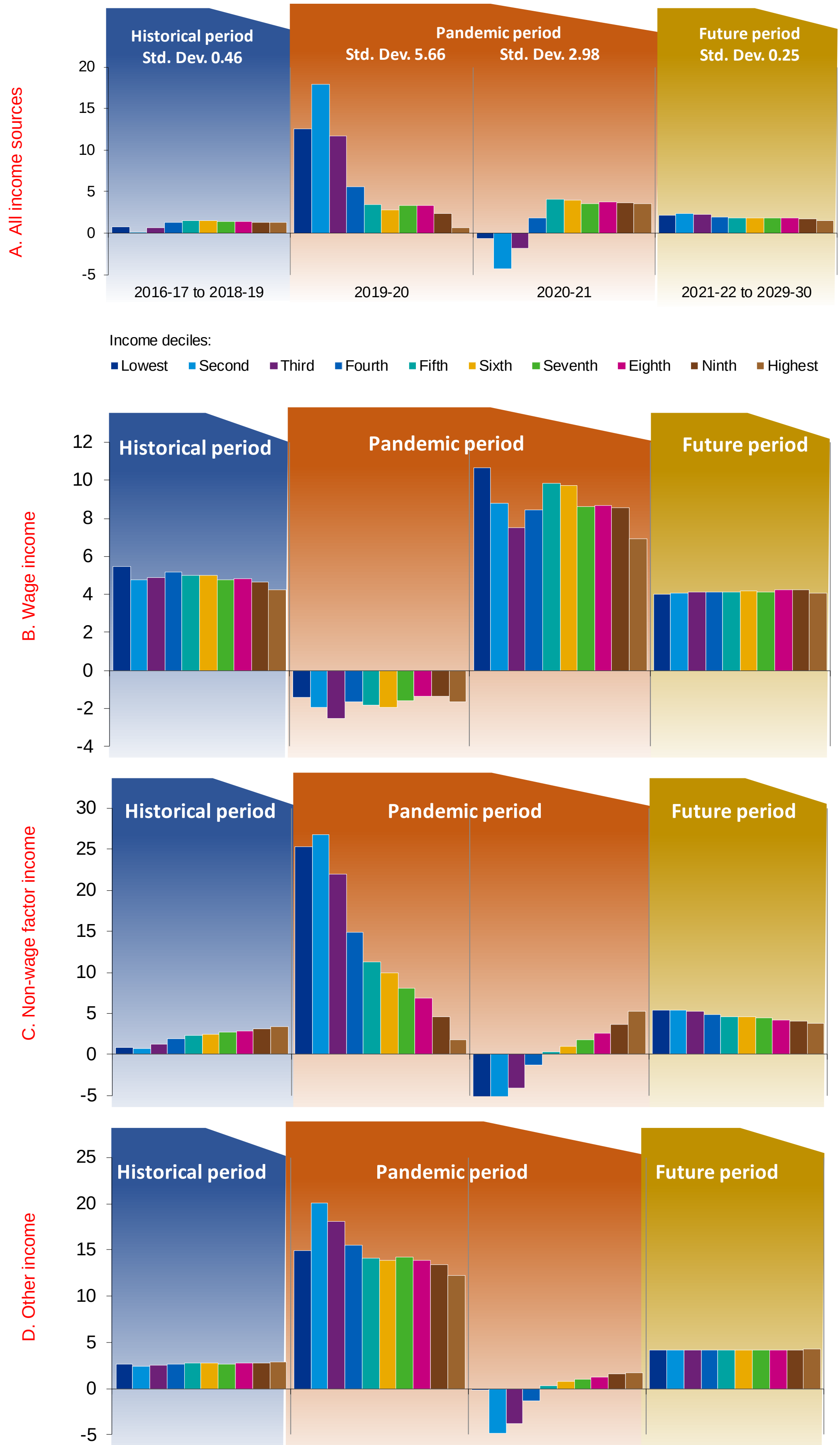
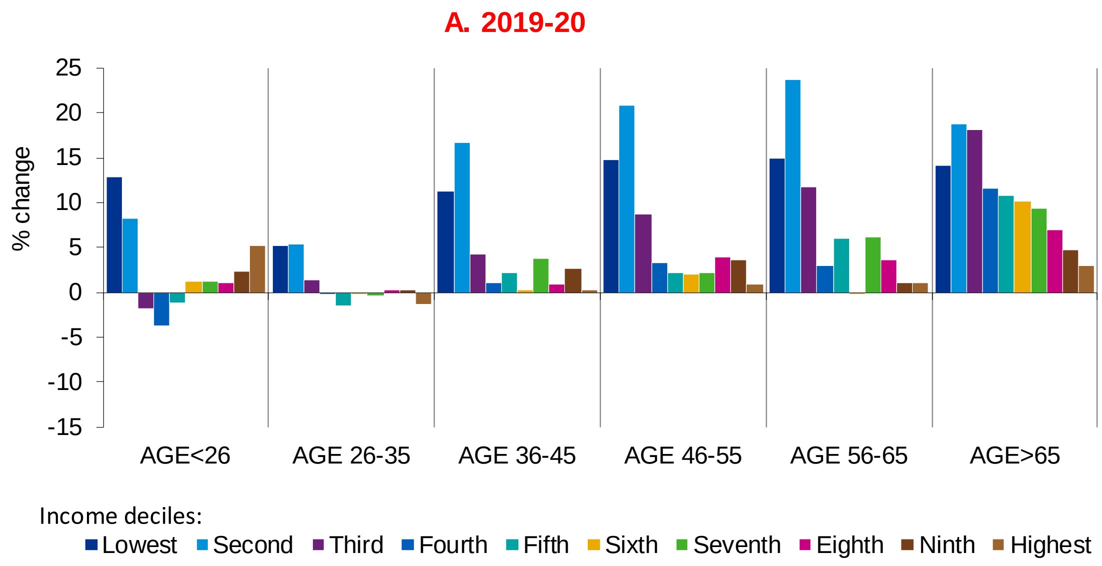
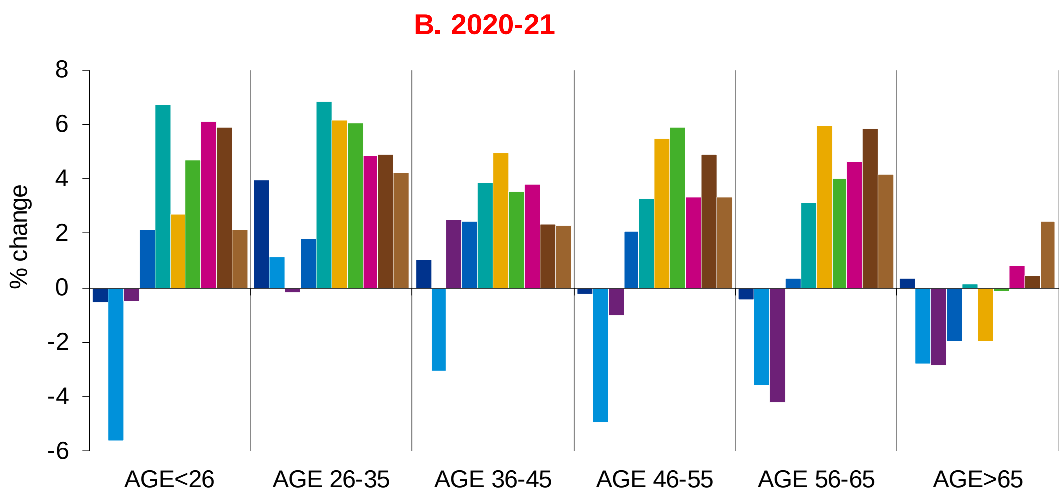


Figure 10. Percentage change in household nominal disposable income by age cohort





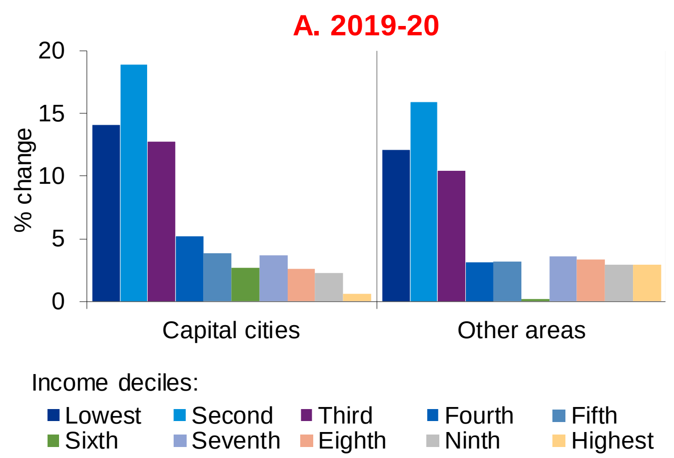
In general, during the first year of the pandemic low-income deciles regardless of age experienced higher disposable income because of the JobSeeker Payment and the early withdrawal of superannuation income. In the second year of the pandemic these effects are reversed and this is explained by two main effects. First, we observe that nearly all age cohorts in the lower income deciles experienced a contraction in disposable income in 2020-21 (Figure 10, Panel B). This is primarily due to the (i) reduction in government transfers and (ii) fall in the dwelling rental price, both of which are important sources of income for the lowest income deciles.[15] More specifically, younger low-income households are affected by (i) while older

[15] Here we are referring to households groups that are found in the lower income deciles but represent different cohorts. Due to means testing, lower-income households rely heavily on government benefits compared to higher income households; this lower income cohort is heavily affected by changes in government benefits. Another lower income cohort is pensioners who own rental dwellings and receive rental income; this lower income cohort is heavily affected by changes in the rental price of dwellings.

low-income households (retirees) are affected by (i) and (ii). Second, higher income deciles in the working age population (aged below 65) experienced an increase in disposable income as many labour-intensive sectors that initially contracted recovered in 2020-21.

To understand the spatial effects on households of the pandemic we stratify households into those living in capital cities and those living outside capital cities. Figure 11 shows that, in general, the changes in disposable income have a similar pattern across geographical areas. Noticeable exceptions to the general pattern are the effects for the sixth and tenth deciles that show different effects in capital city versus non-capital city areas.

Figure 11. Percentage change in household nominal disposable income by geographical area



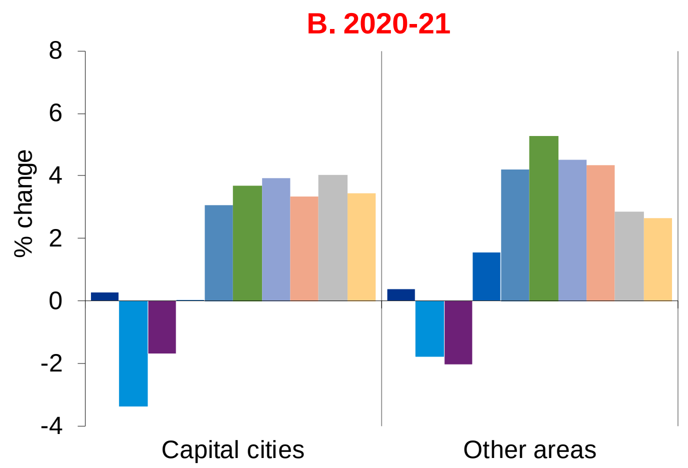
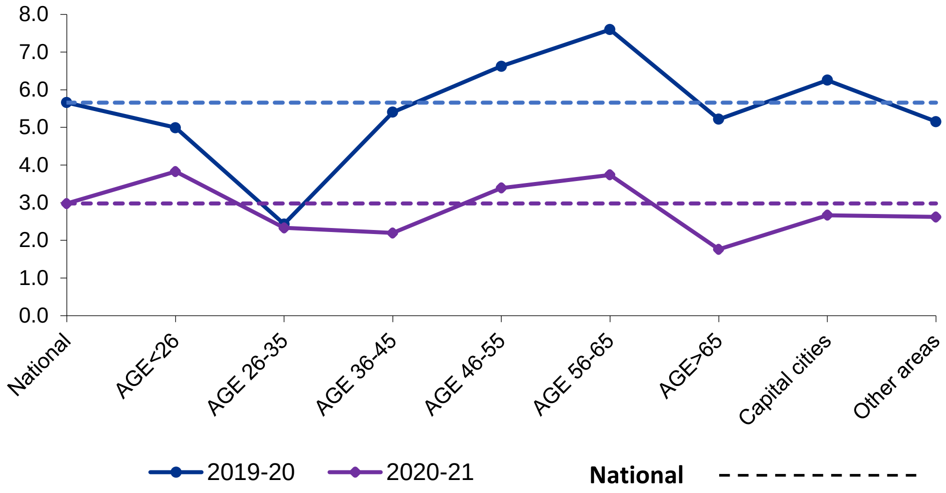


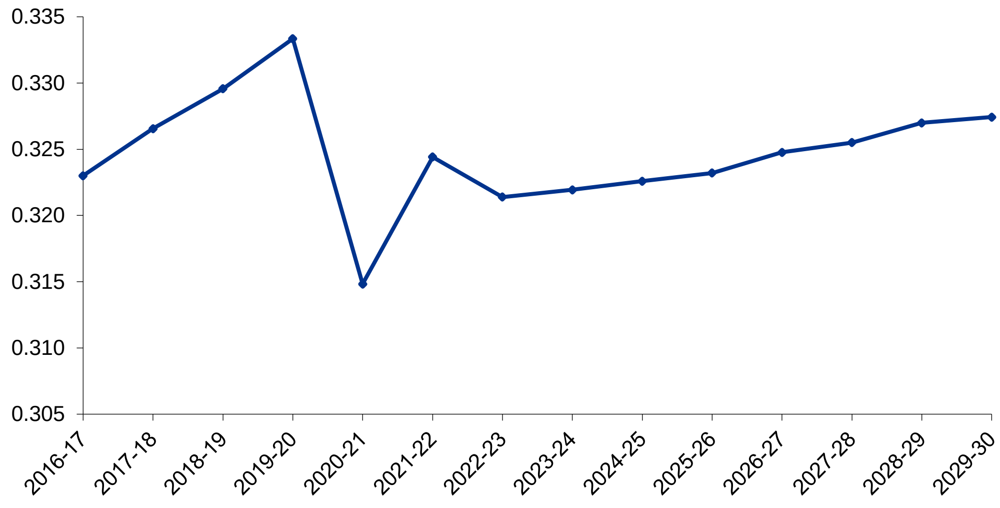
Figure 12 presents the standard deviation (SD) of the household income effects by household type. Across all households the percentage changes in income are more dispersed in the first year of the pandemic (SD = 5.66) than in the second year (SD = 2.98). Across age cohorts, the income effects are more dispersed for the 56-55 and 56-65 age groups in both years while there is a considerable dispersion for the <26 age group in the second year of the pandemic. Across locations, there is a higher dispersion of income effects in capital cities relative to other areas during the first year of the pandemic and a consistent dispersion in the following year. These findings show that the income effects of the pandemic are quite asymmetric across household types.

Figure 12. Standard deviation of percentage change in household nominal disposable income by household type



In terms of income inequality, Figure 13 shows inequality increases slightly in the first year of the pandemic (Gini coefficient = 0.333) and then falls in the second year (Gini coefficient = 0.315). This reflects the effect of the COVID-19 government support payments in providing a temporary safety net for low-income households during the pandemic and thus played an important role in redistributing income across households. This effect is not temporary as (i) the Gini coefficient does not return to its pre-pandemic level after 2020-21 and (ii) it shows a slowly rising rate of inequality albeit at a slower rate than before the pandemic.

Figure 13. Gini coefficient



7. Conclusion

The COVID-19 pandemic led to economic recession that affected nations, businesses, and households globally; Australia was not immune to this effect of the pandemic. The severity of the recession was large and casual empiricism suggests that the impact has been asymmetric across socioeconomic groups. The present paper analyses the economic effects of the pandemic at the macroeconomic and sectoral level and at the individual household level using a computable general equilibrium model complemented with microsimulation features. We model the effects of the pandemic by simulating a 14-year horizon that captures the conditions of the economy in three periods: a historical (pre-pandemic) period from 2016-17 to 2018-19, the pandemic years 2019-20 and 2020-21, and a future (post-pandemic or recovery) period from 2021-22 to 2029-30. From 2016-17 to 2020-21 we incorporate historical data on macroeconomic and sectoral outcomes from the ABS, whereas from 2021-22 onwards we incorporate forecasts of macroeconomic variables using projections from a global macroeconometric model.

At the macro level, the pre-pandemic growth of real GDP is 2.43% per annum on average. This average annual growth fell to 0.74% during the pandemic then recovers to 2.53% p.a. in the longer run. The economic contraction during the pandemic is attributed to a fall in household consumption, investment spending and international trade. At the sectoral level, the pandemic mainly affects tourism-related industries such as *Accommodation and food* and *Arts and recreation*. Business activity in these sectors are largely interrupted due to lockdowns and border closures.

At the micro level, we analyse the distributional effects of the pandemic by decomposing the findings across different household groups. There are 10,046 actual households incorporated into the CGE model to capture the heterogeneity through which economic shocks influence household behaviour, particularly in terms of labour supply, employment and consumption of commodities. To understand the effects on households, we focus on the effects of the pandemic on income distribution, comparing rich to poor, young to old, and capital city and non-capital city areas. We find that the income effects are asymmetric at the household level. There is a considerable dispersion in income effects during the onset of the pandemic most especially across age groups. Overall, income inequality increases slightly in the first year of the pandemic (Gini coefficient = 0.333) and then falls in the following year (Gini coefficient = 0.315). This reflects the effect of the COVID-19 government support payments in providing a temporary safety net for low-income households during the pandemic and thus played an important role in redistributing income across households. Interestingly, the results show that this effect is not temporary as the Gini coefficient does not return to its pre-pandemic level after 2020-21. Furthermore, post-pandemic the Gini coefficient shows a more slowly rising rate of inequality than the pre-pandemic rate.

References

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

Australian Bureau of Statistics (ABS) (2017), *Microdata: Household Expenditure, Income and Housing, 2015-16*, ABS, Cat. no. 6540.0, ABS, Canberra, October.

____ (2018), *Australian National Accounts: Input-Output Tables, 2015-16*, Cat. no. 5209.0.55.001, ABS, Canberra, June.

____ (2019), *ANZSCO - Australian and New Zealand Standard Classification of Occupations, 2013, Version 1.3*, Cat. no. 1220.0, ABS, Canberra, November.

____ (2022), *Household Income and Wealth, Australia, 2019-20*, ABS, Canberra, April.

Boccanfuso, D., Decaluwé, B. and Savard, L. (2003), 'Poverty, income distribution and CGE modeling: Does the functional form of distribution matter?', CIRPEE 03-32, Université Laval, Québec.

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.

Chitiga-Mabugu, M., Henseler, M., Mabugu, R. and Maisonnave, H. (2021), 'Economic and distributional impact of COVID-19: Evidence from macro-micro modelling of the South African economy', *South African Journal of Economics*, vol. 89, no. 1, pp. 82-94.

Chou, J., Kuo, N-F. and Peng, S-L. (2004), 'Potential impacts of the SARS outbreak on Taiwan's economy', *Asian Economic Papers*, vol. 3, no. 1, pp. 84–99.

Clements, K.W., Mariano, MJ.M. and Verikios, G. (2021), 'Foreign-domestic substitution, import penetration, and CGE modelling', *Applied Economics*, vol. 53, pp. 209-31.

____ (2022), 'Expenditure patterns, heterogeneity, and long-term structural change', *Economic Modelling*, vol. 113.

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.

Cockburn, J. (2006), 'Trade liberalisation and poverty in Nepal: a computable general equilibrium micro simulation analysis', in Bussolo M and J Round (eds.), *Globalization and Poverty: Channels and Policies*, Routledge, London, pp. 171-194.

Cockburn, J., Corong, E. and Cororaton, C.B. (2010), 'Integrated computable general equilibrium (CGE) micro-simulation approach', *International Journal of Microsimulation*, vol. 3, no. 1, pp. 60-71.

Cogneau, D. and Robillard, A.S. (2001), 'Growth distribution and poverty in Madagascar: learning from a microsimulation model in a general equilibrium framework', TMD Discussion Paper 61, International Fool Policy Research Institute, Washington, D.C..

Corong E.L. and Horridge, J.M. (2012), 'PHILGEM: A SAM-based computable general equilibrium model of the Philippines', General Paper No. G-227, Centre of Policy Studies, Victoria University.

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

Davies, J. (2004), ‘Microsimulation, CGE and macro modelling for transition and developing economies’, Discussion Paper 2004/08, World Institute for Development Economics Research, United Nations University, Helsinki.

Davies, J. (2009), ‘Combining microsimulation with CGE and macro modelling for distributional analysis in developing and transition countries’, *International Journal of Microsimulation,* vol. 2, no. 1, pp. 49-56.

Fan, E.X. (2003), ‘SARS: economic impacts and implications’, Economics and Research Department Policy Brief Series No. 15. Asian Development Bank, Manila.

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.

Hai, W., Z. Zhao, J., Wang, and Hou, Z-G. (2004), ‘The short-term impact of SARS on the Chinese economy’, *Asian Economic Papers*, vol. 3, no. 1, pp. 57–61.

Hanoch, G. (1971), ‘CRESH production functions’, *Econometrica*, vol. 39, pp. 695–712.

Hantzsche, A., Kara, A. and Young, G. (2018), ‘Prospects for the UK economy’, *National Institute Economic Review*, 246 (November), pp. F4–35.

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.

Hertel, T.W. and Marinos, T. (1997),‘Structure of the GTAP Model’, in Hertel, T.W. (ed.), *Global Trade Analysis: Modeling and Applications*, Cambridge University Press, Cambridge, pp. 9-71.

Jawad, M., Maroof, Z. and Naz, M. (2021), ‘Impact of pandemic COVID-19 on global economies (a seven-scenario analysis)’, *Managerial and Decision Economics*, vol. 42, issue 7, pp. 1897-1908.

Keogh-Brown, M.R., and Smith., R.D. (2008), ‘The economic impact of SARS: How does the reality match the predictions?’, *Health Policy*, vol. 88, no. 1, pp. 110–120.

Kirman A (1992), ‘Whom or what does the representative individual represent?’, *Journal of Economic Perspectives*, vol. 6, no. 2, pp. 117-136.

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.

Liyanaarachchi, T.S. (2015), ‘Trade liberalisation and poverty in Sri Lanka: A computable general equilibrium micro-macro analysis,’ PhD thesis, Griffith University, Brisbane.

Maliszewska, M., Mattoo, A. and Van Der Mensbrugghe, D. (2020), ‘The potential impact of COVID-19 on GDP and trade: A preliminary assessment’, *World Bank Policy Research Working Paper*, 9211, World Bank Group, April.

Malliet, P., Reynès, F., Landa, G., Hamdi-Cherif, M. and Saussay, A. (2020), ‘Assessing short-term and long-term economic and environmental effects of the COVID-19 crisis in France’, *Environmental and Resource Economics*, vol. 76, no. 4, pp. 867-883.

McKibbin, W. and Fernando, R. (2021), ‘The global macroeconomic impacts of COVID-19: Seven scenarios’, *Asian Economic Papers*, vol. 20, no. 2, pp. 1-30.

Robilliard, A.-S., Bourguignon, F. and Robinson, S. (2008), ‘Examining the social impact of the Indonesian financial crisis using a macro-micro model’, in Bourguignon, F., Bussolo, M. and Pereira da Silva, L.A. (eds.), *The Impact of Macroeconomic Policies on Poverty and Income Distribution: Macro-Micro Evaluation Techniques and Tools*, The World Bank and Palgrave Macmillan, New York, pp. 93–118.

Sander, B., Nizam, A., Garrison, L.P., Postma, M.J., Halloran, M.E. and Longini, M.S. (2009), ‘Economic evaluation of influenza pandemic mitigation strategies in the united states using a stochastic microsimulation transmission model’, *Value in Health*, vol. 12, no. 2, pp. 226–233.

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.

Verikios, G. (2020), 'The dynamic effects of infectious disease outbreaks: The case of pandemic influenza and human coronavirus', *Socio-Economic Planning Sciences*, vol. 71.

Verikios, G., McCaw, J., McVernon, J. and Harris, A. (2012), 'H1N1 influenza and the Australian macroeconomy', *Journal of the Asia Pacific Economy,* vol. 17, no. 1, pp. 22–51.

Verikios, G., Hanslow, K., Mariano, M.J. and Clements, K.W. (2021), 'A multi-sector model of Australia: Theory, data and parameters', Discussion Paper 2021-06, Economics and Business Statistics, Department of Accounting, Finance and Economics, Griffith University.

Verikios, G. and Zhang, X. (2013), 'The distributional effects of the Hilmer reforms on the Australian gas industry', *Australian Journal of Agricultural and Resource Economics*, vol. 57, no. 2, pp. 159-77.

Verikios, G. and Zhang, X. (2015), 'Microeconomic reform and income distribution: The case of Australian ports and rail freight', *Contemporary Economic Policy*, vol. 33, no. 1, pp. 159-175.

Verikios, G. and Zhang, X. (2016), 'Structural change and income distribution: The case of Australian telecommunications', *Journal of the Asia Pacific Economy,* vol. 21, no. 4, pp. 549-570.

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.