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### At a glance

- A computable general equilibrium (CGE) model is an economic analysis tool with an economy-wide focus that estimates changes in key economic indicators at the national level, for individual industries and often also for regions, as a result of external changes or policy changes. Principal indicators estimated are impacts on GDP, private consumption, investment, exports, employment and industry outputs.

- CGE models were developed for the purpose of estimating impacts of policy changes with widespread impacts across the economy and high flow-on impacts such as changes to taxes and tariffs, taking into account interactions between all markets (hence the term ‘general equilibrium’). They are sometimes used to model flow-on impacts of transport initiatives or groups of transport initiatives with localised first-round impacts.

- In contrast, cost-benefit analysis (CBA) was developed to estimate changes in the community’s welfare as the result of initiatives that have their primary impact in a single, localised market. It measures welfare changes in the market directly affected, and where material, in closely related markets as well (for example, the effects of a public transport project on road traffic congestion). Hence, CBA is said to be ‘partial equilibrium’ analysis.

- The impact measures produced by CGE models and CBA are not interchangeable, nor additive. Economic welfare measured by CBA aims to gauge community wellbeing by considering all the factors that affect quality of life including non-work time, passenger comfort, public amenity, air and noise pollution and road safety. These do not enter into the national accounts that underlie CGE models. Furthermore, GDP does not recognise consumers’ surplus changes.

- A CGE assessment could only identify significant additional benefits or disbenefits in situations where large economic distortions existed in other sectors of the economy, for example, substantial tariffs, quotas, subsidies, exchange rate controls. That is not the case in Australia. Furthermore, modifications would be needed to the CGE model to output the required welfare change measures.

- Thus, the partial equilibrium analysis of CBA is able to capture virtually the entire welfare impact of an intervention or policy change including allowing for relevant distortions such as unpriced externalities (eg. congestion) and taxes, along with quality of life effects such as private travel time savings and better safety. The ATAP Guidelines therefore consider CBA to be the most appropriate tool for assessing transport initiatives. CGE models can, however, be used to supplement CBA by providing information (not additional benefits) about the economy-wide and regional effects of large initiatives in terms of impacts on GDP, private consumption, investment, exports, employment and industry output. They can also provide useful information about distributional impacts.

- Available CGE models vary in setup (comparative static or dynamic), spatial and industry aggregation, and in representation of the transport sector. Currently, dynamic regional CGE models such as the VURM (formerly MMRF) and TERM models are in common use. Urban CGE models are emerging for experimental use. Project evaluators should choose a model that is well suited for addressing the policy questions at hand.

- When a CGE model assessment is undertaken, the benefits from the CBA of a transport initiative have to be transferred to the CGE model as cost reductions to industries. Modifications may be needed to the CGE model before doing so. Modifications may include disaggregation of the transport sector into passengers and freight and explicit representation of private car use. Cost savings also need to be apportioned between in-house transport by industries and hire-and-reward transport.

- To avoid the CGE model being treated as a ‘black box’, the report from the modellers should describe the model used and the changes made to the model to represent the project or policy change (called shocks) in detail, and interpret the results with qualifications.
The ATAP Guidelines make no recommendation about circumstances where CGE modelling ought to be undertaken. CGE modelling is viewed as an optional extra. Proponents of transport initiatives should weigh up whether the additional information obtained is worth the cost of the modelling. Given the expense, CGE modelling would be considered only for very large transport initiatives.

Transport appraisers are not expected to build or operate CGE models by themselves. Outsourcing to specialist modellers is the usual practice.

Input-output (I-O) analysis might be considered a less expensive alternative to CGE models to supplement CBA. Results of I-O analysis have major limitations and are likely to be biased upward. I-O analysis should not be used in project appraisal except possibly for small projects considered in isolation (not groups of projects) in areas of high unemployment where economic stimulus is a policy objective.
1. Introduction

A computable general equilibrium (CGE) model\(^1\) is an economic analysis tool that has an economy-wide focus. This part of the ATAP guidelines addresses the use of CGE models alongside cost–benefit analysis (CBA) in appraisal of transport initiatives.

1.1 ATAP context

ATAP Part F3 provides guidance on Options Generation and Assessment. Appendix E therein reviews the various types of economic analysis relevant to the Guidelines.

ATAP Part T4 expands on the following statement from ATAP Part F3 Appendix E about use of CGE analysis in appraisal of transport initiatives.

“Where an initiative is so large that CGE assessment is considered worthwhile, the CGE assessment should complement the partial equilibrium-based CBA. Judgment by economic specialists is required to determine when a CGE assessment is required. Note that the CGE assessment does not identify and estimate additional benefits not already covered by the CBA and WEBs assessments. A CGE assessment would only identify additional benefits or disbenefits in situations where large economic distortions existed in other sectors of the economy (e.g. large tariffs, quotas, subsidies). That is not the case in Australia. As discussed above, distortions within the transport sector, such as lack of congestion pricing and subsidised public transport, are accounted for within a rigorous partial-equilibrium-based CBA.”

ATAP Part F3 recommends the following approach for the appraisal of transport initiatives:

- Undertake strategic and problem economic assessments as part of the strategic planning stage (see ATAP Part F0.1 for guidance)
- Undertake a CBA based on partial equilibrium analysis to estimate the net benefit/gain of the proposed initiative (see ATAP Part T2 for guidance)
- Include WEBs in the CBA only for the type of initiatives where WEBs are likely to be of relevance and of sufficient scale (see ATAP Part T3 for guidance, including instructions for how WEBs should be reported separately from conventional benefits).
- A CBA undertaken in this manner is considered the primary indicator of the net worth and value for money of an initiative.
- The CBA can be complemented by other economic analyses as and when deemed necessary:
  - Distributional impacts assessment to highlight which groups gains and lose from an initiative
  - Economy-wide assessment to highlight the impacts and stimuli across the economy by industry sectors, and labour and capital, including employment effects. Economy-wide assessment can consist of:
    - economic impact analysis using input–output (I-O) analysis
    - CGE models, a more sophisticated approach to economic impact modelling than I-O analysis.

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\(^1\) CGE models are also referred to as applied GE models.
1.2 Overview

Major transport initiatives can significantly alter the economies of the regions in which they are located, and if large enough, the national economy as well (Austroads 2005). When evaluating transport infrastructure projects:

- CGE models can be used as a supplement to CBA to analyse the economy-wide and regional effects of large initiatives in terms of impacts on GDP, private consumption, investment, exports, employment and industry output. These impacts cannot be added to benefits or costs in a CBA.

- It is possible to use CGE models to estimate benefits for use in the CBA, but this will only be useful where there are major distortions in markets impacted by the project and is a non-standard methodology requiring high-level economic and CGE modelling expertise to implement. Modifications would be needed to the CGE model to output the required welfare change measures. The Australian economy does not have distortions of size and type (for example, substantial tariffs, quotas, subsidies, exchange rate controls) that warrant CGE modelling to estimate benefits from transport initiatives.

CGE modelling is more sophisticated than I-O analysis because it does not assume resources are available in infinitely elastic supply but allows prices to alter so as to ration their use. A CGE model represents the economy as a system of simultaneous equations that model the supplies and demands for commodities and factors of production.

CGE modelling is expensive. Therefore, its use is limited to assessing large transport initiatives that are expected to have significant geographical and distributional impacts.

Available CGE models vary in setup, spatial and industry disaggregation and in the representation of transport. Project evaluators should choose a model that is well suited for addressing the policy questions at hand.

This paper provides an overview of CGE models, their attributes, limitations, and uses in transport planning and assessment. It is not intended to enable analysts to build or operate CGE models.

1.3 Structure of this guidance

Having established above the context for using CGE models as recommended by the ATAP Guidelines, the rest of this guidance aims to provide information to assist users of transport appraisal information and practitioners when the need arises to use a CGE model in the appraisal of a transport initiative.

Chapter 2 is a high-level summary aimed at users of transport appraisal information. It addresses the main questions of what CGE models do and their relationship to CBA.

Chapter 3 introduces CGE models including how they work, some key features, what outputs they produce and includes a list of Australian CGE models used on transport initiatives.

Chapter 4 discusses the relationship between CGE models and CBA — the difference between their main output measures, GDP and economic welfare; when and how they can be used together.

Chapter 5 covers a range of practical issues and necessary assumptions that arise when applying a CGE model to analyse a transport initiative for which a CBA has been undertaken. It also discusses I-O analysis as a cheaper alternative to CGE modelling.

Appendix A summarises a case study focussing on issues faced when setting up a CGE model simulation of a program of transport projects.
2. Summary and recommendations

This chapter is targeted at a wider, less specialist audience than the rest of the guidance. It contains a less technical summary of the guidance with recommendations.

2.1 Introduction to CGE models

A CGE model is an economic analysis tool with an economy-wide focus that estimates changes in key economic indicators at the national level, for individual industries and often regions, as a result of external changes or policy changes.

A CGE model is calibrated to produce economic forecasts for a given year or years, which corresponds to the base case of a CBA. To assess the impact of a project or policy, a change, referred to as a ‘shock’, is made to one or more user-determined (exogenous) variables in the model, which corresponds to the project case of a CBA. The model is run to find a new equilibrium taking into account the shock. Model outputs without and with the shock can then be compared.

A CGE model represents the economy as a system of simultaneous equations that model supplies and demands for commodities and for factors of production (labour and capital). Typically, CGE models assume pure competition, markets operating at full capacity and without friction, constant returns to scale, full market clearing of all goods and services, perfect mobility of resources and perfect divisibility. Demands and supplies are balanced by market-clearing prices. A CGE model contains a database consisting of an I-O table, elasticities and other parameters governing behavioural responses of economic agents. CGE models can be developed to different levels of sophistication in terms of spatial and industry disaggregation, dynamics and assumptions in relation to returns to scale and market competition.

CGE models can be comparative-static or dynamic. Comparative static models simulate the economy at a single point of time, without and with a shock (change). Most CGE models currently in use for transport assessment are dynamic models. They comprise of a series of annual snapshots of the economy. Simulations from dynamic CGE models feature annual deviations from baseline forecast variables over a number of years into the future.

CGE models forecast changes in a wide range of economic indicators at the macro-economic level and at the level of individual industries. If a regional CGE model is used, these results will be available at the regional level as well as at the national level. The most important summary results available from CGE models to show the economic impact of transport initiatives would be GDP and per capita consumption.

Urban CGE models are emerging for experimental use. They feature high levels of spatial disaggregation and detail on transport links and land-use for a major city.

2.2 Relationship with CBA

GDP changes estimated by CGE models do not measure changes in economic welfare.

The GDP changes estimated by a CGE model are not interchangeable with the economic welfare changes estimated by CBA. The common practice among users of CGE model outputs of using GDP changes to estimate welfare changes can lead to very inaccurate welfare estimates.

Welfare takes into account non-priced goods and ‘bads’ that do not enter into GDP. Private travel time savings are usually a major proportion of benefits from transport initiatives but, being a non-priced good, they do not count towards GDP. Other examples of non-priced ‘bads’ or externalities counted in CBAs but not GDP are air, noise and water pollution.
Computable general equilibrium models

Even in the absence of non-priced goods and ‘bads’, GDP and welfare changes may differ. Consider the case of a cost saving that is passed on, in part, to consumers through a reduction in the price of the good with the remainder of the benefit retained by producers. CBA would count the entire cost saving as a benefit. GDP will recognise only the part retained by producers. CGE models can be set up to calculate changes in welfare, but this is rarely done.

CGE models will only find significant additional benefits and disbenefits over a CBA in an economy with major distortions, which is not the case for Australia, and to do so, the CGE model would require modifications to output welfare changes.

CBA undertakes what is termed a ‘partial equilibrium analysis’. It treats the sector of the economy or market or infrastructure of immediate interest as operating in isolation from the rest of the economy, omitting the economy-wide effects. In contrast, ‘general equilibrium analysis’ considers all markets in the economy with interacting linkages.

A project or policy change is likely to lead to price and quantity changes in a number of related markets. However, when measuring welfare changes, the only markets that need to be considered in addition to the market directly affected by a project or policy change are those with distortions. ‘Distortions’ here refers to prices being different from marginal social costs. Sources of distortions include taxes, subsidies, quantitative restrictions, externalities, imperfect competition and non-constant returns to scale.

CBA would normally estimate benefits and costs due to distortions in closely related markets. For example, a public transport project would count decongestion benefits on roads where the project induces mode shift from road. A benefit arises because of the distortion created by lack of optimal congestion charging. ‘Wider economic benefits’ arise from distortions, but methodologies exist to estimate them without resort to a CGE model.

For the vast majority of transport assessments, partial equilibrium analysis is adequate because it is a good approximation of the results that would be obtained if an economy-wide assessment were undertaken. A CGE assessment would only identify significant additional benefits or disbenefits in situations where large economic distortions existed in other sectors of the economy, for example, substantial tariffs, quotas, subsidies, exchange rate controls. That is not the case in Australia.

CGE models can supplement CBA providing additional information on project impacts, noting that the impact estimates from CGE models are not interchangeable with nor additive to CBA results.

CBA and CGE modelling are different techniques, addressing different outcomes of interest. CGE models can supply decision makers with information on the economy-wide and regional effects of large initiatives in terms of impacts on GDP, private consumption, investment, exports, employment and industry output.

Some CGE models are set up to estimate greenhouse gas emissions.

CGE models can provide useful information about the distributional impacts of transport initiatives. Impacts on industries, regions and occupational groups distinguished by the model will be evident in model outputs for each group. This not to say that a distributional impact analysis cannot be taken without CGE modelling.

In some cutting-edge applications, urban CGE models are being used side-by-side with transport models to estimate benefits of major transport projects taking into account induced traffic caused by land-use changes and trip generation as forecast by the CGE model.

The ATAP Guidelines make no recommendation about the circumstances where CGE modelling ought to be undertaken. CGE modelling is viewed as an optional extra.

Given the cost and effort involved in CGE modelling, its use can only be justified for large projects.
2.3 Practical matters

Available CGE models vary in setup (comparative static or dynamic), spatial and industry disaggregation (i.e. the number of regions and industry sectors) and in the representation of the transport sector (i.e. division into modes and passengers/freight, treatment of private car use). It is important to choose a model with features that are well suited for addressing the policy questions at hand. The large transport projects best suited to CGE analysis take years to construct and for benefits to ramp up following completion making dynamic models more appropriate.

Dynamic models more appropriate for large transport projects with long construction and ramp-up periods.

With a dynamic model, it is necessary to make an assumption about how the transport project is funded. Options include taxes, a reduction in public spending elsewhere, and government borrowing. Typically, with funding from tax increases, a dynamic model would show negative economic impacts during the construction period, when the project is consuming resources with no offsetting benefits, followed by gains after the project becomes operational.

Care is needed in allocating the savings in money costs from a transport initiative estimated in the CBA among households and industries in regions in the CGE model.

Benefits estimated by CBAs are transferred to CGE models as changes in transport costs. CBAs deal with generalised costs (money and non-money [e.g. time] costs). CGE models (excluding urban CGE models) recognise only money costs paid by firms and households for use of transport services. Savings in money costs to transport users estimated by the CBA need to be allocated among households and industries in regions.

Typically, the transport sector in CGE models is disaggregated into road, rail, water, air and other. Three missing elements in standard CGE models that affect modelling of transport initiatives are:

- Disaggregation into passengers and freight. The distinction is important to ensure cost savings are allocated appropriately between households and the various industries.
- Explicit representation of private car use. Private car travel is represented in the ABS National Accounts by consumers’ purchases of vehicles, fuel and other inputs.
- Explicit representation of ancillary road freight transport. Hire & reward transport is explicit in the National Accounts. Ancillary (in-house or own-business) transport is treated as being part of the production costs of user industries. The proportion of cost savings accruing to ancillary freight and business cars should be allocated directly to user industries. The recently available Australian Transport Economic Account from ABS should improve the realism of the assumptions necessary for the allocation.

As CGE models are complex and training staff to operate the model time-consuming and costly, it is recommended that transport agencies outsource the task.

Input-output (I-O) analysis might be considered a less expensive alternative to CGE models to supplement CBA. I-O analysis aims to estimate the impact on economic activity of a policy or economic change, including the ripple effects throughout the economy. It considers only the impact of investment costs, ignoring the benefits of initiatives as measured by a CBA, and so does not provide an indication of the overall merit of a project. It can never replace CBA. Results of I-O analysis have major limitations and are likely to be biased upward.

I-O analysis should not be used in project appraisal except possibly for small projects considered in isolation (not groups of projects) in areas of high unemployment where economic stimulus is a policy objective.
3. **What are CGE models?**

3.1 **Underlying principles**

A CGE model represents the economy as a system of simultaneous equations that model supplies and demands for commodities and for factors of production (labour and capital). The models rely heavily on neoclassical economic theory — households are utility maximisers and firms profit maximisers. Typically, they assume pure competition, markets operating at full capacity and without friction, constant returns to scale, full market clearing of all goods and services, perfect mobility of resources and perfect divisibility. Demands and supplies are balanced by market-clearing prices but with some exceptions — for example, non-market clearing wages for labour associated with unemployment.

That these assumptions generally do not hold in the real world does not necessarily make GE analysis invalid. The aim is to provide insights into the interaction between the micro- and macro-economic processes. They indicate the re-allocation of resources after something is altered in the economy (Docwra and West, 1999). The assumptions could be changed if desired, but such a change is only worth the effort if it is expected to make a significant difference to the results of the particular question being investigated.

At the core of a CGE model is a set of equations describing the behaviour of various economic agents (for example, industries, consumers and governments) when faced with changes in key economic variables, for example, and most importantly, relative prices. Typically, consumers maximise their utility subject to a budget constraint, and industries maximise profits (or minimise costs) subject to their production functions (technologies). The behavioural equations are supplemented with market clearing equations that equate supply and demand in all commodity and factor (labour and capital) markets.

The equations link together the different agents in the economy. Producers employ factors of production (labour and capital) and purchase intermediate goods from other producers in exchange for payments (wages, returns, input costs), and pay taxes to the government. Households spend their income from wages and returns on capital on goods and services, as well as paying taxes to the government and saving. The government spends taxes collected on goods, services and savings. Investors use savings to buy investment goods (Shahraki and Bachmann 2018, p. 737). Foreigners purchase exports from producers and sell imports to households, producers and the government.

The equations can be classified into those describing

- household and other final demands for commodities
- demands for primary factors and intermediate inputs
- pricing equations setting pure profits from all activities to zero
- market clearing equations for primary factors and commodities, and
- definitional equations defining measures such as GDP, aggregate employment and the consumer price index. (Dixon et al. 1997).

Domestic and imported goods are treated as imperfect substitutes with ‘Armington elasticities’ measuring the degree of substitutability.

Elasticities in CGE models generally reflect long-run behaviour. Therefore, although used to forecast short-run outcomes particularly for employment, CGE models are better suited to long-run analysis.

Labour can be disaggregated into occupations, each with its own average wage rate. Each industry has own composition of employment by occupation. For example, the predominant occupations of workers in the retail sector are the sales occupations, while the predominant occupations of workers in the construction sector are the trade and technician occupations (Dixon 2017). The VURM model recognises eight occupational categories (Adams et al. 2015).
3.2 Input-output database

CGE models are calibrated from a numerical database, the core of which is a set of I-O tables. As illustrated in Figure 1, the I-O table has four quadrants that describe intermediate usage, final demand, primary inputs to production, and primary inputs to final demand. The primary inputs include wages and salaries, gross operating surplus and taxes. No industry operates in isolation. I-O table columns show flows of industry output to other industries as inputs to further production.

### Figure 1  Simplified input-output table

![Simplified Input-Output Table](image)

**Source:** ABS 1994

Since 2012-13, the Australian Bureau of Statistics (ABS) has published I-O tables of the Australian National Accounts annually. Australian I-O tables comprise approximately 114 industries/commodities based on the Australian and New Zealand Standard Industrial Classification (ANZSIC). In the ABS I-O tables, transport industries comprise road, rail, water and air. These sectors can be combined or further disaggregated depending on model applications.

In CGE models, hire & reward transport is grouped with ‘margins industries’ together with wholesale and retail trade.²

The official ‘road transport’ sector of the ABS National Accounts covers the hire & reward sector — buses, taxis and outsourced road freight transport. It does not include private car travel nor own-business use of cars, commercial vehicles and trucks. Private car travel is not explicitly accounted for in the ABS National Accounts. It is represented by consumers’ purchases of vehicles, fuel and other inputs to car use.

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² Margins are costs and charges that separate prices paid by purchasers from prices received by producers. They include taxes, retail mark-ups, and costs of transport and distribution.
I-O tables disaggregated to the local level have been used in urban CGE modelling. For example, Ernst & Young (2016) relied on REMPLAN Economy 2015 I-O tables to model the impact of the Western Sydney Airport project in local areas of Sydney.

### 3.3 Comparative static and dynamic models

A comparative static model simulates the economy at a single point of time. An analysis undertaken using a comparative static model would compare the economy without and with the shock. The model will estimate percentage changes in economic variables resulting from the shock. The adjustment path from one equilibrium to the other is not explicitly represented.

A dynamic model is comprised of a series of annual snapshots of the economy connected via forward linkages such as the capital stock and wage and price levels being carried over from the end of one year to the start of the next year. Lagged adjustment processes gradually switch the model from short-run to long-run assumptions. For example, wages adjust sluggishly to eliminate gaps between the supply and demand for labour (Dixon et al. 2017, p 2). A dynamic model can show the adjustment path of a shock expressed as a series of percentage changes from the reference case for each year into the future. They are much more demanding to construct and solve compared with comparative static models.

Most national and regional CGE models applied in transport appraisal are dynamic (for example, the various Centre of Policy Studies models such as Monash, MMRF and TERM listed in Table 1 below). The large transport projects best suited to CGE analysis take years to construct and for benefits to ramp up following completion making dynamic models more suitable than comparative static models.

Urban CGE models tend to be comparative static due to their high levels of disaggregation of geographical areas. Limitations on computing power mean that compromises have to be made between the level of detail in the numbers of industries/commodities and regions, and whether to make the model comparative static or dynamic.

### 3.4 Closure

In a system of simultaneous equations, to have a unique solution, the number of variables must equal the number of equations. For CGE models, the number of variables exceeds the number of equations. If there are $p$ variables and $m$ equations, the modeller has to set values for $p - m$ variables, called exogenous variables, and the model will determine the values for the other $m$ variables, called endogenous variables, that solves the system of equations. Effects of policy changes are assessed by changing or ‘shocking’ one or more of the exogenous variables and observing the changes to the endogenous variables after the model is solved again. Box 1 below describes how CGE models of the prevalent type are solved.

The selection of which variables to make exogenous and which to make endogenous is called the ‘closure’ of the model. Closure plays an important role by creating the economic environment in which the policy scenario is set. Users can change the mix of exogenous and endogenous variables to suit the policy change being modelled and questions asked.

In comparative static models, the short-run closure is to assume real wages and the stock of capital are fixed (exogenous) while employment and the return on capital are variable (endogenous). These settings are reversed for the long-run closure with real wages and the capital stock made variable, while employment and the return on capital are fixed. Employment is determined by long-run population projections, which are set exogenously. In a dynamic model, the transition from the short-run to the long-run assumptions occurs in a series of steps.
Box 1  How CGE models are solved

This box describes how Johansen-type models such as those developed by the Centre of Policy Studies are solved. It also explains why direct model outputs are expressed as percentage changes, and helps clarify the roles of exogenous and endogenous variables.

Many of the relationships in CGE models are highly non-linear. To enable them to be solved, the relationships are written as linear equations in percentage changes of the variables. To illustrate, instead of writing,\( Y = f(X_1, X_2) \) where \( Y \) is output and \( X_1 \) and \( X_2 \) are inputs, the relationship is specified in the linear percentage change form, \( y - \varepsilon_1 x_1 - \varepsilon_2 x_2 = 0 \), where \( \varepsilon_i \) is the elasticity of output with respect to inputs of factor \( i \), and \( y, x_1 \) and \( x_2 \) are the percentage changes in \( Y, X_1 \) and \( X_2 \) (Dixon et al. 1997).

If there are \( m \) relationships and \( p \) variables, the model can be represented in matrix form as

\[
Av = 0
\]

where \( A \) is an \( m \times p \) matrix of coefficients, \( v \) is a \( p \times 1 \) vector of percentage changes in model variables, and \( 0 \) is the \( p \times 1 \) null vector. The number of variables exceeds the number of equations. For a solution to exist, the values \( p - m \) variables have to be set exogenously. The exogenous variables can be changed to shock the model. Once the endogenous variables have been selected, the system can be rewritten as

\[
A_n n + A_x x = 0
\]

where \( n \) and \( x \) are vectors of the percentage changes in endogenous and exogenous variables respectively, and \( A_n \) and \( A_x \) are matrices formed by selecting the columns of \( A \) corresponding to \( n \) and \( x \). Provided \( A_n \) is invertible, the system can be solved to find the values of the percentage changes in the endogenous variables. (Verikios and Zhang 2012; Dixon et al. 1997)

\[
 n = -A_n^{-1}A_x x
\]

The equations in linear percentage form are valid only for small changes. The problem of accurately calculating \( n \) for large changes in \( x \) is addressed by breaking the change in \( x \) into \( i \) equal percentage changes. In a multi-step solution procedure, \( i - 1 \) intermediate values for the underlying levels values of \( n \) are calculated. At each step, the coefficients of the \( A \) matrices are recomputed and the system solved again. (Verikios and Zhang 2012)

3.5  Regional/urban detail

Bröcker and Mercenier (2011) identify three types of CGE models distinguished by the level of regional detail:

- Single-region (national) models
- Multi-region models and
- Urban models.

Robson et al. (2018) classify multi-region and urban models as ‘spatial CGE models’.

Early Australian CGE modes, such as the comparative-static ORANI model and the dynamic Monash model were national models, for which all variables were for the whole country. These have largely been replaced with multi-region models.
Multi-region models treat each region as a separate economy and allow goods, labour and capital to flow between regions. Inter-regional trade flows are predicted as functions of regional supply and demand by commodity type and production prices plus transport costs. The disaggregation of labour into occupations extends to industries within regions. They assume that regional varieties of goods and services are imperfect substitutes using Armington elasticities (Robson et al. 2018, p. 39; Adams et al. 2015, p 3-8.).

The Monash Multi-Regional Forecasting (MMRF) model, now called the Victoria University Regional Model (VURM), and its variants have the eight Australian states and territories as regions. The current version distinguishes between up to 144 commodities/industries depending on the application. The Enormous Regional Model (TERM) model is comparative-static with 144 sectors and 57 regions, nearly corresponding to Australian statistical divisions. The VURM and TERM models are extensively documented by the Centre of Policy Studies (CoPS) at Victoria University and have a proven record of applications in transport project appraisal (see Table 1 below). CoPS claims that “TERM has a particularly detailed treatment of transport costs and is naturally suited to simulating the effects of improving particular road or rail links” (https://www.copsmodels.com/term.htm).

Urban models are a recent development. Zonal disaggregation is high within the urban area of interest while the rest of the state, country and world outside the urban area can be treated as a single zone or a few zones. They focus on the transport–land-use nexus. Discrete choice structures based on random utility theory are incorporated to explain residence, work and shopping decisions as well as travel choices. They may adopt the ideas of New Economic Geography (Krugman 1991, Fujita, et al. 1999 and Tavasszy, et al. 2011) and introduce economies of scale and imperfect competition (Byett et al. 2015). As well as households maximising utility subject to a monetary constraint, households also face a time constraint whereby travel times are traded off against leisure and labour. Producers compete for land, with profit-maximising landlords controlling the supply of floor space and developers constructing and demolishing buildings according to demand and costs (Robson et al. 2018 p, 38). Examples of applications include Anas and Liu (2007) and Truong and Hensher et al. (2012).

Attempts have been made recently in Australia to build urban CGE models to evaluate the impact of large urban transport infrastructure projects. Hensher et al. (2012) applied a discrete choice framework to model Sydney’s North-West Rail Link project in an urban CGE framework. Ernst & Young (2016) used an urban CGE model to forecast the impact of the proposed Western Sydney Airport. See Robson et al. (2018) and Sharaki and Bachman (2018) for recent literature surveys.

3.6 Outputs and interpretation of results

CGE models forecast changes in a wide range of economic indicators. They include GDP, gross national income, gross value added, private consumption, investment, exports, imports, prices, terms of trade, wages, employment, and government tax revenue for the whole economy. Outputs are available for individual industries and labour occupations, and for regions if a regional CGE model is used. Model outputs are normally expressed as percentage changes from the reference case or baseline forecast, and can be converted to absolute measures by multiplying by the relevant reference case total.

For comparative static models, the report should feature tables or bar charts for the short-run and long-run closure showing percentage deviations from the base scenario for macro-economic aggregates and for industry and regional variables. For dynamic models, annual percentage deviations from baseline forecasts for these impact measures can be presented as charts with time on the horizontal axis.
Where dynamic models are used, for large infrastructure projects funded by tax increases, CGE models usually show negative impacts for GDP and per capita consumption during the construction period when resources are diverted to the construction sector with no offsetting economic benefits. After the project becomes operational, cost reductions to industries and greater capital intensity in the economy lead to gains in GDP, real wages and per capita consumption. The gains usually grow over time as utilisation of the new infrastructure increases and greater base case congestion is avoided in the project case leading to greater cost savings to industries.

In a CGE model, industries, regions and labour occupations compete with each other for resources. While some industries, regions and occupations will benefit from a transport initiative, there will also inevitably be losers. Say the region directly benefitting from a transport improvement gains $10 million per year in gross regional product. There could be 16 other regions that lose $0.5 million each on average, with a net gain to the economy of $2.0 million in GDP.

During the construction phase of a project, results for individual industries will show expansion of the non-housing construction industry and increased demand for construction materials, construction labour, and investment goods (construction equipment). If the construction is financed out of domestic savings, as would occur if income taxes were increases to pay for the project, there will be reduced consumption and crowding-out of other investment. Other sectors that compete with the non-housing construction industry for inputs, such as the residential construction industry will be adversely affected by higher input costs without any offsetting higher demand for their products. Industries that sell most of their output to consumers (e.g. accommodation, food services) will also feel some pressure. If the construction period is long enough for wages to change, workers in engineering and construction occupations will see higher than average wage increases, while occupations not used in construction activities (e.g. retailing) will see below-average wage growth. These effects will reverse once construction ceases. (AECOM et al. 2012)

Regional models will show positive impacts on the region or regions in which the initiative is located and negative impacts on other regions. Other regions experience reduced investment during the construction period and reduced output afterward when industries in regions benefitting from the project experience lower costs and hence become more competitive. Labour flows into the region or regions where the initiative is located out of other regions.

Note that the negative impacts forecast by CGE models on industries, regions and occupations are not necessarily reductions in absolute terms. They are deviations from the baseline forecast and could mean only slower rates of positive growth. Also, the comparison is between two states of the world — the baseline forecast without and with the transport initiative. In reality, there will be other transport initiatives, investments in other industries and economic and policy changes throughout the economy that could have offsetting impacts. For example, losses to region A as a result of a transport improvement in region B, could be offset by a transport improvement in region A not recognised in the CGE modelling for the project in region B considered by itself.

Because a CGE model highlights gains and losses to different groups in the economy, it can provide useful information about the distributional impacts of transport initiatives (see ATAP Guidelines Part T5: Distributional (equity) effects). Impacts on industries, regions and occupational groups distinguished by the model will be evident in model outputs for each group. Impacts on households with different income levels are not normally produced because the models usually assume there is a single household for each occupation in each region. However, it is possible to combine model outputs with other data to estimate distributional impacts by income group. Verikios and Zhang (2012 and 2013) derive income distributional effects across income deciles from transport reforms by linking income sources in the MMRF model (8 labour occupational groups, 12 non-labour income sources, 13 types of government benefit and income tax as a negative source) with Household Expenditure Survey data. It would, of course, be possible to modify an existing CGE model so that it distinguishes between groups of households in specified income bands, but it would add considerably to the size and complexity of the model.
3.7 Updating

CGE modellers update the I-O database at intervals of several years and reference case or baseline projections fairly frequently.

Besides relying on published sources, the I-O database, and variables representing industry technologies, household preferences, required rates of return on capital, and positions of export demand curves and import supply curves can be updated by running the model in ‘historical closure’. The variables to be adjusted are made endogenous and variables for which historical observations are available are made exogenous. Historical observations at a detailed commodity/industry level on movements in consumption, investment, government spending, exports, imports, employment, and capital stocks are introduced to the model as shocks. Afterwards, the estimated values of the endogenous variables consistent with the historical observations are made permanent within the model (Dixon et al. 2013, pp. 87-8).

The reference case or baseline projections are the business-as-usual model results from which percentage deviations in variables of interest will be observed when shocks are introduced. To update the reference case projections, modellers select economic forecasts from various sources. Projections might include macroeconomic variables, exports by commodity, and demographic variables for which forecasts are available from government agencies and private forecasters. These values will be made endogenous for the ‘forecasting closure’ with model data and parameter values made endogenous. Afterwards, the estimated values of the endogenous variables consistent with the forecasts are made permanent within the model. (Dixon et al. 2013, p. 88)

Often, parts of the model and database are improved, disaggregated, or updated to meet particular modelling needs.

3.8 Transport applications in Australia

Australia has a long history of using CGE models to assess the economy-wide impacts of large transport infrastructure projects and programs comprising multiple projects. Most of the models used originated from Australian universities with government agencies and consulting firms as the main users. CGE models have been employed in a complementary role to conventional CBAs, not as substitutes for CBA. The studies have covered a wide range of transport projects including road, rail and airports. CGE models have also been used to model impacts of large programs of projects across the transport network. The potential exists to apply them to significant non-infrastructure initiatives such as changes to fuel excise and road-user charging reform, as a supplement to CBAs of the initiatives. Table 1 lists prominent examples of Australian applications.
Table 1  Application of CGE models to transport infrastructure investments in Australia

<table>
<thead>
<tr>
<th>Year</th>
<th>Initiative</th>
<th>Model</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Very Fast Train</td>
<td>ORANI</td>
<td>Centre for Regional Economic Analysis (1990)</td>
</tr>
<tr>
<td>1993</td>
<td>Road investments</td>
<td>ORANI</td>
<td>Allen Consulting (1993)</td>
</tr>
</tbody>
</table>

**National CGE models (comparative static)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Initiative</th>
<th>Model</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Improvement in Melbourne port efficiency</td>
<td>MMRF-GREEN</td>
<td>CoPS (2002)</td>
</tr>
<tr>
<td>2010</td>
<td>Inland Rail</td>
<td>Tasman Global</td>
<td>Acil Tasman (2010)</td>
</tr>
<tr>
<td>2012</td>
<td>Toowoomba Second Range Crossing</td>
<td>MU-TERM</td>
<td>CoPS</td>
</tr>
<tr>
<td>2012</td>
<td>High speed rail</td>
<td>MMRF</td>
<td>AECOM (2012)</td>
</tr>
<tr>
<td>2015</td>
<td>Inland Rail</td>
<td>MMRF</td>
<td>PwC (2015)</td>
</tr>
<tr>
<td>2015</td>
<td>Economic Contribution of Australia’s Toll Roads (program)</td>
<td>MMRF</td>
<td>KPMG (2015)</td>
</tr>
</tbody>
</table>

**Multi-region CGE models (dynamic)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Initiative</th>
<th>Model</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>Western Sydney Airport</td>
<td>SCGE</td>
<td>Ernst &amp; Young (2016)</td>
</tr>
</tbody>
</table>

**Urban CGE models (linked to a transport model at an urban scale, comparative static)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Initiative</th>
<th>Model</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Economic Contribution of Australia’s Toll Roads (program)</td>
<td>MMRF</td>
<td>KPMG (2015)</td>
</tr>
</tbody>
</table>

**Note:** The list of applications is not exhaustive. These are shown as examples.
4. Relationship between CGE modelling and CBA

CGE models are valuable for estimating impacts of policy changes with widespread impacts across the economy and high flow-on impacts such as changes to taxes and tariffs. However, most transport initiatives have highly localised impacts. By directly measuring these impacts at their source (for example, the value of travel time savings), CBA is able to capture the majority of welfare impacts on the nation. So what value can CGE modelling of transport projects add? In this chapter, the relationship between CGE modelling and CBA is explored.

Several papers on CBA theory develop theoretical general equilibrium models to explore how CBA fits with the general equilibrium framework (Dinwiddy and Teal 1996, Dréze and Stern 1987, Kanemoto 2011). The first two sections of this chapter draw on some of their insights to explain the difference between the central outputs of the two approaches, GDP and welfare, and then partial versus general equilibrium analysis. The third section discusses the roles of CBA and CGE modelling when used together in project appraisal.

4.1 GDP and welfare

Transport appraisal, with CBA as its primary analytical tool, is concerned with changes in the community’s welfare, meaning people’s overall well-being. GDP measures everything produced in a given period valued at the prices people pay. Welfare is therefore a broader and better measure of the value of an initiative to society than GDP. Welfare takes into account non-priced goods and ‘bads’ that do not enter into GDP. Private travel time savings are usually a major proportion of benefits from transport initiatives but, being a non-priced good, they do not count towards GDP. Thus CGE models can account for business travel time savings as cost reductions to industries but savings in private time travel usually go unrecognised. Yet non-work travel time savings allow people to arrive at their destinations sooner. People therefore value the gain and so experience a welfare improvement from a travel time saving (DfT 2005). Examples of non-priced ‘bads’ or externalities counted in CBAs but not GDP are air, noise and water pollution. Crash costs valued using the human capital approach reflect GDP impacts, but this is not the case when crash costs are valued using the willingness-to-pay approach, which is the current practice in transport CBAs.

However, even after setting aside private non-priced impacts, the benefit measured by a CBA will not equal the GDP gain except under some very restrictive and unrealistic assumptions. It is demonstrated in Box 2 that one of these assumptions is that all benefits accrue to producers. Consider the case of a cost saving that is passed on, in part, to consumers through a reduction in the price of the good with the remainder of the benefit retained by producers. CBA would count the entire cost saving as a benefit. GDP, being the value of the economy’s output, will recognise only the part retained by producers.

The common practice among users of CGE model outputs of making variables such as unadjusted GDP or consumption proxies for welfare can lead to very inaccurate welfare estimates (Forsyth 2014). All the necessary inputs to calculating changes in consumers’ and producers’ surpluses and impacts on government budgets, with the exception of non-priced goods, are estimated within CGE models, but most models lack a welfare measure (Forsyth 2014).

3 Exceptions for non-work time are urban CGE models and the modified US model in Dixon et al. (2017).
Urban CGE models have been set up to allow welfare measures in the form of equivalent variations and total consumers’ surplus changes to be extracted (Robson et al. 2018, pp 45 and 48). However, these measures may have to be supplemented to represent the full welfare change to the economy. They exclude gains and losses to producers and governments that are not passed on to or taken away from households during the analysis period.

Another source of difference between the welfare change estimated by a conventional CBA and a CGE model is that the latter would incorporate effects of the way the investment is assumed to be financed. For example, if income taxes were raised to finance the investment, the CGE model would allow for the resultant deadweight losses in its welfare measure. CBA, as practiced in Australia and most other countries, typically does not adjust for the marginal cost of public funds (Mackie et al. 2014). Whether the marginal cost of public funds should be recognised in a CBA continues to be debated (see for example Dobes et al. 2016, pp. 205-6).

Box 2  Relationship between GDP and benefits

The relationship between GDP and benefits in the absence of non-priced impacts is explained here using a simple model from Dinwiddy and Teal (1996).

Assuming a two-sector closed economy without any market distortions and investment, let GDP, \( Y \), be the sum of all goods produced, \( q_i \) times the prices consumers pay for them, \( p_i \). With markets clearing, as assumed in CGE models, the quantity of goods of each type produced equals the quantity consumed.

\[
Y = \sum p_i q_i
\]

Taking the total differential

\[
dY = \sum p_i dq_i + \sum q_i dp_i
\]

Rearranging

\[
\sum p_i dq_i = dY - \sum q_i dp_i
\]

Both sides of the above expression equal the change in welfare, \( dW \), from a small change to the economy (ignoring the government sector and externalities).

\[
dW = \sum p_i dq_i
\]

is the welfare change measured using the social welfare approach in NGTSM (2006), Volume 5, the sum of changes in willingness-to-pay minus the changes in social costs. For a unit increase in output of good 1, the willingness-to-pay gain is \( p_1 \). The resources needed to produce the extra unit of good 1 are drawn away from the production of other goods. The value of the forgone output or social cost is \( \sum p_i dq_i \), which will be negative.

---

* Dixon et al. (2017) report a ‘welfare effect’ measure based on real household consumption for the whole economy. It is calculated as the weighted average percentage change in real household consumption over all commodities between the baseline and policy cases, with the weights being baseline shares of each commodity in household expenditure. They further added adjustments for changes in fatal crashes, non-work time saved, and disutility of additional time worked. They report it only as an index without converting it to a dollar amount of welfare change. Using the notation in box 2, their welfare measure based on real household consumption is \( d\bar{W}_h = \sum \frac{dq_i}{q_i} \left( \frac{\Delta c_i}{\Delta c_{q_i}} \right) \right) \frac{1}{\bar{c}_i} \sum p_i dq_i \), where the bracketed term is the share weight for commodity \( i \). Taking the result from box 2, \( dW = \sum p_i dq_i \), the change in welfare in dollars is \( d\bar{W} = d\bar{W}_h \sum p_i q_i \), which is Dixon et al’s welfare measure times GDP.
\[ dW = dY - \sum q_i dp_i \] is the welfare change measured using the gainers and losers approach in NGTSM (2006), Volume 5, the sum of changes in consumers’ and producers’ surpluses, (ignoring the government sector and externalities). \( dY \), the GDP change, is the change in producers’ surpluses. \( \sum q_i dp_i \) is the sum of changes in consumers’ surpluses (negative for a price increase). For a small change in price, the triangular area usually associated with a consumers’ surplus change, \( dp_i dq_i / 2 \) is practically zero and so is ignored. The change in GDP, \( dY \), therefore understates the change in welfare by the amount of the consumers’ surplus gains, \( - \sum q_i dp_i \).

For the welfare change to equal the GDP change, \( dW = dY \), in the simple model presented here, it would be necessary to have \( - \sum q_i dp_i = 0 \), that is prices stay the same so there would be no consumers' surplus gains and the entire benefit from a transport cost saving accrues to producers.\(^5\)

### 4.2 Partial versus general equilibrium analysis

Most transport CBAs and wider economic benefits (WEB) assessments are undertaken (appropriately) as partial equilibrium analyses. A partial equilibrium analysis is an economic analysis that treats the sector of the economy or market or infrastructure of immediate interest as operating in isolation from the rest of the economy, omitting the economy-wide effects. It is therefore a ‘partial’ or ‘limited’ or ‘bound’ analysis of the problem.

In contrast, general equilibrium analysis considers all markets, sectors and regions in the economy with interacting linkages. A project or policy change is likely to lead to price and quantity changes in a number of related markets. However, it is a well-established theoretical result that, when measuring welfare changes, the only markets that need to be considered in addition to the market directly affected by a project or policy change are those with distortions (Dinwiddy and Teal 1996; Kanemoto 2011). ‘Distortions’ here refers to prices being different from marginal social costs. Sources of distortions include taxes, subsidies, quantitative restrictions, externalities, imperfect competition and non-constant returns to scale. ATAP Guidelines Part T2, Chapter 7 on ‘Cross-modal and network effects’ makes the point that, for related infrastructure (substitutes or complements for which the transport initiative being appraised causes demand curve shifts), where the perceived cost incurred by transport users equals the marginal social generalised cost, there are no further benefits or costs to consider.

\(^5\) In an open economy, a further condition for the changes in GDP and welfare to be the same is an absence of terms of trade effects (Forsyth 2014). Exports earn foreign exchange that which can be used to purchase imports. Foreign exchange can be thought of as a separate commodity in its own right. As long as the terms of trade remain fixed, there is a constant conversion factor between the value of exports on the GDP side and the value of imports on the welfare side. This nexus is broken when the terms of trade changes between the base and project cases.
Where there are distortions in related markets, there will be additional benefits and costs to include in a CBA but there are established techniques to do so within the partial equilibrium framework. ATAP Guidelines Part T2, Chapter 7 provides a methodology for estimating benefits and disbenefits from shifts in demand curves for substitute and complementary transport infrastructure (alternative modes and routes) where perceived costs differ from social costs. Techniques exist for estimating wider economic benefits and disbenefits from transport initiatives arising from unpriced external economies of agglomeration, taxes on labour and imperfect competition in markets for which transport is an input. NGTSM (2006), Volume 5 and CBA textbooks discuss use of shadow wage rates for cases where a project employs workers who would otherwise be unemployed.

For markets not covered by these methods, the additional benefits and disbenefits from a transport initiative are likely to be small because the shifts in demand or cost curves will be small and/or the distortions will be small. There is, therefore, unlikely to be much to be gained from employing a CGE model to capture impacts of a transport initiative in markets with distortions across the whole economy. For the vast majority of transport assessments, partial equilibrium analysis is adequate because it is a good approximation of the results that would be obtained if an economy-wide assessment were undertaken.

A CGE assessment would only identify significant additional benefits or disbenefits in situations where large economic distortions existed in other sectors of the economy, for example, substantial tariffs, quotas, subsidies, exchange rate controls. That is not the case in Australia. But even for countries where exchange rates are highly distorted, techniques exist to make the necessary adjustments within a partial equilibrium analysis — either by multiplying border prices of traded goods by a shadow exchange rate factor, or alternatively, making the distorted exchange rate the numeraire and adjusting prices of non-traded goods by ‘conversion factors’ (Squire and van der Tak 1975, Perkins 1994, Dinwiddy and Teal 1996).

Forsyth (2014) expresses a dissenting view that it is possible that CBA misses out on important indirect benefits and disbenefits of which the analyst would not be aware. This can only be resolved empirically and requires care to ensure the welfare gain is correctly measured in the CGE model.

4.3 Use of CGE models in project appraisal

Given the cost and effort involved in CGE modelling, its use can only be justified for large projects or groups of projects.

Forsyth (2014) identified three levels at which CBA and CGE modelling can be used together:

- CBA and CGE modelling viewed as different techniques, addressing different impacts of interest (welfare for CBA, GDP for CGE)
- CBA and CGE modelling viewed as complementary project evaluation tools — use of both will result in more information being made available to decision maker
- CBA and CGE modelling integrated to produce a single general equilibrium evaluation tool.

Forsyth observes that the first level is the way most CGE studies are used in project appraisal. Governments are interested in effects of major transport initiatives on economic activity indicators at national and regional levels. The ATAP Guidelines recommend CGE models be used in this way, supplementing CBA.

At the second level, there are a number of ways in which CGE models can complement CBA. As noted above, they can provide information about the distributional impacts of projects.
Computable general equilibrium models

CGE models such as VURM, formerly MMRF, estimate greenhouse gas emissions. Given a unit cost of emissions, the value of savings or increases in greenhouse gases can be included with project benefits in the CBA. Emissions intensity varies significantly between industries, therefore, any change in economic structure induced by transport infrastructure investment may change emissions beyond the transport emissions estimated from the change in fuel consumed according to the CBA. If the change in greenhouse gas emissions from a transport initiative predicted by the CGE model is found to differ significantly from that estimated from the changes in fuel consumption estimated in the CBA, the analyst should provide an explanation in their report.

Possible use of CGE models to estimate wider economic benefits is discussed in section 5.4 below.

At the third level, if CGE modelling was used to estimate project benefits, it is essential that the welfare gain be properly calculated.

Robson et al. (2018) and Sharaki and Bachmann (2018) discuss use of urban CGE and transport models side-by-side to estimate project benefits taking into account induced travel demand.\(^6\) Given changes in trip times and costs predicted by a transport model in response to a change to the network, an urban CGE model can forecast changes in demand caused by land-use changes and trip generation. The revised trip matrix from the urban CGE model can then be fed back into the transport model to estimate a new set of trip times and costs that allow for the congestion impacts arising from the changed demands. An iterative process — transferring transport time and cost changes from the transport model to the CGE model, followed by transferring demand changes from the CGE model to the transport model — is continued until the two models converge to an equilibrium solution. An urban CGE model with a sufficiently detailed transport sub-model could perform the entire task internally. Thus an urban CGE model can be harnessed to produce the land-use change and demand forecasts needed to move beyond the fixed trip matrix assumption of transport models and adjust for feedback effects on demand from induced congestion.\(^7\)

Use of urban CGE models in transport appraisal in this way is a cutting-edge approach. If adopted, it is recommended that the forecast changes in land-use and trip demands be checked for realism and that the welfare change estimated by the CGE model be compared with benefits estimated from a conventional CBA based on changes in perceived costs and trip numbers from the transport model as discussed in ATAP Part M2, Section 7.4. Consideration should be given to timing and ramp-up assumptions for project benefits because urban CGE models are typically comparative static. The land-use and demand forecasts will take a number of years to materialise. Section 5.3.5 below contains some warnings about divisibility and mobility assumptions in spatial CGE modes that can give rise to unrealistic results.

More generally, whenever a CGE model is used to estimate welfare changes from a transport initiative, it is recommended that that a conventional CBA be carried out and the results compared. Where there are significant differences in results from the two approaches, it is incumbent upon the analyst to provide an explanation. Sensitivity tests can be undertaken by rerunning the CGE model without particular distortions, for example, removing imperfect competition and some taxes, and changing the way the project is financed or the resource mobility assumptions.
5. **Practical matters**

5.1 **Model selection and modification**

Available CGE models vary in setup (comparative static or dynamic), spatial and industry disaggregation (i.e. the number of regions and industry sectors) and in the representation of the transport sector (i.e. division into modes and passengers/freight, treatment of private car use). It is important to choose a model with features that are well suited for addressing the policy questions at hand. The model may have to be modified for the task. However, it is possible that a suitably modified version of the model already exists, having been previously modified for another task.

5.1.1 **Transport sector**

Typically, the transport sector is disaggregated into road, rail, water, air and other, but further disaggregation will most likely be required for a transport application. Three missing elements in standard CGE models to address transport tasks are:

- disaggregation into passengers and freight
- explicit representation of private car use. As noted previously, private car travel is represented in the ABS National Accounts by consumers’ purchases of vehicles, fuel and other inputs, and
- explicit representation of ancillary road freight transport.

Modelling work by BTRE (2003) illustrates modifications to a CGE model to address the first two elements. To estimate the economic impacts of increased spending on transport infrastructure by the Australian Government and, as a separate exercise, to project greenhouse gas emissions from transport, BTRE acquired a copy of the MMRF-GREEN model from CoPS and made enhancements to it.

BTRE and COPs split the four transport modes (road, rail, sea, and air) into passengers and freight. If this is not done, cost savings from transport projects accruing to passengers and freight will be averaged together in calculating cost reductions to each of the four transport industries.

In household budgets, fuel, car repairs and vehicle purchases are treated as separate commodities, not jointly consumed. An increase in the price of one results in less of the others being consumed. Cost savings to private cars would have to be introduced into the model by changing parameters in households’ utility functions so that the same level of utility could be obtained with less consumption of each car-related input. This corresponds to the way cost savings to industries are introduced by altering production functions. However, CGE models include technological change parameters in production functions to facilitate this.

As part of the BTRE (2003) exercise, an artificial industry was introduced to represent private passenger transport. A new industry was created, called private transport services, whose only role was to provide private transport services to households. This industry used privately owned motor vehicles as its capital goods, and fuel and other inputs as its intermediate inputs. In effect, consumers’ purchases of the inputs to private car use in the unmodified CGE model were bundled together to create an artificial industry, from which consumers purchased private car transport.
Dixon et al. (2017) describes a more detailed set of modifications to the transport sector in a CGE model of the US economy to estimate the impacts of increased spending on US highways. They separated out a household car repair industry from purchases of miscellaneous services by households. Then they formed a private road transport industry that had intermediate inputs of household car repair, motor fuel and motor vehicles. The output of the private car transport industry was sold to two further new industries, commuter transport and vacation transport. The commuter and vacation transport industries also purchased inputs of buses, taxis, rail services, and internal air and water transport, formerly purchased directly by households. Substitution between different modes could be introduced among the inputs to the two artificial industries without alternating or complicating the model’s mathematical structure.

Dixon et al. (2017) implemented an innovative way to account for private travel time savings, a major benefit from transport initiatives. Assuming values of time and average travel times, the commuter and vacation transport industries were made to pay ‘phantom taxes’ for each of private road transport, public transport and internal air and water transport. These phantom taxes were not actually collected, serving only to increase the prices paid by households for transport. Benefits from travel time savings were absorbed by a combination of extra labour and extra leisure.

While hire & reward transport is explicit in the National Accounts, variously termed in-house, own-business or ancillary transport is treated as being part of the production costs of user industries. Ancillary transport activity is not measured directly in the I-O tables, but buried in the overall cost of each industry aggregate. Hence, the road transport figures in the national accounts give a distorted and understated measure of the magnitude of the road transport sector in the national economy.

If ancillary transport is ignored, a cost saving to freight transport in a CGE model would be assumed to accrue solely to hire & reward transport distorting the distribution of benefits between industries.

In 2018, the Australian Bureau of Statistics published the Australian Transport Economic Account (ATEA) ABS Cat 5270.0, which is an experimental Transport Satellite Account that provides a more comprehensive picture of transport activity throughout the Australian Economy. The ATEA has been compiled on a basis consistent with the national accounts, but with adjustments to reclassify and identify transport activity across all industries, where transport is defined as the movement of people or goods from one location to another. Total transport activity, as defined in the ATEA, includes activity conducted on a For-hire basis undertaken by businesses classified as being in the Transport, postal and warehousing industry in the National Accounts, and, in addition, a new, explicit measure of In-house transport activity undertaken outside the Transport, postal and warehousing industry.

In 2015-16, the national accounts showed that the Transport, postal and warehousing industry, which represents For-hire transport activity, contributed 4.6% ($77.0 billion) of total GDP. The ATEA showed that In-house transport activity, which is undefined in the national accounts, contributed a further 2.7% ($45.3 billion) to GDP in 2015-16, with overall transport activity contributing $122.3 billion (7.4%) of GDP.

It is unlikely that a CGE model would be modified to move ancillary transport from user industries to the transport sector because it would create a mismatch between industry statistics in the model and in the national accounts. Instead, the ATEA data would be used to allocate the cost savings from a transport initiative between hire & reward and ancillary transport in the first instance, then to apportion the cost savings accruing to ancillary transport among user industries.
5.1.2 Regional and industrial disaggregation

ABS only produce I-O tables at the national level. To model regional effects or the detailed local impact of transport projects, it is necessary to disaggregate ABS national I-O data to the State/Territory level or further into regions and for urban areas, into zones. This task is often undertaken by CGE modellers or other data analysts who synthesise data entries by combining limited evidence with reasoned conjecture (BTE 1999). There is a risk that the quality of I-O tables decreases disproportionately as they are disaggregated geographically.

To do regional disaggregation properly, the analyst needs to understand the quality of the data for the regions and industries of interest and how CGE models work. Estimates in a disaggregated I-O table will necessarily be rough but it is possible to be confident the model will make quality forecasts of variables of interest. This work can be expensive and whether it is worth doing depends on the value agencies see in understanding regional impacts.

5.2 From CBA outputs to CGE model inputs

5.2.1 Differences between the approaches

Benefits estimated by CBAs are transferred to CGE models as changes in transport costs. However, this is not straightforward because definitions of transport costs differ between CBAs and CGE models. In CBAs, transport costs are defined as generalised costs comprising money costs and travel time costs. In CGE models, transport costs refer exclusively to money costs paid by firms and households for use of transport services (except for Dixon et al. ‘s modified model described just above and urban CGE models).

Passenger and freight transport are linked to industries and households in CGE models through different mechanisms. Freight transport services used by goods-producing industries in CGE models are treated as either direct inputs (in-house provision) or margins (out-sourced) on inputs. The same applies to freight transport costs incurred in wholesaling and retailing.

Price- and service quality-induced substitution between road and rail freight, and between car and public transport can be an important in appraising infrastructure initiatives that influence modal shares. In the MMRF-GREEN model with enhanced transport and energy sectors developed by COPS and BTRE, substitution between road and rail was modelled on the basis of a constant elasticity of substitution (CES) production function. Care should be taken in inferring price and cross-elasticity estimates from logit models that include both price and non-price variables. Also, the elasticities implied by logit models apply to an origin–destination pair while the elasticities in a CGE model would apply to the particular level of disaggregation. For example, the entire road freight industry comprises mostly origin–destination pairs for which rail does not offer a competing service.

5.2.2 Simulation design

Simulation design concerns specifying shocks to represent the direct impacts of an initiative or policy change in the CGE model. Detailed documentation and presentation of this process in reports is important for people to understand simulation results.

For dynamic CGE models, there will be one shock or set of shocks from increased infrastructure investment and another set for industry efficiencies arising from the investment. For comparative static models, modelling the construction phase using a short-term closure is optional, but not so for a dynamic model.
Computable general equilibrium models

The impact of increased public infrastructure investment can be simulated by shocking government consumption of construction services. In order to maintain fiscal neutrality, an assumption has to be made about how the investment will be financed. Options include: an increase in tax, for example income tax, fuel excise, or a lump sum tax; a reduction in public spending elsewhere; or government borrowing. Different assumptions about the funding source will have different impacts on the economy over time. Financing with taxes diverts resources away from consumption, reducing consumption during the construction period. The foreign borrowing option tends to have net expansionary effects on the economy during the construction period but does not come free. Higher net foreign liabilities lead to higher interest and dividend payments to foreigners, which reduces income available to households (Dixon et al. 2017, p. 13).

Benefits from an infrastructure investment accrue as a series of annual reductions in transport user costs simulated as an improvement in either industry-specific or commodity/factor- and industry-specific technical change. There are challenges in allocating aggregate savings in transport user costs estimated from CBA models to various industries in different locations over time. Appendix A illustrates how these shocks can be specified and the assumptions needed using BTRE’s (2003) work on the AusLink program as an example.

5.3 Some key assumptions in CGE model simulations

5.3.1 Labour and capital markets

As noted in section 3.4 on model closure, in dynamic CGE modelling, it is normally assumed that real wages are sticky in the short run and flexible in the long run. Accordingly, employment is flexible in the short run and trends towards the base case forecast in the long run. This implies that the long-run effect on the labour market of the policy shock will be seen mainly as percentage changes in real wage rates rather than employment changes. However, labour can move between sectors and regions.

For the capital market, the rate of return on capital is normally assumed to be flexible in the short run and fixed in the long run. Accordingly, the capital stock is inflexible to adjust in the short run and flexible in the long run.

5.3.2 Private and public consumption

In a policy simulation, the average propensity to consume is normally fixed, implying that percentage movements in real private consumption mirror percentage movements in household disposable income.

Public expenditure at the state and national levels can be held fixed or variable, depending on the source of funding. Fiscal neutrality is normally maintained to avoid any effects from the policy shock on aggregate demand.

5.3.3 Production technologies

In the policy simulation, it is normally assumed that the rates of technical progress in production and capital creation in each industry are the same as in the base case forecast simulation, except for any technical change variables directly or indirectly related to the transport sector that are shocked in the policy simulation to represent reductions in transport costs caused by the transport initiative being assessed.
5.3.4 Flexible balance of trade

The closure of the model assumes the balance of trade (exports minus imports) to be flexible, that is, it acts as an endogenous ‘swing’ variable to satisfy the GDP identity. If GDP increases/decreases relative to domestic absorption as a result of the policy shock, the trade balance must move towards surplus/deficit.

5.3.5 Divisibility and mobility

In CGE models, resources are perfectly divisible and are homogeneous within their category. In reality, a substantial shift in resources between industries and regions could occur when an existing plant closes or a new plant is built. Such a sudden, lumpy change would only occur when certain threshold economic conditions were passed, not gradually as a smooth function of changes in economic parameters as in an economic model. This can be important when considering impacts on small areas.

Bröcker et al. (2010) note that assuming perfect mobility of factors made their models too sensitive to changes in transport costs generating unrealistic results.

Tavasszy et al. (2011, p. 16) list three sources of unrealistic land use changes that can occur in spatial CGE models due to the assumption of perfectly mobile resources.

- Hysteresis: Past decisions affect the future. Setting up a new plant in another location instead of extending an existing plant may for some sectors be very costly. Investments in the past should in this case be seen as ‘sunk costs’ in the production process and should be treated in that way if compared to new investments.

- Locational boundedness due to locational inputs: in other words, production factors may be only locally available. An example is the availability of natural resources. In this case one can think about natural gas, but also about the factor land in the agricultural sector.

- Locational boundedness due to locational outputs: these are mainly government-regulated products. For instance, services supplied by municipalities cannot be substituted. That is, one has to consume municipality services from one’s own municipality. This is exogenous local production.

5.4 Relationship with wider economic benefits (WEBs)

WEBs are improvements in economic welfare arising from distortions (prices of goods and services differing from costs to society as a whole) in non-transport markets that are not captured in traditional cost–benefit analysis (CBA). WEBs can add significantly to the benefits estimated for major urban transport infrastructure projects in some circumstances. ATAP Part T3 contains guidance on how to estimate the three types of WEBs expected to arise from urban transport projects: agglomeration benefits; tax revenues from labour markets; and output changes in imperfectly competitive markets.

As sections 2.2 and 4.2 note, established partial equilibrium methodologies exist to estimate WEBs, without resort to a CGE model.
5.4.1 Using CGE models to estimate WEBs

Urban CGE models can be designed to estimate WEBs from agglomeration (given assumptions about values of agglomeration elasticities) by making firm productivity vary with effective density (access to other firms and labour). With appropriate assumptions about the labour market (mobility, labour supply elasticities and tax rates), the model could also estimate WEBs arising from tax impacts of changes in labour markets. Since an urban CGE model would forecast land-use changes, it could estimate dynamic as well as static WEBs. However, apart from making the job location and land-use change forecasts, the model would only be replicating the standard methodology for estimating WEBs and will do so less satisfactorily if the levels of spatial and industrial disaggregation are below those achievable with available data. The CGE model could estimate some indirect effects where the sources of WEBs impact on other markets where there are distortions.

Forecast land-use changes and changes to job locations from an urban CGE model could be used as inputs to estimate of dynamic agglomeration WEBs outside the model.

A regional or national CGE model would not have sufficient spatial disaggregation to estimate agglomeration and labour market WEBs.

WEBs from imperfect competition could be estimated within a regional or urban CGE model if the model features price-cost mark-ups above competitive levels to represent imperfectly competitive markets. The welfare changes to count as WEBs would be changes to firms’ profits, not the value of additional output.

Where a CBA includes WEBs estimated from a CGE model, WEBs estimates using the conventional methodology should be presented in the report with any major differences explained. The values of the different types of WEBs — changes in firms’ costs due to agglomeration, income taxes paid by employees, and profits due to imperfect competition — should be separated out.

5.4.2 Feeding WEBs into CGE models

The conventional methodology to estimate agglomeration WEBs estimates productivity improvements for firms by location and industry and so lends itself to being passed on to CGE models along with other project benefits accruing to industry. Even so, this is not recommended because WEBs estimates are highly approximate. Nothing is known about the ramp-up period for agglomeration WEBs, an essential assumption for dynamic CGE models.

The same recommendation is made more strongly for labour market and imperfect competition WEBs partly on the grounds that they too are highly approximate. But more importantly, they arise from structural characteristics of the economy. Income tax is present in all CGE models and imperfect competition can be incorporated. Hence, labour market and imperfect competition WEBs must be addressed as market distortions within the model. Feeding the values of labour market and imperfect competition WEBs estimated outside a CGE model using the established approaches into a CGE model as cost savings to firms would be an invalid methodology.

5.5 In-house modelling versus outsourcing

The cost of CGE model applications varies, depending on the specifics of the project. Nowadays, it is rarely the case that people have to start from scratch. The usual practice is to obtain an off-the-shelf model and make the necessary modifications to the model for it to be suitable for analysing impacts of transport projects. Experienced modellers can usually implement such changes quickly. Given a suitable model, the cost of a CGE analysis depends on model refinements, the complexity of the project (i.e. spatial scale) and the number of scenarios to be modelled.
In Australia, CGE models are available from university research centres, government agencies and major consulting firms. For use within an organisation, the basic CoPS model (see Table 1 above), for example, can be purchased off the shelf at a reasonable cost. However, training staff to operate the model could be time-consuming and costly. Depending on the level of detail, data collection and analysis could also be time-consuming and costly. If there is an infrequent need to use CGE models, it will be difficult to justify the costs of establishing and maintaining an in-house CGE assessment capability.

If a transport project requires CGE modelling, it is recommended that the practitioner enlist one of the specialist organisations that can undertake the CGE analysis. Examples of economy-wide models that have been used in transport can be found in Table 1.

Transport agencies may want to develop an ongoing relationship with a CGE provider and work to improve the transport-related data underpinning that provider’s model. Some central government agencies such as the Australian Treasury, the Productivity Commission and the Queensland Treasury use CGE models extensively and may be a source of advice.

### 5.6 Documentation and transparency

Full and transparent documentation of a CGE model is essential for understanding the model structure, assumptions made, scenarios considered and the simulation results.

CGE models from commercial institutions tend to be less transparent than those from universities and usually are not publicly available. There is a risk of running these models as black boxes, increasing chances for errors and reducing the usefulness of the model.

For large transport infrastructure projects, a detailed CGE modelling report should be made available alongside the traditional CBA report. The report should describe the model used and the shocks, and interpret the results with qualifications.

Section 3.6 above, drawing on (AECOM et al. 2012), gave a flavour of how CGE model results for a transport project could be interpreted in broad qualitative terms. Dixon et al. (2017) contains examples of charts plotting the year-by-year percentage deviation from the reference case forecast by a dynamic CGE model for a variety of macro-economic variables. They also show how modellers can explain macro-economic results using ‘back-of-the-envelope’ equations — simple equations that represent major structural relationships within the model. As well as serving as a check that the model results are sensible, interpretation of results draws outs information about potential project impacts.

### 5.7 Input–output analysis — an alternative to CGE models

This section considers I-O analysis as a less expensive alternative to CGE models that can be used to supplement CBA.

I-O analysis aims to estimate the impact on economic activity of a policy or economic change, including the ripple effects throughout the economy. It considers only the impact of investment costs, ignoring the benefits of initiatives as measured by a CBA, and so does not provide an indication of the overall merit of a project. It can never replace CBA. I-O analysis comes with major limitations and the results are likely to be biased upward. It is recommended that use of I-O analysis as a supplement to CBA be limited to small projects considered in isolation (not groups of projects) in areas of high unemployment where economic stimulus is a policy objective.

An infrastructure investment has:

- A direct effect in using capital, labour and materials inputs
Computable general equilibrium models

- An indirect effect requiring outputs from supplier industries, such as concrete, steel, bitumen, construction equipment, and
- An induced effect from workers spending the wages earned from working on the project and employed in supplier industries.

Given the construction cost of new investment, the direct and indirect effects can be computed from the matrix of technical coefficients in I-O tables. On the assumption that a fixed proportion of income received by employees is spent on household purchases, the analysis can be extended to calculate induced effects as well.

Indicators produced include changes in measures of economic activity (output, household incomes, and employment) for the whole economy and by industry. Using regional I-O tables, these indicators can be produced at the regional level. Often the results of I-O analysis are presented as ‘multipliers’. The output multiplier for the Heavy and Civil Engineering Construction industry is the total value of production in all sectors of the economy needed to meet a dollar’s worth of final demand for the industry’s output. It can be presented as a ‘simple multiplier’ accounting for direct and indirect effects or a ‘total multiplier’ that includes induced effects. For example, if an additional $1 million spent on construction causes additional demand for intermediate goods and services of $0.12 million, the simple output multiplier would be 1.12. An additional $0.5 million in output from induced effects leads to a total output multiplier of 1.62. Income multipliers give the increase in household incomes — direct and indirect effects for the simple income multiplier and with induced effects for the total income multiplier. Employment multipliers, simple and total, give the number of jobs for each additional direct job.

Unlike CBA and CGE modelling, I-O analysis considers only investment costs, viewed as a generator of economic activity. Project benefits (in the sense of the term used in CBA) are ignored and there is no attempt at welfare measurement. CBA and CGE analysis treat consumption of capital, labour and materials inputs as opportunity costs, hence less is better. I-O analysis turns the welfare economics paradigm on its head, treating costs as stimuli for which more is considered better. CBA calculates the net benefit to society (benefits less costs) of a project, expressed as a net present value, which, indicates the overall economic merit of a project. Projects estimated by a CBA to have high, low, and even negative net present values, will all appear from I-O analysis to be worthwhile because they have positive impacts on economic activity (as they all involve expenditure). I-O analysis therefore does not provide a basis to reject a project based on economic merit as assessed by a CBA. Indeed, a road to nowhere with no traffic would appear to be a good project on the basis that construction of the road generates economic activity.

I-O analysis only allows projects to be compared and ranked in the case where the government’s objective is to maximise economic stimulus per dollar spent either for the whole economy or for one or more particular regions. But even if indicators of economic stimulus based on I-O analysis are what is required to assist decision making, the restrictive assumptions of I-O mean the results should be treated with upmost caution. Critical assumptions include:

- There are no capacity constraints, so the supplies of each good and for labour and capital is perfectly elastic. Prices have no role to play in rationing demand. The term ‘jobs created’ implies everyone in the new jobs will otherwise be unemployed.
- There are constant returns to scale and no substitution between inputs in production or goods in consumption.
- Each commodity has only one production method and each industry has a single homogenous output.

I-O multipliers and forecasts of additional output, income and jobs should be regarded as upper limits. It has been suggested that induced effects computed by endogenising the household sector within an I-O model are implausibly large (Heintz et al 2009, pp. 49-50). ABS (2015 pp. 563) provides a full discussion of the limitations of I-O multipliers. ABS (2015) concludes:
Computable general equilibrium models

“While I-O multipliers may be useful as summary statistics to assist in understanding the degree to which an industry is integrated into the economy, their inherent shortcomings make them inappropriate for economic impact analysis. These shortcomings mean that I-O multipliers are likely to significantly over-state the impacts of projects or events. More complex methodologies, such as those inherent in Computable General Equilibrium (CGE) models, are required to overcome these shortcomings."

For a small project considered in isolation (not a program of projects), in a region for which labour and capital can easily move in and out, and the additional demand for inputs is small in relation to the national total, the assumption of no resource constraints might be reasonable (West 1999, p. 23). This is akin to the ‘small country assumption’ in international economics. If the project occurs in a time and place of high unemployment, the assumption of no resource constraints might be less of a concern too. However, the quality of I-O tables at the regional level is poorer.

If the aim is to estimate impacts on regions, national I-O multipliers are not appropriate. In the words of the ABS (2015, p. 563):

“Multipliers that have been calculated from the national I-O table are not appropriate for use in economic impact analysis of projects in small regions. For small regions multipliers tend to be smaller than national multipliers since their inter–industry linkages are normally relatively shallow. Inter–industry linkages tend to be shallow in small regions since they usually don’t have the capacity to produce the wide range of goods used for inputs and consumption, instead importing a large proportion of these goods from other regions."

National scale multipliers used to estimate impacts at the smaller regional scale are likely to over-estimate the impact. One cause is the degree of leakage as the impact of the activity is not exclusively local. In general, the smaller the region the greater the leakage because many of the inputs (labour, capital, materials) come from outside the region. A given region is by definition just one segment of the national economy. Hence, for internal consistency, the effect estimated using I-O tables at a regional scale must necessarily be lower than the estimated effect on the overall economy — the sum of the effects on all regions cannot be greater than the effect on the economy overall.

Another consideration for regions is that it is more difficult to assume that an industry in one region is identical in the inputs its uses and the product it produces to the same industry in another region.

The assumption of no resource constraints means that claims of additional output, income and jobs are likely to involve double counting. If the project does not proceed, at least part of the capital and labour engaged is likely to be employed elsewhere.

I-O analysis also provides no indication as to time frames. Some of the flow-on effects from a construction project could take longer than the duration of the project for all the impacts to be realised.

The limitations and concerns about using I-O analysis are widely noted in a range of professional sources (e.g. ABS (2015), NSW Treasury (2017), Heinz et al. (2009), West (1999), Forsyth (2014) and many others). Forsyth (2014, p. 5) is particularly highly critical: “… an IO model could be thought of as a poor man’s CGE model except that one would have to be destitute to use them. They are popular in some quarters because they make poor projects look good”.

The ATAP Guidelines recommend I-O analysis not be used except possibly for small projects considered in isolation (not groups of projects) in areas of high unemployment where economic stimulus is a policy objective. In doing so, it is important to understand the limitations of the estimates, in particular that they have an upward bias and that they take no account of the benefits or the opportunity costs of the project.
Appendix A  Case study illustrating specification of policy shocks

This appendix describes how policy shocks (i.e. changes to relevant exogenous variables in the model) can be specified in CGE model simulations. It does so using the BTRE (2003) study of the impacts of increased infrastructure funding under the Australian Government’s proposed AusLink program as an example. The focus is on issues related to shock design. In particular, it indicates the kind of assumptions needed to apportion cost savings estimated in a CBA among the different industries in a CGE model. Note that the ABS Transport Satellite Accounts now provide a much better understanding of ancillary transport activities than was available at the time of BTRE (2003).

A.1  Summary of BTRE (2003) study on AusLink

In 2003, BTRE (now known as BITRE) undertook a project to estimate the macro-economic effects of increased spending on a network of nationally strategic infrastructure (the major highways, urban links to ports and terminals, and the interstate rail network). Maunsell Australia Pty Ltd were engaged as consultants to assist with identifying potential investment projects, and estimating their costs, benefits and optimal implementation times for a 20-year time horizon ending in 2024-25. The economically optimal investment program was developed assuming there were no budget constraints. It was then assumed that funding was constrained to existing levels in real terms. Maintenance needs (separately estimated) were assumed to be met first out of available funds and the residual spent on investment projects. Projects were prioritised on a benefit–cost ratio basis to develop a budget-constrained investment program. The cost of deferring projects from their optimal times was estimated from the savings in transport user benefits forgone.

The macro-economic effects of the increased spending were estimated using an enhanced version of the MMRF-GREEN model sourced from the Centre of Policy Studies (CoPS) at Monash University. The model had 41 industry sectors, the 8 States and Territories as regions, detailed transport and energy sectors, and emissions accounting. BTRE and CoPS had previously collaborated to extend the level of detail in the model on the transport and energy sectors.

The base case was assumed to correspond to business-as-usual transport infrastructure funding levels for the next 20 years. The costs of deferring projects due to imposition of a budget constraint can be reinterpreted as the benefits from increased spending on transport infrastructure, the spending increase being the difference between the budget constrained and the economically warranted levels. The increased spending was modelled as an increase in government spending on construction activities. Income taxes were raised to fund the spending. Financial benefits of increased spending on transport (not economic benefits because savings in non-business travel time do not feature in GDP) were represented as cost reductions to industry sectors.

Results included impacts on GDP, consumption, investment, exports, the exchange rate, and industry outputs.

A.2  Shocks for additional capital expenditure

The economic impact of additional capital expenditure on rail and road was simulated by shocking the Australian Government’s consumption of construction services in the MMRF-GREEN model.
Computable general equilibrium models

The average annual additional capital expenditure on rail and road under AusLink are shown in Table 2 and the corresponding shocks in Table 3. Shocks were given only to the first year of each of the four five-year periods using an incremental/decremental approach. For example, the shock given to New South Wales for 2005/06–2009/10 was 61.6 per cent compared with the base case. In the following five-year period, the additional spending need is lower, so a negative shock was required to the 2005/06–2009/10 policy case, though the absolute amount for the additional spending is still positive compared with the base case.

Table 2  Average annual additional capital expenditure under AusLink program in 2005/06 prices ($m)

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<tbody>
<tr>
<td>NSW</td>
<td>529.3</td>
<td>178.2</td>
<td>358.2</td>
<td>68.4</td>
</tr>
<tr>
<td>VIC</td>
<td>134.9</td>
<td>-27.7</td>
<td>39.8</td>
<td>146.8</td>
</tr>
<tr>
<td>QLD</td>
<td>65.3</td>
<td>504.5</td>
<td>247.2</td>
<td>367.3</td>
</tr>
<tr>
<td>SA</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>WA</td>
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<td>0.0</td>
<td>0.0</td>
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<tr>
<td>TAS</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>NT</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<tr>
<td>ACT</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>729.9</td>
<td>655.1</td>
<td>645.2</td>
<td>582.5</td>
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</table>

Source  Derived from Maunsell (2003)

Table 3  Shocks for additional capital expenditure on rail and road (%)

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<tbody>
<tr>
<td>NSW</td>
<td>61.6</td>
<td>-40.9</td>
<td>21.0</td>
<td>-33.7</td>
</tr>
<tr>
<td>VIC</td>
<td>59.2</td>
<td>-71.3</td>
<td>29.6</td>
<td>47.0</td>
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<td>QLD</td>
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<td>90.2</td>
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<td>24.7</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>WA</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>TAS</td>
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<td>-0.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>NT</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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</tr>
<tr>
<td>ACT</td>
<td>0.0</td>
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<td>0.0</td>
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</table>

Source  BTRE estimates

A.3  Shocks associated with resulting savings in transport user costs

A second round of shocks was implemented to account for the benefits (reduced user costs) of the increased spending on infrastructure. Estimated savings in transport user costs from deferred road and rail projects are presented in Table 4. All values are expressed in 2005/06 prices. Savings in transport user costs for Australia as a whole increase over time rising from $483m a year for 2004/05-2009/10 to $1,813m a year for 2020/21-2024/25.
### Table 4  Average annual savings in transport user costs in 2005/06 prices ($m)

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<tbody>
<tr>
<td><strong>NSW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Road</td>
<td>–279.1</td>
<td>–450.8</td>
<td>–383.4</td>
<td>–538.5</td>
</tr>
<tr>
<td>• Rail</td>
<td>–20.7</td>
<td>–35.6</td>
<td>–79.7</td>
<td>–98.1</td>
</tr>
<tr>
<td>• Total</td>
<td>–299.7</td>
<td>–486.4</td>
<td>–463.1</td>
<td>–636.6</td>
</tr>
<tr>
<td><strong>QLD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Road</td>
<td>–25.7</td>
<td>–392.3</td>
<td>–697.1</td>
<td>–885.1</td>
</tr>
<tr>
<td>• Rail</td>
<td>–0.7</td>
<td>0.0</td>
<td>–34.2</td>
<td>–164.4</td>
</tr>
<tr>
<td>• Total</td>
<td>–26.4</td>
<td>–392.3</td>
<td>–731.3</td>
<td>–1,049.5</td>
</tr>
<tr>
<td><strong>VIC</strong></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>• Road</td>
<td>–156.9</td>
<td>–279.9</td>
<td>–447.9</td>
<td>–97.8</td>
</tr>
<tr>
<td>• Rail</td>
<td>0.0</td>
<td>–10.8</td>
<td>–20.5</td>
<td>–29.1</td>
</tr>
<tr>
<td>• Total</td>
<td>–156.9</td>
<td>–290.7</td>
<td>–468.4</td>
<td>–126.8</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Road</td>
<td>–461.7</td>
<td>–1,123.1</td>
<td>–1,528.5</td>
<td>–1,521.4</td>
</tr>
<tr>
<td>• Rail</td>
<td>–21.4</td>
<td>–46.4</td>
<td>–134.4</td>
<td>–291.6</td>
</tr>
<tr>
<td>• Total</td>
<td>–483.0</td>
<td>–1,169.4</td>
<td>–1,662.9</td>
<td>–1,813.0</td>
</tr>
</tbody>
</table>

**Note:** For ACT, NT, SA, TAS and WA, there was no additional spending (see Table 2) and hence no savings in transport user costs.

**Source:** Derived from Maunsell (2003).

The total savings in transport user costs (primarily for road) had to be distributed across the different states and time periods. Because of the lack of necessary information on road transport, a raft of assumptions had to be made in relation to the:

- split of total road transport between private motorists and business users of the road transport system;
- disaggregation of business road into business passenger and freight;
- allocation of freight between hire & reward and ancillary; and
- apportionment of ancillary road transport to MMRF industries.

The procedure for each of the above steps is discussed, illustrated with Table 5, Table 6 and Table 7.

Savings in road user costs were first split between private motorists and business users of the road transport system. Business use comprises all passenger cars and freight vehicles used for business purposes. According to Maunsell (2003), the split between private and business uses was 13:87. The reason why the share of private use was so low is that the savings in costs for private motorists include financial costs only (that is, they exclude travel time cost savings). This assumption would have to be changed if commuting trips were treated as having an impact on productivity as they are in most urban CGE models.
Of the total business road transport costs, 35 per cent were assumed to be car costs and 65 per cent truck (freight) costs. This guess estimate was used to split the savings in road user cost for business between cars and freight.

Savings for business road freight were further disaggregated into hire & reward and ancillary. Hire & reward and ancillary transport were assumed to have equal shares (50 per cent each). This assumption was based on ad hoc research from an external source.

Business car and ancillary freight were combined together to derive the total savings in road user costs for the ancillary road sector.

Maunsell (2003) provided estimates for savings in transport user costs in the form of time, fuel, vehicle maintenance (parts and other) and oil costs. Time savings by business users would be expected to lead to an improvement in labour productivity in the ancillary transport industry. Labour is the main input used in ancillary transport. In this study, labour, fuel, vehicle maintenance (parts and other) and oil were assumed to contribute 50.5, 29.7, 18.7 and 1.1 per cent to the savings in road user costs for the ancillary sector respectively (see Table 5). The size of the ancillary transport used in each industry was most difficult to estimate with rudimentary assumptions having to be made.

### Table 5 Average cost shares by state used to allocate road transport cost savings (%)

<table>
<thead>
<tr>
<th></th>
<th>NSW</th>
<th>VIC</th>
<th>QLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Private</td>
<td>13.0</td>
<td>13.0</td>
<td>13.0</td>
</tr>
<tr>
<td>• Business</td>
<td>87.0</td>
<td>87.0</td>
<td>87.0</td>
</tr>
<tr>
<td>• Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>• Business transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Cars</td>
<td>35.0</td>
<td>35.0</td>
<td>35.0</td>
</tr>
<tr>
<td>– Trucks (freight)</td>
<td>65.0</td>
<td>65.0</td>
<td>65.0</td>
</tr>
<tr>
<td>– Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>• Business trucks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Hire &amp; reward</td>
<td>50.0</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>o Ancillary</td>
<td>50.0</td>
<td>50.0</td>
<td>50.0</td>
</tr>
<tr>
<td>o Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>• Ancillary road transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fuel</td>
<td>29.7</td>
<td>29.7</td>
<td>29.7</td>
</tr>
<tr>
<td>- Parts</td>
<td>6.2</td>
<td>6.2</td>
<td>6.2</td>
</tr>
<tr>
<td>- Labour</td>
<td>50.5</td>
<td>50.5</td>
<td>50.5</td>
</tr>
<tr>
<td>- Oil</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>- Other</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>- Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Maunsell (2003) and BTRE estimates.

The shares in Table 5 were assumed to remain the same for all states over all the modelled years. This was a crude assumption that could have been improved upon had data been available.
Table 6 shows, as an illustration, the annual savings in road user costs by broad type of road users and by State/Territory for 2005/06–2009/10. The distribution of the total savings in road costs for ancillary road transport across MMRF industries was based on fuel shares (Table 7).

Table 6  Annual savings in road user costs in 2005/06 prices ($m): 2005/06–2009/10

<table>
<thead>
<tr>
<th></th>
<th>NSW</th>
<th>VIC</th>
<th>QLD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road transport</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Private</td>
<td>-37.4</td>
<td>-21.0</td>
<td>-3.4</td>
<td>-61.9</td>
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<tr>
<td>Business</td>
<td>-241.7</td>
<td>-135.9</td>
<td>-22.2</td>
<td>-399.8</td>
</tr>
<tr>
<td>Total</td>
<td>-279.1</td>
<td>-156.9</td>
<td>-25.7</td>
<td>-461.7</td>
</tr>
<tr>
<td>Business transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cars</td>
<td>-84.0</td>
<td>-47.2</td>
<td>-7.7</td>
<td>-139.0</td>
</tr>
<tr>
<td>- Trucks (freight)</td>
<td>-157.7</td>
<td>-88.7</td>
<td>-14.5</td>
<td>-260.8</td>
</tr>
<tr>
<td>- Total</td>
<td>-241.7</td>
<td>-135.9</td>
<td>-22.2</td>
<td>-399.8</td>
</tr>
<tr>
<td>- Business trucks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Hire &amp; reward (trucks)</td>
<td>-78.8</td>
<td>-44.3</td>
<td>-7.3</td>
<td>-130.4</td>
</tr>
<tr>
<td>o Ancillary (trucks)</td>
<td>-78.8</td>
<td>-44.3</td>
<td>-7.3</td>
<td>-130.4</td>
</tr>
<tr>
<td>o Total</td>
<td>-157.7</td>
<td>-88.7</td>
<td>-14.5</td>
<td>-260.8</td>
</tr>
<tr>
<td>- Business trucks and cars</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o Hire &amp; reward</td>
<td>-78.8</td>
<td>-44.3</td>
<td>-7.3</td>
<td>-130.4</td>
</tr>
<tr>
<td>o Ancillary (cars and trucks)</td>
<td>-162.8</td>
<td>-91.6</td>
<td>-15.0</td>
<td>-269.4</td>
</tr>
<tr>
<td>o Total</td>
<td>-241.7</td>
<td>-135.9</td>
<td>-22.2</td>
<td>-399.8</td>
</tr>
<tr>
<td>o Ancillary road transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fuel</td>
<td>-48.4</td>
<td>-27.2</td>
<td>-4.4</td>
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<td>- Parts</td>
<td>-10.2</td>
<td>-5.7</td>
<td>-0.9</td>
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</tr>
<tr>
<td>- Labour</td>
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<td>-46.2</td>
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<tr>
<td>- Oil</td>
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<td>-1.0</td>
<td>-0.2</td>
<td>-3.0</td>
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<tr>
<td>- Other</td>
<td>-20.3</td>
<td>-11.4</td>
<td>-1.9</td>
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<tr>
<td>- Total</td>
<td>-162.8</td>
<td>-91.6</td>
<td>-15.0</td>
<td>-269.4</td>
</tr>
</tbody>
</table>

### Table 7: Industry shares for use in distributing savings in ancillary transport user costs (%): 2005/06–2009/10

<table>
<thead>
<tr>
<th>Industry</th>
<th>NSW</th>
<th>VIC</th>
<th>QLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Agriculture</td>
<td>13.24</td>
<td>6.73</td>
<td>27.83</td>
</tr>
<tr>
<td>2 Forestry</td>
<td>1.19</td>
<td>0.72</td>
<td>3.39</td>
</tr>
<tr>
<td>3 IronOre</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4 NonIronOre</td>
<td>0.39</td>
<td>0.36</td>
<td>4.01</td>
</tr>
<tr>
<td>5 BlackCoal</td>
<td>1.00</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>6 Oil</td>
<td>0.00</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>7 NatGas</td>
<td>0.00</td>
<td>0.01</td>
<td>0.04</td>
</tr>
<tr>
<td>8 BrownCoal</td>
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<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>9 Food</td>
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<td>2.88</td>
<td>11.90</td>
</tr>
<tr>
<td>10 TCF</td>
<td>0.32</td>
<td>0.33</td>
<td>0.37</td>
</tr>
<tr>
<td>11 Woodpaper</td>
<td>4.11</td>
<td>2.77</td>
<td>5.47</td>
</tr>
<tr>
<td>12 Chemicals</td>
<td>4.21</td>
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<td>2.45</td>
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<tr>
<td>13 Petrol</td>
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<td>0.14</td>
<td>0.12</td>
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<tr>
<td>14 Nmet_prods</td>
<td>0.64</td>
<td>1.00</td>
<td>0.38</td>
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<tr>
<td>15 Cement</td>
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<td>0.19</td>
<td>0.30</td>
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<tr>
<td>16 Steel</td>
<td>0.37</td>
<td>0.18</td>
<td>0.11</td>
</tr>
<tr>
<td>17 AlumMagnes</td>
<td>0.88</td>
<td>0.74</td>
<td>3.57</td>
</tr>
<tr>
<td>18 OthMet_prods</td>
<td>1.84</td>
<td>1.81</td>
<td>2.20</td>
</tr>
<tr>
<td>19 CarsParts</td>
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<td>0.32</td>
<td>0.20</td>
</tr>
<tr>
<td>20 Other_man</td>
<td>1.40</td>
<td>1.24</td>
<td>1.02</td>
</tr>
<tr>
<td>21 ElectBlack</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>22 ElectBrown</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>23 ElectGas</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>24 ElectOil</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>25 ElectOther</td>
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<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
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<td>0.01</td>
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<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>32 RailTrans</td>
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<td>0.32</td>
<td>1.36</td>
</tr>
<tr>
<td>33 WaterTrans</td>
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<td>0.28</td>
<td>0.22</td>
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<td>34 AirTrans</td>
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<td>3.90</td>
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<tr>
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<td>0.40</td>
<td>0.19</td>
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<td>36 Commuc</td>
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</tr>
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<td>0.04</td>
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<td>2.06</td>
</tr>
<tr>
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</table>

**Source** BTRE estimates
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