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Australian Transport Assessment and Planning Guidelines

T4 Computable general equilibrium models in transport appraisal

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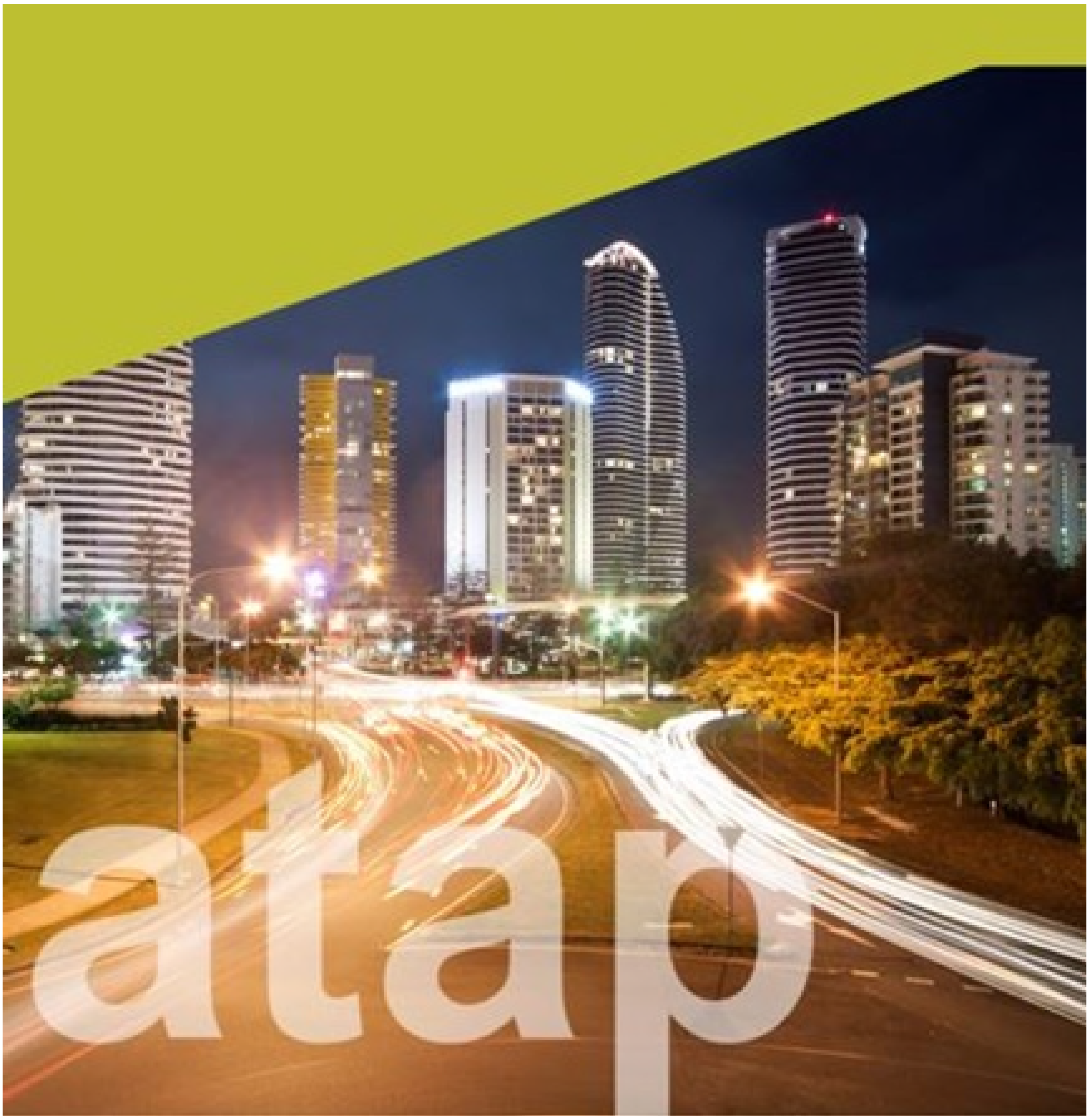

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At a glance

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 regions or small areas, as a result of external changes or policy changes.

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'). 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. CBA considers only the market directly affected by the initiative and closely related markets (hence, the term 'partial equilibrium').

A general and a partial equilibrium analysis will give the same welfare change result if there are no 'distortions' (prices different from marginal social costs) in markets other than those considered in the partial analysis. Sources of distortions include taxes, subsidies, unpriced externalities, regulatory restrictions on land-use, and imperfect competition. CBA takes account of distortions in closely related markets (for example, competing and complementary transport modes and routes) and in other markets through 'wider economic benefits' and 'higher value land-use benefits'. Beyond that, the welfare effects in more distantly related markets are thought to be small because the shifts in demand or cost curves would be small in those markets and the distortions through-out the Australian economy are, for the most part, not large. This view, however, is contested and evidence is needed to resolve the question.

In the meantime, the ATAP Guidelines takes the view that, for the vast majority of transport assessments, the partial equilibrium analysis of CBA is adequate because it gives a good approximation of the results that would be obtained from a general equilibrium assessment.

The ATAP Guidelines does not discourage use of CGE models to estimate benefits of initiatives where the model has a suitable welfare measure and level of disaggregation, but recommends that the CGE analysis be accompanied with a standard CBA, the results compared, and detailed explanations given for major differences.

CGE models forecast changes in a wide range of economic indicators (GDP, private consumption, investment, exports, employment and industry outputs) at the macro-economic level and at the level of individual industries. If a regional or spatial CGE model is used, these results will be available at the regional or small area level as well as at the national level.

Estimates of GDP changes from a CGE model and net benefits from a CBA are not interchangeable, nor additive. However, a CGE model can be set up to estimate changes in economic welfare consistent with a CBA. The more recent spatial CGE models, including urban CGE models, have welfare measures. They also feature high zonal disaggregation, transport costs and travel times, and land-use markets. They can contribute to CBAs by making land-use change forecasts.

CGE models can provide useful information about the distributional impacts of transport initiatives and estimate nationwide greenhouse gas emissions.

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. CGE modelling would be considered only for very large transport initiatives with significant geographical and distributional impacts

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

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.

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.

The traditional use of CGE models in transport appraisal is as a supplement to conventional CBA to provide information about macro-economic and distributional impacts of large projects or programs of multiple projects. Such modelling exercises to not measure additional benefits. Indeed, the models are usually not equipped with a welfare measure consistent with CBA but use indicators such as GDP and aggregate consumption.

Over the last couple of decades there has been a trend, particularly in Europe, towards using CGE models with high levels of spatial detail and a robust welfare measure to estimate benefits of transport initiatives. Such models have been developed for Sydney and Melbourne and have been applied to estimate benefits for project proposals.

As the ATAP Guidelines are targeted at CBA practitioners and users of CBAs in Australia, Part T4 does not offer a literature review of the state-of-the-art in Europe. Only models developed in Australia are relevant to appraisal of Australian transport initiatives and the urban models developed to date are limited to Sydney and Melbourne. T4 aims to give readers an explanation of CGE models with their strengths and limitations for transport assessment covering both the traditional and the new approaches.

Advocates of spatial CGE models make strong claims for their advantages over CBA for appraising major urban initiatives. However, there is as yet, no body of evidence showing the same projects appraised using both approaches with the differences between results explained and justified. Until such an evidence base is developed for Australian models, the ATAP Guidelines must take a conservative stance in recommending that project appraisals in which benefits are estimated using a spatial CGE model should be accompanied by a conventional partial equilibrium CBA with a narrative explaining the main differences.

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 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.

[1] CGE models are also referred to as applied general equilibrium models.

- 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.

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 outputs. These impacts cannot be added to benefits or costs in a CBA. The models can also provide valuable information on the distributional and greenhouse gas impacts of transport initiatives taking account of how transport project impacts ripple through the rest of the economy. The relatively recent spatial CGE models, which includes urban CGE models, can be used to support a CBA by serving as a land-use transport interaction (LUTI) model.

If a model features an appropriate welfare measure, a high level of zonal disaggregation and treatment non-work travel time, it can directly estimate benefits of transport initiatives. Spatial (including urban) CGE models are set up in this way. Whether estimating benefits with a CGE model is preferable to the standard partial equilibrium CBA is unclear. The main issue of contention relates to the size of additional benefits and disbenefits in markets that CBA cannot account for, even with the extensions of wider economic and land-use benefits. In an economy with no ‘distortions’, that is, prices everywhere equal marginal social costs, if a transport initiative causes demand or cost curves to shift in other markets, there will be no additional benefits or disbenefits to consider. This would require perfect competition in all markets, no taxes or subsidies, no unpriced externalities and no regulatory restrictions on land-use. Through valuing externalities, ‘wider economic benefits’ and land-use benefits, CBA has been extended to capture benefits and disbenefits due to significant distortions. A CGE model can also estimate the benefits and disbenefits from these distortions but goes further to encompass distortions in a multitude of other markets where the ripple effects are smaller. It is unclear whether these effects are significant enough to warrant the additional expense and effort of using a CGE model to estimate benefits.

Welfare results from CGE model should be treated with caution because the models have much less detail on zone sizes and representation of transport networks compared with strategic transport models, and involve numerous assumptions about parameter values and assumptions made when synthesising data at the desired level of disaggregation.

The ATAP Guidelines recommends that use of CGE models be limited to assessing large transport initiatives that are expected to have significant geographical and distributional impacts. If the CGE model is used to estimate benefits of an initiative, it is recommended that a standard CBA also be undertaken. Both sets of results should be reported with a narrative explaining the sources of major differences.

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 to addressing the policy questions at hand.

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 to ration resource 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.

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.

Chapter 6 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 input-output (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 industry and spatial 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). Dynamic models comprise of a series of annual snapshots of the economy. Simulations from dynamic CGE models produce 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 or spatial CGE model is used, these results will be available at the regional or small area level as well as at the national level.

2.2 Relationship with CBA

From a transport assessment perspective, there are two broad categories of models each having different uses in the transport context — national and spatial.

The traditional approach to using CGE models in transport assessment has been to supplement the CBA by forecasting macro-economic impacts. The most important summary results are GDP and per capita consumption. In most cases, dynamic national models are used, which may be multi-regional with at least the eight states and territories being distinguished. The models typically do not have a welfare measure consistent with net benefits measured by a CBA.

The new spatial CGE models, including urban models, have high levels of spatial disaggregation particularly for urban areas, are comparative static, model land-use markets and have welfare measures consistent with net benefits in a CBA. They can support a CBA by forecasting land-use change as a result of the transport initiative and thereby assist with estimating ‘second-round’ transport benefits, that is, benefits due to shifts in origin–destination demand curves due to land-use change. They can be used to estimate total benefits from projects.

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 or additive to 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.

Even in the absence of non-priced goods and ‘bads’, GDP and welfare changes are likely to 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

CBA undertakes what is termed a ‘partial equilibrium analysis’. It treats the markets 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, unpriced externalities, imperfect competition, non-constant returns to scale, regulatory restrictions on land-use, and unemployment.

A general equilibrium analysis will only find additional benefits and disbenefits over and above a partial equilibrium analysis in markets where there are distortions.

A 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’ and higher value land-use benefits arise from distortions, but partial equilibrium methodologies exist to estimate them.

The ATAP Guidelines takes the view that for the vast majority of transport assessments, the partial equilibrium analysis of CBA is adequate because it gives a good approximation of the results that would be obtained from a general equilibrium assessment.

The welfare effects in more distantly related markets are thought to be small because the shifts in demand or cost curves would be small in those markets and the distortions through-out the Australian economy are, for the most part, not large. However, this view is contested. Resolution of the issue requires a body of evidence to be accumulated in which the same projects are appraised using both partial and general equilibrium approaches and major differences explained.

The ATAP Guidelines does not discourage use of CGE models to estimate benefits of initiatives where the model has a suitable welfare measure and level of disaggregation, but recommends that the CGE analysis be accompanied with a standard CBA (with wider economic and land-use benefits if relevant), the results compared, and detailed explanations given for major differences.

Roles of CGE models in appraisal of transport initiatives include providing estimates of:

- Macro-economic impacts at national and regional levels for a wide range of variables such as GDP, private consumption, investment, exports, employment and industry outputs
- Distributional impacts at their final incidence, that is, after being passed on through the economy, for industries, regions and occupational groups distinguished by the model. Outside the model, the impacts on households can be disaggregated into income groups if required
- Nationwide greenhouse gas emissions impacts
- In the case of spatial/urban CGE models:
  - land-use change forecasts
  - land-use benefits
  - wider economic benefits
  - benefits taking into account the all distortions represented in the 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. Whether a suitable model is already set up for the location in which the initiative occurs, is a key determinant of the cost.

With any large complex model, there are dangers of treating it as black box and accepting results without checking for realism. A vast number of assumptions go into building and calibrating a CGE model. The models treat resources as being perfectly divisible and homogeneous within their category. The level of zonal disaggregation is much less than for the strategic transport models employed to support CBAs major urban projects. The results from CGE model should not be regarded as having a high level of precision, but rather, as indicative only.

2.3 Practical matters for estimating macro-economic impacts

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 for estimating macro-economic impacts.

With a dynamic model, it is necessary to make an assumption about how the transport project is funded — increasing taxes or government borrowing. The option chosen will have a major effect on macro-economic indicators during the construction period, when the project is consuming resources with no offsetting benefits. After the project commences operation, cost savings to industries will lead to positive macro-economic impacts.

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.

2.4 Input-output analysis as alternative

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 its 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. The simplified representation of the I-O table in Figure 1 shows 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

	SUPPLY \ USAGE	Intermediate Demand					Intermediate usage (sub-total)	Final Demand				Final demand (sub-total)	Total supply
		Agriculture	Mining	Manufacturing	Construction	Services		Construction	Capital expenditure	Change in stocks	Exports		
Intermediate inputs	Agriculture Mining Manufacturing Construction Services	QUADRANT 1 INTERMEDIATE USAGE						QUADRANT 2 FINAL DEMAND					
Primary inputs	Wages, salaries and supplements Gross operating surplus Commodity taxes (net) Indirect taxes (net) Sales by final buyers Complementary imports and duty Australian Production Competing imports and duty Total usage	QUADRANT 3 PRIMARY INPUTS TO PRODUCTION						QUADRANT 4 PRIMARY INPUTS TO FINAL DEMAND					

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.

[2] Margins are costs and charges that separate prices paid by purchasers from prices received by producers. They include 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 results will indicate changes in economic variables 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 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

For a system of simultaneous equations to have a unique solution, the number of unknowns 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 typically to assume real wage rates 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 often 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 ε_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*×*p* matrix of coefficients, *v* is a *p*×*1* vector of percentage changes in model variables, and 0 is the *p*×*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. The value of time can then be made endogenous, and trips can be generated directly from commuting, shopping and recreational activities as a derived demand from these activities as simulated in the model. 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).

Combining characteristics of multi-regional and urban models, CoPs has developed spatial CGE models for

- NSW and ACT at the SA2 level or above with 597 regions (called ‘VU Cities – NSW’)
- Victoria at the SA2 level (called ‘VU Cities – Victoria’)
- All Australia at the SA2 level (called ‘SIRCA’).

VU Cities is primarily a model of commuting and local travel. It has recently been linked to a simplified version of the Victorian Integrated Transport Model to form a full Land Use Transport Interactions (LUTI) modelling framework. The SIRCA (Spatial Interactions within and between Regions and Cities of Australia) model is described in Lennox (2020). Workers in up to 43 occupations commute and goods and services in up to 100 industries are traded.

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/or 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, impacts during the construction period, when resources are diverted to the construction sector with no offsetting economic benefits, depend greatly on how the project is assumed to be financed (taxes or foreign borrowing) and the availability of unemployed labour. After the project becomes operational, cost reductions to industries and greater capital intensity in the economy lead to growth 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 and regions 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). 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 and 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.

Distributional impacts

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 reference case or baseline projections fairly frequently. 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

Year	Initiative	Model	Author
National CGE models (comparative static			
1990	**Very Fast Train**	**ORANI**	**Centre for Regional Economic Analysis (1990)**
1993	Road investments	ORANI	Allen Consulting (1993)
1997	Increased road construction expenditures	AE-CGE (ORANI)	Austroads (1997)
Multi-region CGE models (dynamic)			
1996	**Melbourne City Link**	**Monash MR**	**Allen Consulting, Cox and CoPS (1996)**
2002	Improvement in Melbourne port efficiency	MMRF-GREEN	CoPS (2002)
2010	Inland Rail	Tasman Global	Acil Tasman (2010)
2012	Toowoomba Second Range Crossing	MU-TERM	CoPS
2012	High speed rail	MMRF	AECOM (2012)
2015	Inland Rail	MMRF	PwC (2015)
2016	Melbourne Metro	VU-TERM	CoPS (2015)
2003	AusLink (program)	MMRF-GREEN	BITRE (2003)
2010	Road investment in Victoria (1996-2008) (program)	TERM	Ernst & Young (2010)
2014	State Infrastructure Strategy – Rebuilding NSW (program)	DAE-RGEM	Deloitte Access Economics (2014)
2015	Economic Contribution of Australia's Toll Roads (program)	MMRF	KPMG (2015)
Urban CGE models (linked to a transport model at an urban scale, comparative static)			
2012	**Sydney North-West Rail Link**	**TRESIS–SGEM**	**D. A. Hensher, et al. (2012)**
2016	Western Sydney Airport	SCGE	Ernst & Young (2016)

Note: The list of applications is not exhaustive. These are shown as examples

4. Relationship between CGE modelling and CBA

CGE models have traditionally been used 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 ought to be 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. 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 (UK 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 therefore 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). Model outputs such as changes to GDP, gross national expenditure and total consumption can be adjusted to develop proxies for net economic welfare taking into account gains accruing to foreigners and income saved (Dixon 2009; Gropp et al. 2009). However, these are not equivalent to the welfare change measure of CBA.

The newer spatial CGE models have been set up to allow welfare measures in the form of equivalent or compensating variations and total consumers' surplus changes to be extracted (Robson et al. 2018, pp 45 and 48).[3] However, these measures may have to be supplemented to represent the full welfare change to the economy. Being comparative static, they exclude gains and losses to producers and governments that are not passed on to or taken away from households during the analysis period, for example, changes in the capital stock and level of foreign debt.

Dynamic CGE models permit quite detailed modelling of project financing and funding, which can be another source of differences between the welfare change estimated by a conventional CBA and a CGE model. If a transport project is funded by foreign borrowing, the cost to Australia is deferred to when the debt and interest are repaid. CBA, on the other hand, counts construction costs in the years they are incurred. 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).

[3] 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 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 $dw_h = \sum \frac{dq_i}{q_i}\left(\frac{p_i q_i}{\sum p_i q_i}\right) = \frac{1}{\sum p_i q_i}\sum p_i dq_i$, 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 $dW = dw_h \sum p_i q_i$, which is Dixon et al's welfare measure times GDP.

$dW = \sum p_i dq_i$ 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.[4] 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 $\sum_{i>1} p_i dq_i$, which will be negative.

$dW = dY - \sum q_i dp_i$ is the welfare change measured using the 'beneficiaries' or '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).[5] 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.[6]

4.2 Partial versus general equilibrium analysis

CBAs and wider economic benefits (WEBs) assessments are undertaken 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. 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, unpriced externalities, imperfect competition, non-constant returns to scale, regulatory restrictions on land-use, and unemployment. ATAP Guidelines Part T2, Chapter 7 on 'Cross-modal and network effects' explains that, for related infrastructure (substitutes or complements that experience demand curve shifts as a result of the transport initiative being appraised), where the perceived cost incurred by transport users equals the marginal social generalised cost, there are no further benefits or costs to consider. Thus, in the absence of distortions, partial and general equilibrium analysis give the same result.

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[4] Willingness-to-pay is the area under the demand curve between zero and the quantity, q*, that is, $WTP = \int_0^{q^*} p(q)dq$.
Hence, $\frac{dWTP}{dq^*} = p$, and $dWTP = p \cdot dq^*$.

[5] Consumers' surplus is the area under the demand curve above the price, p*, that is, $CS = \int_{p^*}^{\infty} q(p)dp$.
Hence, $\frac{dCS}{dp^*} = q$, and $dCS = q \cdot dp^*$.

[6] 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 that ought to be included in a CBA. The partial equilibrium analysis of CBA can be extended to account for significant missing indirect effects. 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 (see ATAP Part T3). 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.[7]

The questions are then whether:

- The established techniques are adequate to measure the benefits and disbenefits arising from the distortions they aim to account for, and
- Distortions in markets not covered by these methods give rise to significant additional benefits and disbenefits.

The ATAP Guidelines takes the view that the established techniques, while far from perfect, are fit for purpose, and that welfare effects of transport initiatives from other distortions in the economy are small because the shifts in demand or cost curves will be small and the distortions through-out the Australian economy are, for the most part, not large. 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, the partial equilibrium analysis of CBA is adequate because it gives a good approximation of the results that would be obtained from a general equilibrium assessment.

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. The controversy can only be resolved empirically. As Forsyth et al. (2021) note, it would be instructive and easy to compare benefits for the same project obtained from a CBA and from a CGE model with a welfare measure consistent with the CBA measure, but as yet, this has not been done. Since each national economy has its own particular distortions, the results from one country would not necessarily be transferable to others, so comparisons are needed for Australian transport projects.

The ATAP Guidelines' position is open to change if and when there is a body of evidence supporting change. It would then be important to develop recommendations about the types and sizes of the projects where CGE modelling to estimate benefits is particularly desirable. The Guidelines does not discourage use of CGE models to estimate benefits of initiatives where the model has a suitable welfare measure and level of disaggregation, but recommends that the CGE analysis be accompanied with a standard CBA (with wider economic and higher value land-use benefits if relevant), the results compared, and detailed explanations given for major differences. Having a standard CBA in addition to the CGE analysis will help ensure the initiative is not advantaged or disadvantaged relative to other initiatives appraised only with CBA, and the application of both methods to the same initiatives will provide lessons about the future role of CGE models in transport appraisal.

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[7] While not relevant for Australia, 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).

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:

1. CBA and CGE modelling viewed as different techniques, addressing different impacts of interest (welfare for CBA, GDP for CGE)
2. CBA and CGE modelling viewed as complementary project evaluation tools — use of both will result in more information being made available to decision maker
3. 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.

4.3.1 Complementary use

At the second level, there are a number of ways in which CGE models can complement CBA.

<u>Distributional impacts</u>

As noted in Section 3.6 above, they can provide information about the distributional impacts of projects on the industries, regions and occupational groups distinguished by the model. Impacts on households with different income levels can be estimated outside the model. A CBA can only assess the initial incidence of a project impact, while a CGE model will assess the final incidence. For example, the CBA may predict a transport cost reduction accruing to a particular industry, but this will ultimately be passed on to households in lower prices for consumer goods and dividends paid out of firms' profits.

<u>Widespread externalities</u>

CGE models can capture effects of widely spread externalities such as greenhouse gas emissions (for example the VURM, formerly MMRF, model). Given a unit cost of emissions, the value of savings or increases in greenhouse gases can added to the 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.

<u>Shadow wage rate for otherwise unemployed labour</u>

The shadow wage rate approach to addressing situations of high unemployment in CBAs, is quite demanding in terms of information required. In practice, the shadow wage rate is usually crudely estimated by multiplying wage rates by a factor below one chosen by judgement. A CGE model can help to develop assumptions about the proportion of construction labour that would otherwise be unemployed.

Land use transport interaction (LUTI) modelling

Section 3.5 above described how urban CGE models include a detailed treatment of land use markets. ATAP Part O8 Land use benefits of transport initiatives Chapter 3 briefly reviews approaches to land use forecasting including spatial CGE models.

Robson et al. (2018) and Sharaki and Bachmann (2018) discuss use of urban CGE and transport models side-by-side to estimate ‘second-round transport impacts’, that is, project benefits and disbenefits caused by induced travel demand arising from land-use change.[8] 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 transport demand caused by land-use changes. 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 and externalities 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.[9]

ATAP Part O8 discusses ‘closed city’ and ‘open city’ approaches to land-use modelling. Under the closed city approach the total population and employment of the area, city, or region being assessed are assumed to remain constant between the Base Case and the Project Case. Open city approaches allow for redistribution of population and employment from outside the area of assessment. Multi-regional CGE models, such as TERM and VURM, permit migration of households between regions.

4.3.2 Use to estimate benefits

At the third level in Forsyth’s (2017) categorisation, the CGE model is integrated with the CBA to produce a single general equilibrium evaluation tool. As already emphasised, it is essential that the welfare gain be properly calculated. Further requirements are that the model have a sufficient degree of zonal disaggregation and representation of the transport sector, including non-work time, which does not enter into GDP. This is discussed further below in Section 5.1. The newer spatial CGE models will have all the necessary features, though the level of zonal disaggregation and representation of transport networks will be much less detailed than for strategic transport models. The ability to capture a wide range of distortions over and above those that CBA can capture has been discussed. Spatial CGE models can be used as an alternative to partial equilibrium methods to estimate WEBs and higher value land-use benefits, which arise from distortions. Use of a CGE model to estimate welfare effects in situations of unemployed labour is an interesting possibility. Non-infrastructure initiatives that have widespread effects such as national road pricing schemes would be particularly suitable for appraisal using a CGE model.

Wider economic benefits (WEBs)

ATAP Part T3 Wider economic benefits sets out a detailed methodology with parameter values for estimating WEBs of transport initiatives in Australian cities. Koopmans and Oosterhaven (2011) discuss use of spatial CGE models to estimate WEBs in The Netherlands.

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8 See ATAP PartT 1, Travel demand modelling, Section 3.4 on induced travel demand, which includes a list of sources.

9 According to ATAP Part 1 (p. 30), the fixed trip matrix assumption is only valid for small or short-term schemes.

A spatial or urban CGE model can represent WEBs from agglomeration economies (WB1) by making firm productivity vary with effective density (a measure of access to other firms and labour). The model would have the necessary representation of the labour market and tax system to estimate WEBs from tax impacts of changes in labour markets (WB2). It could also have product prices above marginal costs due to imperfect competition, enabling estimation of WEBs from imperfect competition in product markets (WB3).

Where a CBA includes WEBs estimated from a CGE model, WEBs estimates using the ATAP Part T3 methodology and parameter values should be presented in the report as well, with any major differences explained.

Some points to note are:

- Since, a CGE model estimates all benefits including WEBs together with a single welfare measure, there need be no concerns about double counting, which is an advantage. However, it is difficult to separate out the different benefit categories for purposes of transparency and checking the realism of values.
- The standard partial equilibrium methodology for estimating agglomeration and labour market WEBs, as in in ATAP Part T3, is typically applied to outputs of transport models, which have much smaller zone sizes compared with urban CGE models. This is a disadvantage of the general equilibrium approach compared with the partial equilibrium approach to WEBs estimation.
- The parameters in the CGE model may differ from those recommended in ATAP Part T3.
- The published productivity elasticities used to estimate agglomeration WEBs account for all sources of productivity gains from agglomeration including economies of scale. If production functions in the CGE model feature economies of scale, smaller productivity elasticities should be used to avoid double counting the effects of economies of scale. Some guidance as to the size of the adjustment might be found by running the model with constant costs and published productivity elasticities.
- The labour market WEB in ATAP Part T3 relates solely to income taxes on labour and payroll tax. The methodology makes no allowance for company tax, goods and services tax, and employment benefits. The reason is that the partial equilibrium approach, based solely on change in labour supply, is unable to estimate adequately the effects of these other distortions (see ATAP Part T3, footnote 9 for a detailed explanation). A CGE model will capture labour market-related effects from all distortions included in the model.
- The partial equilibrium approach in ATAP Part T3 to estimating imperfect competition WEBs is very simple, applying a single ‘uprate factor’ to savings in generalised costs for business and freight, based on a single economy-wide price–cost mark-up and price elasticity of demand. A CGE model can have these vary by industry and zone. However, both approaches are highly approximate because the research into actual price–cost mark-ups of Australian firms does not exist.
- Where the CGE model forecasts land-use change, the agglomeration WEB estimate will be ‘dynamic’ (taking into account relocation of employment as well as improved access (‘static’)) and the labour market WEB will take account of both changes in labour supplied and moves to more (or less) productive jobs. ATAP Part T3 does not offer a methodology to estimate WEBs from moves to more (or less) productive jobs because of inadequate data on productivity differences by location, occupation and industry. If the moves to more (or less) productive jobs WEB is reported in a CBA, ATAP Part T3 recommends it be treated as a sensitivity test and lists a number of methodological issues to be addressed.

- ATAP Parts T3 and O8 recommend that the core CBA results table be presented in two parts — without and with land-use benefits and WEBs. WEBs should be broken down into the three categories addressed in T3. If WEBs have been estimated with a CGE model, it may be possible to calculate the components via a 'bottom-up approach' of adding up detailed model estimates for individual industries and occupations in zones, or alternatively a 'top-down' approach of rerunning the CGE model without particular distortions, for example, removing imperfect competition and some taxes. It may be necessary to recognise an 'other' category for benefits and disbenefits arising from other distortions in the model not covered by the ATAP Part T3 WEBs methodology and from interactions between the various distortions.

Land-use benefits

The use of urban CGE models for land-use change forecasting and to support estimation of 'second round' transport benefits was addressed in the previous section. The second round transport benefits could be estimated within the model though with a much less detailed representation of the transport network compared with a strategic transport model.

ATAP Part O8 Land-use benefits of transport initiatives discusses several categories of land-use benefits that arise from distortions. Higher value land-use benefits arise where the transport initiative allows zoning restrictions to be relaxed permitting more intensive land use. The benefit is the gap between the market value of the additional floor space in the project case and the resource cost of supplying it, less the depreciated value of any existing capital demolished to make way for the new developments. These benefits can only be attributed to the transport initiative where the easing of zoning restrictions is dependent and conditional upon implementation of the transport initiative. Urban CGE models take into account zoning restrictions when forecasting land-use change.

The other land-use benefits in ATAP Part O8 relate to public infrastructure, sustainability and public health costs, which may or may not be represented in particular urban CGE models.

Some cautions

With any large complex model, there are dangers of treating it as black box and accepting results without checking for realism. CGE modellers do not have access to superior data than others. Lack of measured data at the detailed level of individual industries and occupations in zones necessitates use of synthetic data as discussed below in Section 5.1.2. A vast number of assumptions go into building and calibrating a CGE model, in particular, about functional forms and elasticities. The parameter values are often 'guestimates' (that is, educated guesses) Bröcker and Mercenier (2011, p. 29). The level of zonal disaggregation is much less than for the strategic transport models employed to support CBAs major urban projects. The results from CGE model should not regarded as having a high level of precision, but rather, as indicative only.

Being comparative static, urban CGE models will provide results for a short-run or long-run equilibrium situation depending on closure for a single snapshot of time. A series of annual costs and benefits is required to calculate a net present value. Land-use change occurs gradually over time. ATAP Parts M1 Public transport and T3 WEBs discuss ramp-up of benefits. Typically, CBAs estimate benefits and costs for selected years, for example, at five- or 10-year intervals, and interpolate for the intervening years and extrapolate beyond. Consideration should be given to how this is done for results from comparative static CGE models recognising that demand changes can ramp up over several years (ATAP Part M1 Public transport, Section 2.3) while land-use change occurs over longer time frames (ATAP Part O8, Chapter 5).

While a dynamic CGE model would cover the construction and operating period for infrastructure projects, a separate run of a comparative static model would be needed to estimate welfare impacts of construction. This might be of particular interest in a situation of high unemployment.

The CGE model may not able to estimate all benefits identified. Benefits not accounted for in the model can be estimated in another framework and added to the final welfare estimate.

In CGE models, resources are perfectly divisible and 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.*

The ATAP Guidelines recommends that, whenever a CGE model is used to estimate welfare changes from a transport initiative, a conventional CBA be carried out, with WEBs and land-use benefit estimation if relevant, 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, changing the way the project is financed or the resource mobility assumptions.

5. Practical matters for estimating macro-economic impacts

This chapter primarily concerns the traditional approach of feeding CBA results into economy-wide CGE models to obtain macro-economic forecasts, rather than urban CGE models that are specifically developed to assess transport initiatives.

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 dis-aggregation 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. This is similar to the way owner-occupied dwellings are treated in the national accounts and I-O tables with owners paying imputed rents to the accommodation industry.

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 were 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 produces 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 (2017) 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.

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.

If WEBs have been estimated using the partial equilibrium methodology in ATAP Part T3, productivity improvements from agglomeration could be incorporated in a simulation.

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 wage rates 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 Public consumption

Public expenditure at the state and national levels can be held fixed or variable, depending on the source of funding. Fiscal neutrality (increasing taxes or reducing other public spending) 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. In the long-run, any change in the net foreign asset position is reflected in payments to foreign owners of capital.

5.4 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.

5.5 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 deviations 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.

6. Input–output analysis — an alternative to CGE models

This chapter 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
- 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:

> *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.

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)

	2005/06–2009/10	2010/11–2014/15	2015/16–2019/20	2020/21–2024/25
NSW	529.3	178.2	358.2	68.4
VIC	134.9	-27.7	39.8	146.8
QLD	65.3	504.5	247.2	367.3
SA	0.0	0.0	0.0	0.0
WA	0.0	0.0	0.0	0.0
TAS	0.4	0.0	0.0	0.0
NT	0.0	0.0	0.0	0.0
ACT	0.0	0.0	0.0	0.0
Total	729.9	655.1	645.2	582.5

Source: Derived from Maunsell (2003)

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

	2005/06–2009/10 (% deviation from 2005/06–2009/10 base case)	2010/11–2014/15 (% deviation from 2005/06–2009/10 policy case)	2015/16–2019/20 (% deviation from 2010/11–2014/15 policy case)	2020/21–2024/25 (% deviation from 2015/16–2019/20 policy case)
NSW	61.6	–40.9	21.0	–33.7
VIC	59.2	–71.3	29.6	47.0
QLD	13.4	90.2	–52.8	24.7
SA	0.0	0.0	0.0	0.0
WA	0.0	0.0	0.0	0.0
TAS	0.6	–0.6	0.0	0.0
NT	0.0	0.0	0.0	0.0
ACT	0.0	0.0	0.0	0.0

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)

	2005/06–2009/10	2010/11–2014/15	2015/16–2019/20	2020/21–2024/25
NSW				
• Road	–279.1	–450.8	–383.4	–538.5
• Rail	–20.7	–35.6	–79.7	–98.1
• Total	–299.7	–486.4	–463.1	–636.6
QLD				
• Road	–25.7	–392.3	–697.1	–885.1
• Rail	–0.7	0.0	–34.2	–164.4
• Total	–26.4	–392.3	–731.3	–1,049.5
VIC				
• Road	–156.9	–279.9	–447.9	–97.8
• Rail	0.0	–10.8	–20.5	–29.1
• Total	–156.9	–290.7	–468.4	–126.8
Australia				
• Road	–461.7	–1,123.1	–1,528.5	–1,521.4
• Rail	–21.4	–46.4	–134.4	–291.6
• Total	–483.0	–1,169.4	–1,662.9	–1,813.0

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% were assumed to be car costs and 65% 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% 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% 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 (%)

	NSW	VIC	QLD
Road transport			
• Private	13.0	13.0	13.0
• Business	87.0	87.0	87.0
• Total	100.0	100.0	100.0
• Business transport			
– Cars	35.0	35.0	35.0
– Trucks (freight)	65.0	65.0	65.0
– Total	100.0	100.0	100.0
– Business trucks			
o Hire & reward	50.0	50.0	50.0
o Ancillary	50.0	50.0	50.0
o Total	100.0	100.0	100.0
o Ancillary road transport			
- Fuel	29.7	29.7	29.7
- Parts	6.2	6.2	6.2
- Labour	50.5	50.5	50.5
- Oil	1.1	1.1	1.1
- Other	12.5	12.5	12.5
- Total	100.0	100.0	100.0

Source: 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

	NSW	VIC	QLD	Total
Road transport				
• Private	–37.4	–21.0	–3.4	–61.9
• Business	–241.7	–135.9	–22.2	–399.8
• Total	–279.1	–156.9	–25.7	–461.7
• Business transport				
– Cars	–84.0	–47.2	–7.7	–139.0
– Trucks (freight)	–157.7	–88.7	–14.5	–260.8
– Total	–241.7	–135.9	–22.2	–399.8
– Business trucks				
o Hire & reward (trucks)	–78.8	–44.3	–7.3	–130.4
o Ancillary (trucks)	–78.8	–44.3	–7.3	–130.4
o Total	–157.7	–88.7	–14.5	–260.8
– Business trucks and cars				
o Hire & reward	–78.8	–44.3	–7.3	–130.4
o Ancillary (cars and trucks)	–162.8	–91.6	–15.0	–269.4
o Total	–241.7	–135.9	–22.2	–399.8
o Ancillary road transport				
- Fuel	–48.4	–27.2	–4.4	–80.0
- Parts	–10.2	–5.7	–0.9	–16.8
- Labour	–82.2	–46.2	–7.6	–136.0
- Oil	–1.8	–1.0	–0.2	–3.0
- Other	–20.3	–11.4	–1.9	–33.6
- Total	–162.8	–91.6	–15.0	–269.4

Source: BTRE estimates based Maunsell (2003).

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

Industry	NSW	VIC	QLD
1 Agriculture	13.24	6.73	27.83
2 Forestry	1.19	0.72	3.39
3 IronOre	0.00	0.00	0.00
4 NonIronOre	0.39	0.36	4.01
5 BlackCoal	1.00	0.00	0.50
6 Oil	0.00	0.03	0.00
7 NatGas	0.00	0.01	0.04
8 BrownCoal	0.00	0.02	0.00
9 Food	4.50	2.88	11.90
10 TCF	0.32	0.33	0.37
11 Woodpaper	4.11	2.77	5.47
12 Chemicals	4.21	6.56	2.45
13 Petrol	0.16	0.14	0.12
14 Nmet_prods	0.64	1.00	0.38
15 Cement	0.24	0.19	0.30
16 Steel	0.37	0.18	0.11
17 AlumMagnes	0.88	0.74	3.57
18 OthMet_prods	1.84	1.81	2.20
19 CarsParts	0.11	0.32	0.20
20 Other_man	1.40	1.24	1.02
21 ElectBlack	0.00	0.00	0.00
22 ElectBrown	0.00	0.00	0.00
23 ElectGas	0.00	0.00	0.00
24 ElectOil	0.00	0.00	0.00
25 ElectOther	0.00	0.00	0.00
26 ElectSupply	0.05	0.10	0.11
27 UrbanGasDis	0.14	0.43	0.00
28 Water	0.15	0.22	0.01
29 Construction	5.86	6.88	3.04
30 TradeHotels	21.57	20.37	15.96
31 RoadTrans	0.00	0.00	0.00
32 RailTrans	0.69	0.32	1.36
33 WaterTrans	0.68	0.28	0.22
34 AirTrans	9.21	8.96	3.90
35 OtherTrans	0.38	0.40	0.19
36 Communic	3.87	4.83	2.53
37 FinBusServ	8.09	10.21	5.22
38 Dwelling	0.56	0.68	0.04
39 PubServ	9.98	14.54	2.06
40 OthServ	4.20	5.77	1.49
Total	100.00	100.00	100.00

Source: BTRE estimates

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