Australian Government
The Treasury

Modelling Industry Specific Policy with TIM

Treasury's multi-sector dynamic general equilibrium model of the Australian economy

Freya Carlton, Linus Gustafsson, Melissa Hinson, Jack Jaensch, Michael Kouparitsas, Niall Peat, Ken Quach, Sebastian Wende and Phillip Womack[1]

Treasury Working Paper[2]

2023–03

Date created: August 2023

Date modified: August 2023

1 Macroeconomic Analysis and Policy Division, The Treasury, Langton Crescent, Parkes ACT 2600, Australia.
We thank Daniel Rees, Mariano Kulish, Damian Mullaly, Paul Cotterill, Louise Lilley, John Bruesch, Jacob Smith, and Daniel Silva Withmory for their valuable feedback on earlier drafts, as well as participants at the 2022 Australian Conference of Economists, ANU-RSE Seminar to QuantEcon, Victoria University – Centre of Policy Studies, 2020 Global Trade Analysis Project Conference, and Macroeconomic Group Expert Panel.

2 The views expressed in this paper are those of the authors and do not necessarily reflect those of The Australian Treasury or the Australian Government.

ISBN 978-1-925832-83-9

Manager
Media Unit
The Treasury
Langton Crescent
Parkes ACT 2600

Email: media@treasury.gov.au

Modelling Industry Specific Policy with TIM: Treasury's multi-sector dynamic general equilibrium model of the Australian economy
Freya Carlton, Linus Gustafsson, Melissa Hinson, Jack Jaensch, Michael Kouparitsas, Niall Peat, Ken Quach, Sebastian Wende and Phillip Womack
2023–03
August 2023

Abstract

The Australian economy is constantly affected by technological, demand and policy shocks from home and abroad. The opportunities and challenges presented by these shocks create demand for government advice on the likely effects on households, firms and the Australian economy, and in turn appropriate policy responses. Treasury has developed a multisector dynamic general equilibrium model to meet this need – the Treasury Industry Model (TIM). As a general equilibrium model, TIM captures the economy's interconnectedness and rich industry detail, enabling the net effects of policy or other exogenous changes to the economy to be assessed. TIM extends previous Australian models by incorporating forward-looking agents that are able to respond rationally to policy and technological changes, a well-defined balanced growth path defined endogenously, and a model-consistent welfare measure. These features, combined with TIM's significant production and industry detail, position the model well for informing advice on a range of industry- and trade-related policy questions.

JEL Classification Numbers: C68, D58, E13, E23, E60, H30
Keywords: many sector modelling, CGE modelling, industry policy analysis, general equilibrium

Freya Carlton, Linus Gustafsson, Melissa Hinson, Jack Jaensch, Michael Kouparitsas, Niall Peat, Ken Quach, Sebastian Wende, and Phillip Womack.

Macroeconomic Analysis and Policy Division
Macroeconomic Group
The Treasury
Langton Crescent
Parkes ACT 2600

1. Introduction

The Australian economy is constantly subjected to technological, demand and policy shocks from home and abroad. These shocks are typically industry specific, meaning they originate in and/or initially affect the functioning of a particular industry or group of industries. The opportunities and challenges presented by these shocks create demand for government advice on the likely effects on households, firms and the Australian economy and, in turn, appropriate policy responses. While this may seem like an opportunity for microeconomic analysis, it has long been observed that industry shocks can typically cause widespread or aggregate fluctuations or transitions. This suggests macroeconomic analysis is required to better understand the implications of such shocks and inform potential policy responses.

The Treasury Industry Model (TIM) has been developed by the Department of the Treasury (Treasury) to meet this policy-advising requirement. TIM is, to a large extent, a small open economy variant of the multisector dynamic general equilibrium models developed in the United States in the late 1990s/early 2000s.[3] The focus of those models was business cycle analysis. By contrast, the intended purpose of TIM is to analyse the effects of industry-specific shocks, trade policy and other policies aimed at raising the welfare of Australians.

TIM extends previous Australian models with many industries (see, for example, Dixon et al. (1982)) by incorporating forward-looking agents and a well-defined balanced growth path.[4] This approach overcomes three limitations of models without these features. First, variables which have a significant bearing on modelling results (for example, the long-run level of net foreign assets, household savings and labour supply/total hours worked) are determined endogenously. Second, (forward-looking) agents realistically respond to anticipated policy and technological changes. This is important for industry analysis as industry-specific policies are typically phased in over time or announced well ahead of implementation to diminish the adjustment costs faced by firms and households (in their role as workers). Finally, as decisions are derived from well-defined optimisation problems, TIM provides a model-consistent welfare measure that is useful for evaluating the benefits and costs of policy.

Given its purpose to inform policy advice, particularly with respect to industry, TIM includes considerably more detail about key economic agents and their interactions than other macroeconomic models used by the Reserve Bank of Australia and Treasury for policy advice.[5] TIM currently incorporates 114 firms representing the 114 industries defined by the Australian Bureau of Statistics (ABS) Input-Output (I-O) tables. TIM also has three additional agents: the household, government and the rest of the world (ROW). As a multisector dynamic general equilibrium model, TIM captures differences between production processes, inter-industry linkages and economy-wide general equilibrium relationships.

3 See, for example, Hornstein and Praschnik (1997), Hornstein (2000) and Horvath (2000). Readers interested in Australian business cycle analysis are well served by multisector models, albeit with fewer sectors, including those by Rees, Smith and Hall (2016), and Kulish and Rees (2017).

4 An example of a previous Australian model incorporating forward-looking agents is Malakellis (2000) which extends the traditional Australian CGE set-up to include intertemporal optimisation. One of the key differences between TIM and Malakellis (2000) is that the household's labour supply is endogenous in TIM, whereas it is assumed to be fixed in Malakellis (2000).

5 See for example RBA models Rees, et al. (2016) and Kulish and Rees (2017), and Treasury models including Bullen, et al., (2021) and Cai, et al., (2023).

TIM retains the details of earlier Australian models that remain important for industry-specific analysis, such as distribution costs captured by so-called margins. These are separately identified within the model from more general intermediate goods and services consumed in production. All domestic production prices are endogenous, with Australian exports competing with differentiated products produced in the ROW. Financial capital is assumed to be perfectly mobile, with marginal investment undertaken by the ROW. The government sector incorporates detailed modelling of expenditure taxes (import duties, excise and goods and services tax (GST)) and production taxes. Modelling of income taxes, government expenditure and fiscal rules is complete, but has been simplified to ensure the analysis is tractable.

This level of detail positions TIM well to support the assessment of the net effects of policy or other exogenous changes to the economy. Take, for example, a policy-induced increase in demand for a particular industry's output. The impact on other industries depends on a range of factors. It could lead to an increase in production costs, given enhanced competition for inputs. Conversely, it could increase demand for other industries' output through both household and inter-industry linkages.

The version of TIM presented in this paper is referred to as TIM Version 1.0. It is one of a suite of policy analysis models currently operated by Treasury.[6] Two key objectives guide Treasury's macroeconomic modelling development programme – *capability readiness* and *fit-for-purpose*. Following the approach used in developing information technology applications, and which has been widely replicated in the economic modelling world, the capability of Treasury's models is designed to advance over time with successive versions incorporating new features, while a working version remains available for policy analysis. To meet the needs of Treasury's disparate stakeholders, the specification of Treasury models – TIM included – typically needs to be far more detailed than general equilibrium models used in academia.

This paper is structured as follows: Section 2 provides a general overview of TIM Version 1.0; Section 3 describes in detail the theoretical structure of TIM Version 1.0; Section 4 describes the model calibration; Section 5 discusses welfare analysis; and Section 6 concludes.

6 In addition to TIM 1.0, Treasury's current suite of macroeconomic models includes an overlapping generations model of the Australian Economy (OLGA) which is intended to be Treasury's workhorse model for fiscal policy analysis (Cai, Gustafsson, Kouparitsas, Smith, & Zhang, 2023). Treasury also has a Macro-econometric Model of Australia (EMMA), which is a framework to support macroeconomic forecasting (Bullen, et al., 2021).

2. Model overview

TIM captures the behaviour of the Australian economy by modelling stylised representations of its key agents. As a general equilibrium model, TIM captures the economy's interconnectedness, showing the net effects of policy changes or exogenous changes to the economy. However, as with all whole-of-economy models, TIM should be thought of as a simplified representation. By removing some detail and complexity, it is possible to focus on select aspects of the economy. Given Treasury's rationale for developing TIM is industry-specific policy analysis, the model contains a large amount of detail on the production side of the Australian economy and representations of other key agents.

TIM is well-suited to informing advice where the transmission of events from one sector to related sectors and the broader economy needs to be understood. This can include scenarios such as the introduction of new technologies, changes in demand for goods by consumers, changes in foreign markets for exports or changes in the costs of imports used in production. TIM is particularly well suited to understanding the economy's response to persistent shocks, including anticipated changes to policy.

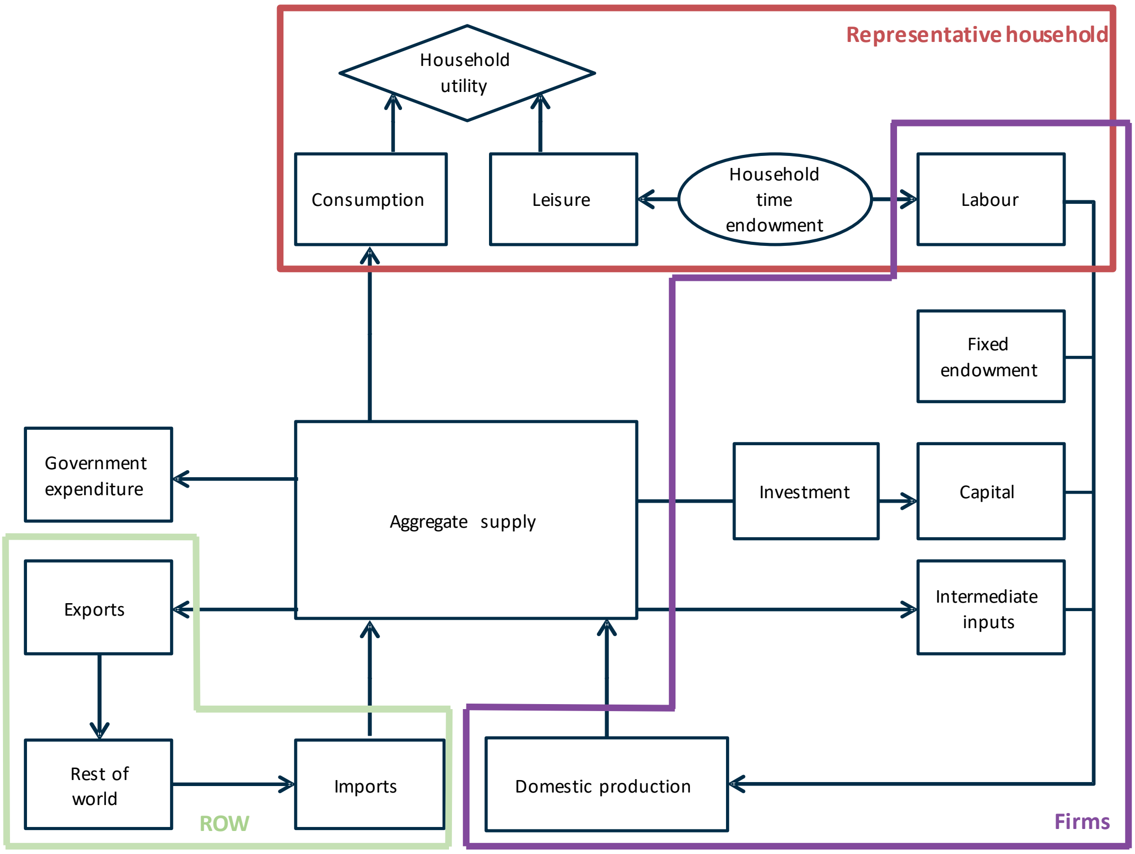
It is useful to note that there are a range of policy questions where Treasury's OLGA model (see Cai, et al., (2023)) or EMMA model (see Bullen, et al., (2021)) are better suited:

- The time interval in TIM is annual and TIM does not include price stickiness – thus, it is not suited to high-frequency analysis. On the other hand, EMMA is a quarterly model estimated with time series data. EMMA is therefore useful for informing Government understanding of how real and nominal disturbances play out as the economy transitions back to its balanced growth path. These insights assist forecasting exercises, analysis of the short-run implications of policy changes, and other scenario and sensitivity analysis.
- For many fiscal policy questions, heterogeneous households and intergenerational detail are important considerations for understanding how a policy affects the economy, as well as how the costs and benefits of the policy are likely to be distributed across the population. For example, a switch between personal income tax and GST will have very different impacts on someone close to retirement compared with someone who has just entered the workforce. OLGA, a dynamic general equilibrium lifecycle model with significant household detail and a detailed description of the Australian tax and transfer system, is therefore best positioned to answer questions around the economy-wide effects of tax and transfers policy within a heterogenous household framework.

Agents

There are four types of agents in TIM who interact with one another and determine economic outcomes: the household, firms, government and ROW. TIM assumes each of these agents acts in their own best interest, taking into consideration the behaviour of other agents. Figure 1 shows the interactions of the agents as modelled in TIM.

Figure 1: Illustration of the flow of goods and services and factors of production within TIM



Households

In TIM, the behaviour of all Australian households is represented by a single infinitely-lived representative household. The household chooses how much it will work or enjoy leisure, how much of its income it will spend or save and what commodities it will buy. These choices determine lifetime welfare, which the household is assumed to maximise. The representative household prefers more consumption and leisure to less, a smooth distribution of consumption and leisure over time, and diversity in its consumption.

The representative household receives wage income for its hours worked, where extra time spent working means less leisure time. The household's total disposable income is the sum of its after-tax labour income, the return on previously purchased equity (such as dividends) and government payments. Total disposable income can be used to buy consumption goods or saved by buying equity.[7]

7 The only saving vehicle in the model is claims to the equity of domestic firms. While this may appear to be a major abstraction from reality, it is not when you consider that TIM assumes debt and equity are perfect substitutes and that all goods and services are produced by firms. For instance, firms in the *Ownership of dwelling* industry produce rental services using capital and fixed factors. The household's claim to the equity of these firms is thus a claim to their capital (houses) and their fixed factors (land). In other words, TIM assumes the household owns houses and land.

The behaviour of the representative household reflects established economic theory. For example:

- The household is forward-looking and makes decisions in line with its preferences. If the household anticipates higher future income, it will consume more now and save less.[8]
- The household responds to higher income by increasing both consumption and leisure. However, if the higher income comes from higher wages, then the inducement to work can either partly or more than offset the preference for more leisure.
- An increase in the price of a consumption commodity will lead the household to reduce its consumption of that commodity to a degree, but not completely. This choice reflects the household's preference for a variety of different goods.

Firms

There are 114 firms in TIM, corresponding to the 114 industries that the ABS identifies in its I-O tables. To give a sense of the level of detail this provides, the I-O tables separately identify the electricity generation and transmission industries, but do not identify generation industries by technology such as coal, gas or renewables.

Each firm represents the aggregate behaviour of a group of Australian firms, classified by their output (that is, the commodity which it primarily produces). Firms use labour, capital, intermediate inputs and fixed factors (representing land and mineral resources) to produce their outputs. A firm owns its capital and fixed factors and can undertake investment to increase capital over time. However, a firm cannot purchase additional fixed factors.

Firms buy labour services from households. They also buy intermediate inputs from other Australian firms or the ROW to help produce their commodities – for example, a construction firm imports lightbulbs to finish its houses. The firms face adjustment costs when undertaking additional investment or changing their labour inputs. Firms act to maximise shareholder returns, with shareholders being the representative household and investors from the ROW.

Key aspects of firm behaviour in TIM include:

- Firms choose the amount of capital, labour and intermediate inputs to minimise production costs.
- Firms respond to higher returns by increasing investment until the expected return equals the required return on investment.
- If a firm expects higher future profits, it will undertake some additional investment and bring on additional workers early to integrate them into its production processes. Conversely, a firm that expects investment to be cheaper in the future may delay investment.

Rest of the world

Given the small and open nature of the Australian economy, it is important for any general equilibrium model to capture interactions with the ROW. In TIM, the household, government and firms can buy commodities from the ROW. Australian firms can also sell commodities to the ROW.

---

8 The representative household in TIM does not make savings decisions with an explicit goal, such as saving for retirement. Instead, its savings decisions reflect its desire to smooth income. As such, the household broadly maintains equity that grows with the economy. If it did not, it would reach a point where it would be forced to cut consumption or end up very wealthy, but with low consumption.

Australian imports are sufficiently small so as not to impact the world price of commodities. That is, from an import perspective, Australia is a price taker. On the other hand, Australian exports are differentiated from goods produced by the ROW. This means that the quantity demanded by the ROW will depend on the price charged.

TIM assumes Australia is a small open economy with perfect financial capital mobility. That is, investors from the ROW are willing to buy equity in Australian firms if the expected return matches that available elsewhere. This means that the required return on investment for Australian firms equals the global after-tax rate of return.

One important characteristic of TIM is that temporary shocks can have permanent effects on the wealth of Australian households, and therefore on Australia's net foreign asset position. This result is driven by the household's desire to smooth consumption over time, which is achieved through changes in savings. This characteristic of infinite-horizon, representative agent, small open economy models is well known in the literature (see for example Correia, et al., (1995) and Schmitt-Grohe and Uribe (2003)).[9]

Government

In TIM, the government collects taxes to fund its spending. The government purchases the same bundle of commodities each period. TIM incorporates detailed expenditure taxes (import duties, excise, and GST) and taxes on production. TIM has limited detail on income tax, government expenditure and transfers.[10] For example, TIM assumes a simple fiscal strategy whereby the government balances its budget in every period by adjusting the level of transfers to households.[11]

Industry supply and commodity use

In any economy, there is a degree of complexity regarding how a firm's output reaches users (that is, the household, government, other firms or ROW). TIM captures the flow of output in significant detail by including domestic and import shares, commodity- and user-specific tax rates and distribution costs (also known as margins).

Bundling goods and services into commodity groups provides a useful way to measure and represent the supply and use of the vast array of different goods in the economy. TIM follows the standard ABS commodity classifications and bundles commodities into 114 groups. This is similar to TIM's bundling of firms according to output. Industry groupings help capture the impact of policies that directly affect production. Certain other features of the economy, however, are best considered on a commodity basis. This includes taxes like GST or excise where the rates vary with commodities. TIM's level of industry and commodity detail allows it to capture both sets of scenarios.

9 Technically, this means that the model has a non-stationary long-run equilibrium. The business cycle literature emphasises that higher-order moments, such as the variance, are not well defined in this case. In that literature, it is therefore common to introduce additional elements to small open economy models to induce stationarity so that business cycle implications can be analysed.

10 These modelling choices reflect the fact that Treasury's suite of models includes OLGA, which incorporates detailed modelling of Australia's income tax system, government expenditure, transfer, pension and means testing system, and allows for complex fiscal rules. See Cai, et al., (2023) for further details.

11 Other fiscal closures are available and can be deployed depending on the policy being analysed.

While TIM explicitly includes 114 commodities groups, it also embodies greater commodity detail. The tax rates applied to commodities, for example, as well as the import and margin shares, vary not only by commodity group, but also by use. In TIM there are 231 such uses. This includes intermediate inputs for TIM's 114 industries, investment by these 114 industries, government consumption, household consumption and exports. Allowing taxes, import shares and margins to vary by use serves as a proxy for the commodity detail not captured separately in TIM.

In reality, many firms produce goods that fall into multiple commodity groups. For example, firms in the *Iron and steel manufacturing* industry also produce some outputs classified under the *Structural metal product manufacturing* commodity group. Hence all firms (industries) in TIM can produce a subset of the model's 114 commodities. Shifting production to other commodities, however, comes at a cost.

In the Australian economy, final users (that is, households, firms, and government) choose between domestic and imported goods. The shares of imported and domestic commodities within the economy are consistent with the historical preferences of Australian consumers. Final users respond to price changes by increasing their use of the cheaper version of the good, regardless of its source.[12]

TIM explicitly models the distribution costs involved in transferring output from firms to users (that is, other firms, the household, the government and the ROW). In general, users do not buy commodities directly from firms. For example, a loaf of bread is often transported from a bakery to a supermarket where it is then purchased for final consumption. This process incurs distribution costs (for example, transport and retail trade) which is included in the price of the loaf of bread paid by the user. In TIM, margins are assumed to be required in specific proportions. That is, bread cannot be purchased without purchasing fixed proportions of transport and retail margins required to distribute the good. TIM includes 11 margins which are a subset of the model's 114 commodities. Some of the margin goods and services, such as road transport, can also be consumed directly (for example, by catching a bus).

12 The shares are consistent with those observed in the ABS I-O table data. The magnitude of the responses is consistent with the literature.

3. Model detail

This section provides details of the economic theory underlying TIM's agents (households, firms, government and the ROW) and equilibrium conditions.[13]

Household

In TIM, the Australian population is modelled as an infinitely-lived representative household that chooses paths for consumption and leisure to maximise its expected lifetime utility. The household has a time endowment, which it has the option of supplying to the labour market at a given wage to earn labour income or utilising as leisure time. The household also earns capital income, which reflects the return on accumulated savings. In turn the household can choose to spend this income on goods and services or save it for future consumption.

Endowments

At time t, the single representative household has a total endowment of time, H_t, that is allocated between working (that is, labour input to production), N_t, and leisure, L_t, such that:

$$N_t = H_t - L_t \tag{1}$$

The population is assumed to grow at rate γ^h, which implies total hours available for work and leisure take the following path:

$$H_{t+1} = (1+\gamma^h)H_t \tag{2}$$

The household is also endowed with human capital in the form of labour-augmenting technical progress denoted by ξ_t, which is assumed to grow at rate γ^ξ:

$$\xi_{t+1} = (1+\gamma^\xi)\xi_t \tag{3}$$

The model is designed to adhere to the 'Kaldor growth facts', including balanced growth, which means that the trend growth rate of non-labour variables is equal to the growth rate of total effective hours, γ:

$$H_{t+1}\xi_{t+1} = (1+\gamma^h)(1+\gamma^\xi)H_t\xi_t$$

$$H_{t+1}\xi_{t+1} = (1+\gamma)H_t\xi_t \tag{4}$$

13 TIM is implemented using Matlab, a commercial software package that is widely used across industry and academia.

Without loss of generality, it is convenient to describe the detrended version of the model. From here on, lower-case non-labour variables are actuals normalised by total effective hours.[14] That is, quantities per unit of effective hours are given by:

$$x_t \equiv \frac{X_t}{\xi_t H_t} \tag{5}$$

Actuals can always be recovered by inflating the normalised variable by total effective hours.

Along the balanced growth path, total working hours per head of population do not change over time. As such, it is convenient to normalise the household's total hours available for work and leisure to 1. Specifically, working time and leisure per hour are derived by dividing aggregate working time and leisure hours by total hours, $n_t \equiv N_t / H_t$ and $l_t \equiv L_t / H_t$, respectively, with lower-case variables denoting the transformed variables.

Preferences

The household's lifetime utility is the sum of current and discounted future utility:

$$\sum_{s=t}^{\infty} \beta^{(s-t)} u\left(c_s, l_s\right) \tag{6}$$

where $\beta \geq 0$ is the discount factor and c_t is the aggregate consumption good at time t.

Utility within each period is an aggregate of consumption and leisure, both of which exhibit decreasing marginal utility, consistent with a constant relative risk aversion (CRRA) utility function:

$$u(c_t, l_t) = \frac{\left(c_t^{\alpha} l_t^{1-\alpha}\right)^{1-\sigma}}{1-\sigma} \tag{7}$$

where σ is the inverse of the intertemporal elasticity of substitution and $0 < \alpha < 1$ is a weighting parameter which measures the household's relative preference for consumption and leisure.

14 Labour variables, such as the hours worked and leisure time, are only normalised for total hours, not productivity.

Consumption of commodities

Households have preferences over a bundle of commodities (typically indexed by j) that are assumed to be imperfect substitutes. Specifically, the aggregate consumption good, c_t, is a composite of commodities, $\{c_{j,t}\}_{j=1}^{114}$, aggregated using a constant elasticity of substitution (CES) function:

$$c_t = \left(\sum_j \theta_j^c c_{j,t}^{\frac{\eta^c - 1}{\eta^c}} \right)^{\frac{\eta^c}{\eta^c - 1}} \quad (8)$$

where $\eta^c > 0$ is the elasticity of substitution between consumption commodities and $0 \le \theta_j^c \le 1$ is the weighting parameter for commodity j.

Total household consumption expenditure is:

$$p_t^c c_t = \sum_j p_{j,t}^c c_{j,t} \quad (9)$$

where $p_{j,t}^c$ is the price of consumption for commodity j and p_t^c is the price of aggregate consumption.

Household's budget constraint

The household begins each period with assets, v_t^h, which reflect accumulated savings and earns a rate of return, r_t^h. The household supplies n_t to the labour market, for which it earns wage w_t and receives labour income $w_t n_t$, which is taxed at rate τ_t^n. The household also receives a lump sum transfer from the government, $tran_t$.[15] The household can choose to spend its income on consumption today, c_t, or save it for the future with the change in assets equal to $(1+\gamma)v_{t+1}^h - v_t^h$.

The household's budget constraint is:

$$(1+\gamma)v_{t+1}^h - v_t^h + p_t^c c_t = r_t^h v_t^h + (1-\tau_t^n) w_t n_t + tran_t \quad (10)$$

Subject to the budget constraint in equation (10), the household chooses consumption and leisure to maximise its lifetime utility, equation (6). The household's expectations for future prices, wages and transfers are consistent with their policy expectations.

15 Positive transfers reflect payments to households, while negative transfers reflect taxes.

Households are also required to satisfy a life-time budget constraint that states that the present value of the household's consumption must equal the sum of its initial wealth and the present value of its after tax labour income and government transfers:

$$\frac{1}{(1+\gamma)}\sum_{i=0}^{\infty}\left[\prod_{j=0}^{i}\frac{(1+\gamma)}{(1+r_{t+j}^{h})}p_{t+i}^{c}c_{t+i}\right]=\frac{1}{(1+\gamma)}\sum_{i=0}^{\infty}\left[\prod_{j=0}^{i}\frac{(1+\gamma)}{(1+r_{t+j}^{h})}\left((1-\tau^{n})w_{t+i}n_{t+i}+tran_{t+i}\right)\right]+v_{t}^{h} \quad (11)$$

Combined with the assumption that the economy reaches a balanced growth path, the life-time budget constraint rules out households engaging in a Ponzi-scheme in which they increase borrowing indefinitely to fund consumption.

Firms: Production sector

Each of TIM's industries (indexed by i) are represented by a single price-taking firm which uses an industry-specific technology to produce output, $y_{i,t}$. Each firm is assumed to make decisions to maximise its market value on behalf of its shareholders.

Production technology

Firms combine labour, $n_{i,t}$, capital, $k_{i,t}$, an industry-specific composite aggregate of intermediate inputs, $zy_{i,t}$, and a fixed factor, $f_{i,t}$, to produce gross output using a CES production technology:

$$\Gamma_{i,t}\left(n_{i,t},k_{i,t},zy_{i,t},f_{i,t}\right)=\lambda_{i,t}^{y}\begin{pmatrix}\theta_{i}^{n}\left(\lambda_{i,t}^{n}n_{i,t}\right)^{\frac{\eta^{y}-1}{\eta^{y}}}+\theta_{i}^{k}\left(\lambda_{i,t}^{k}k_{i,t}\right)^{\frac{\eta^{y}-1}{\eta^{y}}}\\+\theta_{i}^{zy}\left(\lambda_{i,t}^{zy}zy_{i,t}\right)^{\frac{\eta^{y}-1}{\eta^{y}}}+\theta_{i}^{f}\left(\lambda_{i,t}^{f}f_{i,t}\right)^{\frac{\eta^{y}-1}{\eta^{y}}}\end{pmatrix}^{\frac{\eta^{y}}{\eta^{y}-1}} \quad (12)$$

where $0\leq\theta_{i}^{n}\leq1$, $0\leq\theta_{i}^{k}\leq1$, $0\leq\theta_{i}^{zy}\leq1$ and $0\leq\theta_{i}^{f}\leq1$ are the weighting parameters for labour, capital, intermediate inputs and the fixed factor, respectively. The elasticity of substitution between the factors of production is given by $\eta^{y}>0$.

Given that equation (12) has been normalised for trend population and labour-augmenting technical progress, the terms $\lambda_{i,t}^{y}$, $\lambda_{i,t}^{n}$, $\lambda_{i,t}^{k}$, $\lambda_{i,t}^{zy}$ and $\lambda_{i,t}^{f}$ are the total factor, labour, capital, intermediate input and fixed factor productivity shifters, respectively.[16]

Labour input

The labour market is assumed to be perfectly competitive, and labour is perfectly substitutable across production activities. This means, irrespective of where they work, the household earns a common wage. Total labour units supplied by the household must equal aggregate labour demand:[17]

16 It is not necessary to specify the stochastic processes for these productivity shifters because the model is deterministic.

17 Labour is assumed to be internationally immobile implying that the household cannot migrate or supply labour to the ROW in response to economic conditions.

$$n_t = \sum_i n_{i,t} \quad (13)$$

While labour is mobile across industries, firms face a cost of adjusting their labour inputs. For example, new workers are typically less productive, and existing workers are less productive while training new workers. Following Jaimovich and Rebelo (2008) and Arezki et al. (2015), the firm incurs a quadratic adjustment cost when its labour use does not grow in line with trend growth:

$$\Omega^n(n_{i,t}, n_{i,t-1}) = \frac{\zeta_i^n}{2}\left(\frac{n_{i,t}}{n_{i,t-1}} - 1\right)^2 n_{i,t} \quad (14)$$

where $\zeta_i^n \geq 0$ is the labour adjustment cost parameter.

Capital input

Productive capital, $k_{i,t}$, represents durable physical inputs such as machines, buildings and plants, as well as non-physical types of capital, such as intellectual property. Firms accrue capital by investing in an industry-specific capital good, $ib_{i,t}$. The capital stock evolves according to the following identity:

$$(1+\gamma)k_{i,t+1} = (1-\delta_t)k_{i,t} + ib_{i,t} \quad (15)$$

where $\delta_t \geq 0$ is the depreciation rate.

Each firm's investment good, $ib_{i,t}$, is an industry-specific composite of a variety of investment commodities, which are aggregated using a CES function:

$$ib_{i,t} = \left(\sum_j \theta_{j,i}^{ib}\left(ib_{j,i,t}\right)^{\frac{\eta^{ib}-1}{\eta^{ib}}}\right)^{\frac{\eta^{ib}}{\eta^{ib}-1}} \quad (16)$$

where $ib_{j,i,t}$ is the investment in commodity j by industry i, $0 \leq \theta_{j,i}^{ib} \leq 1$ are the weighting parameters and $\eta^{ib} > 0$ is the elasticity of substitution between investment commodities.

The total value of investment at time t for firm i is given by:

$$p_{i,t}^{ib} ib_{i,t} = \sum_j p_{j,i,t}^{ib} ib_{j,i,t} \quad (17)$$

where $p_{j,i,t}^{ib}$ is the price of investment commodity j for industry i and $p_{i,t}^{ib}$ is the industry-specific price of aggregate investment.

Following Lucas (1976) and Uzawa (1969), the firm also incurs a quadratic capital adjustment cost when its investment to capital ratio deviates from its balanced growth ratio. The capital adjustment cost is given by:

$$\Omega^k(ib_{i,t}, k_{i,t}) = \frac{\zeta_i^k}{2}\left(\frac{ib_{i,t}}{k_{i,t}} - (\gamma + \delta)\right)^2 k_{i,t} \qquad (18)$$

where $\zeta_i^k \geq 0$ is the capital adjustment cost parameter. Capital adjustment costs reflect the disruption that is caused by bringing new capital into the production process.

Intermediate input

Production requires the use of intermediate inputs, where these inputs must be used in the period they are produced. Firms purchase intermediate input commodities, which are aggregated into an industry-specific aggregate intermediate input using a CES technology:

$$zy_{i,t} = \left(\sum_j \theta_{j,i}^{zy}(\lambda_{j,i,t}^{zy} zy_{j,i,t})^{\frac{\eta^{zy}-1}{\eta^{zy}}}\right)^{\frac{\eta^{zy}}{\eta^{zy}-1}} \qquad (19)$$

where $\eta^{zy} > 0$ is the elasticity of substitution between intermediate input commodities, $0 \leq \theta_{j,i}^{zy} \leq 1$ are the weighting parameters and $\lambda_{j,i,t}^{zy}$ is an intermediate input commodity productivity shift term. The total value of intermediate inputs used by firm i is:

$$p_{i,t}^{zy} zy_{i,t} = \sum_j p_{j,i,t}^{zy} zy_{j,i,t} \qquad (20)$$

where $p_{j,i,t}^{zy}$ is the price of intermediate commodity j for industry i and $p_{i,t}^{zy}$ is the industry-specific price of aggregate intermediate inputs.

Fixed factor input

The production process also requires fixed factors such as land/resource endowments. Further, the fixed factors are owned by the firm and fixed factor-augmenting technical progress is assumed to grow at the same rate as labour-augmenting technical progress and the population. This ensures the economy is on its balanced growth path in the long run.

Net value of production

Net output

Along the transition path, firms face capital and labour adjustment costs, which prevent them from achieving their potential level of output for a given level of inputs, with actual output in each industry given by $y_{i,t}$ where:

$$y_{i,t} = \Gamma(n_{i,t}, k_{i,t}, zy_{i,t}, f_{i,t}) - \Omega^n(n_{i,t}, n_{i,t-1}) - \Omega^k(ib_{i,t}, k_{i,t}) \tag{21}$$

Domestic supply of commodities

Each firm can produce multiple commodities. Following the literature, this is modelled using a constant elasticity of transformation (CET) function:

$$y_{i,t} = \left(\sum_j \theta^y_{j,i} \left(y_{j,i,t} \right)^{\frac{\nu^y+1}{\nu^y}} \right)^{\frac{\nu^y}{\nu^y+1}} \tag{22}$$

where $y_{j,i,t}$ is the amount of commodity j produced by industry i, $0 \le \theta^y_{j,i} \le 1$ is the CET weight of commodity j, and ν^y is the elasticity of transformation. The latter determines the ease with which firms can transform their output mix in response to changes in the relative prices of commodities.[18]

The gross value of production for industry i is:

$$p^y_{i,t} y_{i,t} = \sum_j p^d_{j,t} y_{j,i,t} \tag{23}$$

where $p^d_{j,t}$ is the basic price of commodity j.

The total quantity of commodity j produced and supplied by domestic industries is:

$$d_{j,t} = \sum_i y_{j,i,t} \tag{24}$$

Market value of the firm

The firm makes production and investment decisions to maximise its market value on behalf of its shareholders. The firm's shareholders are the domestic household and investors from the ROW.

The no-arbitrage condition requires that the expected return on equity equals the required rate of return r^e_t:

$$E_t \left[\frac{q_{i,t} + (1+\gamma)v_{i,t+1} - v_{i,t}}{v_{i,t}} \right] = r^e_t \tag{25}$$

where $q_{i,t}$ is the net cash flow from firms to shareholders and $v_{i,t}$ is the ex-dividend value of the firm's equity at the beginning of period t. The net cash flow includes dividends or share buy-back less net issuance of equity. This implies that:

18 See for example van der Mensbrugghe and Peters (2016).

$$v_{i,t} = E_t\left[\frac{q_{i,t} + (1+\gamma)v_{i,t+1}}{(1+r_t^e)}\right] \tag{26}$$

Forward substitution of this relationship implies the market value of the firm's equity is equivalent to the net present value of current and all future net cash flow to shareholders:

$$v_{i,t} = E_t\left[\sum_{s=t}^{\infty}\left(\prod_{u=t}^{s}\frac{1+\gamma}{1+r_t^e}\right)\left(\frac{q_{i,s}}{1+\gamma}\right)\right] \tag{27}$$

Production taxes and subsidies

The government levies taxes on factors of production: fixed factors, capital and labour. These correspond to land tax, payroll tax and other production taxes, including motor vehicle registration taxes and licencing taxes. The government also pays subsidies to production. Total production tax paid by industry i is the sum of taxes on the fixed factor, capital and labour input minus subsidies:

$$tax_{i,t}^{y} = tax_{i,t}^{fy} + tax_{i,t}^{ky} + tax_{i,t}^{ny} - tax_{i,t}^{sub} \tag{28}$$

A tax on the fixed factor input is levied on the value added that is generated by the fixed factor. Fixed factors include land and mineral resources. As such, the tax rate varies by industry, reflecting land and resource rent taxes or royalties. Fixed factors notionally earn rent $w_{i,t}^{f}$. Therefore, the value added by the fixed factor is $w_{i,t}^{f} f_{i,t}$ to which tax rate $\tau_{i,t}^{fy}$ is applied. The revenue is then given by:

$$tax_{i,t}^{fy} = \tau_{i,t}^{fy} w_{i,t}^{f} f_{i,t} \tag{29}$$

Payroll tax is levied on the compensation of employees and is applied as an industry-wide rate:

$$tax_{i,t}^{ny} = \tau_{i,t}^{ny} w_t n_{i,t} \tag{30}$$

Production taxes on capital are applied to the current replacement value of capital, given by the investment price:

$$tax_{i,t}^{ky} = \tau_{i,t}^{ky} p_{i,t}^{ib} k_{i,t} \tag{31}$$

Subsidies are received ad valorem to the value of output and given by:

$$tax_{i,t}^{sub} = \tau_{i,t}^{sub} p_{i,t}^{y} y_{i,t} \tag{32}$$

Firm's budget constraint

The firm's flow budget constraint is:

$$q_{i,t} + p_{i,t}^{ib} ib_{i,t} = (1-\tau_t^k)(p_{i,t}^{y} y_{i,t} - w_t n_{i,t} - p_{i,t}^{zy} zy_{i,t} - tax_{i,t}^{y}) + \tau_t^k \delta_t p_{i,t}^{ib} k_{i,t} \tag{33}$$

where τ_t^k is the effective company income tax rate levied on the firm's net operating surplus – that is, the gross value of output, less compensation of employees, cost of intermediate inputs, depreciation allowance and production taxes. TIM assumes the firm can deduct depreciation at the economic rate of depreciation and current investment price. The net cash flow from firms to shareholders, $q_{i,t}$, is the residual of the firm's after-tax net operating surplus less the cost of investment.

Firm's objective

The firm's objective is to maximise its equity value, $v_{i,t}$ (equation (27)), by choosing labour, intermediate input commodities, investment commodities and the share of output allocated to each commodity. These choices determine gross output and output of each commodity using the production technologies in equations (12), (14), (15), (16), (18), (19), (21) and (22). This further determines the firm's tax liabilities in equations (29), (30), (31) and (32), and the firm's net cash flow and value. Firms take the prices of inputs and outputs as given when making these choices.

Firms: Distribution sector

TIM captures key complexities in how output from firms and the ROW reaches users. TIM's notional distribution sector attempts to embody this complexity and simplify its exposition. The modelled distribution of commodities to different users is the same in structure, but the parameterisation varies by commodity and use.

Margins

In any economy, some commodities are used for the distribution of other goods and services from their production location to their final-use location. For example, when households purchase fresh produce from the supermarket, transportation, wholesale trade and retail trade services are consumed in making these goods available for purchase and distributing them from the farm gate. In the literature, these intermediate goods and services are referred to as margins.[19]

Margins are effectively an intermediate input used in distribution. However, they are modelled separately from intermediate inputs used in producing other commodities. Unlike intermediate inputs used in production, which are substitutable with other inputs, margin commodities are used in fixed proportions, $\psi_{i,j}$. The proportions are dependent on the commodity being distributed and the use of the commodity, such that:

$$zm_{i,j,t} = \psi_{i,j}^{c} c_{j,t} + \sum_{k} \psi_{i,j}^{ib} ib_{j,k,t} + \sum_{k} \psi_{i,j}^{zy} zy_{j,k,t} + \psi_{i,j}^{g} g_{j,t} + \psi_{i,j}^{x} x_{j,t} \tag{34}$$

where $zm_{i,j,t}$ is the quantity of margin good i required to distribute commodity j to its various uses.

19 TIM includes 11 margins: wholesale trade; retail trade; restaurants, hotels and clubs; road transport; rail transport; pipeline transport; water transport; air transport; port handling and marine insurance; gas distribution; and electricity distribution.

Total supply

The notional distribution sector combines domestically produced and imported commodities to form composite commodities which it supplies to meet demand. This includes consumption, investment by firms, intermediate inputs by firms, government consumption, exports and margins.

Supply can be met by domestic or imported commodities. For a given commodity j and use, $d_{j,t}$ is the distribution sector's demand for domestically produced commodities and $m_{j,t}$ is the demand for imported commodities. These are combined using a CES function, where $0 \le \theta_j^m \le 1$ is the weighting parameter for the domestically produced commodity j, and η^m is the elasticity of substitution between domestic and imported varieties of commodity j:

$$c_{j,t} = \left(\theta_j^{cm} d_{j,t}^{c\ \frac{\eta^m - 1}{\eta^m}} + (1 - \theta_j^{cm}) m_{j,t}^{c\ \frac{\eta^m - 1}{\eta^m}} \right)^{\frac{\eta^m}{\eta^m - 1}} \quad (35)$$

$$ib_{j,i,t} = \left(\theta_{j,i}^{ibm} d_{j,i,t}^{ib\ \frac{\eta^m - 1}{\eta^m}} + (1 - \theta_{j,i}^{ibm}) m_{j,i,t}^{ib\ \frac{\eta^m - 1}{\eta^m}} \right)^{\frac{\eta^m}{\eta^m - 1}}$$

$$zy_{j,i,t} = \left(\theta_{j,i}^{zym} d_{j,i,t}^{zy\ \frac{\eta^m - 1}{\eta^m}} + (1 - \theta_{j,i}^{zym}) m_{j,i,t}^{zy\ \frac{\eta^m - 1}{\eta^m}} \right)^{\frac{\eta^m}{\eta^m - 1}}$$

$$g_{j,t} = \left(\theta_j^{gm} d_{j,t}^{g\ \frac{\eta^m - 1}{\eta^m}} + (1 - \theta_j^{gm}) m_{j,t}^{g\ \frac{\eta^m - 1}{\eta^m}} \right)^{\frac{\eta^m}{\eta^m - 1}}$$

$$x_{j,t} = \left(\theta_j^{xm} d_{j,t}^{x\ \frac{\eta^m - 1}{\eta^m}} + (1 - \theta_j^{xm}) m_{j,t}^{x\ \frac{\eta^m - 1}{\eta^m}} \right)^{\frac{\eta^m}{\eta^m - 1}}$$

$$zm_{j,i,t} = \left(\theta_{j,i}^{zmm} d_{j,i,t}^{zm\ \frac{\eta^m - 1}{\eta^m}} + (1 - \theta_{j,i}^{zmm}) m_{j,i,t}^{zm\ \frac{\eta^m - 1}{\eta^m}} \right)^{\frac{\eta^m}{\eta^m - 1}}$$

Import prices

Let $p^{x*}_{j,t}$ be the ROW's free-on-board (FOB) export price. When imported commodities arrive in Australia, the price is adjusted for import duties and an ad valorem tax, $\tau m_{j,t}$, which varies by the use of the commodity. The import prices faced by Australian users is:

$$pm^{c}_{j,t} = (1+\tau m^{c}_{j,t})\, p^{x*}_{j,t} \tag{36}$$

$$pm^{ib}_{j,t} = (1+\tau m^{ib}_{j,t})\, p^{x*}_{j,t}$$

$$pm^{zy}_{j,i,t} = (1+\tau m^{zy}_{j,i,t})\, p^{x*}_{j,t}$$

$$pm^{g}_{j,t} = (1+\tau m^{g}_{j,t})\, p^{x*}_{j,t}$$

$$pm^{x}_{j,t} = (1+\tau m^{x}_{j,t})\, p^{x*}_{j,t}$$

$$pm^{zm}_{j,i,t} = (1+\tau m^{zm}_{j,i,t})\, p^{x*}_{j,t}$$

Price of supply

The price of Australian supply by use, $ps_{j,t}$, is a composite of the domestic price, $p^{d}_{j,t}$,and import price, $pm_{j,t}$, as follows:

$$ps^{c}_{j,t} c_{j,t} = p^{d}_{j,t} d^{c}_{j,t} + pm^{c}_{j,t} m^{c}_{j,t} \tag{37}$$

$$ps^{ib}_{j,i,t} ib_{j,i,t} = p^{d}_{j,t} d^{ib}_{j,i,t} + pm^{ib}_{j,t} m^{ib}_{j,i,t}$$

$$ps^{zy}_{j,i,t} zy_{j,i,t} = p^{d}_{j,t} d^{zy}_{j,i,t} + pm^{zy}_{j,i,t} m^{zy}_{j,i,t}$$

$$ps^{g}_{j,t} g_{j,t} = p^{d}_{j,t} d^{g}_{j,t} + pm^{g}_{j,t} m^{g}_{j,t}$$

$$ps^{x}_{j,t} x_{j,t} = p^{d}_{j,t} d^{x}_{j,t} + pm^{x}_{j,t} m^{x}_{j,t}$$

$$ps^{zm}_{j,i,t} zm_{j,i,t} = p^{d}_{j,t} d^{zm}_{j,i,t} + pm^{zm}_{j,i,t} m^{zm}_{j,i,t}$$

The total demand for domestically produced commodity j is:

$$d_{j,t} = d_{j,t}^{c} + \sum_i d_{j,i,t}^{ib_i} + \sum_i d_{j,i,t}^{zy_i} + d_{j,t}^{g} + d_{j,t}^{x} + \sum_i d_{j,i,t}^{zm} \tag{38}$$

and total demand for imports of commodity j is:

$$m_{j,t} = m_{j,t}^{c} + \sum_i m_{j,i,t}^{ib_i} + \sum_i m_{j,i,t}^{zy_i} + m_{j,t}^{g} + m_{j,t}^{x} + \sum_i m_{j,i,t}^{zm} \tag{39}$$

Purchaser prices

The final use price of a commodity, commonly known as the purchaser's price, depends on the total supply price, $ps_{j,t}$, the cost of margins required to transfer the commodity to its final use, $ps_{i,t}^{zm}\psi_{i,j}$, and taxes on products (excise, $\tau e_{j,t}$, and sales taxes, $\tau s_{j,t}$).

Excise is levied per unit at rate $\tau e_{j,t}$, which depends on the use category, commodity and industry. Sales tax, $\tau s_{j,t}$, represents a combination of GST, subsidies and other sales taxes, and is levied on the combined basic value of the commodities, the associated margins, import duties and excise.

Hence, the purchaser's price by use of commodity j is given by:

$$p_{j,t}^{c} = (1+\tau s_{j,t}^{c})(ps_{j,t}^{c} + \sum_k ps_{k,t}^{zm}\psi_{k,j}^{c} + \tau e_{j,t}^{c}) \tag{40}$$

$$p_{j,i,t}^{ib} = (1+\tau s_{j,i,t}^{ib})(ps_{j,i,t}^{ib} + \sum_k ps_{k,t}^{zm}\psi_{k,j}^{ib} + \tau e_{j,i,t}^{ib})$$

$$p_{j,i,t}^{zy} = (1+\tau s_{j,i,t}^{zy})(ps_{j,i,t}^{zy} + \sum_k ps_{k,t}^{zm}\psi_{k,j}^{zy} + \tau e_{j,i,t}^{zy})$$

$$p_{j,t}^{g} = ps_{j,t}^{g} + \sum_k ps_{k,t}^{zm}\psi_{k,j}^{g}$$

$$p_{j,t}^{x} = (1+\tau s_{j,t}^{x})(ps_{j,t}^{x} + \sum_k ps_{k,t}^{zm}\psi_{k,j}^{x} + \tau e_{j,t}^{x})$$

Government

Revenue

The government collects revenue by levying taxes on income, commodities and production.

Income taxes

TIM does not incorporate heterogeneous households or different savings vehicles, which limits the modelling of income tax to stylised labour and capital income taxes.

Labour income tax is modelled as a flat rate, τ_t^n, applied to total labour income:

$$tax_t^n = \sum_i \tau_t^n w_t n_{i,t} = \tau_t^n w_t n_t \tag{41}$$

Capital income tax represents company income tax, which is paid by firms on behalf of shareholders. It is levied on corporate earnings after deductions for production taxes and depreciation:

$$tax_t^k = \sum_i \tau_t^k \left(p_{i,t}^y y_{i,t} - w_t n_{i,t} - p_{i,t}^{zy} zy_{i,t} - tax_{i,t}^y - \delta_t p_{i,t}^{ib} k_{i,t} \right) \tag{42}$$

The model ignores other withholding tax or similar taxes on passive income earned by the ROW.

Taxes on products

The government collects excise and sales tax. Sales tax is modelled as an ad valorem tax on the value of household final consumption, government expenditure, exports, intermediate inputs and private gross fixed capital formation:

$$tax_t^{cs} = \sum_j \frac{\tau s_{j,t}^c p_{j,t}^c c_{j,t}}{1 + \tau s_{j,t}^c} \tag{43}$$

$$tax_t^{ibs} = \sum_j \sum_i \frac{\tau s_{j,i.t}^{ib} p_{j,i,t}^{ib} ib_{j,i,t}}{1 + \tau s_{j,i,t}^{ib}}$$

$$tax_t^{zys} = \sum_j \sum_i \frac{\tau s_{j,i,t}^{zy} p_{j,i,t}^{zy} zy_{j,i,t}}{1 + \tau s_{j,i,t}^{zy}}$$

$$tax_t^{xs} = \sum_j \frac{\tau s_{j,t}^x p_{j,t}^x x_{j,t}}{1 + \tau s_{j,t}^x}$$

Excise is levied on the volume of sales, with total revenue given by:

$$tax_t^{ce} = \sum_j \tau e_{j,t}^c c_{j,t} \tag{44}$$

$$tax_t^{ibe} = \sum_j \sum_i \tau e_{j,i,t}^{ib} ib_{j,i,t}$$

$$tax_t^{zye} = \sum_j \sum_i \tau e_{j,i,t}^{zy} zy_{j,i,t}$$

$$tax_t^{xe} = \sum_j \tau e_{j,t}^x x_{j,t}$$

Import duties are levied on the value of imports with total revenue given by:

$$tax_t^{cm} = \sum_j \tau m_{j,t}^{c} p_{j,t}^{x*} m_{j,t}^{c} \tag{45}$$

$$tax_t^{ibm} = \sum_j \tau m_{j,t}^{ib} p_{j,t}^{x*} m_{j,t}^{ib}$$

$$tax_t^{zym} = \sum_j \sum_k \tau m_{j,k,t}^{zy} p_{j,t}^{x*} m_{j,t}^{zy}$$

$$tax_t^{xm} = \sum_j \tau m_{j,t}^{x} p_{j,t}^{x*} m_{j,t}^{x}$$

Expenditure

Tax revenue is used to finance general government consumption and a lump-sum transfer to the household. Government expenditure does not directly affect the welfare of the household or the productivity of private factors of production. Real government expenditure is assumed to grow at the same rate as trend output. That is, in the absence of shocks, the ratio of real government expenditure to real gross domestic product is constant. The total cost of government expenditure is given by:

$$p_t^g g_t = \sum_j p_{j,t}^g g_{j,t} \tag{46}$$

Government's budget constraint

TIM's standard fiscal rule is that the government's budget is balanced in every period (including in the calibration) with lump sum transfers adjusting to offset any changes in revenue. Government transfers are thus given by:

$$tran_t + p_t^g g_t = tax_t^n + tax_t^k + tax_t^y + tax_t^s + tax_t^e + tax_t^m \tag{47}$$

Financial sector

TIM's financial sector allocates household savings to domestic equity. Under the model's small open economy/perfect capital mobility assumption, any shortfall in funds for domestic equity investment is therefore sourced from the foreign sector.

Household saving

For simplicity, TIM assumes that domestic households only hold claims to domestic equity. Before asset and commodity markets open at time t, a notional funds manager allocates a fixed share, $0 < \theta_i^v < 1$, of household savings to equity holdings in industry i, where $\sum_i \theta_i^v = 1$:

$$v_{i,t}^h = \theta_i^v v_t^h \tag{48}$$

The value of the household's equity in industry i at the beginning of period t after shocks are realised is $v_{i,t}^{h}$, and implied household wealth v_t^h is as follows:

$$v_t^h = \sum_i v_{i,t}^h \tag{49}$$

The share of household savings allocated to equity holdings in industry i at the beginning of time t after the realisation of shocks will, in general, vary from the fund manager's initial allocation, $0 < \theta_i^v < 1$, because unexpected sector-specific shocks will have an asymmetric effect on the equity value of firms in different industries.

Foreign liabilities

As a small open economy, TIM assumes Australia has no influence on the global equity market or the global required after-tax rate of return, r_t^*. The supply of foreign capital is assumed to be perfectly elastic at the global required rate of return and Australian equity is a perfect substitute for international equity. This implies that the required after-tax rate of return for domestic equity is the global after-tax rate of return, so that $r_t^e = r_t^*$.

Under these assumptions, the ROW is willing to buy any equity available in Australia if the expected rate of return equals the global rate of return, such that:

$$v_{i,t}^{f*} = v_{i,t} - v_{i,t}^h \tag{50}$$

where $v_{i,t}^{f*}$ is the ROW's holding of equity of Australian industry i.

As such, the ROW is the marginal investor, which means the ROW determines the price of Australian equity and the size of the Australian capital stock.

TIM assumes that Australian households only hold Australian assets, and that Australia is an international net debtor. This implies the value of Australia's net foreign liabilities is given by:

$$v_t^{f*} = \sum_i v_{i,t}^{f*} \tag{51}$$

For simplicity, Version 1.0 of TIM assumes there is no government debt. This assumption will be relaxed in future versions.

Return on household saving

Under the perfect capital mobility assumption, all industries earn the same after-tax rate of return, $r_t^e = r_t^*$. Therefore, the household's assets generate an aggregate return that is the common after-tax return to industries, $r_t^h = r_t^e = r_t^*$.

Rest of the world

The ROW is assumed to trade with the Australian economy in three ways. First, the ROW purchases Australian exports, $x_{j,t}$, at Australian export prices, $p^{x}_{j,t}$. Second, the ROW supplies commodities, $x^{*}_{j,t}$, that are imported by Australians ($m_{j,t} = x^{*}_{j,t}$) at the FOB price, $p^{x*}_{j,t}$. Finally, the ROW supplies capital perfectly elastically at the required rate of return, r^{*}_{t}.

Global goods and services market

Imports

As a small open economy, TIM assumes domestic demand cannot affect the price at which the ROW supplies imports, $p^{x*}_{j,t}$, and that the ROW's supply of imports is perfectly elastic at that price.

Exports

To model Australia's exports, the ROW is assumed to have a similar nested preference structure to Australian households and firms. First, the ROW decides on the mix of commodities it wants to consume, and secondly how much of each commodity will be sourced from Australia and the ROW. This means that Australian exports of commodity j compete with those produced in the ROW.

Australian exports can trade at a different price to their ROW counterparts because they are assumed to be differentiated commodities. This means the response of foreign demand to changes in the price of Australian exports will depend on both the elasticity of substitution between different types of commodities, η^{*}, and the elasticity of substitution between different varieties of the same commodity produced in Australian and the ROW, η^{m*}.

This structure implies that the demand for Australian exports is given by the following foreign import demand relationship:

$$x_{j,t} = (1-\theta_j^{m*})\left(\frac{p^{x}_{j,t}}{ps^{*}_{j,t}}\right)^{-\eta_j^{m*}} \theta_j^{*}\left(\frac{ps^{*}_{j,t}}{ps^{*}_{t}}\right)^{-\eta^{*}} s^{*}_{t} \quad (52)$$

where for commodity j, $x_{j,t}$ is Australian exports (which represents the ROW's imports $m^{*}_{j,t}$), s^{*}_{t} is the ROW's aggregate demand, θ_j^{*} represents the CES weight for commodity j over the set of commodities in the ROW's aggregate demand and $(1-\theta_j^{m*})$ represents the CES weight for Australian commodity j among competing varieties in the ROW. Furthermore, $ps^{*}_{j,t}$ is the ROW's CES price aggregated over all varieties of commodity j, and ps^{*}_{t} is the ROW's total supply price which is exogenous.

The ROW's price aggregated over all varieties of commodity j is an aggregate of the price of Australian exports to the ROW of commodity j (where $pm^{*}_{j,t} = p^{x}_{j,t}$), and the ROW's price of its competing variety of commodity j, $p^{d*}_{j,t}$:

$$ps^{*}_{j,t} = \left((\theta^{m*}_{j})^{\frac{1}{\eta^{m*}_{j}}} \left(p^{d*}_{j,t}\right)^{1-\eta^{m*}_{j}} + (1-\theta^{m*}_{j})^{\frac{1}{\eta^{m*}_{j}}} \left(pm^{*}_{j,t}\right)^{1-\eta^{m*}_{j}} \right)^{\frac{1}{1-\eta^{m*}_{j}}} \tag{53}$$

In a similar vein to the modelling of domestic use prices, the world price against which Australian exports compete, $p^{d*}_{j,t}$, can differ from the price at which the world supplies imports to Australia, $p^{x*}_{j,t}$.

National budget constraint

Given the quantities and prices of imports and exports, as well as the global required rate of return, the national budget constraint is:

$$(1+\gamma)v^{f*}_{t+1} - v^{f*}_{t} = r^{*}_{t} v^{f*}_{t} - \left(\sum_{j} p^{x}_{j,t} x_{j,t} - \sum_{j} p^{x*}_{j,t} m_{j,t} \right) \tag{54}$$

Where r^{*}_{t} is the ROW's realized return on Australian assets.

The trade balance, tb_t, is given by the value of exports minus FOB imports:

$$tb_t = \sum_{j} p^{x}_{j,t} x_{j,t} - \sum_{j} p^{x*}_{j,t} m_{j,t} \tag{55}$$

The capital income paid to the ROW equals the negative of the net foreign income balance nfi_t:

$$-nfi_t = r^{*}_{t} v^{f*}_{t} \tag{56}$$

The balance on the current account ca_t reflects the change in the Australian household's net foreign assets:

$$ca_t = v^{f*}_{t} - (1+\gamma)v^{f*}_{t+1} \tag{57}$$

Equilibrium definition

An equilibrium is defined by agents behaving optimally and markets clearing such that the quantity demanded is equal to the quantity supplied in all markets. TIM assumes that both the household and firms are price takers and firms accept zero economic profits.

Given a sequence of tax rates, government expenditure and transfers, initial capital stock and land owned by each firm, assets initially owned by the household and the ROW, the household's endowment of time, productivity factors, foreign demand and international prices, a competitive equilibrium is given by a sequence of prices, quantities, asset holdings, cash flow from firms to shareholders, and government revenue and expenditure for all commodities and firms that satisfies the following conditions:

1. The household maximises the discounted value of its expected utility, subject to the budget constraint, as per equations (6) and (10).

2. Each firm maximises its equity value, subject to its resource constraint, as per equations (27) and (33).

3. Domestic demand for imports is satisfied as per equation (39).

4. Foreign demand for exports is satisfied as per equation (52).

5. The demand for domestically produced commodities equals the supply of domestically produced commodities as per equations (24) and (38).

6. The distribution sector ensures demand of commodities by use equals supply:

$$\left\{c_{j,t} = s^{c}_{j,t}\right\}_{j=1}^{114}$$

$$\left\{ib_{j,t} = s^{ib}_{j,t}\right\}_{j=1}^{114}$$

$$\left\{zy_{j,t} = s^{zy}_{j,t}\right\}_{j=1}^{114}$$

$$\left\{g_{j,t} = s^{g}_{j,t}\right\}_{j=1}^{114}$$

$$\left\{x_{j,t} = s^{x}_{j,t}\right\}_{j=1}^{114}$$

$$\left\{zm_{j,t} = s^{zm}_{j,t}\right\}_{j=1}^{114}$$

7. The labour market clears as per equation (13).

8. The capital market clears as per equation (50).

9. The government consumes its desired commodities, and its budget is balanced as per equation (47).

Solution method

The algorithm used to solve for the above equilibrium conditions in TIM can be described as a Walrasian auction system that ensures that all markets clear and all agents behave in such a way that they achieve their objectives as defined above.

The auctioneer in this system has no control over the interest rate or commodity prices for goods and services produced by the ROW, as Australia is assumed to be a small open economy. However, the auctioneer does set the price of Australian commodities and the nominal wage, announcing each to a crowd of agents comprising firms, households, the rest of the world, and the government.

Based on this announcement, each agent proposes its own response:

- Firms in each sector determine the level of output and demand for capital, labour and intermediate goods that will maximise their market value.
- Households determine the labour supply and demand for consumption goods that will maximise their utility.
- The government determines how to balance its budget constraint and allocate government spending.
- The ROW determines a level of exports given their preferences and the announced prices.

All agents – firms, households, government, and the ROW – submit their intended responses to the auctioneer. The auctioneer reviews these and continues to adjust prices and the wage until the goods and labour markets have cleared. The system is competitive because neither the firms, households, government, or the ROW can solely determine the prices and wage announced by the auctioneer. The auction therefore results in a competitive equilibrium.

4. Calibration

TIM is calibrated to match Australian economic data. Many of the model's parameters, primarily weighting parameters, are calibrated to directly match Australian data. Response parameters, such as elasticities, reflect consensus estimates in the macroeconomic literature. TIM is designed to approximate the Australian economy using data published in the ABS I-O tables.

TIM Version 1.0 uses the 2018-19 I-O tables (ABS, 2021b) and assumes that the baseline economy is on its long-run balanced growth path.[20] To that end, the growth rates of the model's exogenous trends (population and labour-augmenting technical progress) are constant.

TIM is an annual model with an annual trend output growth rate of 2.9 per cent, where population contributes 1.4 per cent and labour-augmenting technical progress 1.5 per cent.[21]

Table 1: TIM's growth parameters

Parameter	Value	Description
γ	0.029	Trend output growth rate
γ^h	0.014	Population growth rate
γ^ξ	0.015	Growth rate of labour augmenting technical progress

The baseline scenario deviates from the I-O table data along three dimensions. First, the household's consumption and income are consistent with a steady state balanced household budget. Second, investment is consistent with investment along the trend growth path. Finally, goods are produced and used in the same period, precluding any change in inventories.

Household

Following the dynamic stochastic general equilibrium (DSGE) literature, the coefficient of relative risk aversion is set at $\sigma = 2$ for the household (King, Plosser, & Rebelo, 1987). This implies an intertemporal elasticity of substitution of 0.5.

The share of the household's time devoted to working, n, is conditional on the Frisch elasticity of labour supply and the consumption share of utility, α:

$$n = \left[\frac{1-\alpha(1-\sigma)}{\sigma}\right] / \left[\eta^n + \frac{1-\alpha(1-\sigma)}{\sigma}\right]$$

20 The 2018-19 I-O tables were deliberately chosen rather than the latest release as they better reflect the structure of the economy prior to the COVID-19 shutdowns.

21 Version 2.0 of TIM will update the rate of labour-augmenting technical progress to reflect the current trend productivity growth assumption of 1.2 per cent.

Consistent with the micro-econometric literature, as surveyed by Keane (2011), the Frisch elasticity of labour supply is assumed to be 0.46, which is also consistent with the weighted-average calibrated Frisch elasticity used in Treasury's OLGA (Cai, Gustafsson, Kouparitsas, Smith, & Zhang, 2023). The consumption share of utility is estimated using labour's share of income and the household consumption share of expenditure implied by the I-O tables.

Based on these inputs, the share of time devoted to working, n, is calibrated to 0.65. This is higher than the time devoted to working typically assumed in macroeconomic models focused on the study of business cycles (see, for example, Peterman (2015)).

The household's discount rate, β, is calibrated to be consistent with the assumed trend growth rate output and the required rate of return on capital:

$$\beta = \frac{(1+\gamma)}{(1+r^*)}$$

Consumption of commodities

The consumption shares, θ_j^c, are calibrated to match the I-O table data. The consumption commodity elasticity, η^c, is set to 0.5. This value is consistent with OLGA (Cai, Gustafsson, Kouparitsas, Smith, & Zhang, 2023).

Table 2: TIM's household parameters

Parameter	Value	Description
σ	2	Coefficient of relative risk aversion
η^n	0.46	Frisch elasticity of labour supply
n	0.65	Household's share of time devoted to work
α	0.7145	Consumption's share of utility
β	0.9821	Household's discount rate
η^c	0.5	Elasticity of substitution between different consumption commodities.

Firms: Production sector

Primary factor and intermediate input shares

The factor shares of production θ_i^n, θ_i^k, θ_i^{zy} and θ_i^f are calibrated using the shares of compensation of employees (COE), gross operating surplus (GOS), gross mixed income (GMI) and intermediate inputs from the I-O tables. As Version 1.0 of TIM contains 114 industries, there are 114 factor shares for each of θ_i^n, θ_i^k, θ_i^{zy} and θ_i^f.

The values for COE include the labour portion of GMI. The values for GOS include the capital portion of GMI. It is assumed that the ratio of labour to capital income in GMI is the same as the ratio of COE to GOS. Labour's share of sectoral income, θ_i^n , is calculated using this adjusted COE. The fixed factor share of output, θ_i^f , is calculated using a combination of the System of National Accounts, ABS Multifactor Productivity data and the I-O tables (ABS (2020a), ABS (2020b) and ABS (2021b)). Similarly, capital's share of income, θ_i^k , is calculated using the adjusted GOS value from the ABS (2021b), net the adjustment to COE and fixed factor income. The aggregate intermediate input share, θ_i^{zy} , is obtained as a residual of the other three primary factor shares.

Factor substitution

The elasticity of substitution between capital, labour, the fixed factor and intermediate inputs, η^y , is set to 0.5. This is consistent with estimates of the elasticity of substitution between capital and labour reported by Hutchings and Kouparitsas (2012).

Input substitution

The investment input elasticity of substitution, η^{ib} , and the intermediate input elasticity of substitution, η^{zy} , are set to 0.5. This is consistent with OLGA (Cai, Gustafsson, Kouparitsas, Smith, & Zhang, 2023).

Investment and adjustment cost parameters

The industry capital depreciation rate, δ , of 0.053 is estimated from the ABS System of National Accounts 5204.0 Table 65 (ABS, 2020a).

Consistent with the methodology followed by Cai, et al., (2023), an annual capital adjustment cost, ζ^k , of 2.5 is used. This parameter is consistent with D'Erasmo, et al., (2016), who use the elasticity of the capital tax base as the basis of their calibration.

The labour adjustment cost, ζ^n , is set to 2, consistent with Jaimovich and Rebelo (2008).

The firm's investment shares, $\theta_{j,i}^{ib}$, are calibrated using the ABS National Accounts and I-O tables. The ABS System of National Accounts 5204.0 Table 64 (ABS, 2020a) provides private investment by capital type and two-digit industry, and the I-O tables provide commodity use and taxation for private investment.

Table 3: TIM's production parameters

Parameter	Value	Description
η^{y}	0.5	Elasticity of substitution between the fixed factor, labour, capital, and intermediate input
η^{zy}	0.5	Elasticity of substitution between different intermediate input commodities
η^{ib}	0.5	Elasticity of substitution between different investment commodities
ζ^{n}	2	Labour adjustment cost parameter
ζ^{k}	2.5	Capital adjustment cost parameter
δ	0.053	Capital depreciation rate

Firms: Distribution sector

Margins

The margin use coefficients for each final use, $\psi_{i,j}$, are based on the authors' calculations using the ABS margin commodity I-O tables 23–34 (ABS, 2021b). These are calibrated by dividing the total basic price expenditure of each margin commodity paid to transfer that commodity for use, by the total basic value of expenditure, plus the duties of each commodity for use.

Total supply of commodities

The domestic share of use, θ_{j}^{m}, is calculated from the I-O tables (ABS, 2021b). The elasticity of substitution between domestic and imported varieties of commodity j, η^{m}, is set to 2.

Rest of the world

Asset market

Initial asset holdings are calculated from the ABS Economic Activity of Foreign Owned Business Activity dataset (ABS, 2018). This contains information on the domestic and foreign ownership of assets, and the share of assets allocated to each industry. In the baseline, foreigners own around 20 per cent of assets.

The global required after-tax rate of return ($r_t^{*} = r_t^{e}$) is calibrated to observed corporate GOS, corporate capital stock and depreciation. Specifically, the implied global required after-tax rate of return to equity is calibrated such that:

$$r_t^{*} = r_t^{e} = (1-\tau_t^{k})(\omega - \delta) \tag{58}$$

where the gross rental rate of capital, ω, is calculated as the ratio of GOS to market value of the capital stock using data from the ABS.

Export demand

The share of Australian exports relative to global exports, $(1-\theta_j^{m*})$, is calibrated using a mapping between the GTAP database (Aguiar, Chepeliev, Corong, McDougall, & Mensbrugghe, 2019) and the Australian I-O table industries. A composite export demand parameter, $\theta_j^{*}\ s_t^{*}$, is subsequently calibrated using the value of exports from the ABS I-O tables (ABS, 2021b).

The ROW's elasticity of substitution between different types of commodities, η^{*}, is set to the same value as η_j^{c} and η_j^{ib} of 0.5. The elasticity of substitution between Australian exports and ROW exports (for a given commodity η_j^{m*}), is based on elasticities from the GTAP database (Aguiar, Chepeliev, Corong, McDougall, & Mensbrugghe, 2019).

Table 4: TIM's commodity supply and ROW parameters

Parameter	Value	Description
η^{m}	2	Elasticity of substitution between domestic and imported varieties of commodity *j*
η^{*}	0.5	ROW's elasticity of substitution between different commodities
η_j^{m*}	Ranges from 1.8 to 28.8, with an average elasticity of 5.3	Elasticity of substitution between Australian and ROW varieties of commodity *j*
r_t^{*}	0.0479	Global required after-tax rate of return

Government

Revenue

Income taxes

Total company income taxes are obtained from the ABS Taxation Revenue 2019–20 Table 1 (ABS, 2021a). The tax rate on capital, τ_t^{k}, is calculated as company income tax paid, divided by the sum of GOS and land value-added, less the depreciation on private capital obtained from the ABS Australian System of National Accounts (ABS, 2020a).

Labour income taxes for 2018–19 are obtained from the ABS Taxation Revenue 2019–20 Table 1 (ABS, 2021a). The labour tax rate, τ_t^{n}, is calculated as labour income tax paid divided by COE (which is sourced from the I-O tables).

Taxes on production

Payroll tax, the tax on the return to fixed factors, the tax on variable capital, and production subsidies are calculated from taxes on production obtained from the 2018–19 I-O tables Table 2 (ABS, 2021b).

These taxes are allocated to industries consistent with aggregate taxes on production and industry data from the ABS industry dataset (ABS, 2021c), as well as government revenue data and the labour account.

Taxes on products

Taxes on products are obtained from Tables 35–40 of the ABS I-O tables (ABS, 2021b). These tables provide information on duties, GST, subsidies, excise, and other taxes collected on intermediate inputs, consumption, investment, government expenditure and exports.

Table 5: TIM's implied tax rates

Implied tax rate	Calculations
Import duties $\tau m_{j,t}$	Duty revenue divided by competing imports
Excise $\tau e_{j,t}$	Excise revenue divided by the basic value of use including duties
Sales tax $\tau s_{j,t}$	Sales tax revenue divided by the sum of basic value of use plus duty revenue, excise revenue and margins

Expenditure

Government expenditure is obtained from Table 4 of the ABS I-O tables (ABS, 2021b).

5. Welfare criterion for policy analysis

TIM measures welfare gains and losses for the representative household associated with a policy change using a dynamic version of the Hicksian Equivalent Variation (HEV) approach. This approach essentially measures the change in lifetime utility (measured in terms of initial consumption, labour hours, prices, and wages) that would leave the household indifferent to the change in policy. If the policy change increases lifetime utility, the HEV estimate will be positive, and the household will be deemed to be better off.

Assuming the policy change is announced at time t, $\left\{\bar{c}_s, \bar{l}_s\right\}_{s=t}^{\infty}$ is the household's level of consumption and leisure assuming no policy change (which is typically the steady state path) for their remaining life, and $\left\{\tilde{c}_s, \tilde{l}_s\right\}_{s=t}^{\infty}$ is the household's level of consumption and leisure under the policy change for their remaining life. The HEV is estimated via Δ, which is the permanent per cent change in the household's consumption and leisure over their remaining lifetime sufficient to yield the same utility as under the policy change:

$$\sum_{s=t}^{\infty} \beta^{(s-t)} u((1+\Delta)\bar{c}_s, (1+\Delta)\bar{l}_s) = \sum_{s=t}^{\infty} \beta^{(s-t)} u(\tilde{c}_s, \tilde{l}_s) \quad (59)$$

If Δ is positive the household is better off under the policy change. Alternatively, if Δ is negative the household is worse off under the policy change.

This proportional HEV measure can be converted to a dollar or value estimate by noting that:

$$\Delta = \frac{E(p_0, u_1) - E(p_0, u_0)}{E(p_0, u_0)}$$

where $E(p,u)$ is the household's lifetime expenditure function evaluated at the prices/wage vector, p, and utility, u, with prices/wages before the policy change denoted by p_0 and the level of utility before and after the policy change denoted by u_0 and u_1, respectively.

6. Conclusion

TIM serves as a bridge to Treasury's previous industry policy models and modelling. It extends existing Australian models with many industries by incorporating the latest mainstream economic theory into a multi-sector dynamic general equilibrium framework useful for policy analysis. With forward-looking agents and a well-defined balanced growth path, TIM overcomes many of the limitations of previous Australian multi-sector models through three main channels: first, variables which have a significant bearing on modelling results are now determined endogenously; second, forward-looking agents more-realistically respond to anticipated policy and technology changes; and third, as decisions are derived from well-defined optimisation problems, TIM provides a model-consistent welfare measure.

These elements, combined with TIM's significant production and industry detail, position the model well for informing advice on a range of industry- and trade-related policy questions. This includes understanding the potential impact of changes in domestic or foreign demand, the introduction of new technologies, changes in the costs of imports used in production, or anticipated changes in policy.

Noting these strengths, the model does, however remain a representation of the Australian economy, not a replication. We therefore acknowledge the following limitations. First, TIM's welfare measure, while internally consistent, is only for the representative household. It does not directly provide information on the household distributional effects of policy (although the labour market and firm effects by industry provide a guide for the effects on households involved with different industries). Other frameworks in Treasury's broad suite of policy models, such as OLGA, can be used to complement TIM's industry analysis.

Additionally, TIM does not explicitly model unemployment. Multi-sector models that include unemployment typically do so through reduced form expressions, which map unemployment to changes in industry labour demand.[22] Explicitly modelling employment in a micro-founded way, for example by modelling the matching between employers and employees, would add significant complexity to an already-large model whose primary focus is not labour market dynamics. TIM does, however, capture labour market frictions through its inclusion of labour adjustment costs.

The version of TIM presented in this paper is referred to as TIM Version 1.0. In line with Treasury's macroeconomic modelling development programme, it has been designed to be enhanced through future development of discrete modules, which may revisit some of the assumptions included with this core version of TIM. This approach ensures the model continues to meet the evolving needs of our stakeholders, remaining fit for purpose for each policy analysis exercise, current and future.

22 See Adams, Dixon, and Horridge (2015) for an example.

References

ABS. (2018). *5494.0 - Economic Activity of Foreign Owned Businesses in Australia, 2014-15.* Retrieved from Australian Bureau of Statistics: https://www.abs.gov.au/ausstats/abs@.nsf/mf/5494.0

ABS. (2020a). *Australian System of National Accounts, 2019-20.* Retrieved from Australian Bureau of Statistics: https://www.abs.gov.au/statistics/economy/national-accounts/australian-system-national-accounts/2019-20

ABS. (2020b). *Estimates of Industry Multifactor Productivity, 2019-20.* Retrieved from Australian Bureau of Statistics: https://www.abs.gov.au/statistics/industry/industry-overview/estimates-industry-multifactor-productivity/2019-20

ABS. (2021a). *Taxation Revenue, Australia, 2019-20.* Retrieved from Australian Bureau of Statistics: https://www.abs.gov.au/statistics/economy/government/taxation-revenue-australia/2019-20

ABS. (2021b). *Australian National Accounts: Input-Output Tables, 2018-19.* Retrieved from Australian Bureau of Statistics: https://www.abs.gov.au/statistics/economy/national-accounts/australian-national-accounts-input-output-tables/2018-19

ABS. (2021c). *Australian Industry*. Retrieved from Australian Bureau of Statistics: https://www.abs.gov.au/statistics/industry/industry-overview/australian-industry/2019-20

Adams, P., Dixon, J., & Horridge, M. (2015). The Victoria University Regional Model (VURM): Technical Documentation, Version 1.0. *CoPS/IMPACT Working Paper*.

Aguiar, A., Chepeliev, M., Corong, E. L., McDougall, R., & Mensbrugghe, D. v. (2019). The GTAP Data Base: Version 10. *Journal of Global Economic Analysis*.

Arezki, R., Ramey, V. A., & Sheng, L. (2015, January). *News Shocks in Open Economies: Evidence from Giant Oil Discoveries.* Retrieved from The National Bureau of Economic Research (NBER): https://www.nber.org/papers/w20857

Bullen, J., Conigrave, B., Elderfield, A., Karmel, C., Lucas, L., Murphy, C., . . . Yao, H. (2021). *The Treasury Macroeconometric Model of Australia: Modelling Approach.* Canberra: The Treasury.

Cai, Y., Gustafsson, L., Kouparitsas, M., Smith, J., & Zhang, J. (2023). *Modelling Fiscal Policy with OLGA - Treasury's OverLapping Generations model of the Australian Economy.* Canberra: Treasury Working Paper.

Correia, I., Neves, C. J., & Rebelo, S. (1995). Business cycles in a small open economy. *European Economic Review, 39*, 1089-113.

D'Erasmo, P., Mendoza, E. G., & Zhang, J. (2016). What is Sustainable Public Debt. In J. Taylor, & H. Ulrich, *Handbook of Macroeconomics* (1 ed., Vol. 2, pp. 2493-2597). Elsevier. Retrieved from https://doi.org/10.1016/bs.hesmac.2016.03.013

Dixon, P. B., Parmenter, B. R., Sutton, J., & Vincent, D. P. (1982). *ORANI: A Multisectoral Model of the Australian Economy ORANI.* North-Holland.

Hornstein, A. (2000). The Business Cycle and Industry Comovement. *Federal Reserve Bank of Richmod Economic Quarterly, 86*(1).

Hornstein, A., & Praschnik, J. (1997). Intermediate Inputs and Sectoral Comovement in the Business Cycle. *Jornal of Monetary Economics, 40*, 573-595.

Horvath, M. (2000). Sectoral Shocks and Aggregate Fluctioations. *Journal of Monetary Economics, 45*, 69-106.

Hutchings, R., & Kouparitsas, M. (2012). *Modelling Aggregate Labour Demand.* Canberra: Treasury Working Paper.

Jaimovich, N., & Rebelo, S. (2008, December). News and Business Cycles in Open Economies. *Journal of Money, Credit and Banking, 40*(8), 1699-1711.

Keane, M. P. (2011). Labor supply and taxes: A survey. *Journal of Economic Literature 49(4)*, 961-1075.

King, R. G., Plosser, C. I., & Rebelo, T. S. (1987). Production, Growth and Business Cycles. *Journal of Monetary Economics*.

Kulish, M., & Rees, D. (2017). Unprecedented Changes in the Terms of Trade. (Elsevier, Ed.) *Journal of International Economics*, 351-367.

Lucas, R. (1976). Econometric Policy Evaluation. In K. Brunner, & A. Meltzer, *The Phillips Curve and Labor Markets* (pp. 19-46). New York: AMerical Elsevier.

Malakellis, M. (2000). *Integrated Macro-Micro-Modelling Under Rational Expectations With an Application to Tariff Reform in Australia.* Physica-Verlag Heidelberg.

Peterman, W. B. (2015). Reconciling Micro and Macro Estimates of the Frisch Labor Supply Elasticity. *Federal Reserve Board of Governors*.

Rees, D. M., Smith, P., & Hall, J. (2016). A Multi-sector Model of the Australian Economy. *Econonomic Record, 92*, 374-408.

Schmitt-Grohe, S., & Uribe, M. (2003). Closing Small Open Economy Models. *Journal of International Economics, 61*(1), 163-185.

Uzawa, H. (1969). Time preference and the Penrose effect in a two-class model of economic growth. *Journal of Political Economy, 77(4, Part 2)*, 628-652.

van der Mensbrugghe, D., & Peters, J. C. (2016). Volume preserving CES and CET formulations. *19th Annual Conference on Global Economic Analysis.* Purdue University.