CHAPTER 7

Regional Computable General Equilibrium Modeling

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Abstract

Over the past three decades the field of regional computable general equilibrium (CGE) modeling has flourished, growing from a handful of top-down, single-region and low-dimensioned multiregional models, to a mature field, in which output of large-scale general-purpose multiregional CGE models has become a standard input to policy deliberations in a growing number of countries. Researchers have ensured that innovations in theory, data construction and model application have matched growth in both computing power and the appetite of government decision makers for expanding levels of policy-relevant regional and sectoral detail. This chapter focuses on the development of the field, its current state, and its accomplishments in elucidating important research questions and policy issues in regional economics. We begin by discussing the development of regional CGE modeling as a subdiscipline of CGE modeling, expanding on the distinguishing attributes of regional CGE models. We then discuss policy applications of regional CGE models, demonstrating the power of such models to answer important policy questions and providing an application-driven motivation for our discussion of the innovations in the field. We consider the key theoretical features of multiregional CGE models, identifying the many ways researchers have modeled the behavior of economic agents in a multiregional context. The paucity of data at the regional level suitable for CGE modeling has long been a constraint and so we discuss methods for populating a multiregional model's database. We then undertake simulations with a large-scale CGE model and show how output of the model can be communicated in a way that does not presume knowledge of the details of the underlying model. We note that effective communication of the results of regional CGE modeling studies, based on a correct interpretation of the model mechanisms which underlie them, is a prerequisite for its acceptance in policy circles.

Keywords

Regional economic modeling, computable general equilibrium, dynamic modeling, regional economic policy

JEL classification codes

D58, R11, R13, R23, R58

7.1 INTRODUCTION

While computable general equilibrium (CGE) modeling started at a national level, it was not long before models with a regional dimension appeared. Early examples are Dixon

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et al.'s (1978) top-down and Liew's (1984a) bottom-up models for Australia, Whalley's (1982) multicountry model, and Hertel and Mount's (1985) single-region model for New York state. This chapter is about the modeling of subnational regions: multicountry CGE models are discussed elsewhere in this Handbook.

Many current CGE models have a regional dimension, reflecting demand by policy makers for information on regional outcomes of: national shocks (e.g. tariffs); region-specific shocks (e.g. state government fiscal policies); and regionally heterogeneous shocks (e.g. drought with varying regional intensities). Regional CGE models have been applied across the same range of issues (tax, trade, environment, etc.) as their national counterparts as well as to issues that are essentially regional, such as fiscal federalism, regional development, mega events, major disasters, transport policy and regional-government microeconomic reforms.

The focus of this chapter is those aspects that distinguish regional CGE models from national models. On the face of it, it may appear that regional CGE models are no more than national models with an extra dimension added to each of the model's agents: households in region *r* rather than just national households, and so on. However, regional CGE modeling involves several challenges beyond those in national modeling. First, factors are more mobile intranationally than internationally. A regional CGE model needs a satisfactory specification of inter-regional migration. The inter-regional mobility of labor/households has in turn implications for regional welfare analysis and inter-regional variations in preference patterns. Cross-border ownership of productive assets tends to be much higher intranationally than internationally, so that accounting for the inter-regional ownership of capital and land can be important. Second, as argued by Isard *et al*. (1998), multiregional modeling should imply the introduction of distance. Proper modeling of distance requires regionally specified margin services, such as transport and retail and wholesale trade. While a number of national CGE models contain extensive treatment of margins, the matter becomes more complex in a multi-regional setting where margins associated with a commodity flow can be supplied by the region of origin, the region of destination or by third regions. A third challenge faced by regional CGE modelers is the specification of the behavior of different tiers of government: national, provincial/state and local. A fourth challenge is to mold scanty regional data into a comprehensive regional CGE database.

The chapter is organized as follows. Sections 7.2 and 7.3 consider some major themes in the regional CGE literature.[1] Section 7.2 is about applications. We start in this way to motivate the study of methodological issues described in Section 7.3 by immediately

1 Reviews of the regional CGE modeling literature include Kraybill (1993) and Partridge and Rickman (1998). A more recent review (Donaghy, 2009) largely confines its scope to a subset of regional CGE models; ones with a definite spatial orientation. In the course of their discussion of methodology in regional CGE modeling, Partridge and Rickman (2010) update their 1998 review.

demonstrating the power of regional CGE modeling to answer questions of policy relevance. Discussion of applications identifies crucial methodological developments in regional CGE modeling, and points the way to future developments required to increase the scope and quality of regional CGE analyses.

In Section 7.4, we specify key features of a state-level CGE model and focus our discussion on aspects that are special to multiregional modeling. We then examine in Section 7.5 methods for populating a multiregional model's database, before putting such a model to work in Section 7.6 on two illustrative simulations. The simulations we choose involve shocks typical of those in real-life policy applications. The aim in discussing these simulations is to demonstrate how to uncover the driving factors behind CGE results at the regional level. We do so with the aid of back-of-the-envelope (BOTE) techniques. While there are many examples of BOTE interpretations of national results, the adoption of this level of rigor in interpreting regional results is rare. In doing so, we demonstrate the essential driving mechanisms in regional CGE results in both the short and long runs.

Concluding remarks are in Section 7.7.

7.2 WHAT REGIONAL MODELS CAN TELL US

In this section we provide an overview of regional CGE applications in terms of the major classes of issues investigated, while adumbrating the required methodological developments to be discussed in the next section. In the course of the overview we discuss a small number of studies in a little more detail. The selected publications are good examples of regional CGE studies which answer questions that: have been keenly debated in policy fora; exhibit regional mechanisms at work in the CGE framework; and demonstrate sound interpretations of the factors underlying the results.

We start by considering policy shocks in the order of the geographical level at which they occur.[2] Thus, we begin our overview with shocks which we will term national shocks (i.e. shocks that are uniform across regions, in the sense of not actively discriminating between regions). We then look at policy applications involving region-specific shocks, starting with those where regionally non-uniform shocks tend to occur across all or most regions, before moving to policies and events that are confined to particular regions.

7.2.1 Regional effects from national shocks

Kraybill *et al.* (1992, p. 726) observed from a CGE simulation of the effects of the increased US federal budget and trade deficits of the first half of the 1980s, that

2 We interpret policy shocks broadly to also include economic events (e.g. a world oil price rise).

"seemingly aspatial national policies may shift the geographical distribution of national output and income."[3] Such an observation may provide a motivation for regional CGE analysis of national policies. With the question of trade barriers being an intensely debated topic in the late 1970s and early 1980s, the same time that regional CGE models began to emerge, it was natural that trade studies figured prominently among early applications.[4] Early regional CGE studies (Dixon *et al.*, 1982; Liew, 1984b; Whalley and Trela, 1986) identified those regions that were winners from trade restrictions and those that were losers, and by how much.

An important element in considering regional CGE studies is the degree to which they explain the factors driving their regional results. A study that does this well is Dixon *et al.* (2007). They examined the effects on US states of removing tariffs and quotas on the 45 most heavily protected of the 500 commodities in their regional CGE model. They found that the worst-affected states in terms of employment were Idaho and North Carolina, which were over-represented in adversely affected activities (sugar and dairy in the former, textiles in the latter). The most positively affected state, Washington, was over-represented in export-oriented activities (e.g. aircraft), which gained via the real devaluation that resulted from the trade liberalization. The authors used regression analysis to show that a state's commodity composition of employment, combined with percentage changes in nationwide employment producing each commodity, explained almost three-quarters of the state's employment result.[5] They then used their regression results to search for other factors underlying their state employment simulation results. They proceeded by comparing state employment results from the simulation against those predicted by the regression. They noticed that the regression strongly under-estimated aggregate employment results for a number of states that had in common the presence of a major port. While the regression equation took no account of interstate differences in employment effects for individual commodities, Dixon *et al.*'s (2007) regional CGE model recognized that the increased international trade arising from trade liberalization provided a bigger percentage boost for margin services (e.g. road and rail transport) in those states with a major port. Adding a port index to their regression equation increased the R^2 to 0.88.[6] They then searched for further factors underlying

3 Their simulation is with a comparative-static two-region CGE model of the US (Virginia and Rest of US) in short-run mode.

4 With the tariff debate a central political issue at that time, trade liberalization was also among the earliest applications with national CGE models (for an early example, see Dixon and Sutton, 1977), and also with multicountry models (for an early example, see Whalley, 1982). It has remained a major topic of CGE analysis, particularly with multicountry models (recent examples are Francois *et al.*, 2005; Dimaranan *et al.*, 2007).

5 They regressed state aggregate employment impacts against an index which was computed for each state as the weighted average of the percentage changes in each commodity's employment nationally, where the weights were that region's commodity employment shares. The R^2 was 0.73.

6 The port index is the ratio of the state's share of US international trade through its ports to the state's share of national employment.

their state employment results by comparing the gaps between fitted values from the *amended* regression equation and the simulation results. This revealed gaps for some other groups of states. The explanation for the gaps could be attributed successfully to sales patterns of states in the group differing in a common way from the national sales pattern. For instance, one group whose employment results the regression under-predicted were tourism-oriented states. Commodities such as restaurants and hotels in "holiday" states tend to be sold more to tourism, which is favored by real devaluation (as it leads to substitution of domestic for foreign holidays and expands foreign tourism to the US). Dixon *et al.* (2007) confirmed this as one of the factors behind the impact on the "holiday" states by adding a holiday index to the regression equation which increased the R^2 to 0.90.

Dixon *et al.* (2007, p. 50) state that the "most striking feature of the state employment results … is the narrowness of their range."[7] As opposed to the Kraybill *et al.* (1992) study referred to above where large macroeconomic shocks were involved, tariff reductions, even when they are across the board, tend to significantly affect only a subset of industries. For reasonably aggregated regions, such as states or provinces, the industrial structure of the regional economies, at least at the broad sectoral level, tend to have roughly similar patterns. Even with substantial regional multiplier effects, it is unlikely that the most affected industries are sufficiently over-represented in particular regions to dramatically increase the dispersion of the regional impacts.[8]

While the bulk of regional CGE studies have moved away from examining purely national shocks, the range of national shocks subjected to regional CGE analysis has increased. In the trade policy area, there have been a number of studies of the regional consequences of free trade areas (e.g. Gazel *et al.*, 1996; Haddad *et al.*, 2002a) and multilateral initiatives (Diao *et al.*, 2006; Anderson *et al.*, 2010). In the central government tax area, Giesecke (1999) examined the regional effects of the national fringe benefits tax, Cardenete and Sancho (2003) analyzed the effects of reforms to the Spanish income tax, and Dixon and Rimmer (1999) assessed the regional effects of a value-added tax. The first two studies were aimed at analyzing the effects of national tax changes on particular regions, Western Australian regions and Andalusia, respectively. On the other hand, the primary focus of Dixon and Rimmer's study was national, with regional results being one of the major disaggregated results also given attention.

Other areas where the shock has been national include: central government defense expenditure cuts (Hoffmann *et al.*, 1996); tourism (Adams and Parmenter, 1995; Blake

7 Bröcker and Schneider (2002) similarly found a narrow range of effects across Austrian regions from increased trade between Austria and four Central European countries.

8 Dixon *et al.* (2007) note the following. While sugar and dairy might have a share in Idaho's aggregate employment five times their share nationally, the share for Idaho is still only 0.91%. Thus, the significant employment contraction in these activities directly contributes only 0.13% towards the state's aggregate employment loss. Idaho is projected to experience the largest employment effect, but it is still only a reduction of 0.5%.

and Gilham, 2001); climate change (Madden, 1991; Li and Rose, 1995; Oladosu and Rose, 2007; Snoddon and Wigle, 2008; Garnaut Climate Change Review, 2008); foreign direct investment (Gillespie *et al*., 2002a); and nationally-set minimum wage rates (Dixon *et al*., 2010). Again, while most of the cited studies are concerned essentially with regional analysis, some (Adams and Parmenter, and the Garnaut Review) include regional analysis as one component of wider studies. These latter studies nevertheless can provide interesting regional results that defy commonly-held views. For instance, Adams and Parmenter (1995, p. 991) find that Queensland, the Australian state whose "economy is most oriented towards servicing overseas tourists," suffers a reduction in its Gross State Product (GSP) growth rate as a result of a uniform economy-wide increase in the growth rate of foreign tourism demand. Victoria, on the hand, the state least oriented to foreign tourism is found to be a net gainer from the tourism shock. The key explanation for this lies in Queensland being significantly over-represented, and Victoria under-represented, in traditional export industries (principally agriculture and mining). Traditional exports are strongly crowded-out by the tourism shock.[9]

7.2.2 Analyzing fiscal federalism

Fiscal federalism is a topic to which regional CGE models are manifestly suitable. A major focus of fiscal federalism applications relates to fiscal equalization issues. Early studies looked at the regional economic impacts of changing the allocation of federal government grants among states in Australia (Madden *et al*., 1983) and provinces in Canada (Whalley and Trela, 1986) – the two countries with the most developed equalization systems.[10] Dixon *et al*. (1993) reported on the effects on states (and territories), and on Australia's economic efficiency, of discontinuing fiscal equalization arrangements. Dixon *et al*. (1993) found that the arrangements generated inefficiencies arising from overmigration to regions with location-specific disabilities, but they argued that this sort of inefficiency is necessarily small. They also found that discarding just the location-disability part of the fiscal equalization system would still deliver the same

[9] It is noteworthy that traditional exports are particularly strongly crowded-out in Adams and Parmenter's simulation due to the medium-term nature of their model closure. With the shock delivering an increase in Australia's terms of trade and the average rate of return on capital assumed fixed, real rental costs of capital to producers fall. This induces an increase in investment. With no change in aggregate employment assumed, GDP is largely constrained and as the non-investment components of gross national expenditure are also largely unaffected, the trade balance must deteriorate. While the import content of the increased investment makes a contribution towards the required trade balance deterioration, the real exchange rate must still appreciate to cause net exports to fall sufficiently. With the increased tourism exports causing an initial movement towards surplus, traditional exports must be particularly negatively affected.

[10] Under (horizontal) fiscal equalization the federal government adjusts its grants to the states away from *per capita* shares to offset state differences in tax bases (in both Australia and Canada) and the cost of providing public services (location-specific disabilities – Australia only). See Madden (2006) and Bird and Vaillancourt (2006) for a discussion of Australian and Canadian fiscal federalism arrangements.

efficiency gains, but considerably reduce the size of the large interstate migration from the states which lose from the policy change.[11]

Subsequent regional CGE studies of fiscal equalization arrangements by Dixon *et al.* (2002, 2005) found a much higher level of inter-regional inefficiency from the arrangements once the so-called "flypaper" effect is taken into account.[12] The flypaper effect refers to a tendency by subnational governments to spend a higher proportion of intergovernmental grant income than it would for any other increase in the region's income. Dixon *et al.* (2002) also found that the effects of diminishing marginal returns from labor tax reductions (and increasing marginal congestion costs) in a positively-affected state meant that the welfare benefits from a reallocation of funds towards a donor state, or away from a subsidized state, initially rise and then fall. Their simulations indicate that interstate differences in the slopes of these benefit curves means that the optimal allocation of grants (in pure economic efficiency terms) differs from equal *per capita* grants.

The implementation of fiscal equalization normally only occurs when there is a situation of vertical fiscal imbalance (VFI), i.e. where the higher tier government's share of national tax receipts is higher than its share of expenditure responsibilities. There has been only limited regional CGE modeling of the effects of changes to VFI, notable examples being Madden (1993) and Hirte (1998).[13]

7.2.3 Regional policies and events

The analysis of regional policies or economic events has now become the major area of regional CGE application and the range of questions examined under this broad heading has become very wide. We briefly run through the range of applications, referencing notable examples, with a short discussion of a few papers that provide compelling illustrations of the power of regional CGE models to answer key regional policy questions.

Most regional CGE modeling has been conducted for regions that correspond with subnational administrative boundaries, generally for governments with substantial areas of

[11] The bulk of the efficiency loss related to the Northern Territory which would lose over 20% of employment/population under complete abandonment and 15% under discarding just the location-specific disability component. The corresponding figures for Tasmania, the other state Dixon *et al.* model, were 4 and about 0.5%.

[12] Inefficiency is about 4 times greater in real terms in the new studies compared with the 1993 studies. However, as Dixon *et al.* (2002, p. 313) note, this is "only a moderate contribution to Australian welfare."

[13] In the 1990s the Australian federal government justified maintaining that nation's very high VFI in the interest of ensuring its control over macroeconomic management. Madden (1993) conducted regional CGE simulations to test possible state government fiscal reactions and concluded that a very high level of VFI is unlikely to ensure that states' reactions do not run contrary to federal government aims for fiscal contractionary policies. Hirte (1998) examined changes recommended for Germany by an advisory board to allow, *inter alia*, regional governments to levy income taxes and found that depending on institutional arrangements the welfare effects might be negative.

autonomy (as is the case with the states/provinces considered under fiscal federalism above).[14] Thus there have been many applications in the key state/provincial government policy areas of fiscal policy, regional development and infrastructure. These areas are highly inter-related, so for instance one finds tax measures modeled as an instrument for regional development and applications on infrastructure conducted under varying state government budgetary measures for providing the finance. While there are examples of regional CGE studies fundamentally relating to tax efficiency (e.g. Dixon *et al.*, 2004) and to tax incidence (Mutti *et al.*, 1989), most studies of regional government fiscal policies are concerned to a reasonable extent with their effects on regional macroeconomic aggregates.[15] For instance, Seung and Kraybill (1999) examined the effects of removing Ohio's state corporate tax on the state's macroeconomic aggregates, while Morgan *et al.* (1989) investigated the effects of all regional taxes on regional growth under different factor mobility assumptions. Madden (1989) examined the efficacy of changing the Tasmanian tax mix in increasing that state's employment, while Berck *et al.* (1997) carried out a similar exercise for California.[16] Morgan *et al.* (1996) found that the degree of tax exporting (i.e. tax burden borne by out-of-region residents) does not necessarily coincide with regional growth effects, which in turn does not correspond with the effects on regional welfare. Giesecke (2003) examined whether it is within the power of an Australian state government to halt the continued decline in the share of its region (Tasmania) in national GDP through a budget-neutral rearrangement of its fiscal instruments. His results showed that to gain a temporary halt in Tasmania's relative decline would involve the introduction of unfeasibly large combinations of subsidies and taxes.[17]

Regional, and national, governments frequently use industry assistance measures as a regional development policy, but these measures have received little attention from regional CGE modelers. An example of CGE modeling of regional government assistance is Challen *et al.* (1984) who simulated labor subsidies to selected Tasmanian

14 Note that subnational governments with considerable autonomy can be found in unitary as well as federal systems. This occurs where the central government has devolved powers to regions. Thus, there has been a good deal of modeling of Scotland to which the UK central government has now devolved many powers (e.g. responsibilities for health, education, justice, transport). Also, of relevance to the discussion in Section 7.2.2, is Ferguson *et al.*'s (2007) modeling of the effects of the formula for the allocation of central government funds to Scotland.

15 Mutti *et al.* (1989) – as do Morgan *et al.* (1989) and Morgan *et al.* (1996), mentioned immediately below – use a six-region model of the US. It provides an example of where aggregated states are assumed to act as a single state.

16 Madden (1989) also looks at changes in the state government expenditure mix, and in the fiscal mix generally. Berck *et al.*'s chief concern is the extent to which cuts in taxes on labor and capital are self-financing – a question their simulations answer in the negative.

17 Giesecke further found that even to achieve a slight, and temporary, diminution in the rate of decline would require a change in the fiscal mix that involved the elimination of the state's major tax category, payroll tax. Other studies look at national government regional assistance policies. For instance, in a recent study Rutherford and Törmä (2010) found that *nationally-funded* reductions in taxes on labor and capital have the capacity to combat out-migration from Northern Finland. They report a slightly positive impact on the welfare of Finland as a whole.

industries financed by a tax surcharge on the region's households and by state government expenditure cuts.[18] An example of a CGE application of national government assistance to a region is Gillespie *et al.* (2001) who examined the effects on Scotland of nationally-funded regional selective assistance for Scottish industry projects.

Major industrial projects are the subject of numerous regional CGE studies commissioned by business and government. Examples of regional CGE modeling of the construction and operating phases of mining projects are Higgs and Powell (1992) and Clements *et al.* (1996). Dixon *et al.* (1992a) examined the economic effects of establishing a proposed science city, simulating its location in each of the bidding states in turn. A feature of this study was the modeling of alternative financing assumptions – two in which the nation paid for the project in the construction phase (fixed balance of trade and reductions in private and public consumption) and one in which the nation paid for the project in the operating phase. The core idea of ensuring that all debt financing of a project from foreigners is repaid within the period simulated (or that the present value of the debt enter welfare calculations) has been central to many regional (and national) CGE studies of major projects since then.

There is a large literature supporting the existence of a positive relationship between public infrastructure and regional economic development outcomes (e.g. Aschauer, 2000), as is the case nationally.[19] In countries such as Australia, much of the responsibility for the provision of public infrastructure rests with regional governments. Giesecke *et al.* (2008) evaluated a state government infrastructure project program under four alternative financing measures – three regional tax types and debt – over each year of a 25-year period. A key feature of this paper is the level of explanation of results for both the short and long terms. Giesecke *et al.* (2008) achieve this through an extended BOTE model; essentially a miniature regional CGE model parameterized using the database of the large-scale multiregional CGE. Their aim was to develop this "model of a model" sufficiently to capture the key mechanisms of the large model, but at the same time keeping it small enough for journal presentation. The authors were able to accurately reproduce the results from the main model with the miniature model and at the same time isolate the mechanisms driving their results, from the early years of the program to the long term. In Section 7.6, we undertake a similar exercise with our illustrative modern regional CGE model.

We consider that if regional CGE modeling is to influence policy, identification and explanation of the key model mechanisms underlying the results is critical. The topic of regional government financing alternatives is an important current policy question. Australia, for instance, has seen reduced spending on public infrastructure over the past

[18] Giesecke and Madden (1997) included industry assistance measures, as well as fiscal measures, in their examination of fully-funded regional-stimulus policies.

[19] Although debate remains on the size of the effect.

two decades, as regional governments have sought to restore their fiscal positions, following their exposure to failed government enterprises. Despite now having quite robust fiscal positions, Australian regional governments are reluctant to finance infrastructure through debt, and traditional regional taxes are seen as unpopular. Regional CGE modeling such as that undertaken by Giesecke *et al.* (2008) provide valuable insights to regional governments not only on the ranking of fiscal instruments, but also on the time paths of the total effects of both the infrastructure and each of the financing instruments.

Regional governments often see major events, such as the Olympic Games, as a major economic attractor to their region, leaving a legacy of inbound tourism and sporting and other infrastructure. Giesecke and Madden (2011) examined whether the large economic benefits often predicted for Olympics host countries necessarily materialize. They re-examined the Sydney 2000 Olympics via historical regional CGE modeling, taking care to avoid common sources of overestimation such as elastic factor supply assumptions and the failure to treat public inputs as costs. In particular, they conducted a simulation from 1997/98 to 2005/06 to uncover whether the Olympics did in fact give a tourism boost to the host region of New South Wales, as *ex ante* regional CGE modeling had predicted. Their historical simulation results did not provide support for the presence of an Olympics-induced tourism effect.[20] They then conducted a simulation for a no-Olympics counterfactual and find the Sydney Olympics generated a real consumption loss of $AUD2.1 billion; an economic cost against which the apparent non-use benefits from the Games could be compared.

Giesecke and Madden (1997, p. 16) suggest that: "Regional governments may have only a limited ability to influence the standard targets of regional development policy with either fiscal or industry assistance instruments" and that their ability "to influence *per capita* measures of well-being using conventional policy instruments is even more limited."[21] They note that implementing the program of microeconomic reforms as proposed under the national competition policy (NCP) agenda that was agreed to by the Australian federal, state and territory governments in 1995 would bring gains that dwarf any potential gains from industry assistance packages. Productivity Commission (1999) find that the major proposed NCP reforms would bring benefits in terms of real *per capita* regional income for states and territories ranging from 2.4% (Victoria) to 2.9% (Tasmania) and for substate regions from 1.5% (Goldfields-Esperance) to 7.4% (Gippsland).[22] Economic modeling of both national effects (Industry Commission, 1995) and regional

20 Giesecke and Madden argue that this is consistent with other information on the tourism effects of mega events in established tourism destinations and that econometric results for induced tourism in host cities (such as Seoul in 1988) that are emerging tourism destinations cannot be simply transplanted to more established tourism locations.

21 Indeed, like Morgan *et al.* (1996), Giesecke and Madden (1997) find that policies that have stimulatory effect on output and employment tend to have per/capita real consumption impacts of the opposite sign.

22 For a summary of regional CGE modeling of NCP, see Madden (2004).

effects (Madden, 1995) of NCP played a valuable role in obtaining the 1995 intergovernmental agreement.

An area of regional government policy which has been subject to a good deal of regional CGE modeling is the area of transport, a topic central to regional analysis. Much of the CGE analysis of infrastructure development concerns transport projects (e.g. Dixon and Madden, 1990; Haddad *et al.*, 2010). In the case of road transport projects benefits are usually computed as savings from reduced congestion (Conrad and Heng, 2002).[23] Kim *et al.* (2004), on the other hand, model investments in inter-regional highway networks as increasing accessibility, and evaluate benefits in terms of macroeconomic aggregates.

Regional CGE transport studies cover a much wider range of questions than purely infrastructure ones. These include tax-deductibility of commuting costs (Hirte and Tscharaaktschiew, 2011), freight pricing reforms (e.g. Norrie and Percy, 1983), rural development (Kilkenny, 1998) and urban spatial structure (Horridge, 1994). These applications have been associated with various extensions to the spatial aspects of regional CGE modeling, which we shall discuss in the next section.

Among the other topics to which regional CGE models have been applied are: industrial relations (Dixon and Wittwer, 2004); higher education (Giesecke and Madden, 2006); terrorism (Thissen, 2004; Giesecke *et al.*, 2012); regional resource, environmental and energy issues (e.g. Miyata, 1995; Cattaneo, 2001; Hanley *et al.*, 2009; Seung and Waters, 2010); and natural disasters (Rose and Liao, 2005; Horridge *et al.*, 2005; Wittwer *et al.*, 2005; Shibusawa and Miyata, 2011). The capability of a regional CGE model to provide convincing answers to a current controversial environmental question involving local and inter-regional issues is demonstrated in a recent paper by Dixon *et al.* (2011).

Dixon *et al.*'s (2011) paper relates to a controversial government policy to buy back irrigation water rights from farmers in the Southern Murray—Darling Basin (SMDB). The Murray—Darling Basin covers a large part of south-east Australia containing the country's most significant agricultural area.[24] Over the past two decades there has been much concern about the ecological health of the SMDB river system. In the 1990s, a cap was placed on the amount of water available to irrigators and a system of tradeable water rights was introduced. Water quality and salinity problems remained, however, and in 2010, a plan to reduce the quantity of water rights was released. This led to vehement protests in the SMDB amid fears that entire communities in the area were under threat.

23 Conrad and Heng compute congestion benefits within the CGE model, but most studies (normally contract research studies) impose time, fuel and repairs savings from external transport models, with the regional CGE model's task being to compute the real consumption benefits over the construction and operating years.

24 The Basin covers about one-seventh of Australia (an area over 1.5 times the size of Texas). Three quarters of all farming output from the Murray-Darling Basin is produced in the SMDB.

Dixon *et al*. (2011) examined a buyback scheme being implemented by the federal government that would reduce water rights by almost a quarter. Their results indicated that the scheme would actually slightly increase economic activity in the SMDB. While the scheme would sharply increase the irrigation water price and greatly reduce the output of some irrigated agricultural activities, resources would largely move from these to other SMDB farm activities, leaving total farm output in the 13 regions that make up the SMDB with reductions ranging from just over 0.5% to less than 2.5% (on average a reduction of 1.3%). Furthermore, farmers as holders of water rights, would gain from the increase in the water price, thus leading to an increase in real consumption in 10 of the SMDB regions.

With such a set of simulation results in a political environment of strong protest against the proposal, it was clearly important to be able to explain to policy makers the reasons underlying them. Dixon *et al*. (2011) start by discussing the effects of the buyback scheme on the price of water as this is the key variable in understanding the effects of the scheme. The buyback occurs in the first eight years of the simulation period of 2009–2018, with an assumed yearly purchase by government of one-eighth of the permanent water rights to be withdrawn under the scheme. While the *baseline* price rises to over $AUD80 per megaliter (Ml) by 2009, it falls with an assumed easing of the drought to less than $AUD20/Ml by 2018. Under the buyback scheme, which started in 2009, the price still initially falls, although at a lesser rate, before starting to climb sharply in 2013, reaching around $AUD110/Ml by 2018. A regression equation between the simulation price results for each year to 2018 and the proportionate reduction in irrigation water supply is then estimated (yielding an $R^2 = 0.99$).[25] The authors then point out that their result of a negligible effect of the scheme on GDP (0.0059% by 2018) is to be expected. A valuation of the lost contribution to GDP from the withdrawn water rights can be computed from the entire area under the demand curve for irrigation water (already estimated) between the new and old caps. In 2018 this is equal to $AUD97 million, or 0.0052% of GDP, which closely corresponds to the simulation result.

Dixon *et al*. (2011) provide similar reasoning as to why the impact on aggregate farm output for the SMDB is so low. $AUD97 million is 1.1% of SMDB farm output. The rest of the simulation result of −1.3 can be attributed to a small reduction in capital usage by the SMDB farm sector, particularly capital which can be used in the SMDB only by irrigated farms (e.g. vineyards). The authors also present farm industry output impacts for 2018 by the 13 regions within the SMDB. There are 17 industries producing 10 agricultural commodities. Three commodities are produced by an irrigated industry (Rice, Grapes and Vegetables); the other seven are produced by both an irrigated industry and by a dry-land farming industry (e.g. Cereal Dry and Cereal Irrigated). In

25 The authors note that their implied demand elasticity values for irrigation water (ranging from −0.13 with a low price to −0.30 with a high price) are close to those of a recent econometric study.

general, as might be expected, irrigated industries are negatively impacted, in some cases very severely, while dry-land industries are positively affected. There are exceptions, however, with some irrigated industries being positively impacted in two regions and one irrigated industry, Vegetables, being positively impacted in all regions. Also, in only five of the 13 regions is the expectation met that the relative size of the impact on a region would correlate well with the size of the region's share of irrigated industries in their total farm output. The authors observe that there are superficial explanations that can be given for each of these results. For instance, they note (Dixon *et al.*, 2011, p. 162) that with high water prices, vegetable farming is a better use of irrigable land and water than cultivating other crops such as rice. They are not satisfied, however, with such superficial answers and proceed to develop a proper understanding of their regional farm industry results.

We provide here a detailed summary of their investigation of their results. We do so because it provides an excellent example of how to unravel regional CGE results using a regression method. Dixon *et al.* (2011) commence their investigations by developing an equation that regresses the output impact on a particular farm industry in a particular region in a particular year against three indices of competitiveness. These indices are: (i) The SMDB's competitiveness in producing the industry's output, (ii) the competiveness of the region against other SMDB regions in producing the industry's output and (iii) the competitiveness of the industry against other producers of its output within the region (i.e. irrigated versus dry-land industries). These competitiveness indices are computed as relative effects of the schemes' impacts on regional industry costs. For any regional industry in any year the cost impact is initially assumed to be the percentage impact on the price of water multiplied by the regional industry's share of the value of irrigation water in its total costs.[26] The authors find that this equation provides quite a good explanation of output impacts with an R^2 of 0.76.

There were some regional industry results, however, for which the estimated equation was inadequate in providing an explanation. In Central Murray, Rice enjoys a positive impact while in other regions its impact is negative (though there is no interregional dissimilarity in irrigated water intensity) and the positive output impact for Vegetables is many times that for the industry in other regions. The explanation for this, the authors surmise, involves a collapse in the rental prices for irrigable land in Central Murray. Dixon *et al.* (2011, p. 163) say they would "expect increases in the price of irrigation water to cause relatively sharp reductions in rental prices of irrigable land in regions with two characteristics: (a) A high ratio for the value of irrigation water to irrigable land; and (b) limited options for using irrigable land in dry-land activities." They confirmed this surmise by regressing the percentage change in the rental price of

[26] The percentage impact on a variable is the percentage deviation between its policy forecast level and its base case (no buyback scheme) forecast level.

irrigable land in the region at time *t* against the percentage impact on the price of water in the region at *t* multiplied by shares representing these two characteristics and obtaining a very close fit ($R^2 = 0.95$). In particular, it explained why the average rental price in Central Murray fell so sharply, as it was very strong in both characteristics. Cost impacts were thus recomputed as equal to an appropriately weighted sum for the regional industry of the price of water *and* the rental price of land in the region. A re-estimation of the output to cost indices equation using the new cost impact estimates increases the equation fit ($R^2 = 0.80$) and more importantly finds simulated outputs for irrigated industries much closer to the new regression line.

Thus, by following their regression procedure for interpretation the authors are able to explain an important finding of their model: "In irrigation industries based on land with limited dry-land uses, land rents rather than outputs bear much of the damage from higher water prices" (Dixon *et al.*, 2011, p. 164). The subdued contractions in these industries are afforded by the purchase of water from other regions where irrigable land can be more easily adapted for use in dry-land activities. The fact that their model recognizes that irrigable land can be used as dry land, explains a remaining anomaly with the updated regression – it is poor in explaining the output impact on dry-land industries in Central Murray. The authors note that movements on the rental rates on irrigable and dry land in a region should show a close correspondence. When cost impacts are adjusted to also include the rental price of dry land the regression of output on cost indices yields an R^2 of 0.89.

Finally, the authors explain their real regional consumption results in terms of water exports, including the sale of permanent water rights to the federal government. Water which could have been used to make $AUD97 million in annual value added is sold under the scheme to the federal government for a price generating $AUD173 million in annual income. The authors also examine the case where half of these gains are not spent in the SMDB due to some farmers deciding to leave the region after permanently selling their water rights. This reduced the real consumption gains from over 0.3% to less than 0.1%, but had virtually no effect on farm outputs which direct little of their sales to local consumer demands. There are unlikely to be severe equity problems say the authors, as the owners of water rights will experience a simultaneous increase in the price of this asset and a reduction in returns to their irrigable land.

Dixon *et al.* (2011, p. 154) state: "No knowledge of CGE modeling is required to understand our results: they are explained in terms of familiar economic mechanisms." The above summary clearly demonstrates just how successful the authors were in this task.[27] Their article is a clear demonstration of how the intricate regional CGE model mechanisms can be

[27] It is true that Dixon *et al.* (2011) do start by alerting their readers to the agricultural production technology used in their particular model. The key aspects of this technology have been revealed in our summary, again clearly demonstrating how CGE stories can be told in a convincing way to the non-CGE modeler. We summarize the details of the technology in Section 7.3.5.5.

drawn out in such a way that a transparent account of modeling results can be presented to economists unfamiliar with CGE. It should also be clear from our summary that the essence of the story is extractable in a way that could be understood by a general audience.

7.2.4 Forecasting and historical analyses

We complete this section by considering regional CGE modeling as a forecasting tool and as a vehicle for explaining regional economic performance. As with national models over recent years, dynamic regional CGE models have been applied to forecasting (e.g. Adams *et al.*, 2000; Giesecke and Madden, 2003) and historical analysis (Parmenter and Welsh, 2001; Giesecke, 2002, 2008). As with national CGE models, historical modeling performs a number of purposes, including the updating of databases, uncovering trends in unobservable variables (e.g. technological and taste changes) to provide information for forecasting simulations, and detecting the major reasons underlying past movements in macroeconomic variables. Uncovering why some regional economies perform better than others has been a major research activity of regional economists for a long time. Giesecke and Madden (2010) argue that historical CGE modeling provides an avenue for obtaining a much richer set of results than more traditional methods such as shift-share analysis. They undertake an historical modeling exercise for the Australian states for the eight years to 2003/04. They isolate the key driving factors for the economies of Australia's six states and two territories. An instance of their findings is that tariff reductions, blamed by a number of commentators for the relatively slow growth of South Australia and Victoria over the period, had little effect. Rather, the "Dutch Disease" phenomenon had a far more important role, as the import-competing industries, in which South Australia and Victoria are over-represented, suffered from real appreciation resulting from the expansion of foreign demand for goods produced by the export-oriented states.

7.3 SHORT REVIEW OF THE DEVELOPMENT OF REGIONAL CGE MODELS

7.3.1 Basic regional CGE model types

In relation to their purely regional aspect, there are three basic types of regional CGE models. They are:

(i) Regional disaggregation attachment to national CGE models ("top-down" models).
(ii) Multiregional models of the national economy ("bottom-up" models).
(iii) Stand-alone models of single subnational regions.

There are variants of these basic types as we shall see, such as hybrid (top-down models with bottom-up elements) and multiregional models of just a part of a nation (e.g. regions of a single city). We look at each of these regional model types, including variants in the next three sections.

7.3.2 Top-down models

The essence of a top-down approach (in the terminology of Klein and Glickman, 1977) is the sequential running of a model at the super-regional level to obtain economy-wide results and then feeding these results into a second model that decomposes the national results into a set of regional results. The first of the regional CGE models, ORANI-ORES (Dixon *et al.*, 1978), was of this type.[28]

ORES (ORANI Regional Equation System) is based upon a method devised by Leontief *et al.* (1965) – commonly referred to as the LMPST method – for the frugal use of regional data in a multiregional input-output (MRIO) system. Central to the method is a division of industries into two groups: national and local. National industries produce only commodities that are inter-regionally tradable. Local industries produce commodities that can be traded only intra-regionally. Regional shares in aggregate output of national industries are assumed to stay constant and thus in ORES the percentage change in an industry's output in each region is simply equal to the industry's percentage change nationally (which is endogenous in ORANI, but effectively exogenous to ORES).[29] ORES determines the regional output of local industries via regional market-clearing equations for local commodities. Local demands involve intra-regional sales to producers, final demanders and margin services. Right-hand-side variables of this equation involve either constant regional shares (e.g. investment in national industries move by the same percentage in all regions) or variable shares computed so as to ensure aggregation of regional to national results.[30] An example of the latter is that investment in a local industry in region *r* moves with investment in that local industry nationally and with the movement in the ratio of the industry's output in *r* to the industry's output nationally. Similarly, regional consumption is driven by national consumption modified by movements in the ratio of the regional wage bill to the national wage bill; which in turn is a function of industry output. The regional balance equation thus captures regional multiplier effects. If a region is over-represented in strongly performing national industries – or under-represented in poorly performing ones – demand for local goods will be relatively stronger in that region.

Given an assumption of the same input-output technology in all regions, ORES' simple sourcing assumptions mean that very little regional data is required. ORES also has the advantage of having a simple theoretical structure, possessing attractive aggregation properties and incorporating two factors likely to be central to the determination of the distribution across regions of the effects of national economic shocks. These

28 For a full description of ORANI and ORES, see Dixon *et al.* (1982).

29 Note that, this is equivalent to the Leontief *et al.* (1965) assumption that all users of a national commodity, in every region, share the same geographical sourcing mix for that commodity (for details, see Dixon *et al.*, 1982).

30 For a full proof of ORES aggregation properties, see Dixon *et al.* (1982, pp. 277–283).

factors are: (i) Inter-regional differences in the industry composition of total regional output and (ii) intra-regional multiplier effects. ORES, however, has some obvious drawbacks: (i) There is no constraint on the mobility of capital across regions, (ii) there is no regional variation in any regional prices from those determined nationally in ORANI, (iii) the inter-regional pattern of a national industry's output is not responsive to any changes in the inter-regional pattern of demand, and (iv) the dichotomy between national and local industries may not be particularly realistic.

The first two drawbacks mean that the ORES decomposition is more appropriate to the long run than the short run. Even in the short run, however, problem (i) may be serious only for a few local industries which are highly capital intensive (particularly ownership of dwellings). Australian experience suggests that ORES works quite well in the case of national shocks. Parmenter and Welsh (2001, p. 209) note that the method "gives acceptable rankings of regional economic prospects but understates inter-regional differences."[31] One reason may be that problem (iv) is unlikely to be significant in the Australian context due to an aspect of Australian geography. Australia's principal population centers are generally a long way from state boundaries, and most commonly states have been the regions to which the method has been employed.

Problem (iv) can present more serious difficulties for disaggregating to substate regions, or even to the state level, for many other countries. Dixon *et al*. (2007) note the proximity in the US of many major cities to state borders across which virtually all commodities are traded. While practically none of the traditional local commodities (services and perishables) could be classified as local in the US, they find these commodities do not fit the national classification either. Advances in regional data estimation techniques that do not require a local—national dichotomy, however, meant that Dixon *et al*. (2007) were able to develop an updated top-down method that also dispensed with the national—local division. The new method is essentially a generalization of the original LMPST method. Its core idea is that equations for domestic demands can be specified in percentage change terms as follows:[32]

$$vR(r) = v + relR(r) - \sum_{g \in \mathrm{REG}} SHRV(g) \times relR(g), \tag{7.1}$$

where vR is a regional demand variable,[33] v is the corresponding national variable (essentially exogenous to the regional decomposition), $relR$ is a regional variable

31 Parmenter and Welsh find that they can improve their forecasts significantly by imposing information on regional macroeconomic aggregates and the regional distribution of output for national industries. They find satisfactory results are computed for local industries.

32 All variables beginning with a lower case letter are in percentage changes.

33 For example vR might be the percentage change in the demand by industry j in region r for commodity i from source s (domestic or foreign import) for purpose k (current production or capital formation).

(determined elsewhere in the top-down system) that is an appropriate variable for determining the difference between vR and v, and $SHRV$ is region g's share in the national level of V. Summing Equation (7.1) across regions gives:

$$\sum_{r \in \mathrm{REG}} SHRV(r) \times vR(r) = v. \tag{7.2}$$

Thus, we see from Equation (7.2) that the method produces regional results which aggregate to the national results.

Looking briefly at the major equations of the regional equation system described by Dixon *et al.* (2007), we note that the relevant variable for material demands for current and capital formation by industry j in region r, is the output of the industry. The relevant variable for region r household demands for each commodity from each source is the region's household disposable income. The relevant variable for export goods by region of exit is a shift variable which is normally exogenous, but could be shocked to alter regional shares in place of export. Government demands can be handled similarly. For margin demands to facilitate the flows of a good produced or landed in region r, the relevant variable is regional supplies of the good. Similarly, for margin demands on direct demand by region r for a good (by users and exit ports), the relevant variable is the region's demand for that good. Region r's aggregate demand for margin m is a weighted aggregation of all demands for the margin for which region r is responsible for organizing. Thus, Dixon *et al.* (2007) incorporate the idea that margins on the flow of a good from supplier to user can be supplied by more than one region. Disposable income movements vary regionally with regional employment differentials, which in turn are related to commodity supply differentials. Finally, the total supply of a commodity from a region (production or port of entry) is obtained by applying sourcing shares to all regional demands and summing all demands for the region of supply.

The new top-down theory could of course have been applied to a MRIO database computed by the LMPST method, but there would have been no advantage to this. We discuss details of methods for generating MRIOs in Section 7.5, in particular the "Horridge method" (Horridge *et al.*, 2005), which by generating sourcing shares as an intermediary step allows for the latest development in top-down modeling, as well as for advances in bottom-up modeling discussed in Section 7.3.2.

We discussed Dixon *et al.*'s (2007) first results with their new top-down method in Section 7.2.1, where the capabilities of the method for regionally decomposing national model results for economy-wide shocks were evident from the richness of their analysis of the effects of a tariff cuts on US regions. Giesecke (2008) similarly displays the advantages of employing the new top-down framework for historical CGE analysis.

Notwithstanding these capabilities for regionally distributing the effects of national shocks, the top-down method provides hardly any scope for modeling shocks emanating at the regional level.[34] A proper capacity for modeling region-specific shocks within a multiregional context requires a bottom-up model. Higgs *et al.* (1988) sought to avoid the cost of full-scale bottom-up modeling by introducing a hybrid method that incorporated some modeling of regional economic agents' behavior into the top-down method. This regional dimension was accomplished by redefining some industries as being region specific. In Higgs *et al.*'s model, ORANI-TAS, they focused on the island state of Tasmania, splitting certain industries into a Tasmanian component and an Australian mainland component. This allowed for a limited range of regional shocks (to variables associated with the regionally defined industries). Higgs *et al.*'s main motivation for improving on the top-down method was to lessen the ORES problem of constant regional shares in the output of national industries. Thus they regionally specified ORANI industries where the costs or sales shares of an industry differ substantially across regions. Thus, for instance, they split the Fruit industry for which Tasmania had a foreign export share of 60% compared to an 11% share in the mainland regions and a 66% labor cost share in value added compared to 42% on the mainland. As expected, these features make the Tasmanian Fruit industry much more responsive (3.5 times in fact) in Higgs *et al.*'s tariff-cut simulation. The recent developments in top-down modeling by Dixon *et al.* (2007) greatly lessen the value of the hybrid method as far as regional divergences in sales-share patterns are concerned.

The Higgs method may still have applications, particularly where the focus is on subregional areas within a bottom-up multiregional model — the class of models we are about to discuss next. Giesecke (1999) provides an example of this use of top-down modeling in decomposing Western Australian results from a two-region version of the FEDERAL model.[35] He employed the hybrid method by modeling key components of the Pilbara region within the Western Australian component of the bottom-up CGE model. Giesecke showed that explicit modeling of certain substate cost and sales differences were important to his results. While a budget-neutral removal of the fringe benefits tax was shown to have little impact at the national level, Giesecke projected a significant positive effect on the Western Australian economy and a very substantial positive impact on the Pilbara economy.[36]

34 Madden *et al.* (1983) did model a set of regional demand-side shocks with ORANI-ORES by decomposing the shocks into (small) national-level shocks to ORANI and shocks to ORES shift variables that changed regional shares in national expenditures (by government). This approach, however, basically picked up only input-output mechanisms at the regional level and, in any event, could not handle supply-side shocks.

35 The FEDERAL model is discussed in Section 7.3.3.

36 The fringe benefits tax is an Australian federal government tax on employer-provided non-cash benefits. Fringe benefits (and the associated tax) make up a relatively high proportion of labor costs of certain industry sectors in the remote mining region of the Pilbara.

7.3.3 Bottom-up models

The advent of a bottom-up multiregional CGE model in the early 1980s allowed for the possibility of a large range of supply-side shocks to be imposed at the regional level. The first such model was by Liew (1981, 1984a, 1984b) who built a six-region model of Australia, MRSMAE (Multi-Regional Multi-Sectoral Model of Australian Economy). As it turned out Liew's only application with MRSMAE was for a national shock – tariff reform. A major motivation of Liew's was to compare bottom-up with top-down modeling. He found more pronounced gross output effects regionally, and nationally, with MRSMAE than ORANI-ORES, but the reverse for employment. He intimates, however, that the differences may not be of a size sufficient to justify the extra effort of bottom-up modeling; particularly when subject to the data limitations that restricted the richness of his regional modeling.

While Liew's model was experimental, the next few years saw the advent of bottom-up multiregional CGE models that were aimed at capturing detailed regional features that would allow them to simulate a wide-range of regional questions, particularly in the area of fiscal federalism. The first of these was the six-region six-commodity model of Canada by Whalley and Trela (1986), which incorporated both regional and federal governments (each taxing and spending) plus inter-governmental transfers. A key feature was the model's handling of imperfect labor mobility across regions (which we report on in detail in Section 7.3.5.1). Whalley and Trela reported a range of simulations of national and regional reform policies and changes in fiscal federalism arrangements, although they reported only briefly on each of them. Further applications are reported in Jones and Whalley (1988 and 1989). Whalley and Trela (1986) also noted that they had constructed a 13-commodity version of their model, plus variants which treated: transport margins, returns to scale and a pure public good.

In order to realize his pioneering bottom-up model, Liew had reverted to treating margin sales as direct sales in his implemented version of MRSMAE. He also linked regional income to only wage income, treated commodity demands from a single government buyer as exogenous and did not allow for technical or taste changes.

An explicit treatment of transport as a supplier of margins is seen as being a highly desirable property for regional CGE models (Isard *et al.*, 1998). At the start of the 1990s a number of bottom-up CGE models (Madden, 1990; Buckley, 1992; Wigle, 1992) appeared that incorporated a detailed treatment of margins facilitating the delivery of goods. The latter two authors developed multiregional CGE models with a specific transport focus. Buckley's five-sector model, which covered three regions of the US, had similarities with the Jones and Whalley (1989) six-region Canadian model, with the particular inclusion of transport and wholesale margin services on direct flows being supplied by the origin and destination regions respectively.[37] Wigle aimed to capture a spatial dimension by introducing transport margins into his seven-region (six Canadian and the US) 13-commodity model. As his focus was on the importance of transport costs in trade restrictions, he kept the rest of his model simple, with goods being produced by a single technology and output distributed according to a regional production possibility frontier.

The third model to incorporate explicit modeling of margins was the FEDERAL model (Madden, 1990).[38] FEDERAL provided an early example of detailed general-purpose bottom-up multiregional modeling. Like MRSMAE, the starting point for FEDERAL's theory was the ORANI model, but unlike Liew, Madden retained all of ORANI's features, developing them into their full multiregional complexity, and then added a very detailed treatment of regional household income and a full treatment of two tiers of government.

A primary example of the multiregional complexity of FEDERAL is its handling of margins which could be supplied by both origin and destination regions on inter-regional trade. Similarly, it separately models commodity taxes levied by the federal government and each regional government (provided the good originates from or is sold in their region) with the rate varying according to the type of commodity, source of supply and class of purchaser. Detailed modeling of expenditures and revenue-raising by all governments (including intergovernmental transfers) is accompanied by a set of income and outlay accounts. These features allowed for detailed modeling of fiscal federalism and regional policy issues (e.g. Madden, 1989, 1993; Dixon *et al.*, 1993; Giesecke and Madden, 1997). A key feature of FEDERAL is its treatment of real disposable income that was probably the most detailed for a CGE model at that time. For each regional household, it is calculated as the sum of all factor incomes earned by residents from all regions, plus all transfer income (such as unemployment benefits and interest receipts) less all direct taxes (such as income taxes, land taxes and fines) and interest payments.[39] Madden (1996) demonstrates that inter-regional variations in the extent of local ownership and the degree of reliance on social security payments can play a significant role in regional short-run results. A number of later variants of FEDERAL were constructed during the 1990s, by far the most important of which was a dynamic version, FEDERAL-F, constructed by Giesecke (2002, 2003). FEDERAL-F contains all

37 While the six-region Canadian model was reported first in Whalley and Trela (1986), it is often cited in the literature as the Jones and Whalley model.

38 FEDERAL was initially entitled TASMAIN and its theoretical structure was first outlined in Madden (1987).

39 An aspect of FEDERAL worth noting is its treatment of investment. It incorporates a multiregional version of the ORANI investment theory, with all domestic and foreign investors allocating investment across regional industries in order to equate expected rates of return. This contrasts with the Whalley and Trela model, which does not treat investment behavior. Madden (1989) showed this distinction can be particularly important in short-run simulations of regional taxes that fall on fixed capital. As we show in Section 7.6, it is also important in correctly modeling short-run regional aggregate demand responses for a more general range of shocks.

the features required for detailed forecasting and historical, as well as policy, analysis and we discuss this in Section 7.3.5.2.

Due to computing restrictions in the late 1980s, and the increase in dimensions required to allow for margins to be supplied, and commodity taxes to be imposed, by both origin and destination regions, Madden (1990) kept his model to a two-region implementation – a region of focus (initially Tasmania) and the rest of the country – and initially kept the number of industries to nine.[40] A desire to overcome these restrictions led to the construction of an eight-region model of Australia with minimal dynamics, MMRF (Naqvi and Peter, 1996). MMRF again was fashioned on the ORANI model, and overcame the dimensionality problem from the larger number of regions by assuming margins to be supplied only by destination regions and (in the initial version) by not distinguishing governments in the imposition of indirect taxes (tax revenues being assigned to their respective government by a decomposition on the basis of base-year shares). MMRF has become the workhorse model for Australian CGE modeling, having been used in hundreds of applications over almost two decades. It too has been converted to a recursive dynamic model (Adams *et al.*, 2000) and has been subject to continuous development, including the incorporation of extensive greenhouse gas accounting and climate change policy features, disaggregated treatment of the transport sector (including a private motor vehicle industry), and government and income modeling along similar lines to FEDERAL.[41] Multiregional CGE models for other countries, notably the B-MARIA (Haddad, 1999) model of Brazil, have used the MMRF code.

While a large-scale general purpose multiregional CGE model like MMRF provides a powerful tool for analyzing a very wide range of regional economic issues for a model containing a moderate number of regions (like the eight regions of Australia in the standard MMRF model), it suffers from problems of dimensionality when bottom-up modeling is required for a large number of regions. In order to overcome this problem Horridge *et al.* (2005) adopted an approach commonly used in multicountry modeling to develop TERM (The Enormous Regional Model). This involves different classes of agents being assumed to be identical in certain aspects of their technology or tastes. Horridge *et al.* assume that all agents in any region *r* source their inter-regional imports from the other regions in identical proportions.[42] This assumption allows for inter-regional sourcing and associated margins data to be stored in satellite accounts. The authors demonstrate TERM's capacity for modeling many (45) regions and many (38) sectors in an application on the effects of the

40 Later versions of FEDERAL focused on other Australian states (or in the case of Dixon *et al.*, 1990, an aggregation of two states) and featured a substantial number of industries (over 100 in the Western Australian version).

41 As a consequence of its extensive greenhouse gas features, the dynamic version of MMRF is sometimes referred to as MMRF-GREEN. See Adams and Parmenter in Chapter 9 of this Handbook for a review of greenhouse modeling with MMRF. For detailed documentation of MMRF, see Adams, *et al.* (2010).

42 This assumption carries virtually no penalty, since it is likely that in most cases there is little information on how a region's economic agents might differ in their sourcing patterns.

2002–2003 Australian drought, which had variable rainfall impacts across the country. In order to further increase the capacity of TERM to include very small regions in their multiregional structure for particular applications, Wittwer and Horridge (2010) construct a massive database for many small regions from census data, and introduce a variable aggregation facility for regions, industries and commodities.

A feature of TERM is that its use of satellite accounts reduces the dimensions of the margins matrix sufficiently to allow for margins to be imposed at origin (place of manufacture or port of entry), destination (place of use or port of exit) and by any region along the transport route. TERM has opened up a new scope of multiregional CGE modeling of individual nations. Versions have now been created for Brazil, China, Finland, Indonesia, Japan, Poland and South Africa.

Bottom-up multiregional models have become the most common general purpose type in regional CGE analysis. Outside the Australian and Brazilian general purpose multiregional CGE models, AMOSRUK – a CGE model of Scotland and the rest of the UK (McGregor *et al.*, 1999; Gillespie *et al.*, 2002b) – is one of the best known. We will look at a further group of multiregional CGE models in Section 7.3.5.4 relating to transport and land use.

7.3.4 Single-region models

A substantial number of regional CGE models have been of just one region (almost half the regional CGE models listed in Partridge and Rickman (1998) fall into this category). This would seem a very reasonable approach for models designed for specific purposes, particularly when the region is quite small – such as Churchill County, Nevada (Seung *et al.*, 2000) or Fort Collins, Colorado (Schwarm and Cutler, 2006). It is true that once an input-output table is available for the region in question, a two-region database for the nation can be computed by a residual method (Madden, 1990), but this is likely to be an unnecessary time-consuming task for many regional CGE model applications. It is also true that single-region general-purpose CGE models can be very successful. The best known of such single-region models is the AMOS model of Scotland (Harrigan *et al.*, 1991), which has been used continuously for the past two decades.[43]

Lofgren and Robinson (2002) express a concern that subnational single-region models "may generate misleading results since they do not allow for inter-regional and nation-region feedbacks." Experience has shown, however, that for regional economies of 10%, or even more, of the nation's output, such feedback effects are not of a large order of magnitude. For instance, McGregor *et al.* (1999) find the same basic results for

[43] A characteristic of successful single-region models is that they properly treat net migration to (or from) the region. Such migration modeling has always been a feature of the AMOS model. Inter-regional population movement is particularly important for small-region models. Examples of small-region CGE models are Seung *et al.* (2000) who treat inter-regional migration, and Schwarm and Cutler (2006) who also account for commuting.

Scotland for long-run simulations with AMOSRUK, as they did with AMOS (McGregor *et al.*, 1996a). In essence, they find with both models that the own-region effects of a regional demand shock in a CGE model converge on an input-output result in the long run where virtually all factors are inter-regionally mobile. The point of their 1999 paper, however, is that for the other region (rest of UK), the long-run result is nothing like an input-output result, being completely opposite in sign. This points to a potential problem with single-region models in a policy context. By concentrating on the effects on a single region resulting from, say, regional development policies that are not self-funded within the region, negative effects on other regions are ignored. This can give rise to misleading perceptions and it is important that researchers using single-region CGE models bring attention to any such qualification of their results.

7.3.5 Developments in incorporating key regional features

7.3.5.1 Regional labor markets and inter-regional migration

Regional and multiregional models have taken a variety of approaches to the treatment of inter-regional migration. A substantial number of regional CGE models assume that labor is immobile across regions, particularly single-region models (e.g. Despotakis and Fisher, 1988). This assumption is more likely to be the case when the study is just for the short run (e.g. Li and Rose, 1995). Other studies take the opposite long-run approach and allow for endogenous inter-regional migration to equalize wages (e.g. Morgan *et al.*, 1989) or utility (e.g. Groenewold *et al.*, 2003). Many other regional CGE models, however, allow for *imperfect* inter-regional labor mobility.

Whalley and Trela (1986) were the first to incorporate imperfect inter-regional labor mobility into a regional CGE model.[44] Their migration theory was developed from their observation that individuals have "direct associations with specific regions" (p. 74). They assume that there is a distribution of individuals within each region who differ only by their intensity of preference for remaining in the region. In making decisions about migration, individuals compare the utility they would receive from residing in each of the regions. The marginal individual (i.e. the individual indifferent to migrating or remaining) is assumed to treat utility as just coming from income and (as they are the marginal individual) the income receivable is the same for each region of residence.[45] All other individuals face a utility penalty from relocating, with the penalty increasing with the intensity of their location preference. If out-of-region income were to increase following some shock, out-migration would occur – until for the *new* marginal individual, home region income would just equal the income they could receive outside the region less the location penalty from shifting. That is, individuals tradeoff the extra

[44] A description detailing the model's migration theory can also be found in Jones and Whalley (1989).

[45] "Income" is the sum of real incomes from labor, natural resource taxes and federal government transfers to the region.

income they would receive by migrating against the loss from leaving their preferred location. Thus, in the new equilibrium inter-regional wage differentials are consistent with zero migration.

The responsiveness of inter-regional migration to inter-regional income differentials depends on the parameterization of location preferences. Jones and Whalley (1989, p. 386) point to difficulties in setting the value of this parameter to be consistent with econometrically estimated elasticities of out-migration. Other modelers use equations directly employing econometrically estimated parameters for net migration (e.g. Rickman, 1992; McGregor *et al.*, 1995, 1996b; Fry *et al.*, 1999; Rutherford and Törmä, 2010).[46] McGregor *et al.* model net migration to equalize a function of inter-regional differences in unemployment, wage rates and regional amenities, with gradual adjustment of regional wage rates to return populations to equilibrium (i.e. a zero net migration rate).[47]

In Section 7.4.11 we develop an alternative treatment of inter-regional migration. As with McGregor *et al.*, persons decide on the region they will reside in on the basis of differentials in wage and employment rates and amenities. Shocks to these differentials cause a disequilibrium in gross regional migration rates according to a logistic curve. Migration occurs until the disparities in real regional wage relativities reach a new equilibrium. The advantage of this approach is that it allows gross migration flows to be tracked. The latter is useful in keeping account of movements in regional ownership of capital and land.

Regional CGE models use a variety of regional wage setting alternatives. A feature of the AMOS model is the range of alternative labor-market closures that can be used (Harrigan *et al.*, 1991). In countries where national wage-setting institutions exist, it has often been assumed that wages are set at the national level.[48] Models with an imperfect inter-regional migration theory often incorporate some type of regional wage-bargaining mechanism. For instance, Ferguson *et al.* (2007) employs a standard econometrically estimated regional bargaining equation for AMOS. In Section 7.4.10.1 we present an alternative wage equation that returns the regional employment rate to its base case path after a number of years.

7.3.5.2 Dynamics

Most regional CGE models have been comparative static, but as with their national counterparts, there has been a move in regional CGE models towards a dynamic

46 Berck *et al.* (1997) allow the regional working population to be affected by both migration and the participation rate, which in turn is a function of real after-tax wages.

47 McGregor *et al.* (1996b) simulate an improvement in amenities in Scotland and find that while population, employment and output in the region are positively affected, the Scottish employment market is adversely affected. Depending on the labor market closure employed there is a fall in the real consumer wage rate and/or an increase in the unemployment rate. That is, the inducement to migrate to Scotland by the higher amenities is eventually completely offset by the region's weaker labor market, thus re-establishing a zero net migration rate.

48 See, e.g. Madden (1993). In Australia, it is now less common to assume national wage settings as the central wage system has been very much weakened.

specification. Examples are the AMOS model (see, e.g. McGregor *et al.*, 1996) and the multiregional model of Korea by Kim and Kim (2003). In general, such models assume a base case of a steady-state growth path (e.g. Seung and Kraybill, 1999). On the other hand, the dynamics in FEDERAL and MMRF have been fashioned on the MONASH model, and therefore can be run under historical, decomposition, forecast and policy closures. These closures are discussed in Dixon *et al.* in Chapter 2 of this Handbook in this volume and thus we do not discuss them here, except to point out the advantages of this approach in: producing regional forecasts (Adams *et al.*, 2000), identifying regional adjustment issues (Giesecke and Madden, 2007) and allowing for the effects of underlying movements in the database (Dixon and Rimmer, 1999).

7.3.5.3 Government and intergovernmental finances

A detailed treatment of national and regional government expenditures and revenues, and intergovernmental financial transfers is usually incorporated into large-scale general-purpose multiregional models. These features are not only useful for considering fiscal federal issues and regional government fiscal policies, but also enable applications on a wide range of shocks to report impacts on regional budgets – a factor usually of quite some interest to regional policy makers. Models explicitly set up for revenue analysis are likely to contain significant regional tax details. The DRAM model (Berck *et al.*, 1996), for instance, contains separate modeling of state and local governments. They also capture a feature of the US economy that regional taxes affect federal tax liabilities. For countries with fiscal equalization arrangements, some models explicitly incorporate central-regional grant distribution formulae (e.g. Whalley and Trela, 1986).

Special-purpose regional CGE models have been constructed to introduce innovations in modeling fiscal federalism. For instance, Groenewold *et al.* (2003) constructed a small experimental model that merged a CGE component with a political-economy component that contained competitive regional governments which solve an optimization problem subject to the CGE results. In Section 7.3.2 we discussed the Dixon *et al.* (2002, 2005) simulation of changes in fiscal equalization arrangements. They constructed the CSF (Commonwealth-State Funding) model aimed at including those things important to modeling the efficiency effects of the allocation of central government grants to regional governments. CSF included: optimizing state governments that incorporated a flypaper effect in their social welfare function; a labor–leisure tradeoff; mineral resource rents; and congestion in intra-regional travel.

7.3.5.4 Transport, land use and agglomeration

One of the main areas of developments in regional CGE models in recent years has related to the issues of transport and agglomeration. A driving force for this has been the advent of the new economic geography (Krugman, 1991). There have now been a considerable number of multiregional CGE models constructed that incorporate agglomeration economies — essentially external economies of scale related to regional economic size and spatial compactness. The most prevalent approach to capturing agglomeration economies is by incorporating in the regional CGE model the well-known Dixit—Stiglitz specification of monopolistic completion.[49] Prominent papers are by Kilkenny (1998, 1999) and Bröcker (2001, 2002). Kilkenny (1998), for example, employs her model to show a non-monotonic relationship between relative transport costs (agriculture to non-farm transport) and the rural share of the US national work-force. The result is consistent with long-term rural—urban trends — the reduction in non-farm products transport costs gradually eroded local natural protection for manufacturing in rural areas, but as these transport costs fell further, along with the rural—urban wage rate ratio, it became profitable for certain activities such as mail-order retailers to move to cheap labor rural locations.

The above models used, like Krugman, the "iceberg" transport assumption. The RAEM model of the Netherlands (Thissen, 2005), however, incorporates a transport industry that supplies freight margins. RAEM models both commuting and migration in the computation of regional labor supply. Regional labor market behavior is based on search theory, with the outcome generating the matrix of commuting. In medium-run analysis there is limited migration, but in the long run migration acts to equalize utility across regions. Utility is a constant elasticity of substitution (CES) combination of consumption utility (itself a Stone—Geary function of non-transport consumption) and amenities utility. The latter is dependent on the ratio of a given amount of housing stock to resident population. Agglomeration economies are captured via a Dixit—Stiglitz CES aggregation of varieties of each intermediate input from regional sources.[50] Transport costs for freight, commuting and shopping, however, are computed in a separate transport model that takes into account all transport infrastructure and transport logistics.[51]

An alternative to using the Dixit—Stiglitz approach is to capture agglomeration economies through the use of an accessibility approach (Kim *et al*., 2004; Haddad and Hewings, 2005; Madden and Gwee, 2010). Kim *et al*., and Madden and Gwee both use a separate transport model to compute accessibility indices.[52] An improvement/

49 For reviews of this class of regional CGE models, see Bröcker (2004) and Donaghy (2007).

50 Similarly, the regional consumers' utility function allows for a love of variety.

51 Thissen (2005) notes that shopping costs are generally non-monetary costs. He observes that, while often ignored in models treating monopolistic competition, shopping costs "are definitely not negligible in the case of services" (p. 69).

52 There are various definitions of accessibility indices characterizing economic agglomeration. A typical index for any region j is computed as the aggregation across all regions in some wider area encompassing j of their regional economic size discounted by their effective travel distance from j. Common measures used for regional economic size are income, population and employment. Effective travel distance takes into account the cost of travel, including time.

deterioration in accessibility drives an improvement/deterioration in productivity in their multiregional CGE models.[53] Kim *et al.* (2004) found that the Korean Highway projects examined increased both economic activity and regional welfare.[54] Madden and Gwee (2010) found that the regional economic effects of the change in accessible workforce induced by a transport infrastructure shock are swamped by the conventional labor-market effects resulting from the shock.[55]

While the RAEM model takes regional housing stocks as given, Horridge (1994) constructed a model of the city of Melbourne, Australia, which explicitly models two types of residential land (houses and apartments), industrial land and other land. In Horridge's model workers decide according to a logit model where to work, where to live and the plot size of the land they reside on. Utility for each person in income class s working in region w, residing in region h on plot size r is obtained from the consumption of land services and other goods. Disposable income for each person is comprised of wage income, rental and redistributed tax income less commuting transport costs. Thus a person's work location determines income before transport costs. Their choice of region of residence and plot size implies their spending on transport and land, with remaining income being available for spending on other goods. Alternative closures specify the degree to which land can be swapped between alternative uses in each of nine residential zones.

CGE models of cities, or commuting regions (e.g. the 44 regions of the Netherlands modeled in RAEM), tend to be specific to certain areas of applications (such as transport economic questions), rather than being general-purpose models. For instance, Horridge's model is for regions within one city, excludes freight costs and trade external to Melbourne. However, his model has proved powerful in uncovering the likely effects of policies designed to reduce transport costs and urban sprawl. For instance, Horridge (1994) found that taxes on travel tend to be successful as they create an incentive to work and live in the same, or geographically, close regions. He also simulated urban consolidation (an increase in apartments compared with houses) and found it led to a more compact city, but had little effect in reducing transport use.[56]

53 For instance, Madden and Gwee (2010) adopt elasticities of productivity to agglomeration estimated by Graham (2007) for the UK, to compute the productivity loss from commuter congestion.

54 In a subsequent regional CGE study of the Korean transport network, Kim and Hewings (2009) found synergy effects from a set of highway infrastructure developments across the network.

55 Madden and Gwee (2010) use a five-region variant of the TERM model, featuring three regions in the city of Melbourne which are subject to the infrastructure shock.

56 The reason for the smallness of the effect on transport use (and associated energy use) was partly due to geometry; travel distances do not fall at the same rate as city area. The other reason arose from the substantially lower rent payments resulting from the policy. Lower expenditure on land leaves more income for expenditure on transport, which while not directly entering utility, increases options for work and residential locations.

7.3.5.5 Other innovations

We look at just a further two innovations here. One is the embedding of specific-purpose modules within general-purpose regional CGE models. Examples are the inclusion of travel modules to incorporate congestions, such as in the CSF model discussed in Section 7.3.5.3 and Conrad and Heng's (2002) model referred to in Section 7.2.3. Another example is the model used by Dixon *et al.* (2011) to analyze a scheme to buyback water rights from farmers in the SMDB of Australia; a simulation discussed in detail in Section 7.2.3. They used a variant of the TERM model (TERM-H_2O). The features of this model are alluded to in our explanation of their results. In essence, their TERM-H_2O involved a detailed modeling of agricultural inputs. This chiefly involved a specification of each regional farm industry's production function in a way that captured the essential features of farmers' input choices. Labor was split into hired labor and farm owner-operators, and capital into specific farm capital and general capital. At the top level, primary factors is a CES aggregation of land and operator, general capital and hired labor. Land and operator is a CES aggregation of specific capital (e.g. orchards), operator labor and total land, itself a CES combination of effective land and cereal (i.e. feed for livestock). Effective land is made up of a CES combination of dry land, irrigated land and unwatered irrigable land. In turn, irrigated land is a Leontief combination of unwatered irrigable land and water. Unwatered irrigable land is allocated to an irrigated use or a dryland (i.e. unwatered) alternative according to a CET function. Water and cereal are inter-regionally tradable. It will be clear from our earlier discussion that the introduction of this specification of farm production is sufficient to generate a very policy-relevant set of results that meet the essential realities of farm production.

The other innovation is a top-down linkage of two CGE models – a national CGE model, MONASH, and a multiregional one, MMRF. In practice, regional CGE modelers in responding to requests from industry and government to provide policy analyses with short deadlines are at times torn between alternative models, each appropriate to aspects of the question, but no model covering all aspects. Dixon *et al.* (2010) were asked by the Australian government to model a proposed wage increase to Australian workers covered by federal awards and to provide detailed regional results. MONASH contained detailed modeling of labor demand and supply by award and non-award workers, but lacked the required regional dimension (top-down being inappropriate for awards that fell unevenly across states). The authors ran the models in sequence, using MONASH to compute the degree of pass-through of award wage changes to non-award wage rates. MMRF was then shocked with a set of industry by state wage rate changes, which combined award wage rate shocks together with the non-award wage rate results from MONASH, according to state-specific shares. The models were kept compatible by imposing national macroeconomic results from MONASH on MMRF.

7.4 A MODERN MULTIREGIONAL CGE MODEL

We now turn to look at the features of a bottom-up multiregional CGE model in more detail. In doing so, we describe the major components that comprise a typical modern multiregional CGE model. We build our explanation around a fully-dimensioned MRIO database and ancillary regional accounts, as depicted in Figures 7.1 and 7.2. The MRIO database is a helpful framework around which to discuss the structure of a multiregional CGE model. One way of conceiving of such a model is as a set of equations sufficient to describe the value flows of the MRIO database. To facilitate our use of the MRIO database to describe the equations of a multiregional CGE model, we identify in Figure 7.1 the price, quantity and tax variables underlying each value flow. These variables are described in Table 7.1. In Sections 7.4.1–7.4.13 below, we describe the decisions that builders of multiregional CGE models have made in modeling the individual variables identified in Figures 7.1 and 7.2. As we do so, we also point out specific features of the version of the dynamic multiregional CGE model, MMRF, that we use in Section 7.6 to illustrate the use of BOTE methods to describe simulation results.

7.4.1 Demand for inputs to current production

Examining the first column of Figure 7.1 (in conjunction with the variable descriptions in Table 7.1), we find region-specific industries requiring intermediate inputs $\left(X^{(1)(j,r)}_{(i,s)}\right)$, labor $\left(X^{(1)(L)(j,r)}_{(o,h,s)}\right)$, capital $\left(X^{(1)(K)(j,r)}_{(h,s)}\right)$ and natural resources $\left(X^{(1)(N)(j,r)}_{(h,s)(t)}\right)$ as inputs to current production. Use of these inputs generates output, or in a multiproduction model, a generalized capacity to produce output, which we describe in Figure 7.1 by $Z^{(1)}_{(j,r)}$.

The large number of inputs to any regional industry (j,r)'s output described in Figure 7.1 by $X^{(1)(j,r)}_{(i,s)}$, $X^{(1)(L)(j,r)}_{(o,h,s)}$, $X^{(1)(K)(j,r)}_{(h,s)}$ and $X^{(1)(N)(j,r)}_{(h,s)(t)}$ potentially introduces a very large number of substitution elasticities for which the modeler must obtain independent econometric estimates. In practice, this task is normally simplified by assuming that industries face nested production functions. Generally, the top-level of the production nests is Leontief, or fixed proportions. Thus in MMRF, which we employ in Section 7.6, industry (j,r) uses effective inputs of intermediate inputs undifferentiated by source $\left(X^{(1)(j,r)}_{(i,\bullet)}\right)$ and effective inputs of primary factors undifferentiated by factor type and factor ownership $\left(X^{(1)(\bullet)(j,r)}_{(\bullet)}\right)$ in fixed proportions to produce a given level of activity $\left(Z^{(1)}_{(j,r)}\right)$.

			(1)	(2)	(3)	(4)	(5)
		agent:	**Producers**	**Investors**	**Household**	**Export**	**Government**
	Flow type:	Size	$J \times R$	$J \times R$	$H \times R$	1	G
(1)	**Basic flows**	$I \times S$	$BAS1^{(j,r)}_{(i,s)} = P^{(0)}_{(i,s)} \cdot X^{(1)(j,r)}_{(i,s)}$	$BAS2^{(j,r)}_{(i,s)} = P^{(0)}_{(i,s)} \cdot X^{(2)(j,r)}_{(i,s)}$	$BAS3^{(h,r)}_{(i,s)} = P^{(0)}_{(i,s)} \cdot X^{(3)(h,r)}_{(i,s)}$	$BAS4^{(r)}_{(i)} = P^{(0)}_{(i,r)} \cdot X^{(4)(r)}_{(i)}$	$BAS5^{(g,r)}_{(i,s)} = P^{(0)}_{(i,s)} \cdot X^{(5)(g,r)}_{(i,s)}$
(2)	**Margins**	$I \times S \times M \times R$	$MAR1^{(j,r)}_{(i,s)(m,k)} = P^{(0)}_{(m,k)} \cdot X^{(1)(j,r)}_{(i,s)(m,k)}$	$MAR2^{(j,r)}_{(i,s)(m,k)} = P^{(0)}_{(m,k)} \cdot X^{(2)(j,r)}_{(i,s)(m,k)}$	$MAR3^{(h,r)}_{(i,s)(m,k)} = P^{(0)}_{(m,k)} \cdot X^{(3)(h,r)}_{(i,s)(m,k)}$	$MAR4^{(r)}_{(i)(m,k)} = P^{(0)}_{(m,k)} \cdot X^{(4)(r)}_{(i)(m,k)}$	$MAR5^{(g,r)}_{(i,s)(m,k)} = P^{(0)}_{(m,k)} \cdot X^{(5)(g,r)}_{(i,s)(m,k)}$
(3)	**Commodity taxes**	$I \times S \times G \times R$	$TAX1^{(j,r)}_{(i,s)(g)} = P^{(0)}_{(i,s)} \cdot X^{(1)(j,r)}_{(i,s)} \cdot T^{(1)(j,r)}_{(i,s)(g)}$	$TAX2^{(j,r)}_{(i,s)(g)} = P^{(0)}_{(i,s)} \cdot X^{(2)(j,r)}_{(i,s)} \cdot T^{(2)(j,r)}_{(i,s)(g)}$	$TAX3^{(h,r)}_{(i,s)(g)} = P^{(0)}_{(i,s)} \cdot X^{(3)(h,r)}_{(i,s)} \cdot T^{(3)(r)}_{(i,s)(g)}$	$TAX4^{(r)}_{(i)(g)} = P^{(0)}_{(i,r)} \cdot X^{(4)(r)}_{(i)} \cdot T^{(4)(r)}_{(i)(g)}$	$TAX5^{(g,r)}_{(i,s)(g)} = P^{(0)}_{(i,s)} \cdot X^{(5)(g,r)}_{(i,s)} \cdot T^{(5)(g,r)}_{(i,s)(g)}$
(4)	**Labor**	$O \times H \times R$	$LABR^{(j,r)}_{(o,h,k)} = W^{(j,r)}_{(o)} \cdot X^{(1)(L)(j,r)}_{(o.h,k)}$				
(5)	**Labor taxes**	$O \times H \times R \times G$	$LABT^{(j,r)}_{(o,h,k)(g)} = W^{(j,r)}_{(o)} \cdot X^{(1)(L)(j,r)}_{(o,h,k)} \cdot T^{(1)(L)(j,r)}_{(o,k)(g)}$				
(6)	**Capital**	$H \times S$	$CAPR^{(j,r)}_{(h,s)} = R^{(K)(j,r)} \cdot X^{(1)(K)(j,r)}_{(h,s)}$				
(7)	**Capital taxes**	$G \times H \times S$	$CAPT^{(j,r)}_{(h,s)(g)} = R^{(K)(j,r)} \cdot X^{(1)(K)(j,r)}_{(h,s)} \cdot T^{(1)(K)(j,r)}_{(s)(g)}$				
(8)	**Natural resources**	$H \times S \times T$	$NATR^{(j,r)}_{(h,s)(t)} = R^{(N)(j,r)}_{(t)} \cdot X^{(I)(N)(j,r)}_{(h,s)(t)}$				
(9)	**Natural resource taxes**	$G \times H \times S \times T$	$NATT^{(j,r)}_{(h,s)(t)(g)} = R^{(N)(j,r)}_{(t)} \cdot X^{(1)(N)(j,r)}_{(h,s)(t)} \cdot T^{(1)(N)(j,r)}_{(s)(t)(g)}$				
(10)	**Production taxes**	G	$PTAX^{(1)(j,r)}_{(g)} = P^{(1)}_{(j,r)} \cdot Z^{(1)}_{(j,r)} \cdot T^{(1)(g)}_{(j,r)}$	$PTAX^{(2)(j,r)}_{(g)} = P^{(2)}_{(j,r)} \cdot Z^{(2)}_{(j,r)} \cdot T^{(2)(g)}_{(j,r)}$			

Trade taxes	Commodities
I	$TARF^{(fed)}_{(i)} = P^{(0)}_{(i,imp)} \cdot X_{(i,imp)} \cdot T^{(fed)}_{(i,imp)}$

Multi-production	Regional industries
Regional commodities	$MAKE^{(i)}_{(j,r)} = P^{(0)}_{(i,r)} \cdot X^{(0)(i)}_{(j,r)}$

Figure 7.1 MRIO database and associated price, quantity and value variables.

(A)	**Household net interest on foreign debt**	H x R	$HINT^{(h,r)}$
(B)	**Foreign net transfers to the private sector**	H x R	$FTRN^{(h,r)}$
(C)	**Government transfer payments**	G x H R	$GTRN^{(h,r)}_{(g)}$
(D)	**Private inter-regional transfers**	H x R H x R	$HTRN^{(h,r)}_{(t,k)}$
(E)	**Inter-governmental grants**	G x G	$GRNT^{(k)}_{(g)}$
(F)	**Household direct tax**	G x H x R	$HTAX^{(h,r)}_{(g)}$
(G)	**Government net interest on foreign debt**	G	$GINT_{(g)}$
(H)	**Foreign net transfers to the public sector**	G	$FTRN_{(g)}$

Set definitions

J: Set of all industries.
R: Set of all domestic regions.
I: Set of all commodities.
S: Set of all regions, namely, all domestic regions and foreign. Hence, S = R + 1.
M: Set of all margin commodities. Note that M is a subset of I.
G: Set of all regional governments and the federal government.
O: Set of all occupations.
T: Set of all natural resource types.
H: Set of all households.

Figure 7.2 Ancillary income and expenditure accounts.

Table 7.1 Variable descriptions for Figures 7.1 and 7.2

$\mathrm{BAS1}_{(i,s)}^{(j,r)}$	The value, at basic prices, of commodity *i* from source *s* used by industry *j* in region *r* for input to current production
$\mathrm{BAS2}_{(\mathrm{i,s})}^{(\mathrm{j,r})}$	The value, at basic prices, of commodity *i* from source *s* used by industry *j* in region *r* for input to gross fixed capital formation
$\mathrm{BAS3}_{(i,s)}^{(h,r)}$	The value, at basic prices, of commodity *i* from source *s* used by household *h* in region *r* for current consumption purposes
$\mathrm{BAS4}_{(i)}^{(r)}$	The value, at basic prices, of foreign exports of commodity *i* from domestic source *r*
$\mathrm{BAS5}_{(i,s)}^{(g,r)}$	The value, at basic prices, of commodity *i* from source *s* used by government *g* for public consumption purposes in region *r*
$\mathrm{CAPR}_{(h,s)}^{(j,r)}$	Post tax capital income earned by household *h* in region *s* on capital rented to industry *j* in region *r*
$\mathrm{CAPT}_{(h,s)(g)}^{(j,r)}$	Value of tax paid to government *g* on capital income earned by household *h* in region *s* on capital rented to industry *j* in region *r*
$\mathrm{FTRN}^{(h,r)}$	Domestic currency value of net foreign unrequited transfers to household *h* in region *r*
$\mathrm{FTRN}_{(g)}$	Domestic currency value of net unrequited foreign transfers to government *g*
$\mathrm{GINT}_{(g)}$	Domestic currency value of interest payments on net foreign liabilities of government *g*
$\mathrm{GRNT}_{(g)}^{(k)}$	Inter-governmental grant, by government *g* to government *k*
$\mathrm{GTRN}_{(g)}^{(h,r)}$	Transfer payments by government *g* to household *h* in region *r*
$\mathrm{HINT}^{(h,r)}$	Domestic currency value of net foreign interest payments by household *h* in region *r*
$\mathrm{HTAX}_{(g)}^{(h,r)}$	Direct tax payments levied by government *g* on household *h* in region *r*
$\mathrm{HTRN}_{(t,k)}^{(h,r)}$	Transfer payments by household *t* in region *k* to household *h* in region *r*
$\mathrm{LABR}_{(o,h,k)}^{(j,r)}$	Post tax value of labor payments earned by household *h* in region *k* working in occupation *o* in industry *j* in region *r*
$\mathrm{LABT}_{(o,h,k)(g)}^{(j,r)}$	Value of tax paid to government *g* on labor payments earned by household *h* in region *k* working in occupation *o* in industry *j* in region *r*

(*Continued*)

$\mathrm{MAKE}^{(i)}_{(j,r)}$	Value, at basic prices, of commodity *i* produced by industry *j* in region *r*
$\mathrm{MAR1}^{(j,r)}_{(i,s)(m,k)}$	The value of margin commodity *m* produced in region *k* used to facilitate intermediate input purchases of commodity *i* from source *s* by industry *j* in region *r*
$\mathrm{MAR2}^{(j,r)}_{(i,s)(m,k)}$	The value of margin commodity *m* produced in region *k* used to facilitate purchases of commodity *i* from source *s* for input to capital formation by industry *j* in region *r*
$\mathrm{MAR3}^{(h,r)}_{(i,s)(m,k)}$	The value of margin commodity *m* produced in region *k* used to facilitate private consumption purchases of commodity *i* from source *s* by household *h* in region *r*
$\mathrm{MAR4}^{(r)}_{(i)(m,k)}$	The value of margin commodity *m* produced in region *k* used to facilitate foreign exports of commodity *i* from region *r*
$\mathrm{MAR5}^{(g,r)}_{(i,s)(m,k)}$	The value of margin commodity *m* produced in region *k* used to facilitate public consumption purchases of commodity *i* from source *s* in region *r* by government *g*
$\mathrm{NATR}^{(j,r)}_{(h,s)(t)}$	Post tax natural resource rent earned by household *h* in region *s* on natural resource type *t* used by industry *j* in region *r*
$\mathrm{NATT}^{(j,r)}_{(h,s)(t)(g)}$	Tax paid to government *g* on resource rent earned by household *h* in region *s* on natural resource *t* used by industry *j* in region *r*
$P^{(0)}_{(i,s)}$	Basic price of commodity *i* from source *s*
$P^{(1)}_{(j,r)}$	Average output price received by industry *j* in region *r*
$P^{(2)}_{(j,r)}$	Purchaser's price of new units of capital installed in regional industry *j*,*r*
$\mathrm{PTAX}^{(1)(j,r)}_{(g)}$	The value of production taxes levied by government *g* on industry *j* in region *r*
$\mathrm{PTAX}^{(2)(j,r)}_{(g)}$	The value of per-unit or ad-valorem taxes collected by government *g* on gross fixed capital formation in regional industry *j*,*r*
$R^{(N)(j,r)}_{(t)}$	Rental price of natural resource type *t* used by industry *j* in region *r*
$R^{(K)(j,r)}$	Rental price of capital used by industry *j* in region *r*
$T^{(1)(N)(j,r)}_{(s)(t)(g)}$	Tax rate levied by government *g* on rents earned on natural resource *t* used by industry *j* in region *r* owned by domestic or foreign agent *s*
$T^{(1)(K)(j,r)}_{(s)(g)}$	Tax rate levied by government *g* on rents earned on capital used by industry *j* in region *r* owned by domestic or foreign households in *s*
$T^{(1)(L)(j,r)}_{(o,k)(g)}$	Tax rate levied by government *g* on wages earned by labor type *o* supplied by residents of region *k*, employed by industry *j* in region *r*
$T^{(1)(g)}_{(j,r)}$	*Ad valorem* production tax rate on output of industry *j*,*r*
$T^{(2)(g)}_{(j,r)}$	*Ad valorem* tax rate on units of new capital purchased by regional industry *j*,*r*

$T^{(1)(j,r)}_{(i,s)(g)}$	Rate of indirect tax levied by government g on purchases of commodity i from source s by industry j in region r for input to current production
$T^{(2)(j,r)}_{(i,s)(g)}$	Rate of indirect tax levied by government g on purchases of commodity i from source s by industry j in region r for input to capital formation
$T^{(3)(r)}_{(i,s)(g)}$	Rate of indirect tax levied by government g on purchases of commodity i from source s by households in region r
$T^{(4)(r)}_{(i)(g)}$	Rate of indirect tax levied by government g on exports of commodity i from region r
$T^{(5)(k,r)}_{(i,s)(g)}$	Rate of indirect tax levied by government g on purchases of commodity i from source s by government k for public consumption purposes in region r
$T^{(\mathrm{fed})}_{(i,\mathrm{imp})}$	Rate of duty levied by the federal government on foreign imports of commodity i
$\mathrm{TARF}^{(g)}_{(i)}$	Tariff revenue collected on commodity i by government g
$\mathrm{TAX1}^{(j,r)}_{(i,s)(g)}$	Value of indirect taxes collected by government g on purchases by industry j in region r of commodity i from source s for input to current production
$\mathrm{TAX2}^{(j,r)}_{(i,s)(g)}$	Value of indirect taxes collected by government g on purchases by industry j in region r of commodity i from source s for input to capital formation
$\mathrm{TAX3}^{(h,r)}_{(i,s)(g)}$	Value of indirect taxes collected by government g on current consumption purchases of commodity i from source s by household h in region r
$\mathrm{TAX4}^{(r)}_{(i)(g)}$	Value of indirect taxes collected by government g on exports of commodity i from region r
$\mathrm{TAX5}^{(k,r)}_{(i,s)(g)}$	Value of indirect taxes collected by government g on purchases of commodity i from source s by government k for public consumption purposes in region r
$W^{(j,r)}_{(o)}$	Wage paid by industry j in region r for labor type o
$X_{(i,\mathrm{imp})}$	Economy-wide imports of commodity i
$X^{(1)(L)(j,r)}_{(o,h,k)}$	Inputs of labor type o, supplied by household h resident in region k, used by industry j in region r for current production purposes
$X^{(1)(K)(j,r)}_{(h,s)}$	Inputs of physical capital to industry j in region r, owned by household h in region s
$X^{(1)(N)(j,r)}_{(h,s)(t)}$	Inputs of natural resource type t to industry j in region r, owned by household h in region s

(*Continued*)

$X^{(1)(j,r)}_{(i,s)(m,k)}$	Demand for margin commodity m produced in region k to facilitate intermediate input purchases of commodity i from source s by industry j in region r
$X^{(2)(j,r)}_{(i,s)(m,k)}$	Demand for margin commodity m produced in region k to facilitate purchases of commodity i from source s for input to capital formation by industry j in region r
$X^{(3)(h,r)}_{(i,s)(m,k)}$	Demand for margin commodity m produced in region k to facilitate private consumption purchases of commodity i from source s by household h in region r
$X^{(4)(r)}_{(i)(m,k)}$	Demand for margin commodity m produced in region k to facilitate foreign exports of commodity i from region r
$X^{(5)(g,r)}_{(i,s)(m,k)}$	Demand for margin commodity m produced in region k to facilitate public consumption purchases of commodity i from source s in region r by government g
$X^{(0)(i)}_{(j,r)}$	Production of commodity i by industry j in region r
$X^{(1)(j,r)}_{(i,s)}$	Inputs of commodity i from source s, used by industry j in region r for current production purposes
$X^{(2)(j,r)}_{(i,s)}$	Demand for commodity i from source s by industry j in region r for input to gross fixed capital formation
$X^{(3)(h,r)}_{(i,s)}$	Demand for commodity i from source s by household h resident in region r
$X^{(4)(r)}_{(i)}$	Demand for commodity i produced in region r by foreign economic agents
$X^{(5)(g,r)}_{(i,s)}$	Public consumption demand in region r for commodity i from source s by government g
$Z^{(1)}_{(j,r)}$	Activity level of industry j in region r
$Z^{(2)}_{(j,r)}$	Gross fixed capital formation by industry j in region r

Having defined an effective intermediate input $X_{(i,\bullet)}^{(1)(j,r)}$, the theory governing inter-regional sourcing of intermediate inputs becomes one of choosing between alternative functional forms describing how $X_{(i,\bullet)}^{(1)(j,r)}$ comprises $X_{(i,s)}^{(1)(j,r)}$ from the R domestic sources ($s = 1, \ldots, R$) and the foreign source ($s = R + 1$). For example, in the FEDERAL model, single-tiered CRESH[57] aggregation functions govern regional industry (j,r)'s substitution possibilities across all domestic and foreign sources for commodity i. In MMRF, two-tiered CES aggregation functions govern commodity sourcing. In the first tier, effective inputs of commodity i are assumed to be a cost-minimizing CES composite of foreign imported i $\left(X_{(i,r+1)}^{(1)(j,r)}\right)$ and a domestic composite $\left(X_{(i,\mathrm{Dom})}^{(1)(j,r)}\right)$. The domestic composite in turn is assumed to be a cost-minimizing CES composite of commodity i sourced from the R domestic regional sources for i $\left(X_{(i,s)}^{(1)(j,r)},\ s \leq R\right)$.

CES, or CRESH functions, are common choices for describing substitution possibilities across primary factors.[58] Regional models differ in the detail and importance they attach to inter-regional factor ownership. In Figure 7.1, we allow for the possibility that occupation specific labor (o) used by industry (j,r) might be distinguished by both the region of residence (k) of the households supplying the labor and some characteristic of the household (h). Similarly, we allow for the possible identification of S (R domestic regions and foreign) ownership claims by H household types on returns from the physical capital and natural resources used by each regional industry. Accounting for out-of-region ownership is a feature of only some regional CGE models.[59] The need to maintain inter-regional capital and land ownership as a standard part of a multiregional CGE model is likely to grow, for two reasons. First, the trend in regional CGE model development has been to identify a growing number of smaller regions. As the level of regional detail rises, so too does: (i) The likelihood that households resident in any given small region will source a significant proportion of their rental income from outside the region and (ii) regional heterogeneity, raising the possibility that a number of rentier regions might appear among a list of small geographic regions. Second, many countries are experiencing a strong rise in the share of their populations that are retired. A proportion of retired households finance all or part of their consumption from capital income earned on diversified portfolios. Hence, even in regional models containing a few large and thus relatively homogeneous regions, we might still anticipate that

57 Constant ratios of elasticities of substitution, homothetic (Hanoch, 1971).

58 Some smaller-scale regional CGE model have used Cobb–Douglas functions, while there has been occasional use of flexible functional forms (see Table 1 of Partridge and Rickman, 1998, for examples).

59 Examples of models accounting for out-of-region ownership are: Morgan *et al.* (1989), Madden (1990), Buckley (1992), Rickman (1992), Giesecke (2000) and Gillespie *et al.* (2002b).

modeling of rental income sourced from outside the home region will grow in importance in countries where the aged dependency ratio is rising.

In the MMRF variant employed in Section 7.6, capital and natural resource ownership detail is suppressed. It is assumed that an effective primary factor unit $\left(X^{(1)(\bullet)(j,r)}_{(\bullet)}\right)$ is a cost-minimizing CES combination of regional-industry-specific capital $\left(X^{(1)(K)(j,r)}_{(\bullet)}\right)$, regional-industry-specific agricultural land $\left(X^{(1)(N)(j,r)}_{(\bullet)}\right)$ and a labor composite $\left(X^{(1)(L)(j,r)}_{(\bullet,\bullet)}\right)$. The labor composite is assumed to be a cost-minimizing CES combination of labor distinguished by occupation $\left(X^{(1)(L)(j,r)}_{(o,\bullet)}\right)$.

7.4.2 Commodity composition of regional industry output

National input-output tables often contain a supply table detailing multiproduction across industries. With multiproduction a feature of the structure of production at the national level, we might presume that it is also a feature of regional economic structure. Figure 7.1 allows for this possibility, describing the value of regional multiproduction by $\mathrm{MAKE}^{(i)}_{(j,r)}$: the value, at basic prices $\left(P^{(0)}_{(i,r)}\right)$, of production $\left(X^{(0)(i)}_{(j,r)}\right)$ of commodity (i) by regional industry (j,r).[60] In models like FEDERAL and MMRF, supply functions describing how regional industry activity levels $\left(Z^{(1)}_{(j,r)}\right)$ are transformed into commodity-specific output $\left(X^{(0)(i)}_{(j,r)}\right)$ are derived from constrained revenue maximization problems in which $Z^{(1)}_{(j,r)}$ is assumed to be a CET or CRETH function of $X^{(0)(i)}_{(j,r)}$.[61]

[60] A common assumption is that the different industrial producers of i in region r receive a common basic price. Under this assumption, commodity i from r is assumed to be undifferentiated by its industry of production, simply entering a total supply pool for i produced in r. However, in some applications, it may be useful to allow for the possibility that the basic price received by producers of commodity i in region r differs across alternative producers, j. For example, this may be important in dynamic simulations of models in which a given commodity may be produced by a number of different industries employing factors that are largely mobile in the long run. In such simulations, minor differences in the costs of the alternative producers of a given commodity can generate large movements in the activity levels of those producers. For example, applications of MMRF-GREEN to the study of carbon abatement policies have recognized production of a single commodity (electricity) by a variety of alternative electricity production technologies. To prevent this introducing long-run over-determination of the supply price of electricity, electricity users (and, in particular, the national electricity grid) are assumed to face imperfect substitution possibilities in their use of electricity from alternative generation technologies. More generally, purchasers of commodity i from region r can be assumed to minimize the cost of acquiring i from the alternative j producers of i, subject to substitution possibilities described by CES or CRESH functions. Such treatment introduces an industry (j) dimension to the total demand functions for commodity i produced in region r, and with it, an industry (j) dimension to the basic price variable.

[61] Respectively, constant elasticity of transformation and constant ratio of elasticities of transformation, homothetic. See Powell and Gruen (1968) and Vincent *et al.* (1980), respectively.

7.4.3 Demand for inputs to capital formation

The second column block of Figure 7.1 describes the cost structure of inputs to capital formation for $J \times R$ regional industries. In identifying an industry (j) dimension to the investment data, Figure 7.1 recognizes that capital formation input structures can differ across regional industries. This can be important in long-run dynamic simulations, where changes in capital cost conditions eventually flow through into the supply cost of industry production. For example, in a simulation of the effects of reducing tariffs on imported machinery, a model with investment theory describing variables in the second column of Figure 7.1 will recognize that the cost of capital in the agricultural sector (which is intensive in the use of imported machinery) will fall by more than the cost of capital in the dwellings construction sector (which is intensive in the use of labor and local manufactured inputs).

In Section 7.4.10.2 we describe how regional industry gross fixed capital formation $\left(Z^{(2)}_{(j,r)}\right)$, is determined on the basis of expected rates of return on capital specific to each regional industry. For the moment, we take this variable as given, and describe the determination of inputs to capital formation $\left(X^{(2)(j,r)}_{(i,s)}\right)$. In MMRF, capital creation is subject to a three-tiered production structure. At the top level of this structure, new units of industry-specific capital in each region $\left(Z^{(2)}_{(j,r)}\right)$ are formed as a cost-minimizing combination of composite commodities that are undifferentiated by source $\left(X^{(2)(j,r)}_{(i,\bullet)}\right)$. These composite commodities are assumed to be used in fixed proportions in the composition of new units of capital, $Z^{(2)}_{(j,r)}$. Below the fixed proportions tier of the production structure sit two tiers of CES aggregation functions governing commodity sourcing. First, effective inputs of commodity i are assumed to be a cost-minimizing CES composite of imported i $\left(X^{(2)(j,r)}_{(i,R+1)}\right)$ and a domestic composite $\left(X^{(2)(j,r)}_{(i,\mathrm{Dom})}\right)$. The domestic composite, in turn, is assumed to be a cost-minimizing CES composite of commodity i sourced from the R domestic sources for i $\left(X^{(2)(j,r)}_{(i,r)}\right)$.

7.4.4 Demand for commodities for private consumption

The third column of Figure 7.1 identifies the basic value flows, taxes and margins associated with the purchases of source-specific commodities by each household in each region $\left(X^{(3)(h,r)}_{(i,s)}\right)$. Commonly, regional CGE models recognize a single representative household in each region.[62] In the MMRF model employed in Section 7.6, consumption

62 This is the case for the MMRF model used in Section 7.6. Examples of models containing multiple households in each region are Kim and Kim (2002), Ferreira and Horridge (2006), Cutler and Davies (2007), and Decaluwé *et al.* (2010). Ferreira and Horridge's model is notable for linking a multiple-household 27-region CGE model of Brazil to a microsimulation model containing over 100,000 households. The models are solved iteratively to obtain consistent results.

decisions of the region r household are governed by a nested three-tiered decision process. At the top tier of this process, regional households maximize a Stone–Geary or Klein–Rubin utility function by choosing among composite units of commodity i $\left(X^{(3)(\bullet,r)}_{(i,\bullet)}\right)$ subject to an aggregate expenditure constraint. The next two tiers describe the manner in which households choose commodity i from among the competing alternative sources for i. This pattern follows a structure similar to that outlined above for current production and capital formation. First, composite units of commodity i $\left(X^{(3)(\bullet,r)}_{(i,\bullet)}\right)$ are modeled as cost-minimizing CES composites of imported i $\left(X^{(3)(\bullet,r)}_{(i,R+1)}\right)$ and a composite of domestically-sourced i $\left(X^{(3)(\bullet,r)}_{(i,\mathrm{Dom})}\right)$. The domestic composite, in turn, is modeled as a cost-minimizing CES composite of commodity i sourced from the R domestic regional sources for i $\left(X^{(3)(\bullet,r)}_{(i,r)}\right)$.

7.4.5 Export demands

The fourth column of Figure 7.1 identifies the tax, margin and basic flow components of the purchaser's value of regional foreign exports. In Figure 7.1, we define the basic value of foreign export sales $\left(\mathrm{BAS4}^{(r)}_{(i)}\right)$ as the product of export volumes $\left(X^{(4)(r)}_{(i)}\right)$ and the regional basic price common to all purchasers of commodity i across row 1 $\left(P^{(0)}_{(i,r)}\right)$. This is illustrative of the treatment in the MMRF variant we employ in Section 7.6, which does not distinguish between exported and domestic varieties of commodities. Many models, however, add a product transformation stage to the regional production structure, in which export and domestic product varieties are differentiated in a constrained revenue maximizing way (e.g. Hoffmann *et al.*, 1996; Kim and Kim, 2002; Rose and Liao, 2005). From this decision problem are derived revenue-maximizing supply functions for domestic and exported varieties of each good, allowing the basic price in cell (1,4) of Figure 7.1 to differ from the basic price faced by the remaining users across row 1. This approach can be attractive in models which carry a small country assumption of highly elastic export demand. In such models, independent functions describing the supply of commodity i to the domestic and foreign market are helpful in avoiding long-run overspecialization in the structure of production. The MMRF model used in Section 7.6, carries the assumption that the export volume for any given commodity i from region r $\left(X^{(4)(r)}_{(i)}\right)$ is inversely related to the export's f.o.b. (free on board) foreign currency price via a constant elasticity export demand function. We set export demand elasticities at around −4, consistent with evidence collected for Australian national models.[63]

[63] Dixon and Rimmer (2010) make a good case for Australian export demand elasticities in the vicinity of −4.

7.4.6 Demand for commodities for public consumption purposes

Explicit behavioral assumptions governing the composition of spending by regional and federal government levels are rare in the regional CGE literature (Groenewold *et al.*, 2003). In most models, $X^{(5)(g,r)}_{(i,s)}$ is treated as an exogenous policy variable, or held at a constant ratio of regional consumption spending (in the case of regional government) or national consumption spending (in the case of the federal government). In our simulations discussed in Section 7.6, our default setting for the determination of real public consumption spending by regional governments is to maintain a constant ratio with real regional private consumption spending. In determining federal government spending, we impose two restrictions. At the national level, we determine real federal public consumption spending by determining exogenously the ratio of real federal public consumption spending to economy-wide real private consumption spending. To determine the regional allocation of federal consumption spending, we assume that base-period *per capita* federal spending relativities across regions are exogenous for certain relevant commodities, such as education and health. For other commodities, such as defense, we assume that the regional shares in national spending are exogenous. In our dynamic simulations with the MMRF model, this has the effect of ensuring that federal spending has a tendency to follow inter-regional population movements, but with stickiness in some regional federal spending, via the fixity of spending on certain public administration and defense functions.

7.4.7 Demand for commodities as margin services

Row 2 of Figure 7.1 identifies the basic value of demands for commodities as margin services to facilitate commodity purchases by each of the agents described across the figure's five columns. For example, cell (2,1) describes the value of margin services $\left(P^{(0)}_{(m,k)} \cdot X^{(1)(j,r)}_{(i,s)(m,k)}\right)$ used to facilitate intermediate input purchases. In explicitly identifying the region of margin supply, k, we follow Madden (1990) and Horridge *et al.* (2005). The former identified margin supply in both source and destination regions for each commodity flow. The latter allows for the possibility that certain margins, such as transport, may also be supplied by regions between the source and destination regions for the underlying commodity flow. The MMRF model employed in Section 7.6 identifies destination margins only. This reduces the effective dimension of the cells in row 2 of Figure (4.1). For example, cell (2,2), which describes demand for margin services to facilitate purchases by investors, in MMRF defines $P^{(0)}_{(m,r)} \cdot X^{(2)(j,r)}_{(i,s)(m,r)}$, since $X^{(2)(j,r)}_{(i,s)(m,k)} = 0$ if $k \neq r$.

MMRF follows the Dixon *et al.* (1982) assumption that margin services are used in fixed proportions with the underlying transaction that they facilitate. Hence, a 1% increase in the value of $X^{(3)(\bullet,r)}_{(i,s)}$ produces a 1% increase in the value of $X^{(3)(\bullet,r)}_{(i,s)(m,r)}$ for all m. For some applications, other assumptions may be useful. For example, Adams *et al.*

(2010) allow for price-responsive intermodal substitution in demands for transport margins, reflecting the importance of road/rail competition in the Australian long-distance transport market.

7.4.8 Commodity market clearing conditions

Market clearing basic prices for domestic commodities are endogenously determined by equating the supply of, and the demand for, commodity i produced in region r. In terms of the notation in Figure 7.1, the multiregional CGE model endogenously determines the market clearing basic price for commodity i,r, $P^{(0)}_{(i,r)}$ via:

$$\sum_{j\in \mathrm{IND}} X^{(0)(i)}_{(j,r)} = \sum_{k\in \mathrm{REG}} \left(\sum_{j\in \mathrm{IND}} \left(X^{(1)(j,k)}_{(i,r)} + X^{(2)(j,k)}_{(i,r)} \right) + \sum_{h\in \mathrm{HOU}} X^{(3)(h,k)}_{(i,r)} + \sum_{g\in \mathrm{GOV}} X^{(5)(g,k)}_{(i,r)} \right) + X^{(4)(r)}_{(i)} + X^{(M)}_{(i,r)}, \tag{7.3}$$

where $X^{(M)}_{(i,r)}$ is the demand for i produced in r as a margin service, defined as:

$$X^{(M)}_{(i,r)} = \sum_{c\in \mathrm{COM}} \sum_{t\in \mathrm{REG}} \left(X^{(4)(t)}_{(c)(i,r)} + \sum_{k\in \mathrm{REG}} \left(\sum_{j\in \mathrm{IND}} \left(X^{(1)(j,k)}_{(c,t)(i,r)} + X^{(2)(j,k)}_{(c,t)(i,r)} \right) + \sum_{h\in \mathrm{HOU}} X^{(3)(h,k)}_{(c,t)(i,r)} + \sum_{g\in \mathrm{GOV}} X^{(5)(g,k)}_{(c,t)(i,r)} \right) \right).$$

In determining the basic price of imported commodities ($P^{(0)}_{(i,\mathrm{imp})}$ in Figure 7.1), a typical starting point is the exogenous determination of c.i.f. (cost, insurance and freight) foreign currency import prices. Landed duty paid domestic currency import prices are calculated endogenously, after translating c.i.f. foreign currency prices to domestic currency through the national exchange rate, and after applying federal import tariffs.

7.4.9 Zero-pure-profit conditions on current production, capital formation and commodity purchases

A typical regional CGE model will apply zero-pure-profit conditions on the activities of current production, the supply of commodities to domestic agents, exporting and importing. This allows the endogenous determination of all the purchaser's prices and regional industry activity levels.

Using Figure 7.1 as a template, zero-pure-profit conditions allow purchaser's prices to be determined endogenously for each of the transactions described in cells (1,1) through (1,5). For example, domestic currency purchaser's prices for exports $\left(P^{(4)}_{(i,r)}\right)$ are determined by (7.4):

$$P^{(4)}_{(i,r)} \cdot X^{(4)(r)}_{(i)} = P^{(0)}_{(i,r)} \cdot X^{(4)(r)}_{(i)} + \sum_{m\in \mathrm{MAR}} \sum_{k\in \mathrm{REG}} P^{(0)}_{(m,k)} \cdot X^{(4)(r)}_{(i)(m,k)} + \sum_{g\in \mathrm{GOV}} P^{(0)}_{(i,r)} \cdot X^{(4)(r)}_{(i)} \cdot T^{(4)(r)}_{(i)(g)}. \tag{7.4}$$

With $X_{(i)}^{(4)(r)}$ largely determined by the export demand function for (i,r) (see Section 7.4.5 above); $P_{(i,r)}^{(0)}$ and $P_{(m,k)}^{(0)}$ largely determined by the market clearing conditions for (i,r) and (m,k) (Section 7.4.8 above); $X_{(i)(m,k)}^{(4)(r)}$ determined by the margin demand functions (Section 7.4.7 above); and with export tax rates $\left(T_{(i)(g)}^{(4)(r)}\right)$ exogenous, (7.4) can be viewed as determining $P_{(i,r)}^{(4)}$.

The reader will note that cells (2,1) through (2,5) of Figure 7.1 also involve transactions in the form of purchases of margin services. In Figure 7.1 we have assumed that the cost of a margin service is its basic price. In a detailed fiscal model, more complex expressions are possible. For example, MMRF allows for the price paid for margin services to include relevant indirect taxes, such as VAT.

Again, using Figure 7.1 as a template, zero pure profits in current production can be expressed as:

$$
\begin{aligned}
P_{(j,r)}^{(1)} \cdot Z_{(j,r)}^{(1)} = & \sum_{g \in \mathrm{GOV}} P_{(j,r)}^{(0)} \cdot Z_{(j,r)}^{(1)} \cdot T_{(j,r)}^{(1)(g)} \\
& + \sum_{i \in \mathrm{COM}} \sum_{s \in \mathrm{SRC}} \left(P_{(i,s)}^{(0)} \cdot X_{(i,s)}^{(1)(j,r)} + \sum_{m \in \mathrm{MAR}} \sum_{k \in \mathrm{REG}} P_{(m,k)}^{(0)} \cdot X_{(i,s)(m,k)}^{(1)(j,r)} + \sum_{g \in \mathrm{GOV}} P_{(i,s)}^{(0)} \cdot X_{(i,s)}^{(1)(j,r)} \cdot T_{(i,s)(g)}^{(1)(j,r)} \right) \\
& + \sum_{o \in \mathrm{OCC}} \sum_{h \in \mathrm{HOU}} \sum_{k \in \mathrm{REG}} \left(W_{(o,k)}^{(j,r)} \cdot X_{(o,h,k)}^{(1)(L)(j,r)} + \sum_{g \in \mathrm{GOV}} W_{(o,k)}^{(j,r)} \cdot X_{(o,h,k)}^{(1)(L)(j,r)} \cdot T_{(o,k)(g)}^{(1)(L)(j,r)} \right) \\
& + \sum_{h \in \mathrm{HOU}} \sum_{s \in \mathrm{SRC}} \left(R^{(K)(j,r)} \cdot X_{(h,s)}^{(1)(K)(j,r)} + \sum_{g \in \mathrm{GOV}} R^{(K)(j,r)} \cdot X_{(h,s)}^{(1)(K)(j,r)} \cdot T_{(s)(g)}^{(1)(K)(j,r)} \right) \\
& + \sum_{h \in \mathrm{HOU}} \sum_{s \in \mathrm{SRC}} \sum_{t \in \mathrm{RES}} \left(R_{(t)}^{(N)(j,r)} \cdot X_{(h,s)(t)}^{(1)(N)(j,r)} + \sum_{g \in \mathrm{GOV}} R_{(t)}^{(N)(j,r)} \cdot X_{(h,s)(t)}^{(1)(N)(j,r)} \cdot T_{(s)(t)(g)}^{(1)(N)(j,r)} \right).
\end{aligned} \tag{7.5}
$$

The j,r Equations of (7.5) can, in conjunction with the market clearing conditions and commodity supply equations discussed in Sections 7.4.8 and 7.4.2 above, be viewed as largely determining regional industry activity levels, $Z_{(j,r)}^{(1)}$. Equation (7.5) introduces the average price of industry (j,r)'s output $\left(P_{(j,r)}^{(1)}\right)$, which is defined via:

$$
P_{(j,r)}^{(1)} \cdot Z_{(j,r)}^{(1)} = \sum_{i \in \mathrm{COM}} P_{(i,r)}^{(0)} \cdot X_{(j,r)}^{(0)(i)}. \tag{7.6}
$$

The unit cost of capital in regional industry j,r $\left(P^{(2)}_{(j,r)}\right)$ is determined by zero-pure-profit equations of the form:

$$\begin{aligned}P^{(2)}_{(j,r)}\cdot Z^{(2)}_{(j,r)} = & \sum_{g\in \mathrm{GOV}} P^{(2)}_{(j,r)}\cdot Z^{(2)}_{(j,r)}\cdot T^{(2)(g)}_{(j,r)} \\ & + \sum_{i\in \mathrm{COM}}\sum_{s\in \mathrm{SRC}}\left(P^{(0)}_{(i,s)}\cdot X^{(2)(j,r)}_{(i,s)} + \sum_{m\in \mathrm{MAR}}\sum_{k\in \mathrm{REG}} P^{(0)}_{(m,k)}\cdot X^{(2)(j,r)}_{(i,s)(m,k)}\right. \\ & \left. + \sum_{g\in \mathrm{GOV}} P^{(0)}_{(i,s)}\cdot X^{(2)(j,r)}_{(i,s)}\cdot T^{(2)(j,r)}_{(i,s)(g)}\right). \end{aligned} \tag{7.7}$$

7.4.10 Regional factor markets

As noted in Section 7.4.1, three broad types of primary factor are identified in Figure 7.1 — labor, capital and natural resources. In Figure 7.1, we have allowed for the possibility that employees may be distinguished by occupation and region of residence. Figure 7.1 also provides for the possibility that capital and natural resources may be distinguished by the asset owner's region of residence.

7.4.10.1 Regional wages and employment in the short run and long run

In thinking about how regional labor markets have been modeled in CGE models, we begin by distinguishing comparative static and dynamic models. In comparative static applications, modeling of the labor market, particularly as it relates to wage and employment flexibility, is one of the ways in which short-run and long-run analytical timeframes are commonly distinguished. In short-run applications, a common assumption is that institutional or structural features of the regional labor market generate short-run stickiness in the regional wage rate. With short-run regional wages sticky, regional labor market pressures are mainly expressed as movements in short-run regional employment. With short-run regional populations given, these short-run regional employment movements are expressed as short-run movements in the regional employment rate and/or participation rate. As stated in Section 7.3.5.1, the modeling of long-run labor markets is intertwined with assumptions governing the long-run mobility of populations across regions. For example, the long-run implementations of the MMRF model assume that long-run inter-regional wage relativities are exogenous. At the level of the regional labor market, this translates to near exogeneity of the regional wage rate, with long-run regional employment endogenously adjusting via long-run movements in regional populations.

In discussing modeling of labor markets within a dynamic CGE model, we begin with the Dixon and Rimmer (2002, p. 15) distinction between baseline and policy simulations. In its broadest sense, a baseline simulation represents a forecast of the economy, typically undertaken under an assumption that the particular policy that is the subject of the research is not implemented. The policy simulation is typically identical to the baseline simulation in all respects other than the addition of shocks representing the particular policy under analysis. In undertaking the baseline simulation with a regional CGE model, a common assumption is to allow regional labor forces to adjust endogenously each period, under an environment of given regional wage relativities. Under this closure, labor market clearing is imposed at the national level, with regional wages adjusting in tandem with the national wage so as to maintain given regional wage relativities. In policy simulations, a similar closure structure may be imposed, that is, labor market clearing occurring at the national level, with endogenous regional labor forces maintaining given regional wage relativities. An extension of this approach in standard MMRF implementations allows for short-run sticky wage adjustment at the national level, using the method outlined in Dixon and Rimmer (2002, p. 205). Under this approach, sticky or gradual adjustment of the national wage allows the level of national employment in the policy simulation to deviate from its level in the baseline simulation. Over time, gradual adjustment of the national wage returns the level of national employment in the policy simulation back to its baseline value.

In our variant of the standard MMRF model employed in Section 7.6, we allow for short-run stickiness in both regional populations and regional wage rates. Regional populations adjust slowly, via inter-regional migration, to movements in regional wage relativities. We discuss our treatment of inter-regional migration in Section 7.4.11 below; however, readers need not follow this forward reference to understand the remainder of our discussion here. In our policy simulations, we allow for limited deviations in short-run regional wages away from their baseline values. With short-run regional populations also sticky, we allow short-run labor market pressures to be mainly manifested as short-run deviations in regional employment rates. More explicitly, we allow the path of real regional consumer wages in policy simulations to be governed by:[64]

$$\begin{aligned}\left(W_r^{(\text{Policy})}/W_r^{(\text{Baseline})}-1\right) = {} & \left(W_{(t-1),r}^{(\text{Policy})}/W_{(t-1),r}^{(\text{Baseline})}-1\right)\\ & +\alpha\left(ER_r^{(\text{Policy})}/ER_r^{(\text{Baseline})}-1\right),\end{aligned} \tag{7.8}$$

where $W_r^{(\text{Baseline})}$ and $W_r^{(\text{Policy})}$ are the real consumer wage in region r in the baseline and policy simulation, respectively; $W_{(t-1),r}^{(\text{Baseline})}$ and $W_{(t-1),r}^{(\text{Policy})}$ are the lagged values for the regional real wage in the baseline and policy simulations, respectively; $ER_r^{(\text{Baseline})}$ and $ER_r^{(\text{Policy})}$ are regional employment rates ($1-$ the unemployment rate) in the baseline and policy simulations respectively; and α is a positive parameter.

64 We define the real regional consumer wage as the ratio of the nominal regional wage to the regional household consumption deflator.

With (7.8) activated in the policy simulation, the deviation in the real regional consumer wage grows (declines) as long as the regional employment rate remains above (below) its baseline level. A value for α is chosen that ensures the regional employment effects of a shock in year t are largely eliminated by year $t + 5$. Equation (7.8) represents an implementation at the regional level of the national sticky wage adjustment mechanism described in Dixon and Rimmer (2002, p. 205).[65] Use of a *national* sticky wage mechanism (i.e. one that imposes short-run stickiness of the national wage before transitioning to a long-run flexible national wage that gradually returns the economy-wide employment rate to its baseline level) is not appropriate in a regional model that has explicit location decision modeling, such as that discussed in Section 7.4.11 below, because it introduces a wage determination process that is independent of movements in region-specific labor forces. To introduce short-run sticky wages but long-run labor market clearing to a regional model with a regional labor supply theory that does not passively adjust to movements in regional wages, we require theory implementing short-run stickiness in region-specific wages. For example, Giesecke (2003) implements a regional variant of the Dixon and Rimmer (2002) national mechanism, one in which region-specific real wages gradually adjust in policy simulation to return the number of unemployed persons in each region to baseline. This approach has the advantage of ensuring that the national long-run employment deviation is zero, since region-specific numbers of unemployed persons are eventually returned to their baseline values. A disadvantage of this approach is that regional unemployment rates will deviate from baseline in any policy simulation that generates deviations in regional populations. Another option is to return the regional unemployment rate or the regional employment rate (1 − the unemployment rate) to baseline. This is the function of (7.8). However, in cases where baseline unemployment rates differ across regions, (7.8) can lead to small deviations in national employment when the policy shock causes the national population to move between regions.

7.4.10.2 Rates of return and capital stocks in the short run and long run

In Section 7.4.1 we discussed the derivation of cost-minimizing demands for capital inputs by regional industries. On the supply side of regional industry capital markets, comparative static regional CGE models, in common with their national counterparts, generally draw a distinction between their modeling of the short run and the long run. Typically, the short run has been defined as a period sufficiently long for firms to have time to adjust investment to changes in expected rates of return, but too short for new investment to affect installed capital. In terms of model closure, this is implemented via

[65] Equation (7.8) follows the basic structure of the wage adjustment equation described by Equation (24.2) in Dixon and Rimmer (2002, p. 205). The difference is that in (24.2) the national wage deviation rises (falls) so long as national employment in the policy case is above (below) its base-case level. In (7.8) the regional wage deviation rises (falls) so long as the regional employment rate is above (below) its base-case level.

the exogenous determination of regional industry capital stocks $\left(X_{(\bullet)}^{(1)(K)(j,r)}\right)$, requiring $J \times R$ market clearing capital rental prices $\left(R^{(K)(j,r)}\right)$ to be determined endogenously.

While capital stocks are, by definition, unable to adjust in the short-run, a typical short-run closure allows for adjustment of gross fixed capital formation $\left(Z_{(j,r)}^{(2)}\right)$ in response to movements in rates of return. Rates of return on regional industry capital ($\mathrm{ROR}_{(j,r)}$) may be approximated by:

$$\mathrm{ROR}_{(j,r)} = R^{(K)(j,r)}/P_{(j,r)}^{(2)} - D_{(j,r)}, \tag{7.9}$$

where $D_{(j,r)}$ is the depreciation rate on regional industry j,r's capital stock.

Regional industry investment can then be determined by:

$$Z_{(j,r)}^{(2)}/X_{(\bullet)}^{(1)(K)(j,r)} = F^{(2)}\left(\mathrm{ROR}_{(j,r)}/\mathrm{RORN}_{(j,r)}, \mathrm{GN}_{(j,r)}^{(2)}\right), \tag{7.10}$$

where $F^{(2)}$ is an increasing positive function of $\mathrm{ROR}_{(j,r)}/\mathrm{RORN}_{(j,r)}$, $\mathrm{RORN}_{(j,r)}$ is an exogenously determined trend or normal rate of return, and $\mathrm{GN}_{(j,r)}^{(2)}$ is an exogenously determined trend or normal rate of capital growth. In MMRF, $F^{(2)}$ takes the inverse logistic form described in Dixon and Rimmer (2002, pp. 190–195).

The long-run in comparative static applications of regional CGE models is typically defined as a period sufficiently long that regional industry capital stocks have adjusted to return $\mathrm{ROR}_{(j,r)}$ to some exogenously specified level (such as $\mathrm{RORN}_{(j,r)}$). In practice, this is effected by exogenously determining $\mathrm{ROR}_{(j,r)}$ and endogenously determining $X_{(\bullet)}^{(1)(K)(j,r)}$. Under this closure, long-run capital rental rates $\mathrm{R}^{(K)(j,r)}$ move with long-run capital construction costs $\left(P_{(j,r)}^{(2)}\right)$ via (7.9) and long-run real investment $\left(Z_{(j,r)}^{(2)}\right)$ moves with long-run capital stocks $\left(X_{(\bullet)}^{(1)(K)(j,r)}\right)$ via (7.10).

In dynamic simulations, MMRF follows the Dixon and Rimmer (2002) approach of linking a sequence of comparative static short-run equilibria via the addition of stock/flow accounting equations. For MMRF's investment and capital supply theory, this means including equations of the form:

$$X_{(\bullet)(t+1)}^{(1)(K)(j,r)} = X_{(\bullet)(t)}^{(1)(K)(j,r)} \times \left[1 - D^{(j,r)}\right] + Z_{(j,r)(t)}^{(2)}, \tag{7.11}$$

where $X_{(\bullet)(t)}^{(1)(K)(j,r)}$ and $X_{(\bullet)(t+1)}^{(1)(K)(j,r)}$ are regional industry capital stocks in years t and $t+1$, respectively, and $Z_{(j,r)(t)}^{(2)}$ is real investment in regional industry j,r in year t. In dynamic simulations, (7.10) and (7.11) together allow for short-run capital market pressures to be mainly expressed as movements in rates of return with gradual adjustment of capital stocks and long-run capital market pressures to be expressed as adjustment of capital stocks with rates of return deviating little from their normal values.

7.4.10.3 Natural resource use and rental rates in the short run and long run

Figure 7.1 distinguishes returns to physical capital from returns to natural resources, identifying $X^{(1)(N)(j,r)}_{(h,s)(t)}$, the quantity of natural resource type *t*, in region *r*, used by industry *j* and owned by household *h* in region *s*. In many of the large-scale general purpose models that make the distinction between capital and land rentals, the ownership dimension is absent and the resource type dimension (*t*) may be defined by the employing industry (*j*). For example, in general purpose models, non-agricultural natural resources, such as mining subsoil assets and fishery resources, may be modeled as specific to the industries in which they are employed. However, regional modelers with a specific interest in natural resource issues, particularly in agriculture, will typically expand the detail in which natural resource endowments are defined within their models. In Sections 7.2.3 and 7.3.5.5 we described the detailed treatment of agricultural land use and supply necessary to properly model water allocation policy in the SMDB region (Dixon *et al.*, 2011). Ferreira and Horridge (2011) identify three types of region-specific agricultural land in use − forestry, crops and pasture.

Figure 7.1, identifies the natural resource rental price $R^{(N)(j,r)}_{(t)}$. By suppressing the ownership dimension on the rental rate, it is assumed that different owners receive the same rental rate on a given natural resource employed in a given regional industry. $R^{(N)(j,r)}_{(t)}$ typically serves two functions. (i) It maintains equality of supply of, and demand for, $X^{(1)(N)(j,r)}_{(\bullet)(t)}$. (ii) It guides the allocation of region *r*'s endowment of resource type *t*, across alternative uses, *j*.

In comparative static models, region *r*'s endowment of resource type *t* is typically treated as exogenous. However, as regional models have become dynamic, model builders have begun turning their attention to modeling resource supply change. Ferreira and Horridge (2011) allow land to transition from one year to the next between forestry, crops and pasture, and for unused land to enter production via one of these three routes, in response to movements in land rental rates. Within any year, land within any one of the three categories can be applied to alternative agricultural production. For example, pasture land can be used for beef or dairy production, with the allocation across these uses changing in response to movements in the relative profitability of beef and dairy production. By modeling the transition of unused land into one of three agricultural uses, Ferreira and Horridge break with the traditional assumption of exogenous region-specific agricultural land supply.

In our application of MMRF in Section 7.6, we adopt a simple specification for natural resource supply, identifying resources that are specific to each regional industry, $X^{(1)(N)(j,r)}_{(\bullet)(\bullet)}$, with market clearing rental rates $R^{(N)(j,r)}_{(\bullet)}$. Under this specification, the *j* dimension not only identifies the industry using the natural resource, it also defines the natural resource type. For example, natural resources used by the agriculture and mining industries represent agricultural land and subsoil assets, respectively.

7.4.11 Inter-regional migration

As foreshadowed in Section 7.3.5.1, we develop an alternative migration theory in this chapter. This new theory is then employed in the variant of MMRF we use to undertake the simulations reported in Section 7.6. We begin by assuming that gross inter-regional migration flows respond to movements in *per capita* regional income relativities. We call the measure of income that is relevant to the migration decision "migration income." Equation (7.12) defines migration income in region r as the expected wage per worker:

$$Y_r^{(\mathrm{M})} = W_r \cdot E_r, \tag{7.12}$$

where $Y_r^{(\mathrm{M})}$ is migration income in region r, W_r is the wage rate in region r and E_r is the employment rate (1 − the unemployment rate) in region r.

We define movements in *per capita* migration income relativities via:

$$\frac{Y_d^{(\mathrm{M})}}{Y_o^{(\mathrm{M})}} = Y_{o,d}^{(\mathrm{Diseq})} \cdot \frac{F_d^{(\mathrm{M})}}{F_o^{(\mathrm{M})}}, \tag{7.13}$$

where $Y_r^{(\mathrm{M})}$ is migration income in region r, $Y_{o,d}^{(\mathrm{Diseq})}$ is a measure of disequilibrium in migration income relativities between migration origin region o and migration destination region d, and $F_r^{(\mathrm{M})}$ is a shift-variable for calibrating migration income ratios.

We assume that a rise, say, in $Y_{o,d}^{(\mathrm{Diseq})}$ will generate a rise in the gross emigration rate from region o to region d ($GEMR_{o,d}$) and a fall in the gross emigration rate from region d to region o ($GEMR_{d,o}$).

We adopt the inverse logistic function, used by Dixon and Rimmer (2002, pp. 190−193) to model capital supply, to model the relationship between $Y_{o,d}^{(\mathrm{Diseq})}$ and $GEMR_{o,d}$. For modeling a region's gross emigration rate, this function has the useful property of allowing us to limit the minimum and maximum rates of gross emigration.[66] The inverse logistic relationship is described in Figure 7.3. The equation describing Figure 7.3 is:

$$\begin{aligned} Y_{o,d}^{(\mathrm{Diseq})} = {} & 1 + F_{o,d} + \left(1/C_{o,d}\right) \\ & * \Big\{ \Big[\ln\Big(GEMR_{o,d} - GEMR_{o,d}^{(\mathrm{MIN})}\Big) - \ln\Big(GEMR_{o,d}^{(\mathrm{MAX})} - GEMR_{o,d}\Big)\Big] \\ & - \Big[\ln\Big(GEMR_{o,d}^{(\mathrm{TREND})} - GEMR_{o,d}^{(\mathrm{MIN})}\Big) - \ln\Big(GEMR_{o,d}^{(\mathrm{MAX})} - GEMR_{o,d}^{(\mathrm{TREND})}\Big)\Big]\Big\}, \end{aligned} \tag{7.14}$$

[66] We choose minimum and maximum emigration rates by examining the historical data on origin- and destination-specific gross regional emigration rates.

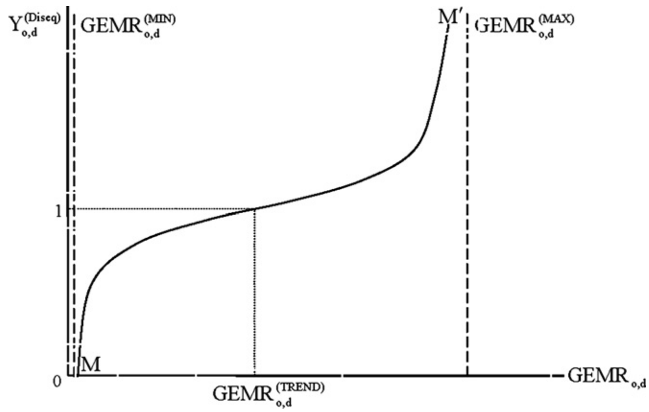

Figure 7.3 Relationship between gross regional emigration rates and disequilibrium in regional migration income.

where $F_{o,d}$ is a parameter governing the vertical position of the function MM′ in Figure 7.3, $C_{o,d}$ is a positive parameter, governing the sensitivity of the gross emigration rate from region o to region d to movements in disequilibrium in the migration income ratio between region o and d,[67] $GEMR_{o,d}$ is the gross emigration rate from region o to region d, expressed as a proportion of region o's population, $GEMR^{(MIN)}_{o,d}$ is the historically observed minimum proportion of region o's population that emigrates to region d each year, $GEMR^{(MAX)}_{o,d}$ is the historically observed maximum proportion of region o's population that emigrates to region d each year, and $GEMR^{(TREND)}_{o,d}$ is the trend or normal rate of emigration from region o to region d.

To parameterize (7.13), we begin by calculating $Y^{(Diseq)}_{o,d}$ from (7.14) using the known initial values for $GEMR_{o,d}$ from official statistics and assuming initial values for $F_{o,d}$ of zero. With the initial values for $Y^{(Diseq)}_{o,d}$ calculated from (7.14), initial values for $F^{(M)}_{r}$ can be calculated from (7.13).

In year-on-year simulations, we treat $GEMR^{(TREND)}_{o,d}$ as a variable and update its value each year according to the rule:

$$\left[100/GEMR^{(TREND)}_{o,d}\right] \times \Delta GEMR^{(TREND)}_{o,d} = q_d - q, \tag{7.15}$$

where q_d is the percentage change in the population of region d, and q is the percentage change in national population.

[67] We choose a value for $C_{o,d}$ that generates migration dynamics consistent with those described for Australia in Debelle and Vickery (1999). They find that net emigration from an Australian state following a relative downturn in its labor market occurs steadily over a number of years, with the bulk of the population adjustment having occurred by year four and the process largely complete by year seven.

Equation (7.15) ensures that the trend value for origin region o's gross emigration rate to region d moves in proportion with region d's share of the national population.

To translate movements in $GEMR_{o,d}$ to movements in gross emigration numbers, we multiply the year t value of $GEMR_{o,d}$ by the year t population of region o. The resulting population flows affect start of year populations in year $t+1$. Movements in $GEMR_{o,d}$ can thus be interpreted as changes in planned emigration in year t, with an average 6-month lag before the population movement occurs at the beginning of year $t+1$.

7.4.12 Regional household income and expenditure

Figure 7.1 contains a large amount of information about the income and expenditure accounts of regional households. However, full accounting of regional household income and expenditure requires that the MRIO data of Figure 7.1 be supplemented with a set of ancillary income and expenditure accounts. These are presented in Figure 7.2. Before discussing Figure 7.2 we expand on the household accounts information contained in Figure 7.1.

Column (3) of Figure 7.1 sets out the components of regional household consumption. Calculation of private consumption at market prices by household h in region r ($\mathrm{CON}^{(h,r)}$) is a simple matter of aggregating the commodity, source, margin and tax detail in column (3):

$$\mathrm{CON}^{(h,r)} = \sum_{i\in \mathrm{COM}} \sum_{s\in \mathrm{SRC}} \left(\mathrm{BAS3}_{(i,s)}^{(h,r)} + \sum_{m\in \mathrm{MAR}} \sum_{k\in \mathrm{REG}} \mathrm{MAR3}_{(i,s)(m,k)}^{(h,r)} + \sum_{g\in \mathrm{GOV}} \mathrm{TAX3}_{(i,s)(g)}^{(h,r)} \right). \tag{7.16}$$

Rows 4, 6 and 8 of Figure 7.1 set out the components of the post-tax primary factor income of household h in region r ($\mathrm{PFPT}^{(h,r)}$):

$$\mathrm{PFPT}^{(h,r)} = \sum_{j\in \mathrm{IND}} \sum_{k\in \mathrm{REG}} \left[\sum_{o\in \mathrm{OCC}} \mathrm{LABR}_{(o,h,r)}^{(j,k)} + \mathrm{CAPR}_{(h,r)}^{(j,k)} + \sum_{t\in \mathrm{RES}} \mathrm{NATR}_{(h,r)(t)}^{(j,k)} \right]. \tag{7.17}$$

Post-tax primary factor income is an important, but not the sole, determinant of total post-tax regional household income. The remaining categories of regional household income and outlays are set out in broad terms in Figure 7.2. Via Figure 7.2, the net household income of household h in region r ($\mathrm{HINC}^{(h,r)}$) can be calculated as:

$$\begin{aligned} \mathrm{HINC}^{(h,r)} = {} & \mathrm{PFPT}^{(h,r)} - \sum_{g\in \mathrm{GOV}} \mathrm{HTAX}_{(g)}^{(h,r)} + \sum_{g\in \mathrm{GOV}} \mathrm{GTRN}_{(g)}^{(h,r)} \\ & + \sum_{t\in \mathrm{HOU}} \sum_{k\in \mathrm{REG}} \left[\mathrm{HTRN}_{(t,k)}^{(h,r)} - \mathrm{HTRN}_{(h,r)}^{(t,k)} \right] + \mathrm{FTRN}^{(h,r)} - \mathrm{HINT}^{(h,r)}. \end{aligned} \tag{7.18}$$

Together, (7.16) and (7.18) imply household savings of:

$$\mathrm{HSAV}^{(h,r)} = \mathrm{HINC}^{(h,r)} - \mathrm{CON}^{(h,r)}. \tag{7.19}$$

In a comparative static model, a working assumption for household net interest payments on foreign debt, $\mathrm{HINT}^{(h,r)}$ is that they are exogenous. In a dynamic model, stock/flow accounting for household interest payments can be implemented via:

$$\mathrm{HINT}^{(h,r)} = \Phi \times \mathrm{HNFL}_t^{(h,r)} \times \rho_t \tag{7.20}$$

$$\mathrm{HNFL}_{t+1}^{(h,r)} = \mathrm{HNFL}_t^{(h,r)} - (1/\Phi)\left[\mathrm{HSAV}_t^{(h,r)} - \mathrm{HINV}_t^{(h,r)}\right], \tag{7.21}$$

where Φ is the nominal exchange rate expressed as domestic currency units per foreign currency unit, ρ_t is the rate of interest on net foreign debt $\mathrm{HNFL}_{t+1}^{(h,r)}$ and $\mathrm{HNFL}_t^{(h,r)}$ are household net foreign liabilities in foreign currency terms in years $t+1$ and t, respectively, and $\mathrm{HINV}_t^{(h,r)}$ is that part of the nation's gross fixed capital formation financed by household h in region r.

Equations (7.20) and (7.21) suppress many potential details. (i) Equation (7.21) assumes all net financing occurs via foreign transactions, thus excluding the possibility of inter-regional domestic net liability positions. (ii) Both Equations (7.20) and (7.21) assume that claims on assets are via debt only, thus excluding the possibility of equity positions. (iii) By identifying a single interest rate on a net debt position only, Equation (7.20) excludes the possibility of differential rates of return on debt and equity positions at home and abroad. (iv) Equations (7.20) and (7.21) assume that net foreign borrowings are denominated in foreign currency terms only. These assumptions may be relaxed in a detailed large-scale model.

7.4.13 Government accounts

The MRIO database set out in Figure 7.1 contains many elements of the regional and federal government accounts. From column (5) we can identify aggregate public consumption at market prices by government g in region r as:

$$\mathrm{GOV}_{(g)}^{(r)} = \sum_{i\in \mathrm{COM}} \sum_{s\in \mathrm{SRC}} \left(\mathrm{BAS5}_{(i,s)}^{(g,r)} + \sum_{m\in \mathrm{MAR}} \sum_{k\in \mathrm{REG}} \mathrm{MAR5}_{(i,s)(m,k)}^{(g,r)} + \sum_{h\in \mathrm{GOV}} \mathrm{TAX5}_{(i,s)(h)}^{(g,r)} \right). \tag{7.22}$$

The elements of rows 3 and 10, together with the tariff array $\mathrm{TARF}_{(i)}^{(g)}$, allow us to identify aggregate indirect tax revenue as:

$$\begin{aligned}\mathrm{ITAX}_{(g)} &= \sum_{j\in \mathrm{IND}} \sum_{r\in \mathrm{REG}} \left(\sum_{i\in \mathrm{COM}} \sum_{s\in \mathrm{SRC}} \left(\mathrm{TAX1}_{(i,s)(g)}^{(j,r)} + \mathrm{TAX2}_{(i,s)(g)}^{(j,r)} \right) + \mathrm{PTAX}_{(g)}^{(1)(j,r)} + \mathrm{PTAX}_{(g)}^{(2)(j,r)} \right) \\ &+ \sum_{i\in \mathrm{COM}} \left(\sum_{r\in \mathrm{REG}} \left(\sum_{s\in \mathrm{SRC}} \left(\sum_{h\in \mathrm{HOU}} \mathrm{TAX3}_{(i,s)(g)}^{(h,r)} + \sum_{k\in \mathrm{GOV}} \mathrm{TAX5}_{(i,s)(g)}^{(k,r)} \right) + \mathrm{TAX4}_{(i)(g)}^{(r)} \right) + \mathrm{TARF}_{(i)}^{(g)} \right).\end{aligned} \tag{7.23}$$

Note that among the indirect taxes on commodity- and source-specific inputs Figure 7.1 allows for per-unit or *ad valorem* taxes levied by government g on new capital formation in regional industry j,r, via $\mathrm{PTAX}_{(g)}^{(2)(j,r)}$. $\mathrm{PTAX}_{(g)}^{(2)(j,r)}$ is not a typical feature of a MRIO database. Nevertheless, in simulations investigating a new capital tax levied on the installation of new units of capital, $\mathrm{PTAX}_{(g)}^{(2)(j,r)}$ must be recognized. For example, Giesecke *et al.* (2008), investigating the impact of a developer charge on new residential developments, model the charge as a production tax on new units of capital in the ownership of dwellings sector. In Jorgenson and Yun in Chapter 10 of this Handbook, taxation of new housing forms an important part of their tax reform package.

The elements of rows 5, 7 and 9 of Figure 7.1, together with $\mathrm{HTAX}_{(g)}^{(h,r)}$ from the ancillary accounts, allow us to identify aggregate direct tax revenue as:

$$\mathrm{DTAX}_{(g)} = \sum_{j\in \mathrm{IND}} \sum_{r\in \mathrm{REG}} \left[\sum_{o\in \mathrm{OCC}} \sum_{h\in \mathrm{HOU}} \sum_{k\in \mathrm{REG}} \mathrm{LABT}_{(o,h,k)(g)}^{(j,r)} + \sum_{h\in \mathrm{HOU}} \sum_{s\in \mathrm{SRC}} \left(\mathrm{CAPT}_{(h,s)(g)}^{(j,r)} + \sum_{t\in \mathrm{RES}} \mathrm{NATT}_{(h,s)(t)(g)}^{(j,r)} \right) \right] + \sum_{r\in \mathrm{REG}} \sum_{h\in \mathrm{HOU}} \mathrm{HTAX}_{(g)}^{(h,r)}. \tag{7.24}$$

Equations (7.22), (7.23) and (7.24), together with the ancillary revenue and expenditure items identified in Figure 7.2, allows us to identify public sector savings:

$$\mathrm{GSAV}_{(g)} = \mathrm{DTAX}_{(g)} + \mathrm{ITAX}_{(g)} + \mathrm{FTRN}_{(g)} + \sum_{k\in \mathrm{GOV}} \mathrm{GRNT}_{(k)}^{(g)} - \sum_{r\in \mathrm{REG}} \left(\mathrm{GOV}_{(g)}^{(r)} + \sum_{h\in \mathrm{HOU}} \mathrm{GTRN}_{(g)}^{(h,r)} \right) - \sum_{k\in \mathrm{GOV}} \mathrm{GRNT}_{(g)}^{(k)} - \mathrm{GINT}_{(g)}. \tag{7.25}$$

In a comparative static model, a working assumption for government net interest payments on foreign debt, $\mathrm{GINT}_{(g)}$ is that they are exogenous. In a dynamic model, stock/flow accounting for government interest payments can be implemented via:

$$\mathrm{GINT}_{(g)} = \Phi \times \mathrm{GNFL}_{(g)}^{t} \times \rho_{(g)}^{t} \tag{7.26}$$

$$\mathrm{GNFL}_{(g)}^{t+1} = \mathrm{GNFL}_{(g)}^{t} - (1/\Phi)\left[\mathrm{GSAV}_{(g)}^{t} - \mathrm{GINV}_{(g)}^{t}\right], \tag{7.27}$$

where Φ is the nominal exchange rate expressed as domestic currency units per foreign currency unit; $\rho_{(g)}^{t}$ is the rate of interest on net foreign debt; $\mathrm{GNFL}_{(g)}^{t+1}$ and $\mathrm{GNFL}_{(g)}^{t}$ are government net foreign liabilities in foreign currency terms in years $t+1$ and t, respectively; and $\mathrm{GINV}_{(g)}^{t}$ is that part of the nation's gross fixed capital formation undertaken by government (g).

Like the stylized interest and foreign liability accounting equations identified for the household sector, (7.26) and (7.27) abstract considerably from the full national income accounting details available in official statistics. In a large applied fiscal model, more detail can be introduced on assets and liabilities distinguished by debt and equity, the currencies in which liabilities are denominated, differences in interest rates and rates of return across asset and liability categories and government levels, and valuation impacts on net asset positions.[68]

7.5 CONSTRUCTING (MULTI)REGIONAL DATABASES

7.5.1 Regional data limitations

Partridge and Rickman (1998) speculate that scarcity of regional data may lie behind the slow adoption of CGE techniques for regional modeling. Certainly, as is clear from Section 7.4, regional CGE models, particularly of the bottom-up variety, demand large amounts of regional data, of which only a meager amount is available from statistical agencies and other data sources. However, an array of estimation techniques is available to fill in the many data gaps for which no statistics have been collected.

Regional CGE models share part of their data requirements with other types of regional models and there is a considerable literature on estimating techniques in this area (e.g. Round, 1983). We limit our discussion of input-output and other social accounting data to the development of recent methods of particular use to regional CGE modelers.

7.5.2 Structural data

Of the three basic types of regional CGE models, bottom-up multiregional is the type which naturally has the most extensive data requirements. The structural data required for a full-blown multiregional CGE model can be seen in Figures 7.1 and 7.2 that depict MRIO, and income and government accounts, respectively. We consider estimation techniques for just the former here, since the latter tends to be peculiar to an individual country and the level of regional disaggregation.[69]

While there have been standard (largely) computerized techniques for the non-survey generation of input-output tables for several decades (e.g. Jensen *et al.*, 1979), comparable techniques for MRIO tables have been less in evidence.[70] The LMPST method referred to in Section 7.3.2 was an early method for generating an MRIO with minimal information, see Dixon *et al.* (1982) for a detailed discussion of how an

68 See, e.g. Dixon and Rimmer (2002, pp. 212–219).

69 Most regional CGE models are defined on regions which equate with jurisdictions, but these might be as aggregated as states/provinces or as disaggregated as counties or local government areas.

70 Jensen *et al.*, provides an extensive guide to the GRIT (Generation of Input-Output Table) method. Alternatively, see West (1984) or Johns and Leat (1987).

MRIO is formed via LMPST. This method could have formed the basis for estimating a multiregional CGE database, although perhaps only after a readily-made improvement to the method's treatment of the sourcing of national commodities. LMPST assumes that all users, regardless of their region, source their purchases of a commodity in proportion to the supplying region's share in the national production of that commodity. At least for some goods in geographically spread countries such as the US, production shares might have been modified by distances between origin and destination regions. This would amount to employing the gravity method (Leontief and Stroud, 1963).

Multiregional CGE modelers have used a variety of methods to estimate the required MRIO database (Haddad *et al.*, 2002b). Here, we will address ourselves to a method developed by (Horridge *et al.*, 2005), which combines variants of previous methods, and which has been successfully applied to Australia, the US, China and other countries.

The first step in the Horridge procedure is to establish, for each industry, regional shares in nationwide output. Usually employment by regional industry figures are used, although for certain industries such as ownership of dwellings (which has zero employment) other information, like regional rental income, needs to be used. The major other information requirement is regional estimates for household and government consumption, and information on ports of import and export by commodity. Together with national input-output data, this is enough to establish total regional demands and supplies by commodity and sources. The procedure then computes a matrix of regional sourcing estimates. Diagonal elements (i.e. the degree of local sourcing of commodities) are computed for each domestic and each imported commodity by a modified location quotient expressed as:[71]

$$\text{Min}\left\{\frac{\text{Local supply}}{\text{Local demand}}, 1\right\} \times F, \tag{7.28}$$

where F is a parameter varying between 0.5 and 1.0, with a value close to the latter where the commodity is not easily tradable. The introduction of the F parameter allows for cross-hauling of commodities.

Off-diagonal elements (out-of-region sourcing) are estimated according to a gravity formula that in its general form can be represented as:[72]

$$\frac{V(r,d)}{V(\bullet,d)} \propto \frac{V(r,\bullet)}{D(r,d)^K}\, r \neq d, \tag{7.29}$$

71 A location quotient is a ratio of an industry's share in aggregate regional output to its share in economy-wide output (see Johns and Leat, 1987).

72 Subscripts for commodity and international source (domestic or imported) are omitted for convenience.

where $V(r,d)$ is the value of the flow from origin r to destination d, $V(\bullet,\mathrm{d})$ is local demand from all sources, $V(r,\bullet)$ is the value of production, $D(r,d)$ is the distance between regions r and d, and K is a commodity-specific parameter valued between 0.5 and 2, with values being inversely related to the ease of tradability.

The F parameters are adjusted and a RAS procedure undertaken to ensure all estimated flows from r add to r's total supply and all estimated demands by d add to d's total demands.

The above provides only a general summary of what is in practice a set of complex computations, particularly in relation to margin commodities. Dixon and Rimmer (2004) provide a detailed discussion of the intricacies of these computations. It is worth noting here, however, that in estimating margins, transport costs $T(r,d)$ are related to distance:

$$\frac{T(r,d)}{V(r,d)} \propto \sqrt{D(r,d)}. \tag{7.30}$$

A major advantage of the Horridge data estimation routines is that they deliver an MRIO database in suitable form for use in most CGE models. These values are in basic prices, and margins and taxes are shown separately in their full specification. This allows the purchasers' value of each flow to be computed by a simple addition of the corresponding elements of the direct flow, margins and tax matrices. This greatly enhances the ease of usability for modelers.

Similarly, Giesecke (2011) provides a method for estimating single-region input-output data for regional CGE models. While input-output data for single regions are often readily available (e.g. in the US from IMPLAN), this data often is not in a suitable format to directly use in a single-region CGE model. Giesecke (2011) provides procedures for adjusting IMPLAN single-region input-output matrices to generate the required data matrices for CGE modeling through the application of national share information to perform appropriate disaggregations.

7.5.3 Behavioral parameters

It is common practice for regional CGE models to use elasticities borrowed from their national counterparts (e.g. Jones and Whalley, 1989; Madden, 1990). While this is a reasonable approach in the case of most types of elasticities, frequent concern is expressed in the case of the inter-regional trade Armington elasticities (e.g. Partridge and Rickman, 2010). It is commonplace for regional CGE modelers to undertake sensitivity analysis on these latter elasticities (Turner, 2009).

In the case of many countries, there is a dearth of the regional data required to undertake econometric estimates of inter-regional trade elasticities. There have been, however, some studies (e.g. Bilgic *et al.*, 2002; Ha *et al.*, 2010) that econometrically estimate inter-regional Armington elasticities for the US where commodity flow surveys are undertaken by the Bureau of Transportation Statistics at 5-year intervals. Ha *et al*. compare their results for inter-regional elasticities with Bilgic *et al*.'s, and with three studies estimating Armington estimates in international trade.[73] The comparison is made for agriculture, mining and seven manufacturing commodities, and it suggests, in general, that inter-regional and international elasticities are within the same broad order of magnitude. They give no support to the often-held idea that international trade elasticities form a lower bound for the corresponding inter-regional import elasticities.

Certainly, it is an area calling for further econometric work. Examination of the movement in inter-regional twist parameters and price movements from historical multiregional CGE simulations might reveal evidence as to whether the inter-regional import elasticity estimates currently being used are reasonable. However, on the face of it, the use of inter-regional import elasticities equal to or close to their international counterparts would seem reasonable.

7.6 SIMULATIONS AND INTERPRETATION OF MULTIREGIONAL MODEL MECHANISMS

In this section, we use the MMRF model to investigate two regional economic shocks. The first, a supply-side shock, explores the effects of a change in regional labor productivity. The second, a demand-side shock, explores the effects of a change in the regional distribution of demand. The purpose of the section is to set out techniques for explaining regional CGE results in ways that can be readily understood by readers unfamiliar with a multiregional CGE model. To do this we explain our results in terms of a miniature or BOTE model. Use of stylized models to describe the workings of large-scale CGE models has a long tradition in the application of national CGE models.[74] However, they are found less frequently in the regional CGE literature. In presenting the BOTE model, and using it to analyze our regional shocks, we hope to demonstrate the value of the BOTE technique in explicating results from large-scale regional models.

While the BOTE model is small and aggregated, it is sufficient to explain the major regional macroeconomic outcomes of the full-scale multiregional model. The BOTE model is a stylized single-region representation of a regional macroeconomy as it operates within MMRF, with coefficient values evaluated using the MMRF database. We use an aggregated MMRF model for these simulations, one recognizing three Australian regions: north (comprising Western Australia, the Northern Territory and

73 Ha *et al*.'s study is for Illinois inter-regional imports, while Bilgic *et al*.'s estimates are for inter-regional imports for the US in general. Two of the international studies were for US foreign imports, the other for the Organization for Economic Cooperation and Development (OECD) countries.

74 See Dixon *et al*. (1984) for an early example.

Queensland), South (comprising South Australia, Victoria and Tasmania) and East (comprising New South Wales and the Australian Capital Territory).

We begin by describing the BOTE model in Section 7.6.1. Section 7.6.2 describes the closure of BOTE. Section 7.6.3 uses the BOTE equations to derive compact equations describing regional aggregate demand and aggregate supply in the short run and long run. We then proceed to investigate two region-specific shocks: a rise in regional labor productivity (Section 7.6.4) and a shift in the spatial distribution of regional sourcing preferences (Section 7.6.5). In each case, we provide BOTE explanations of the regional consequences of the shock.

7.6.1 BOTE: A back-of-the-envelope representation of regional CGE macroeconomic mechanisms

BOTE is described in Tables 7.2—7.5. Table 7.2 presents the BOTE equations. Variable descriptions, together with short-run and long-run closures of BOTE, are presented in Table 7.3. We use short-run (2012) and long-run (2030) values from the baseline simulation of the full-scale MMRF model to evaluate the coefficients of BOTE. These coefficients and their values are described in Tables 7.4 and 7.5.

As discussed in Section 7.4.1, in deriving primary factor input demand equations, MMRF carries the assumption that each regional industry faces primary factor substitution possibilities described by CES functional forms. These give rise to cost-minimizing input demand and unit cost equations that, expressed in terms of percentage changes, are of the form:[75]

$$x^{\mathrm{v}}_{j,r} = a^{\mathrm{v}}_{j,r} + y_{j,r} - \sigma\left(p^{\mathrm{v}}_{j,r} + a^{\mathrm{v}}_{j,r} - p_{j,r}\right) \tag{7.31}$$

$$p_{j,r} = \sum_{v} S^{\mathrm{v}}_{j,r} \cdot \left(p^{\mathrm{v}}_{j,r} + a^{\mathrm{v}}_{j,r}\right), \tag{7.32}$$

where $x^{\mathrm{v}}_{j,r}$ is the percentage change in demand for factor v by regional industry j,r, $a^{\mathrm{v}}_{j,r}$ is the percentage change in the technical efficiency of primary factor input v in regional industry j,r, $y_{j,r}$ is the percentage change in the output of regional industry j,r, $p^{\mathrm{v}}_{j,r}$ is the percentage change in the price faced by regional industry j,r for factor v, $p_{j,r}$ is the percentage change in the average price of primary factors faced by regional industry j,r, σ is the elasticity of substitution between primary factor inputs, and $S^{\mathrm{v}}_{j,r}$ is the share of payments to factor v in industry j,r's total primary factor costs.

75 See Dixon *et al*. (1992b, pp. 124—125) for the derivation of the percentage change form of the input demand and unit cost functions arising from a CES production function.

Table 7.2 BOTE: A calibrated back-of-the-envelope representation of regional macroeconomic relationships in MMRF

Demand for labor	
(B1)	$l_r - a_r^{\mathrm{L}} = y_r - \sigma(\{w_r + a_r^{\mathrm{L}}\} - p_r)$
Demand for capital	
(B2)	$k_r = y_r - \sigma(r_r^{\mathrm{K}} - p_r)$
Demand for natural resources	
(B3)	$n_r = y_r - \sigma(r_r^{\mathrm{N}} - p_r)$
Regional GDP deflator	
(B4)	$p_r = S_r^{\mathrm{L}}\{w_r + a_r^{\mathrm{L}}\} + S_r^{\mathrm{K}} r_r^{\mathrm{K}} + S_r^{\mathrm{N}} r_r^{\mathrm{N}}$
Rate of return on capital	
(B5)	$ror_r = r_r^{\mathrm{K}} - p_r^{\mathrm{I}}$
Investment price index	
(B6)	$p_r^{\mathrm{I}} = \mathrm{S}_{\mathrm{r}}^{(\mathrm{D})\mathrm{I}} p_r$
Real gross regional expenditure	
(B7)	$e_r = S_r^{(\mathrm{E})\mathrm{C}} c_r + S_r^{(\mathrm{E})\mathrm{I}} i_r + S_r^{(\mathrm{E})\mathrm{S}} g_r^{(\mathrm{S})} + S_r^{(\mathrm{E})\mathrm{F}} g_r^{(\mathrm{F})}$
Real private consumption	
(B8)	$c_r = apc_r + y_r$
Gross capital growth rate	
(B9)	$\psi_r = i_r - k_r$
Relationship between rate of return on capital and the capital growth rate	
(B10)	$\psi_r = \beta_r[ror_r - \lambda_r]$
Ratio of regional government consumption to private consumption	
(B11)	$\lambda_r^{(\mathrm{S})} = g_r^{(\mathrm{S})} - c_r$
Federal government consumption *per capita*	
(B12)	$\lambda_r^{(\mathrm{F})} = g_r^{(\mathrm{F})} - q_r$
Regional expenditure-side real GDP	
(B13)	$y_r = S_r^{(\mathrm{Y})\mathrm{E}} e_r + \left(S_r^{(\mathrm{Y})\mathrm{XF}} x_r^{(\mathrm{F})} - S_r^{(\mathrm{Y})\mathrm{MF}} m_r^{(\mathrm{F})}\right) + \left(S_r^{(\mathrm{Y})\mathrm{XR}} x_r^{(\mathrm{R})} - S_r^{(\mathrm{Y})\mathrm{MR}} m_r^{(\mathrm{R})}\right)$
Foreign export volumes	
(B14)	$x_r^{(\mathrm{F})} = -\eta_r^{(\mathrm{XF})}(p_r - v_r)$
Foreign import volumes	
(B15)	$m_r^{(\mathrm{F})} = y_r + \left[\sigma_r^{(2)} S_r^{(\mathrm{Dom})} S_r^{(\mathrm{Local})}\right] p_r$
Inter-regional export volumes	
(B16)	$x_r^{(\mathrm{R})} = -\left[\sigma^{(2)} S_{(\mathrm{Imp})r}^{(\mathrm{RoC})} S_r^{(\mathrm{RoC})} + \sigma^{(3)}\left(1 - S_r^{(\mathrm{RoC})}\right)\right] S_r^{\mathrm{BAS}} p_r + (1 - S_r^{(\mathrm{RoC})})\xi_r$
Inter-regional import volumes	
(B17)	$m_r^{(\mathrm{R})} = y_r + \left[\sigma^{(3)} S_r^{(\mathrm{Local})} - \sigma^{(2)} S_r^{(\mathrm{Local})}\left(1 - S_r^{(\mathrm{Dom})}\right)\right] p_r - S_r^{(\mathrm{Local})}\xi_r$
Short-run sticky wage mechanism	
(B18)	$w_r - p_r^{\mathrm{C}} = \alpha \cdot er_r + f_r^{(\mathrm{W})}$
Consumption price index	
(B19)	$p_r^{\mathrm{C}} = \mathrm{S}_{\mathrm{r}}^{(\mathrm{D})\mathrm{C}} p_r$
Employment decomposition population, participation rate and employment rate	
(B20)	$l_r = q_r + pr_r + er_r$
Net inter-regional immigration rate	
(B21)	$\varphi_r = nim_r - q_r$
Relationship between inter-regional net immigration rate and expected regional wage	
(B22)	$\varphi_r = \phi_r\left[w_r + er_r - f_r^{(\mathrm{SR})}\right]$
Regional wage relativity	
(B23)	$f_r^{(\mathrm{LR})} = w_r - w$

Table 7.3 Variables of the BOTE model

Variable and variable description (all variables are percentage change, unless otherwise indicated)		Closure[a] Short-run	Long-run
a_r^{L}	Regional labor augmenting technical change	X	X
apc_r	Regional average propensity to consume	X	X
c_r	Real regional private consumption spending	N	N
e_r	Real gross regional expenditure	N	N
er_r	Region *r*'s employment rate (1 − the unemployment rate)	N	X
$f_r^{(SR)}$	Shift variable on the short-run net regional immigration function	X	N
$f_r^{(LR)}$	Ratio of the regional wage to the national wage	N	X
$f_r^{(W)}$	Shift variable on the short-run regional wage equation	X	N
$g_r^{(S)}$	Real regional government consumption spending	N	N
$g_r^{(F)}$	Real federal government consumption spending	N	N
i_r	Real regional gross fixed capital formation	N	N
k_r	Region *r*'s capital stock	X	N
l_r	Employment of persons in region *r*	N	N
$m_r^{(F)}$	Region *r*'s foreign import volumes	N	N
$m_r^{(R)}$	Region *r*'s inter-regional import volumes	N	N
n_r	Region *r*'s land endowment	X	X
nim_r	Net immigration to region *r*	N	N
p_r	Regional GDP deflator	N	N
p_r^{C}	Region *r*'s household consumption price deflator	N	N
p_r^{I}	Region *r*'s investment price deflator	N	N
pr_r	Region *r*'s participation rate	X	X
q_r	Region *r*'s population	X	N
r_r^{K}	Average capital rental price in region *r*	N	N
r_r^{N}	Region *r*'s land rental price	N	N
ror_r	Rate of return on capital in region *r*	N	X
v_r	Vertical scalar on the position of the regional export demand schedule	X	X
w	The economy-wide wage rate	X	X
w_r	Nominal wage per person in region *r*	N	N
$x_r^{(F)}$	Region *r*'s foreign export volumes	N	N
$x_r^{(R)}$	Region *r*'s inter-regional export volumes	N	N
y_r	Real regional GDP	N	N
λ_r	The normal rate of return in region *r*	X	N

(*Continued*)

Table 7.3 Variables of the BOTE model—cont'd

	Variable and variable description (all variables are percentage change, unless otherwise indicated)	Closure[a] Short-run	Long-run
$\lambda_r^{(S)}$	Ratio of regional government public consumption to private consumption	X	X
$\lambda_r^{(F)}$	Regional *per capita* federal consumption spending	X	X
ξ_r	Cost-neutral change in regional sourcing preferences towards region *r*'s goods	X	X
φ_r	Region *r*'s net inter-regional immigration rate	N	X
ψ_r	Regional investment/capital ratio	N	X

[a]X = exogenous; N = endogenous.

Table 7.4 Short-run parameter and coefficient values of the calibrated BOTE model[a]

	Parameters and coefficients of the BOTE model	North	East	South
σ	Primary factor substitution elasticity	0.30	0.30	0.30
S_r^{N}	Share of payments to land in regional GDP at factor cost	0.07	0.07	0.07
S_r^{K}	Share of payments to capital in regional GDP at factor cost	0.45	0.38	0.40
S_r^{L}	Share of payments to labor in regional GDP at factor cost	0.48	0.55	0.54
$S_r^{(D)I}$	Share of region (*r*)-sourced inputs in region (*r*)'s investment	0.60	0.64	0.64
$S_r^{(E)C}$	Share of private consumption in gross regional expenditure	0.51	0.55	0.55
$S_r^{(E)S}$	Share of state government consumption in gross regional expenditure	0.11	0.11	0.11
$S_r^{(E)I}$	Share of investment in gross regional expenditure	0.32	0.27	0.27
$S_r^{(E)F}$	Share of federal government consumption in gross reg. expenditure	0.06	0.07	0.07
$S_r^{(Y)XF}$	Share of foreign exports in regional GDP	0.29	0.15	0.16
$S_r^{(Y)MF}$	Share of foreign imports in regional GDP	0.19	0.19	0.22
$S_r^{(Y)XR}$	Share of inter-regional exports in regional GDP	0.16	0.21	0.22
$S_r^{(Y)MR}$	Share of inter-regional imports in regional GDP	0.23	0.18	0.18
$S_r^{(Y)E}$	Share of gross regional expenditure in regional GDP	0.98	1.01	1.02
$\eta_r^{(XF)}$	Foreign export price elasticity of demand	4.00	4.00	4.00
$\sigma^{(2)}$	Import/domestic substitution elasticity	2.50	2.50	2.50
$\sigma^{(3)}$	Inter-regional substitution elasticity	2.50	2.50	2.50
S_r^{BAS}	Basic value share in the purchaser's value of inter-regional exports	0.85	0.86	0.79
$S_{(Imp)r}^{(RoC)}$	Share of foreign imports, in total traded goods use, in the rest of the country	0.23	0.23	0.22
$S_r^{(Local)}$	Share of use of own supply in region *r*'s use of domestic goods	0.82	0.80	0.87

(*Continued*)

Table 7.4 Short-run parameter and coefficient values of the calibrated BOTE model[a]—cont'd

	Parameters and coefficients of the BOTE model	North	East	South
$S_r^{(\mathrm{Dom})}$	Share of domestically sourced goods in region *r*'s total use of traded goods	0.78	0.78	0.76
$S_r^{(\mathrm{RoC})}$	Region *r*'s trade share in use of traded domestic goods in the rest of the country	0.08	0.07	0.11
$S_r^{(\mathrm{D})\mathrm{C}}$	Share of region *r*-sourced goods in region *r* private consumption	0.79	0.83	0.84
β_r	Elasticity of regional investment to rates of return	1.25	1.25	1.25
ϕ_r	Elasticity of immigration rate to migration income relativity	0.20	0.20	0.20
α	Elasticity of the short-run regional real wage deviation to the employment rate deviation	0.50	0.50	0.50
$\Omega_r^{(1)}$	See Equation (7.39)	0.81	0.71	0.73
$\Omega_r^{(2)}$	See Equation (7.39)	−2.13	−1.62	−1.67
$\Omega_r^{(3)}$	See Equation (7.39)	0.61	0.67	0.67
$\Omega_r^{(4)}$	See Equation (7.39)	0.31	0.27	0.28
$\Omega_r^{(5)}$	See Equation (7.39)	0.11	0.11	0.11
$\Omega_r^{(6)}$	See Equation (7.39)	0.06	0.08	0.07
$\Omega_r^{(7)}$	See Equation (7.39)	1.15	0.61	0.63
$\Omega_r^{(8)}$	See Equation (7.39)	0.33	0.34	0.35
$A_r^{(1)}$	See Equation (7.37)	0.04	0.05	0.04
$A_r^{(2)}$	See Equation (7.37)	0.32	0.41	0.40
$A_r^{(3)}$	See Equation (7.37)	1.71	1.92	1.88

[a]Evaluated from the short-run (year 2012) MMRF database.

Table 7.5 Long-run parameter and coefficient values of the calibrated BOTE model[a]

	Parameters and coefficients of the BOTE model	North	East	South
σ	Primary factor substitution elasticity	0.30	0.30	0.30
S_r^{N}	Share of payments to land in regional GDP at factor cost	0.14	0.10	0.11
S_r^{K}	Share of payments to capital in regional GDP at factor cost	0.35	0.30	0.31
S_r^{L}	Share of payments to labor in regional GDP at factor cost	0.51	0.60	0.58
$S_r^{(\mathrm{D})\mathrm{I}}$	Share of region (*r*)-sourced inputs in region (*r*)'s investment	0.60	0.64	0.63
$S_r^{(\mathrm{E})\mathrm{C}}$	Share of private consumption in gross regional expenditure	0.56	0.59	0.59
$S_r^{(\mathrm{E})\mathrm{S}}$	Share of state government consumption in gross regional expenditure	0.12	0.12	0.11

(*Continued*)

Table 7.5 Long-run parameter and coefficient values of the calibrated BOTE model[a]—cont'd

	Parameters and coefficients of the BOTE model	North	East	South
$S_r^{(E)I}$	Share of investment in gross regional expenditure	0.26	0.22	0.22
$S_r^{(E)F}$	Share of federal government consumption in gross regional expenditure	0.06	0.08	0.07
$S_r^{(Y)XF}$	Share of foreign exports in regional GDP	0.34	0.20	0.21
$S_r^{(Y)MF}$	Share of foreign imports in regional GDP	0.17	0.18	0.20
$S_r^{(Y)XR}$	Share of inter-regional exports in regional GDP	0.14	0.21	0.22
$S_r^{(Y)MR}$	Share of inter-regional imports in regional GDP	0.21	0.18	0.17
$S_r^{(Y)E}$	Share of gross regional expenditure in regional GDP	0.90	0.95	0.96
$\eta_r^{(XF)}$	Foreign export price elasticity of demand	4.00	4.00	4.00
$\sigma^{(2)}$	Import/domestic substitution elasticity	2.50	2.50	2.50
$\sigma^{(3)}$	Inter-regional substitution elasticity	2.50	2.50	2.50
S_r^{BAS}	Basic value share in the purchaser's value of inter-regional exports	0.86	0.86	0.80
$S_{(Imp)r}^{(RoC)}$	Share of foreign imports, in total traded goods use, in the rest of the country	0.23	0.23	0.22
$S_r^{(Local)}$	Share of use of own supply in region *r*'s use of domestic goods	0.81	0.78	0.86
$S_r^{(Dom)}$	Share of domestically sourced goods in region *r*'s total use of traded goods	0.79	0.77	0.76
$S_r^{(RoC)}$	Region *r*'s trade share in use of traded domestic goods in the rest of the country	0.08	0.07	0.11
$S_r^{(D)C}$	Share of region *r*-sourced goods in region *r* private consumption	0.81	0.84	0.85
$\Psi_r^{(1)}$	See Equation (7.52)	0.54	0.49	0.49
$\Psi_r^{(2)}$	See Equation (7.52)	−2.27	−1.78	−1.85
$\Psi_r^{(3)}$	See Equation (7.52)	0.06	0.08	0.07
$\Psi_r^{(4)}$	See Equation (7.52)	1.37	0.80	0.83
$\Psi_r^{(5)}$	See Equation (7.52)	0.32	0.35	0.37
$\Phi_r^{(1)}$	See Equation (7.44)	0.46	0.35	0.36
$\Phi_r^{(2)}$	See Equation (7.44)	0.65	0.70	0.69
$\Phi_r^{(3)}$	See Equation (7.44)	0.51	0.60	0.58
$\Theta_r^{(1)}$	See Equation (7.68)	0.88	0.90	0.90
$\Theta_r^{(2)}$	See Equation (7.68)	0.96	1.23	1.20

[a]Evaluated from the long-run (year 2030) MMRF database.

On the basis of (7.31) and (7.32), BOTE Equations (B1)−(B4) approximately hold at the regionwide level for any given region.[76]

BOTE Equation (B5) defines the percentage change in the regional rate of return on capital. (B5) introduces the percentage change in the regional cost of capital, which we define by (B6).[77]

Equation (B7) defines the percentage change in real gross regional expenditure as the share-weighted-sum of the percentage changes in regional real private consumption, real investment and real state and federal government public consumption.

Equation (B8) presents a stylized consumption function, describing regional real private consumption as a function of real regional GDP and a given regional average propensity to consume.

Equation (B9) defines the gross growth rate of the regional capital stock. Equation (B10) is a short-run investment function, relating the gross growth rate of the regional capital stock to movements in the regional rate of return on capital.

Equation (B11) defines the ratio of real regional public consumption to real regional private consumption. Equation (B12) defines regional *per capita* federal government consumption.

Equation (B13) defines the percentage change form of the regional GDP identity in constant price terms.

Equation (B14) models demand for region *r*'s foreign exports via a constant elasticity demand function.

As discussed in Section 7.4.1, MMRF carries the assumption that region-specific economic actors make their commodity sourcing decisions in a nested two stage manner: they first choose between foreign and domestic sources for each commodity, before choosing between alternative region-specific sources for the domestic commodity. At both stages of the decision process, CES functions are used to describe imperfect substitution possibilities across alternative supply sources. On the basis of this nested CES structure, we employ (B15), (B16) and (B17) to describe regional foreign imports, inter-regional imports and inter-regional exports, respectively.[78] We describe the terms in

76 Let $\widehat{S}^{v}_{j,r}$ be industry *j*'s share of region *r*'s total use of primary factor *v*. Let $\widehat{S}^{\bullet}_{j,r}$ be industry *j*'s share of value added in region *r*. To derive (B1)−(B3), multiply (7.31) through by $\widehat{S}^{v}_{j,r}$ and sum over *j*. If factor intensities do not differ significantly across industries, then $\widehat{S}^{v}_{j,r} \approx \widehat{S}^{\bullet}_{j,r}$, yielding (B1)−(B3). To derive (B4), multiply (7.32) through by $\widehat{S}^{\bullet}_{j,r}$ and sum over *j*. In (B2) and (B3) we suppress technical change in capital and land usage.

77 Note that in (B6), and other equations of BOTE, we treat the region's import prices (foreign and inter-regional) as exogenous and unshocked, and thus suitable for omission from the equation system.

78 The derivation of (B15)−(B17) is available from the authors on request. Note that in deriving these BOTE equations, we adopt a number of simplifying assumptions. (i) We assume that the region is sufficiently small that it does not materially influence the prices it faces for foreign or inter-regional imports. (ii) We assume that the percentage change in demand for traded goods within a region, undifferentiated by source, can be approximated by the percentage change in that region's real GDP.

(B16) and (B17) relating to structural change in inter-regional sourcing preferences in Section 7.6.5.

Equation (B18) describes the operation, in the first year of a simulation, of the short-run sticky wage assumption described by Equation (7.8). Equation (B18) introduces the regional consumer price index, which we define in BOTE via (B19). Equation (B20) decomposes the percentage change in regional employment into movements in the regional population, the regional participation rate and the regional employment rate.

Equation (B21) defines the regional net immigration rate as the ratio of regional net immigration to population. Equation (B22) relates the regional net immigration rate to the expected regional wage. This equation is a stylized representation of the operation of Equations (7.12)−(7.14). Equation (B23) defines the percentage change in the ratio of the regional wage to the national wage.

7.6.2 Short-run and long-run closures of the BOTE model

Table 7.3 presents short-run and long-run closures of BOTE. Since MMRF is a dynamic model, the essentially comparative-static concepts of "short-run" closure and "long-run" closure do not directly apply to it. Nevertheless, these closures are very useful frameworks for understanding the operation of MMRF over the full course of a simulation, with the short-run closure being a good description of how MMRF operates within the first few years of a shock and the long-run closure being a good description of how MMRF operates a number of years following a shock.

7.6.2.1 Short-run closure

In describing the BOTE closures, we begin by noting that certain variables are exogenous in both the short-run and the long-run. These variables are of three types. (i) Certain elements of the closure reflect the absence in MMRF of theory, either of a short-run or long-run nature, explaining the determination of the variable in question. This explains the exogenous status of labor augmenting technical change (a_r^L), the regional land endowment (n_r), foreign willingness to pay for regional exports (v_r), cost-neutral shifts in inter-regional sourcing preferences (ξ_r) and the regional participation rate (pr_r). (ii) In BOTE we assume that our region is too small to exert a material influence over certain economy-wide variables. This accounts for the exogenous status of the national wage rate (w).[79] (iii) The exogenous status of certain variables allows us to describe particular behavioral assumptions governing the regional private and public sectors in the MMRF simulations. In MMRF, household consumption is a fixed proportion of regional income. This is represented in BOTE by the exogenous determination of apc_r. The MMRF simulations carry the assumption that regional governments maintain their

[79] It also accounts for the omission of certain otherwise exogenous and unshocked variables, such as the regional import price index.

spending as a fixed proportion of regional private consumption. In BOTE, this is described via the exogenous status of $\lambda_r^{(S)}$. To represent the MMRF modeling of federal government consumption in BOTE, $\lambda_r^{(F)}$ is exogenous.

Of the remaining variables that are exogenous in the short run, all are endogenous in the long run. These variables are of two types. The first reflect the time period with which we are concerned: a period too short for the variables in question to have time to adjust to a given shock. Variables in this category of short-run exogenous variable are the regional capital stock (k_r) and the regional population (q_r). The second category of such variables is made up of shifters whose exogenous status activate short-run mechanisms describing how the economy transitions from the short run to the long run. In this category are λ_r, $f_r^{(SR)}$ and $f_r^{(W)}$. With λ_r exogenous, short-run movements in regional investment are related to movements in rates of return via (B10). With $f_r^{(SR)}$ exogenous, short-run movements in the region's net inter-regional migration rate are related to expected regional wages via (B22). With $f_r^{(W)}$ exogenous, short-run movements in the regional real wage are related to movements in the regional employment rate via (B18).

7.6.2.2 Long-run closure and operation of BOTE

The final column of Table 7.3 presents the long-run closure of BOTE. Our description of the long-run closure differs in four respects from the short-run closure described above:

(i) Equation (7.8) of our MMRF variant (represented in BOTE by B18) ensures that the policy-case level of the regional employment rate (er_r) is eventually returned to its baseline level via regional wage adjustment. In BOTE, the end-point of this process is represented by long-run exogeneity of er_r and endogeneity of $f_r^{(W)}$.

(ii) The short-run operation of (B10) gradually drives rates of return towards baseline via capital adjustment. In (B10), λ_r can be interpreted as a normal rate of return. Hence, via (B10), the regional capital growth rate will be above (below) baseline so long as the rate of return is above (below) the normal rate of return. Capital accumulation (or depreciation) gradually drives convergence of actual and normal rates of return. In Table 7.3, we describe the long-run outcome of this process as effective exogeneity of ror_r and endogeneity of k_r.

(iii) Long-run change in the equilibrium regional capital stock requires long-run adjustment of the level of real regional investment in order to maintain the new level of capital. We describe this via the long-run exogenous status of ψ_r. With (B9) determining long-run real regional investment, we describe (B10) as inactive in the long run via the endogenous status of λ_r.

(iv) The short-run operation of (7.12)–(7.14) generates movements in population that eventually return expected inter-regional wage relativities to some independently given level. In BOTE, we represent this by the long-run endogenous status of q_r and exogenous status of $f_r^{(LR)}$. Once long-run regional populations have adjusted to maintain independently determined inter-regional expected wage relativities, inter-regional migration rates return to independently established values. In BOTE, this is represented by the exogenous status of φ_r. With the long-run annual value of nim_r determined by (B21), we describe (B22) as inactive in the long run via the endogenous status of $f_r^{(\mathrm{SR})}$.

7.6.3 BOTE representations of regional aggregate demand and supply in both the short run and long run

In Sections 7.6.4 and 7.6.5, we will use BOTE to explain long-run outcomes (in the labor productivity example) and short-run outcomes (in the regional demand switching example) for the size of the regional economy as predicted by the full MMRF model. We begin by using BOTE Equations (B1)−(B23) to find reduced-form BOTE solutions for regional price and regional GDP outcomes under both short-run and long-run closures of the model.

7.6.3.1 Short-run regional aggregate supply

We begin by noting that in the short-run representation of BOTE, the operation of MMRF's sticky wage assumption in the first year of the simulation is described by (B18). Turning to (B20), the regional participation rate (pr_r) is exogenous and, we shall assume, unshocked (hence $pr_r = 0$). The regional population (q_r) does not deviate from baseline in the first year of the simulation, and thus $q_r = 0$. Substituting (B20) into (B18) for er_r thus provides:

$$w_r - p_r^{\mathrm{C}} = \alpha \cdot l_r. \tag{7.33}$$

Substituting (B19) into (7.33) for p_r^{C} provides:

$$w_r = \alpha \cdot l_r + S_r^{(\mathrm{D})\mathrm{C}} p_r. \tag{7.34}$$

Substituting (7.34) into (B1) for w_r provides:

$$l_r = [1/(1+\sigma\alpha)]((1-\sigma)a_r^{\mathrm{L}} + y_r + \sigma(1 - S_r^{(\mathrm{D})\mathrm{C}})p_r). \tag{7.35}$$

BOTE Equations (B1)−(B4) together imply the regional production function:[80]

$$y_r = S_r^{\mathrm{L}}\{l_r - a_r^{\mathrm{L}}\} + S_r^{\mathrm{K}} k_r + S_r^{\mathrm{N}} n_r. \tag{7.36}$$

Substituting (7.35) into (7.36) provides the percentage change expression for short-run regional aggregate supply:

$$y_r = A_r^{(1)} p_r - A_r^{(2)} a_r^{\mathrm{L}} + A_r^{(3)}\left(S_r^{\mathrm{K}} k_r + S_r^{\mathrm{N}} n_r\right), \tag{7.37}$$

80 Multiply (B1), (B2) and (B3) through by S_r^{L}, S_r^{K} and S_r^{N}, respectively. Add the resulting expressions, and use (B4) to substitute out p_r. Noting that $S_r^{\mathrm{L}} + S_r^{\mathrm{K}} + S_r^{\mathrm{N}} = 1$, provides (7.36).

where:

$$A_r^{(1)} = \frac{S_r^{\mathrm{L}}\sigma\left(1 - S_r^{(\mathrm{D})\mathrm{C}}\right)}{S_r^{\mathrm{K}} + S_r^{\mathrm{N}} + \sigma\alpha},\quad A_r^{(2)} = \frac{S_r^{\mathrm{L}}\sigma(1+\alpha)}{S_r^{\mathrm{K}} + S_r^{\mathrm{N}} + \sigma\alpha},\quad A_r^{(3)} = \frac{1+\sigma\alpha}{S_r^{\mathrm{K}} + S_r^{\mathrm{N}} + \sigma\alpha}.$$

Table 7.4 reports values for $A_r^{(1)}$, $A_r^{(2)}$ and $A_r^{(3)}$, evaluated from the MMRF database.

7.6.3.2 Short-run regional aggregate demand

We turn now to the derivation of the short-run regional aggregate demand function. We start by substituting (B8), (B11) and (B12) into (B7) to produce a reduced-form expression for real gross regional expenditure:

$$e_r = \left[S_r^{(\mathrm{E})\mathrm{C}} + S_r^{(\mathrm{E})\mathrm{S}}\right]apc_r + \left[S_r^{(\mathrm{E})\mathrm{C}} + S_r^{(\mathrm{E})\mathrm{S}}\right]y_r + S_r^{(\mathrm{E})\mathrm{I}}i_r + S_r^{(\mathrm{E})\mathrm{S}}\lambda_r^{(\mathrm{S})} + S_r^{(\mathrm{E})\mathrm{F}}\lambda_r^{(\mathrm{F})}. \tag{7.38}$$

To derive the short-run regional aggregate demand function (7.39), we substitute (7.38), (B14), (B15), (B16) and (B17) into (B13):

$$\Omega_r^{(1)}y_r = \Omega_r^{(2)}p_r + \Omega_r^{(3)}apc_r + \Omega_r^{(4)}i_r + \Omega_r^{(5)}\lambda_r^{(\mathrm{S})} + \Omega_r^{(6)}\lambda_r^{(\mathrm{F})} + \Omega_r^{(7)}v_r + \Omega_r^{(8)}\xi_r, \tag{7.39}$$

where:

$$\Omega_r^{(1)} = 1 - S_r^{(\mathrm{Y})\mathrm{E}}\left[S_r^{(\mathrm{E})\mathrm{C}} + S_r^{(\mathrm{E})\mathrm{S}}\right] + S_r^{(\mathrm{Y})\mathrm{MF}} + S_r^{(\mathrm{Y})\mathrm{MR}}$$

$$\begin{aligned}\Omega_r^{(2)} = &-S_r^{(\mathrm{Y})\mathrm{MF}}\left[\sigma_r^{(2)}S_r^{(\mathrm{Dom})}S_r^{(\mathrm{Local})}\right] - \left[\eta_r^{(\mathrm{XF})}S_r^{(\mathrm{Y})\mathrm{XF}}\right] \\ &-S_r^{(\mathrm{Y})\mathrm{XR}}\left[\sigma^{(2)}S_{(\mathrm{Imp})r}^{(\mathrm{RoC})}S_r^{(\mathrm{RoC})} + \sigma^{(3)}\left(1 - S_r^{(\mathrm{RoC})}\right)\right]S_r^{\mathrm{BAS}} \\ &-S_r^{(\mathrm{Y})\mathrm{MR}}\left[\sigma^{(3)}S_r^{(\mathrm{Local})} - \sigma^{(2)}S_r^{(\mathrm{Local})}\left(1 - S_r^{(\mathrm{Dom})}\right)\right]\end{aligned}$$

$$\Omega_r^{(3)} = S_r^{(\mathrm{Y})\mathrm{E}}\left[S_r^{(\mathrm{E})\mathrm{C}} + S_r^{(\mathrm{E})\mathrm{S}}\right] \quad \Omega_r^{(4)} = S_r^{(\mathrm{Y})\mathrm{E}}S_r^{(\mathrm{E})\mathrm{I}}$$

$$\Omega_r^{(5)} = S_r^{(\mathrm{Y})\mathrm{E}}S_r^{(\mathrm{E})\mathrm{S}} \quad \Omega_r^{(6)} = S_r^{(\mathrm{Y})\mathrm{E}}S_r^{(\mathrm{E})\mathrm{F}}$$

$$\Omega_r^{(7)} = \eta_r^{(\mathrm{XF})}S_r^{(\mathrm{Y})\mathrm{XF}} \quad \Omega_r^{(8)} = S_r^{(\mathrm{Y})\mathrm{MR}}S_r^{(\mathrm{Local})} + S_r^{(\mathrm{Y})\mathrm{XR}}\left(1 - S_r^{(\mathrm{RoC})}\right).$$

Table 7.4 reports values for $\Omega_r^{(1)} - \Omega_r^{(8)}$ evaluated from the MMRF database.

In (7.39) we treat real regional investment as a shift variable on the regional aggregate demand function. However, real investment is endogenous, and thus will respond to movements in regional prices and regional GDP induced by movements in the exogenous variables in (7.37) and (7.39). To derive a reduced form equation for short-run real investment, we note that in the very short-run, with capital stocks unchanged from baseline ($k_r = 0$) in the short run, (B2) implies that:

$$r_r^{\mathrm{K}} = [1/\sigma]y_r + p_r. \tag{7.40}$$

Substituting (7.40) and (B6) into (B5) provides the following short-run expression for the regional rate of return on capital:

$$ror_r = [1/\sigma]y_r + \left(1 - S_r^{(\mathrm{D})\mathrm{I}}\right)p_r. \tag{7.41}$$

Substituting (7.41) into (B10) and then substituting the resulting expression into (B9) while noting that $k_r = 0$, we have:

$$i_r = \beta_r \left[\left(1/\sigma\right)y_r + \left(1 - S_{\mathrm{r}}^{(\mathrm{D})\mathrm{I}}\right) p_r - \lambda_r\right], \tag{7.42}$$

which is our BOTE expression for short-run real investment.[81]

7.6.3.3 Long-run regional aggregate supply

Our derivation of the long-run regional aggregate supply function begins with BOTE Equations (B5) and (B6). As discussed in Section 7.6.2.2, we describe ror_r as exogenous in the long-run. Via (B5), this ensures that movements in regional capital construction costs flow into the long-run regional rental price of capital, that is $r_r^{\mathrm{K}} = p_r^{\mathrm{I}}$. Substituting (B6) into (B5), and substituting the resulting expression into (B4) provides:

$$p_r = \left(1\Big/\left(1 - S_r^{\mathrm{K}} S_r^{(\mathrm{D})\mathrm{I}}\right)\right)\left(S_r^{\mathrm{L}}\left\{w_r + a_r^{\mathrm{L}}\right\} + S_r^{\mathrm{N}} r_r^{\mathrm{N}}\right). \tag{7.43}$$

On the right-hand side of (7.43) we find the regional wage, w_r, and regional natural resource rental prices, r_r^{N}. As discussed in Section 7.6.2.2, $f_r^{(\mathrm{LR})}$ is exogenous in the long-run, reflecting the MMRF assumption that long-run inter-regional population movements return inter-regional wage relativities to baseline. Hence, via (B23), $w_r = w$. To understand the long-run movement in r_r^{N}, we use (B3). Natural resource supply does not deviate from its baseline value, hence $n_r = 0$.[82] Substituting (B3) into (7.43) for r_r^{N},

[81] The reader will note that with y_r and p_r appearing on the right-hand side of (7.42), neither regional investment (i_r), nor, via the appearance of i_r in (7.39), regional aggregate demand, are independent of movements in the exogenous shift variables in (7.37) or (7.39). For example, a positive shock to apc_r, with investment held at its initial level, will, via (7.37) and (7.39), cause positive deviations in y_r and p_r. Via (7.42), this will produce a positive deviation in real investment, and thus, via (7.39), a further 'north-easterly' shift in the regional aggregate demand schedule described by (7.39). A demonstration that this process generates convergent movements in y_r, p_r and i_r under reasonable parameter values is available from the authors on request.

[82] Naturally, we would choose to retain n_r as an explicit (rather than omitted) exogenous variable in any derivation of long-run aggregate supply in which we sought to explain a multiregional CGE simulation in which natural resources were a shocked exogenous variable. Equation (7.37) is an example of the retention of n_r as an exogenous variable in the derivation of short-run aggregate supply.

and substituting $w_r = w$ into (7.43) for w_r, provides (7.44), the BOTE representation of region r's long-run aggregate supply function:

$$\Phi_r^{(1)} y_r = \Phi_r^{(2)} p_r - \Phi_r^{(3)} \{w + a_r^{\mathrm{L}}\}, \tag{7.44}$$

where $\Phi_r^{(1)} = S_r^{\mathrm{N}}/\sigma$, $\Phi_r^{(2)} = 1 - S_r^{\mathrm{K}} S_r^{(\mathrm{D})\mathrm{I}} - S_r^{\mathrm{N}}$ and $\Phi_r^{(3)} = S_r^{\mathrm{L}}$.

Table 7.5 reports values for $\Phi_r^{(1)} - \Phi_r^{(3)}$ evaluated from the MMRF database.

7.6.3.4 Long-run regional aggregate demand

To derive the BOTE representation of the long-run regional aggregate demand function, we begin with (B7). Our first task is to describe the long-run determination of the right-hand components of (B7): c_r, i_r, $g_r^{(\mathrm{S})}$ and $g_r^{(\mathrm{F})}$.

Long-run determination of real private and public consumption is relatively straightforward. With $\lambda_r^{(\mathrm{F})}$, $\lambda_r^{(\mathrm{S})}$ and apc_r exogenous and unshocked (thus $\lambda_r^{(\mathrm{F})} = \lambda_r^{(\mathrm{S})} = apc_r = 0$), we have, via (B8), (B11) and (B12), respectively:

$$c_r = y_r \tag{7.45}$$

$$g_r^{(\mathrm{S})} = c_r \tag{7.46}$$

$$g_r^{(\mathrm{F})} = q_r. \tag{7.47}$$

With ψ_r exogenous and unshocked in the long-run, real investment is determined by (B9), i.e.:

$$i_r = k_r. \tag{7.48}$$

In the long run, k_r is endogenous and determined by (B2). Substituting (B6) into (B5), and substituting the resulting expression into (B2) for r_r^{K}, provides:

$$k_r = y_r - \sigma\left(S_r^{(\mathrm{D})\mathrm{I}} - 1\right) p_r. \tag{7.49}$$

Substituting (7.49) into (7.48) provides:

$$i_r = y_r - \sigma\left(S_r^{(\mathrm{D})\mathrm{I}} - 1\right) p_r. \tag{7.50}$$

Substituting (7.45), (7.46), (7.47) and (7.50) into (B7) we have:[83]

$$e_r = \left[S_r^{(\mathrm{E})\mathrm{C}} + S_r^{(\mathrm{E})\mathrm{S}} + S_r^{(\mathrm{E})\mathrm{I}}\right] y_r + \sigma S_r^{(\mathrm{E})\mathrm{I}}\left(1 - S_r^{(\mathrm{D})\mathrm{I}}\right) p_r + S_r^{(\mathrm{E})\mathrm{F}} q_r. \tag{7.51}$$

[83] Naturally, if our aim was to use BOTE to explain the long-run effects of shifts in $\lambda_r^{(\mathrm{F})}$, $\lambda_r^{(\mathrm{S})}$, apc_r and ψ_r, we would not omit these exogenous variables from the derivation of the long-run aggregate demand schedule as we have done here. For an example of the retention of these exogenous variables in the derivation of short-run regional aggregate demand, see (7.40).

As is clear from (7.51), in the long run gross regional expenditure is inelastic to the regional GDP deflator, *cet. par.* In (7.51), the regional price level directly affects gross regional expenditure only through demand for capital, via the coefficient $\sigma S_r^{(\mathrm{E})\mathrm{I}}\left(1 - S_r^{(\mathrm{D})\mathrm{I}}\right)$. This coefficient recognizes that a rise in the long-run regional price level will typically signal a fall in the relative price of regional capital, since, for many regions, a large share of the cost of capital is determined by import prices.

Our next step in deriving the percentage change form for the regional aggregate demand function is to consider (B13). While gross regional expenditure may not be price elastic, overall aggregate demand at the regional level is rendered price elastic via net interstate and overseas trade. Finally, substituting (7.51), (B14), (B15), (B16) and (B17) into (B13) generates the long-run regional aggregate demand function:

$$\Psi_r^{(1)} y_r = \Psi_r^{(2)} p_r + \Psi_r^{(3)} q_r + \Psi_r^{(4)} v_r + \Psi_r^{(5)} \xi_r, \tag{7.52}$$

where:

$$\Psi_r^{(1)} = 1 - S_r^{(\mathrm{Y})\mathrm{E}}\left[S_r^{(\mathrm{E})\mathrm{C}} + S_r^{(\mathrm{E})\mathrm{S}} + S_r^{(\mathrm{E})\mathrm{I}}\right] + S_r^{(\mathrm{Y})\mathrm{MF}} + S_r^{(\mathrm{Y})\mathrm{MR}}$$

$$\begin{aligned}\Psi_r^{(2)} = {} & -\sigma S_r^{(\mathrm{Y})\mathrm{E}} S_r^{(\mathrm{E})\mathrm{I}}\left(S_r^{(\mathrm{D})\mathrm{I}} - 1\right) - \eta_r^{(\mathrm{XF})} S_r^{(\mathrm{Y})\mathrm{XF}} - \sigma_r^{(2)} S_r^{(\mathrm{Y})\mathrm{MF}} S_r^{(\mathrm{Dom})} S_r^{(\mathrm{Local})} \\ & - S_r^{(\mathrm{Y})\mathrm{XR}}\left[\sigma^{(2)} S_{(\mathrm{Imp})r}^{(\mathrm{RoC})} S_r^{(\mathrm{RoC})} + \sigma^{(3)}\left(1 - S_r^{(\mathrm{RoC})}\right)\right] S_r^{\mathrm{BAS}} \\ & - S_r^{(\mathrm{Y})\mathrm{MR}}\left[\sigma^{(3)} S_r^{(\mathrm{Local})} - \sigma^{(2)} S_r^{(\mathrm{Local})}\left(1 - S_r^{(\mathrm{Dom})}\right)\right]\end{aligned}$$

$$\Psi_r^{(3)} = S_r^{(\mathrm{Y})\mathrm{E}} S_r^{(\mathrm{E})\mathrm{F}} \quad \Psi_r^{(4)} = \eta_r^{(\mathrm{XF})} S_r^{(\mathrm{Y})\mathrm{XF}}$$

$$\Psi_r^{(5)} = S_r^{(\mathrm{Y})\mathrm{XR}}\left(1 - S_r^{(\mathrm{RoC})}\right) + S_r^{(\mathrm{Y})\mathrm{MR}} S_r^{(\mathrm{Local})}.$$

Table 7.5 reports values for $\Psi_r^{(1)} - \Psi_r^{(5)}$ evaluated from the MMRF database.

7.6.4 Regional labor-saving technical change

We investigate the regional impact of a 1% labor-saving technical change in the South region, such as might be caused by a region-specific program of microeconomic reform.[84] In this section, we use BOTE primarily as a vehicle for exploring long-run regional impacts. In Section 7.6.5, we turn BOTE to the task of exploring short-run regional impacts in particular.

We begin by noting that in BOTE, labor-saving technical change is represented by a_r^{L}, the number of units of labor required per effective labor input. A 1% labor-saving

[84] See, e.g. Productivity Commission (2006, pp. 349–356).

technical change in South represents a −1% shock to $a^{\mathrm{L}}_{\mathrm{South}}$. To trace the impact of this on short-run employment, we begin by subtracting (B2) from (B1), which provides:

$$\left\{l_r - a_r^{\mathrm{L}}\right\} - k_r = -\sigma\left(\left\{w_r + a_r^{\mathrm{L}}\right\} - r_r^{\mathrm{K}}\right). \tag{7.53}$$

In the very short-run, k_r does not deviate from its baseline value. Hence, (7.53) can be viewed as determining l_r in the short run. Substituting (7.40) into (7.53) for r_r^{K} provides:

$$l_r = (1-\sigma)a_r^{\mathrm{L}} + y_r - \sigma(w_r - p_r). \tag{7.54}$$

The first term of (7.54) indicates that a 1% fall in a_r^{L} has two direct effects on regional employment − a productivity effect and a factor price effect. (i) By reducing by 1% the number of persons required to secure an effective labor unit, the productivity effect reduces employment of persons by 1%. (ii) By reducing the cost of acquiring an effective labor unit by 1%, the factor price effect increases demand for effective labor units, and with it, persons, by σ. With $\sigma = 0.3$ (see Table 7.4), the factor price effect lifts employment of persons by 0.3%. Hence, a region-specific 1% labor-saving technical change has a *direct* short-run effect on South's employment of $-1 + 0.30 = -0.70$%. For values of σ less than 1, (7.54) indicates that labor-saving technical change has a negative direct short-run impact on regional employment. However, (7.54) also points to general equilibrium impacts on regional employment via changes in regional activity and/or the real producer price of labor. To explore this general equilibrium effect further, and moreover, to examine the likelihood of this effect offsetting the direct employment loss, we begin with the regional aggregate demand Equation (7.39):

$$y_r = \left[\Omega_r^{(2)}/\Omega_r^{(1)}\right]p_r + \left[\Omega_r^{(4)}/\Omega_r^{(1)}\right]i_r = \eta_r^{(1)}p_r + \eta_r^{(2)}i_r. \tag{7.55}$$

Next, we note that in the short-run, with capital stocks and natural resource endowments exogenous and unshocked, $k_r = n_r = 0$. Hence, via (B2) and (B3) it must be that $r_r^{\mathrm{K}} = r_r^{\mathrm{N}}$. Hence, (B4) becomes:

$$p_r = S_r^{\mathrm{L}}\left\{w_r + a_r^{\mathrm{L}}\right\} + \left(1 - S_r^{\mathrm{L}}\right)r_r^{\mathrm{K}}. \tag{7.56}$$

Substitute (7.56) into (7.55):

$$y_r = \eta_r^{(1)}\left(S_r^{\mathrm{L}}\left\{w_r + a_r^{\mathrm{L}}\right\} + \left(1 - S_r^{\mathrm{L}}\right)r_r^{\mathrm{K}}\right) + \eta_r^{(2)}i_r. \tag{7.57}$$

Substitute (7.56) and (7.57) into (B2):

$$r_r^{\mathrm{K}} = \left(\frac{-\left[\eta_r^{(1)} + \sigma\right]S_r^{\mathrm{L}}}{\left[\eta_r^{(1)}\left(1 - S_r^{\mathrm{L}}\right) - \sigma S_r^{\mathrm{L}}\right]}\right)\left\{w_r + a_r^{\mathrm{L}}\right\} - \left(\frac{\eta_r^{(2)}}{\left[\eta_r^{(1)}\left(1 - S_r^{\mathrm{L}}\right) - \sigma S_r^{\mathrm{L}}\right]}\right)i_r. \tag{7.58}$$

Substitute (7.56) and (7.57) into the labor demand Equation (B1):

$$l_r = a_r^{\mathrm{L}} + \left[\eta_r^{(1)} S_r^{\mathrm{L}} - \sigma\left(1 - S_r^{\mathrm{L}}\right)\right]\left\{w_r + a_r^{\mathrm{L}}\right\} + \left(1 - S_r^{\mathrm{L}}\right)\left[\sigma + \eta_r^{(1)}\right] r_r^{\mathrm{K}} + \eta_r^{(2)} i_r. \quad (7.59)$$

Substituting (7.58) into (7.59) provides our short-run employment function:

$$l_r = \left((1-\sigma) - \frac{\sigma S_r^{\mathrm{L}}}{1/\left(1+\sigma/\eta_r^{(1)}\right) - S_r^{\mathrm{L}}}\right) a_r^{\mathrm{L}} - \left(\frac{\sigma}{\eta_r^{(1)}\left(1-S_r^{\mathrm{L}}\right) - \sigma S_r^{\mathrm{L}}}\right)\left(\eta_r^{(1)} w_r + \eta_r^{(2)} i_r\right). \quad (7.60)$$

Abstracting from movements in the regional wage (w_r) and regional investment (i_r), the first coefficient on the right-hand side of (7.60) identifies the direct and indirect routes via which a movement in a_r^{L} affects regional employment. We established earlier that the direct effect, the strength of which is represented by $(1-\sigma)$, will be negative for values of $\sigma < 1$. The value of the general equilibrium effect, the strength of which is represented by the term $-\sigma S_r^{\mathrm{L}}/\left(1/\left(1+\sigma/\eta_r^{(1)}\right) - S_r^{\mathrm{L}}\right)$, is governed by three parameters: σ, S_r^{L} and $\eta_r^{(1)}$. The value of this term is most sensitive to the values of σ and S_r^{L}, both of which will normally be known with some confidence. The term's value is less sensitive to $\eta_r^{(1)}$, over which there may be more uncertainty given the role of Armington elasticities and export demand elasticities in determining its value.[85] For South, the value of the general equilibrium term is 0.30.[86] This is not sufficient to offset the employment loss generated by the direct effect $(1-\sigma)$. Hence, South experiences a short-run negative deviation in employment (Figure 7.4). Certainly, with sufficient wage flexibility or a large induced investment response, the short-run employment outcome could be positive. However (7.60) suggests this is not a likely outcome under plausible parameter value ranges.

We now investigate the long-run regional consequences of region-specific labor-saving technical change. In particular, we investigate how changes in regional labor efficiency affect the long-run size of the regional economy, in terms of real GDP, population and employment. As we shall see, while regional labor-saving technical change unambiguously increases long-run real regional GDP, it may cause regional population and employment to either rise or fall. Our approach will be to find BOTE solutions for long-run regional price and real GDP outcomes by drawing on the long-run expressions for regional aggregate supply and aggregate demand derived in Section 7.6.3.

We begin by considering the consequences of the shock for the long-run regional wage. In the long-run, the inter-regional migration theory described by (7.12)–(7.14)

85 $\eta_r^{(1)} = \Omega_r^{(2)}/\Omega_r^{(1)}$. Via (7.39), we see that values for inter-regional sourcing elasticities and export demand elasticities play a dominant role in determining the value of $\Omega_r^{(2)}$.

86 $0.3 * 0.58/(1/(1+0.3/-2.29)-0.58) = 0.30$.

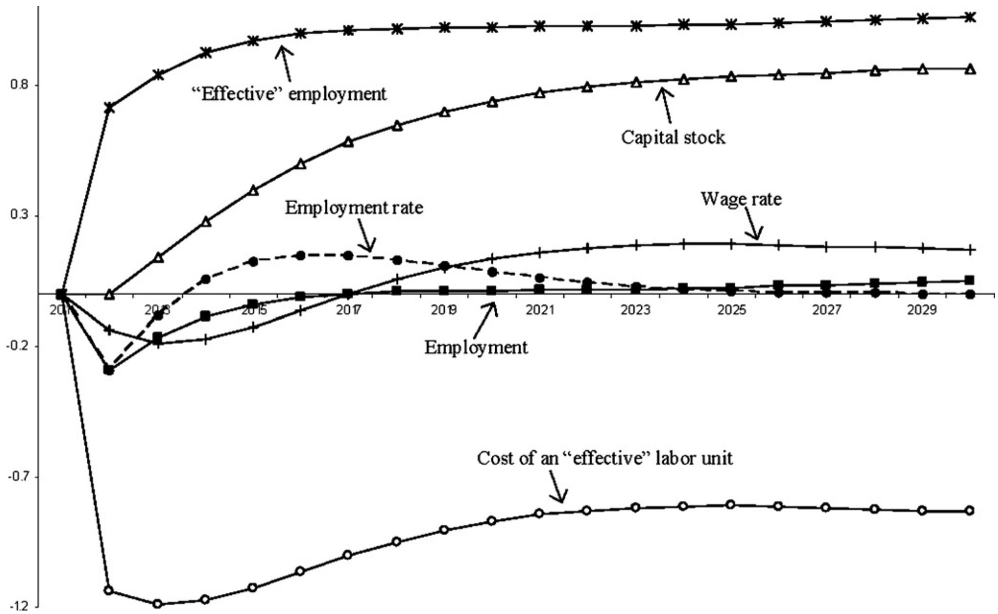

Figure 7.4 Labor-saving technical change in South. Capital stock, employment, effective employment, wage rates per hour and effective labor unit, and employment rate for the South region (percentage deviation from baseline).

returns long-run migration income relativities to their baseline levels. In our MMRF implementation, we define migration income as expected (employment probability weighted) wage income via (7.12). Since our long-run wage adjustment mechanism returns long-run region-specific employment rates to their baseline levels, our migration theory generates a convergence of long-run wage deviations. Hence, in Figure 7.5, we find that South's long-run wage deviation eventually converges on the long-run national wage deviation. Note that the long-run national wage deviation is positive. With employment rates returning to baseline in every region, and the national population unchanged from baseline, the national employment deviation must be close to zero.[87] With capital adjusting in the long-run to return rates of return to baseline levels, the labor-saving technical change must be expressed as a rise in returns to the fixed factor, labor. This accounts for the long-run increase in the national wage (Figure 7.5).

Table 7.5 reports long-run values for the parameters and shares of our calibrated BOTE model. For the South region, the parameterized long-run regional aggregate supply and demand functions are:

$$y_{\text{South}} = 1.92\, p_{\text{South}} - 1.61\, \left\{w + a^{\text{L}}_{\text{South}}\right\} \quad \text{Aggregate supply} \tag{7.61}$$

[87] Recall population movements between regions with differing base-case unemployment rates can generate small deviations in national employment.

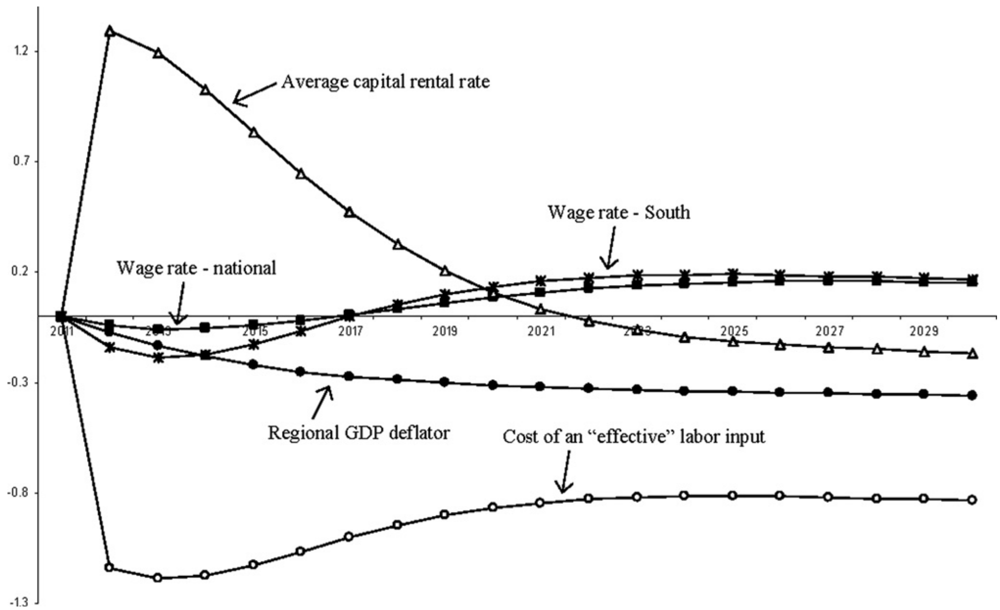

Figure 7.5 Labor-saving technical change in South. Wage rate, wage rate per effective labor input, capital rental rate and GSP deflator for the South region (percentage deviation from baseline).

$$y_{\text{South}} = -3.78\ p_{\text{South}} + 0.143\ q_{\text{South}} \quad \text{Aggregate demand.} \tag{7.62}$$

We draw the reader's attention to $\Psi^{(2)}$ in (7.52), and in particular the collection of coefficients and parameters that determine the long-run sensitivity of demand for region r's output to the price of region r's output. Note that, as discussed in reference to (7.51), the value of the first term in $\Psi_r^{(2)}$, $\sigma S_r^{(\text{Y})\text{E}} S_r^{(\text{E})\text{I}} \left(S_r^{(\text{D})\text{I}} - 1 \right)$, is small (−0.02 for South). This leaves three salient behavioral parameters in $\Psi_r^{(2)}$ important to determining the price elasticity of region r's aggregate demand: η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$. Shortly, we show that these three parameters exert a strong influence on the long-run regional employment consequences of regional labor-saving technical change.

Our aim is to understand how regional labor-saving technical change affects the long-run size of the regional economy, both in terms of real GDP, and population and employment. We begin by substituting the regional aggregate demand function (7.52) into the regional aggregate supply function (7.44) and solving for y_r:

$$y_r = \left(\frac{\Psi_r^{(2)}}{\Phi_r^{(2)} \Psi_r^{(1)} - \Phi_r^{(1)} \Psi_r^{(2)}} \right) \left[\frac{\Phi_r^{(2)} \Psi_r^{(3)}}{\Psi_r^{(2)}} q_r + \Phi_r^{(3)} \left\{ w_r + a_r^{\text{L}} \right\} \right]. \tag{7.63}$$

Using Table 7.5 to evaluate (7.63) for South provides:

$$y_{\text{South}} = 0.05\ q_{\text{South}} - 1.07\ \left\{ w_{\text{South}} + a_{\text{South}}^{\text{L}} \right\}. \tag{7.64}$$

Equation (7.64) suggests that the long-run elasticity of South's real GDP at factor cost to movements in the regional effective wage rate $(w_{\text{South}} + a^{\text{L}}_{\text{South}})$ is a little over -1. The long-run deviation in South's wage per effective labor unit is -0.83% (Figure 7.5). Equation (7.64) suggests that this should generate a long-run deviation in South's real GDP at factor cost of approximately $-1.07 * -0.83 = +0.89$, which proves to be identical to that generated by MMRF (Figure 7.6). To understand the implications for regional employment and population of a 0.89% expansion in real GDP, we begin by considering BOTE Equations (B1)−(B4) which together imply the regional production function:[88]

$$y_r = S^{\text{L}}_r\{l_r - a^{\text{L}}_r\} + S^{\text{K}}_r k_r + S^{\text{N}}_r n_r. \tag{7.65}$$

Together, (7.65) and (7.53) remind us that in the long-run, regional demand for effective primary factor inputs will tend to move proportionately with movements in real regional GDP, unless there is a change in relative regional factor prices. Substituting (7.53) into (7.65) for k_r provides region r's long-run demand equation for effective labor inputs:

$$\{l_r - a^{\text{L}}_r\} = \left(\frac{1}{1 - S^{\text{N}}_r}\right)\left[y_r - \sigma S^{\text{K}}_r\left(\{w_r + a^{\text{L}}_r\} - r^{\text{K}}_r\right) - S^{\text{N}}_r n_r\right]. \tag{7.66}$$

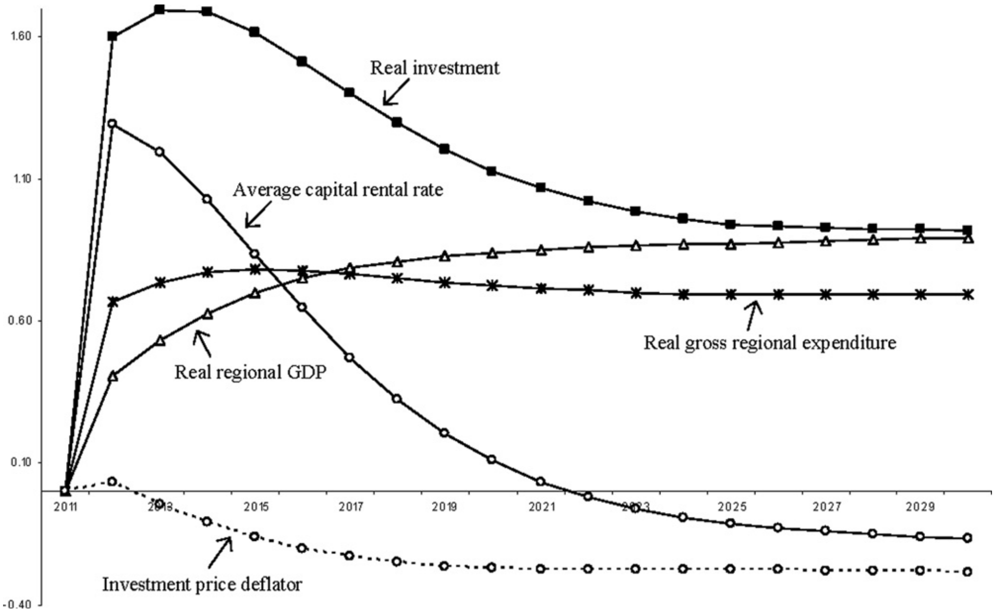

Figure 7.6 Labor-saving technical change in South. Real investment, real gross regional expenditure, real GDP, investment price deflator and average capital rental rate for the South region (percentage deviation from baseline).

88 Multiply (B1), (B2) and (B3) through by S^{L}_r, S^{K}_r and S^{N}_r, respectively. Add the resulting expressions and use (B4) to substitute out p_r. Noting that $S^{\text{L}}_r + S^{\text{K}}_r + S^{\text{N}}_r = 1$, provides (7.65).

Using Table 7.5 to calibrate (7.66) for South provides:

$$l_{\text{South}} - a^{\text{L}}_{\text{South}} = 1.1\ y_{\text{South}} - 0.10\ \left(\left\{w_{\text{South}} + a^{\text{L}}_{\text{South}}\right\} - r^{\text{K}}_{\text{South}}\right) + 0.12\ n_{\text{South}}. \tag{7.67}$$

Via (7.64) we established that South's 1% labor-saving technical change lifts the region's real GDP by approximately 0.89% in the long-run. Via (7.67), we see that this causes demand for effective employment ($l_{\text{south}} - a^{\text{L}}_{\text{South}}$) to rise by 0.98%, *cet. par.* However, the 1% labor-saving technical change alone provides a 1% rise in effective Southern employment. Hence, *cet. par.*, (7.67) suggests long-run employment of persons must fall by 0.02%. The true long-run employment outcome, calculated by MMRF, is a small rise of 0.05% (Figure 7.4). The difference is due to the relative factor price effect in (7.67). As discussed above, the wage per effective labor unit in South falls by −0.83%. At the same time, the long-run rental price of South's capital falls by 0.17% (Figure 7.6). This induces substitution towards labor which contributes the remaining +0.07 percentage points (= −0.10 * {0.17 − 1 − −0.17}) of South's long-run employment deviation.

In the long-run, we assume that region-specific participation rates and employment rates do not deviate from their baseline values. Hence, with South's long-run employment 0.05% above baseline, via (B20), South's population is also 0.05% above baseline. Note that to keep our explanation of long-run employment results simple, in Equations (7.52), (7.63) and (7.64) above, we treated the regional population, q_r, as exogenous. Regional population appears in the long-run regional aggregate demand function because region-specific *per capita* federal government consumption spending remains at baseline levels. For South, the small long-run population increase associated with labor-saving technical change signals a second, albeit small, round of increases in aggregate demand, real GDP and employment via additional federal government consumption spending.

We now turn to explore more generally the long-run consequences for regional employment and population of region-specific labor-saving technical change. To do so, we substitute (7.63) into (7.66) for y_r, which yields (7.68). To focus on the impact on regional employment of labor-saving technical change, (7.68) omits all variables other than a^{L}_r:

$$l_r = \left[\Theta^{(1)}_r - \Theta^{(2)}_r\right] a^{\text{L}}_r, \tag{7.68}$$

where:

$$\Theta^{(1)}_r = \left(1 - \left(\frac{\sigma S^{\text{K}}_r}{1 - S^{\text{N}}_r}\right)\right) \quad \text{and} \quad \Theta^{(2)}_r = \left(\frac{1}{1 - S^{\text{N}}_r}\right)\left(\frac{\Phi^{(3)}_r \Psi^{(2)}_r}{\Phi^{(1)}_r \Psi^{(2)}_r - \Phi^{(2)}_r \Psi^{(1)}_r}\right).$$

(7.68) identifies two routes via which labor-saving technical change affects regional employment.[89] The first, $\Theta_r^{(1)}$, recognizes the direct impact of labor-saving technical change on regional employment for a *given level* of regional GDP. The second, $\Theta_r^{(2)}$, recognizes labor productivity's indirect impact on regional employment via its impact on regional GDP, and with it, demand for labor inputs. Examining Table 7.5, we see that $\Theta_r^{(1)} \approx \Theta_r^{(2)}$. Hence, we might expect that labor-saving technical change will tend to have small effects on long-run regional employment, and that these effects will be of uncertain sign. To investigate this further, we must consider the structural and behavioral parameters that comprise $\Theta_r^{(1)}$ and $\Theta_r^{(2)}$.

In Table 7.5, we see that a typical value for $\sigma S_r^{\mathrm{K}}/(1 - S_r^{\mathrm{N}})$ is small, approximately 0.10. Hence a typical value for $\Theta_r^{(1)}$ will be around 0.9. The components of $\Theta_r^{(1)}$ will normally be known with some confidence. The structural parameters S_r^{K} and S_r^{N} are available from regional input output data. The value for the behavioral parameter σ may be known with less certainty, but a nevertheless plausible and limited range of values can be inferred from econometric studies of the wage elasticity of labor demand.[90]

Like $\Theta_r^{(1)}$, many of the components of $\Theta_r^{(2)}$ also relate to share parameters describing economic structure that are readily available from regional input output data. An exception is $\Psi_r^{(2)}$, which contains parameters governing the price elasticity of demand for output of the region's traded goods sector: η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$. Increasing the values of η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$ will increase the value of $\Theta_r^{(2)}$, generating larger regional employment gains for a given labor-saving technical change. Recall that $\sigma_r^{(2)}$ and $\sigma^{(3)}$ are international and inter-regional Armington elasticities, and implicit in estimates for η_r are Armington elasticities in the foreign destinations for region r's exports (Dixon and Rimmer, 2010). As McDaniel and Balistreri (2003) note, there is a range of estimates in the literature for these parameters.[91] While sensitivity analysis is in general not a good alternative to the BOTE analysis, the BOTE analysis that has taken us to (7.68) allows us to identify the parameters most

89 (7.68) suppresses three second-order effects. The first, via population-driven movements in federal spending, is small, and is in any case determined by the outcome for regional employment via (B20) and (B12). The second, via movements in the regional wage, will also be small if the region represents a sufficiently small share of the national labor market since, via (B23), the long-run regional wage deviation will track the national wage deviation. The third indirect effect on regional employment, also small, is via movements in r_r^{K} in (7.66). In the long-run, with rates of return exogenous, movements in the regional price level induced by labor-saving technical change will affect the user cost of capital via (B6) and (B5). The impact of this on long-run labor demand is small for three reasons. (i) With the price elasticity of long-run regional aggregate demand quite high, the scope for large relative movements in the long-run regional price level are constrained. (ii) The effect of movements in the long-run regional price level on the rental price of capital is mediated by the share $S_r^{(\mathrm{D})\mathrm{I}}$ in (B6). (iii) The impact of long-run movements in the rental price of capital on labor demand is mediated by the product of σ and S_r^{K} in (7.66) (note that because S_r^{N} will be small for most regions, the term $1/(1- S_r^{\mathrm{N}})$ in (7.66) will typically be close to 1).

90 See Dixon (2009).

91 See also the discussion in Section 7.5.3.

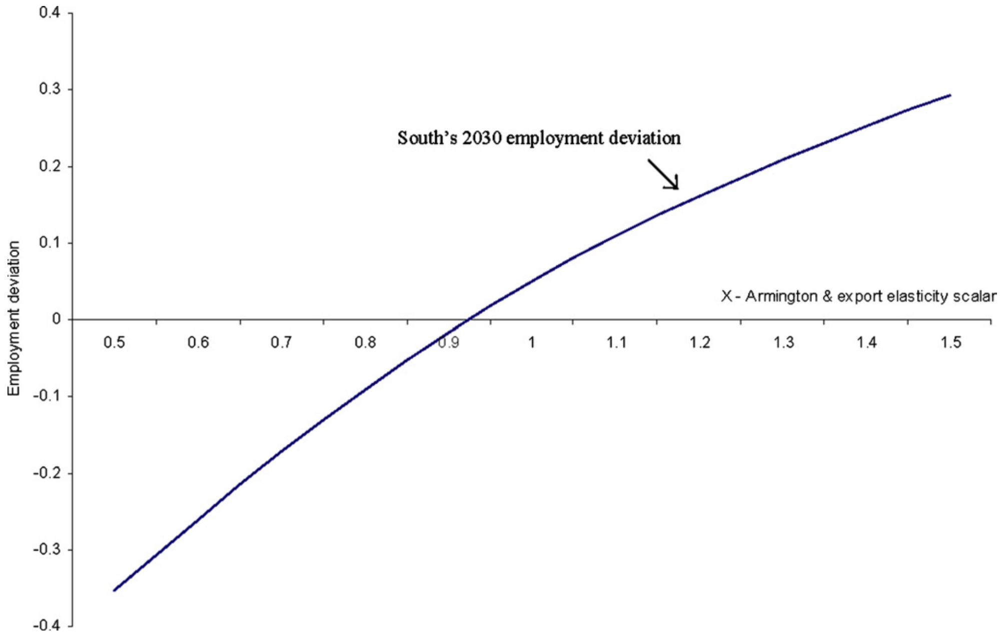

Figure 7.7 Labor-saving technical change in South. Sensitivity analysis: Long-run (year 2030) percentage deviation in South's employment under alternative values for Armington and export elasticities.

relevant to determining the long-run employment consequences of region-specific labor-saving technical change. Equipped with this finding, (Figure 7.7) explores the sensitivity of South's long-run employment outcome to alternative values for η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$. In determining alternative values for these parameters, we apply a uniform scalar (X in Figure 7.7), ranging between 0.5 and 1.5, to our preferred values for η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$. For example, when $X = 1$, η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$ have the values reported in Table 7.5, and when $X = 0.5$, the values for η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$ are half those reported in Table 7.5. The sensitivity analysis reported in Figure 7.7 confirms our conclusion from inspection of (7.68). At our preferred settings for η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$ (i.e. when $X = 1$), the employment promoting and employment contracting impacts of region-specific labor-saving technical change, i.e. $\Theta_r^{(2)}$ and $\Theta_r^{(1)}$, are evenly balanced. Hence, even a small decrease in η_r, $\sigma_r^{(2)}$ and $\sigma^{(3)}$ away from our preferred values may change the sign of the long-run deviations in regional employment and population.

7.6.5 Change in the spatial distribution of domestic demand

In this section, we investigate the effects of a change in preferences over alternative sources of domestic commodity supply. We describe the change in preferences through an inter-regional sourcing twist, defined as a cost-neutral combination of changes in source-specific input requirements that, taken together, achieve a given change in the ratio of locally sourced to interstate-sourced inputs. As Dixon and Rimmer (2002, p. 173) describe, national and commodity-specific twist variables have proved valuable in forecasting and historical analysis with national CGE models. Similarly, in developing baseline forecasts with multiregional CGE models, national import/domestic twists and labor/capital twists are important in allowing the models to accommodate independent forecasts for national import volumes and the national average wage rate. Inter-regional sourcing twist variables have also proved useful in historical analysis with multiregional models (Giesecke, 2002; Giesecke and Madden, 2010). Giesecke *et al*. (2012) use twist-like revenue-neutral tax variables to model region-specific demand shifts associated with a rise in regional risk perception following a hypothetical terrorist attack. Twist variables are also valuable in simulating the effects of new projects or major events that involve economic agents transferring their purchases from one region to another. For example, in modeling domestic mineral sales by a new mining enterprise located in North, we might implement a cost-neutral twist in sourcing preferences by domestic users of the mineral, with the twist favoring greater use of the North source and lower use of alternative domestic sources. Similarly, in modeling, say, a successful domestic interstate tourism campaign by the North, we might implement a twist in sourcing preferences by households in all regions, with the twist favoring the Northern source for commodities related to tourism. In both examples, the inter-regional sourcing twist allows us to vary the spatial distribution of commodity sourcing decisions, while leaving unchanged the economy's level of technical efficiency. In this section, we explore the effects of the inter-regional sourcing twist, by modeling a 1% twist towards the Northern source for all commodities. We begin by deriving the twist variable. This derivation extends to the multiregional setting the import/domestic twist formulated by Horridge (2003). We start with (7.69), which describes the percentage change form of MMRF's cost-minimizing demand equations for region-specific commodity demands by agent t in region k:

$$x_{(i,r)}^{(t,k)} = a_{(i,r)}^{(t,k)} + x_{(i,\mathrm{Dom})}^{(t,k)} - \sigma^{(3)}\left(p_{(i,r)}^{(t,k)} + a_{(i,r)}^{(\mathrm{t,k})} - p_{(i,\mathrm{Dom})}^{(t,k)}\right), \tag{7.69}$$

where $x_{(i,r)}^{(t,k)}$ is the percentage change in demand for commodity i from domestic region r by agent t located in domestic region k, $a_{(i,r)}^{(t,k)}$ is the percentage change in a technical efficiency variable describing the number of units of commodity i from region r required to sustain an effective input of i from r by agent t located in domestic region k, $x_{(i,\mathrm{Dom})}^{(t,k)}$ is the percentage change in demand by agent t in region k for domestic commodity i irrespective of source, $\sigma^{(3)}$ is the elasticity of substitution across alternative domestic commodity sources, $p_{(i,r)}^{(t,k)}$ is the percentage change in the price faced by agent t in region

k for commodity i from domestic source r, and $p_{(i,\text{Dom})}^{(t,k)}$ is the percentage change in the average price faced by agent t in region k for domestic commodity i irrespective of source, defined as:

$$p_{(i,\text{Dom})}^{(t,k)} = \sum_{r=1}^{\text{R}} S_{(i,r)}^{(t,k)} \left(p_{(i,r)}^{(t,k)} + a_{(i,r)}^{(t,k)} \right), \tag{7.70}$$

where $S_{(i,r)}^{(t,k)}$ is the value share of commodity i from domestic source r in agent (t,k)'s total purchases of i from all domestic sources.

We define a twist $\left(\xi_{(i,1)}^{(t,k)} \right)$ by agent (t,k) towards region 1 as a source for commodity i as:

$$\xi_{(i,1)}^{(t,k)} = x_{(i,1)}^{(t,k)} - x_{(i)^*}^{(t,k)}, \tag{7.71}$$

where the movements in the right-hand side variables $x_{(i,1)}^{(t,k)}$ and $x_{(i)^*}^{(t,k)}$ are confined to those generated by the cost-neutral combination of technical change terms defining the twist, and where $x_{(i)^*}^{(t,k)}$ is the percentage change in agent (t,k)'s demand for commodity i from all domestic sources other than 1, defined as:

$$\left[1 - S_{(i,1)}^{(t,k)} \right] x_{(i)^*}^{(t,k)} = \sum_{s=2}^{\text{R}} S_{(i,s)}^{(t,k)} x_{(i,s)}^{(t,k)}. \tag{7.72}$$

Our aim is to find the combination of technical change terms $a_{(i,1)}^{(t,k)}$, and $a_{(i,2)}^{(t,k)} = a_{(i,3)}^{(t,k)} = \ldots = a_{(i,R)}^{(t,k)} = a_{(i)^*}^{(t,k)}$ that achieves (7.71) while ensuring that, for given prices, the unit cost of commodity i to agent (t,k) remains unchanged. That is, find $a_{(i,1)}^{(t,k)}$ and $a_{(i)^*}^{(t,k)}$ such that:

$$S_{(i,1)}^{(t,k)} a_{(i,1)}^{(t,k)} + \sum_{r=2}^{\text{R}} S_{(i,r)}^{(t,k)} a_{(i)^*}^{(t,k)} = 0 \tag{7.73}$$

$$\xi_{(i,1)}^{(t,k)} = x_{(i,1)}^{(t,k)} - x_{(i)^*}^{(t,k)}. \tag{7.74}$$

To begin the derivation of the twist terms, we begin by noting that, for given prices, (7.69) simplifies to:

$$x_{(i,r)}^{(t,k)} = x_{(i,\text{Dom})}^{(t,k)} + \left(1 - \sigma^{(3)} \right) a_{(i,r)}^{(t,k)}. \tag{7.75}$$

Substituting (7.75) for sources 2, …, R into (7.72) and noting that $a_{(i,2)}^{(t,k)} = a_{(i,3)}^{(t,k)} = \ldots = a_{(i,R)}^{(t,k)} = a_{(i)^*}^{(t,k)}$ provides:

$$x_{(i)^*}^{(t,k)} = x_{(i,\text{Dom})}^{(t,k)} + \left(1 - \sigma^{(3)} \right) a_{(i)^*}^{(t,k)}. \tag{7.76}$$

Substituting both (7.75) (for source 1) and (7.76) into (7.74) provides:

$$\xi_{(i,1)}^{(t,k)} = \left(1 - \sigma^{(3)}\right)\left(a_{(i,1)}^{(t,k)} - a_{(i)^*}^{(t,k)}\right). \tag{7.77}$$

Rearranging (7.73) we have:

$$a_{(i)^*}^{(t,k)} = -\left[S_{(i,1)}^{(t,k)} \Big/ \left(1 - S_{(i,1)}^{(t,k)}\right)\right] a_{(i,1)}^{(t,k)}. \tag{7.78}$$

Substituting (7.78) into (7.77):

$$a_{(i,1)}^{(t,k)} = \left[\left(1 - S_{(i,1)}^{(t,k)}\right) \Big/ \left(1 - \sigma^{(3)}\right)\right] \xi_{(i,1)}^{(t,k)}. \tag{7.79}$$

Substituting (7.79) into (7.73):

$$a_{(i)^*}^{(t,k)} = -\left[S_{(i,1)}^{(t,k)} \Big/ \left(1 - \sigma^{(3)}\right)\right] \xi_{(i,1)}^{(t,k)}. \tag{7.80}$$

Together, (7.79) and (7.80) constitute the combination of technical changes required to achieve the cost-neutral change in sourcing preferences described by $\xi_{(i,1)}^{(t,k)}$. Substituting (7.79) and (7.80) back into (7.69) for $a_{(i,r)}^{(t,k)}$ provides:[92]

$$x_{(i,1)}^{(t,k)} = a_{(i,1)}^{(t,k)} + x_{(i,\bullet)}^{(t,k)} - \sigma^{(3)}\left(p_{(i,1)}^{(t,k)} + a_{(i,1)}^{(t,k)} - p_{(i,\bullet)}^{(t,k)}\right) + \left(1 - S_{(i,1)}^{(t,k)}\right)\xi_{(i,1)}^{(t,k)} \tag{7.81}$$

$$x_{(i,r)}^{(t,k)} = a_{(i,r)}^{(\mathrm{t,k})} + x_{(i,\bullet)}^{(t,k)} - \sigma^{(3)}\left(p_{(i,r)}^{(t,k)} + a_{(i,r)}^{(t,k)} - p_{(i,\bullet)}^{(t,k)}\right) - S_{(i,1)}^{(t,k)}\xi_{(i,1)}^{(t,k)} \quad (r = 2, \ldots R). \tag{7.82}$$

Returning to the BOTE model, we now complete (B16) and (B17), first discussed in Section 7.6.1, by including twist terms. Mirroring (7.81), we complete (B16) by adding the twist term $(1 - S_r^{\mathrm{ROC}})\xi_r$. Mirroring (7.82), we complete (B17) with the twist term $-S_r^{(\mathrm{Local})}\xi_r$.

In our MMRF simulation, we shock $\xi_{(i,\mathrm{North})}^{(t,k)} = 1$. Via (B16) and (B17) we expect this to increase interstate exports from North while simultaneously reducing interstate imports into North. We see this outcome confirmed in Figure 7.8.[93] Note, however, that Figure 7.8 shows that, while the twist generates a movement towards surplus in

92 In making this substitution, we assume that the technical change movements described by the a terms in (7.69) can be divided into two parts: one related to the twist, and one related to all other sources of change in sourcing preferences. The latter accounts for the continued presence of the a terms in (7.81) and (7.82).

93 Note that (B16) and (B17) somewhat overestimate the MMRF outcomes for North's interstate exports and imports, because they omit prices in the rest of the country. In the MMRF simulation, by reducing demand for goods outside of North, the twist reduces the relative price of goods produced in the rest of Australia (see Figure 7.10). This damps interstate exports from North while simultaneously expanding interstate imports into North.

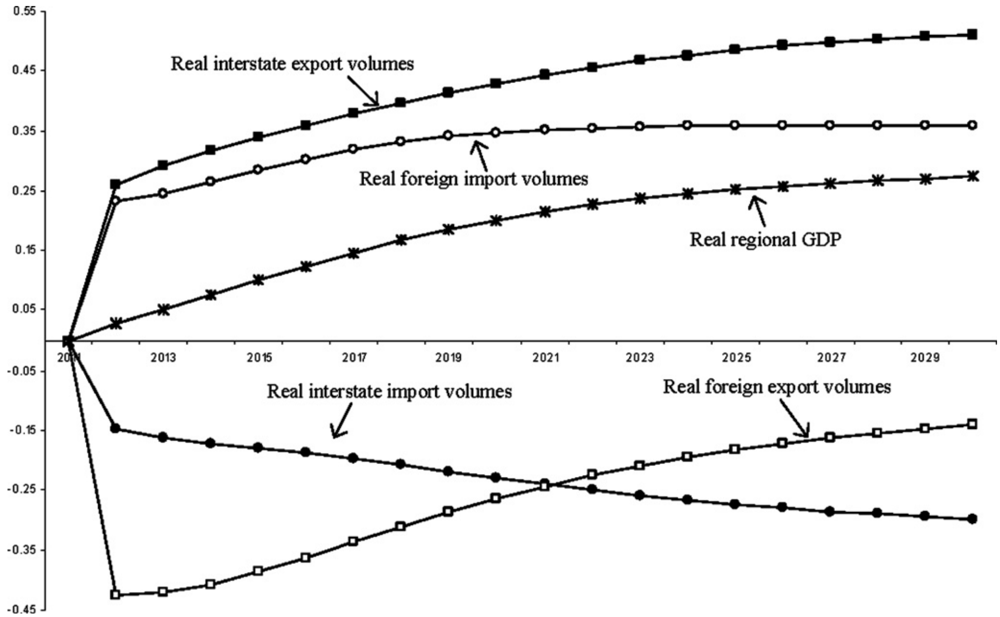

Figure 7.8 Simulating a twist towards Northern goods. Export volumes (interstate and foreign), import volumes (interstate and foreign) and real GDP for the North region (percentage deviation from baseline).

North's interstate balance of trade, it simultaneously produces a movement towards deficit in the region's international balance of trade. As we shall find, short-run regional output is price inelastic. In the short-run, the regional demand stimulus afforded by the twist thus serves mainly to increase the regional price level, moving the region's international balance of trade towards deficit even as it moves the inter-regional balance of trade towards surplus.

To explore further the initial regional macroeconomic consequences of the shock, we begin by substituting Northern values for y_r, w_r and p_r into (B1).[94] In so doing, we see that our BOTE model predicts a deviation in 2012 Northern employment of 0.03%.[95] The true (MMRF) result is 0.06% (Figure 7.9). As Adams and Parmenter (1994) note, while (B1) holds exactly at the level of an individual industry, it is an approximation only at the economy-wide level.[96] We draw attention to (B1)'s underestimate of the employment outcome, because it will shortly prove important in explaining why (7.37), our short-run aggregate supply equation, underestimates the MMRF real GDP

94 $y_{\mathrm{North}} = 0.028$ (Figure 7.10). $w_{\mathrm{North}} = 0.25$ (Figure 7.13). $p_{\mathrm{North}} = 0.27$ (Figure 7.10).

95 $0.03\% = 0.028 - 0.3 * (0.25 - 0.27)$.

96 In our simulation (B1) underestimates short-run regional employment because employment outcomes by industry are positively correlated with the ranking of industries by labor intensity.

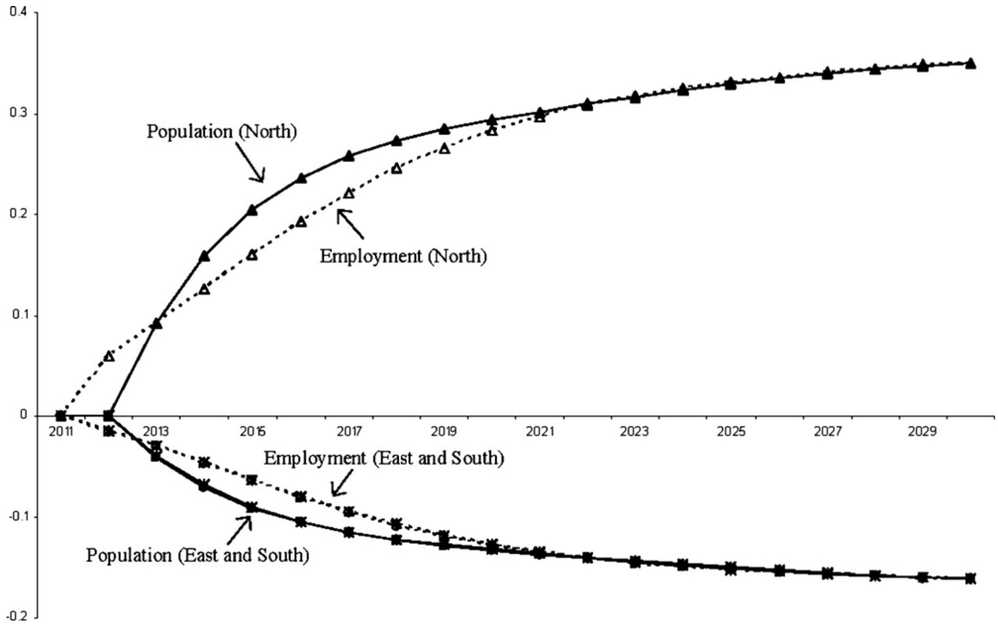

Figure 7.9 Simulating a twist towards Northern goods. Employment and population, by region (percentage deviation from baseline).

outcome. Table 7.4 reports short-run (year 2012) values for the coefficients of (7.37). For North, the short-run aggregate supply function is:

$$y_{\text{North}} = 0.045p_{\text{North}} - 0.32a^{\text{L}}_{\text{North}} + 0.78k_{\text{North}} + 0.12n_{\text{North}}. \tag{7.83}$$

In 2012, the twist causes a 0.28% deviation in North's GDP deflator (Figure 7.10). Via (7.83), we expect this to produce a positive deviation in North's real GDP of approximately 0.012%. The true result, 0.028% (Figure 7.10), is approximately twice that predicted by (7.83). Equation (7.83)'s underestimation of the GDP outcome follows from (B1)'s underestimation of the employment outcome. Despite (7.83)'s underestimation of the short-run GDP outcome, the equation makes clear that even in the presence of sticky wages, the regional short-run supply schedule is price inelastic. This follows from three characteristics of MMRF's short-run regional macro closure. (i) Land and capital cannot deviate from their baseline values in the simulation's first year. (ii) Stickiness of the real consumer wage has the effect that short-run movements in nominal wages almost keep pace with short-run movements in the GDP deflator (see B19 and B18), leaving limited scope for short-run movements in the real producer wage. (iii) Positive short-run labor market pressures begin to be expressed in short-run movements in the real regional wage via (B18). This limits the scope for short-run employment-generated movements in regional GDP.

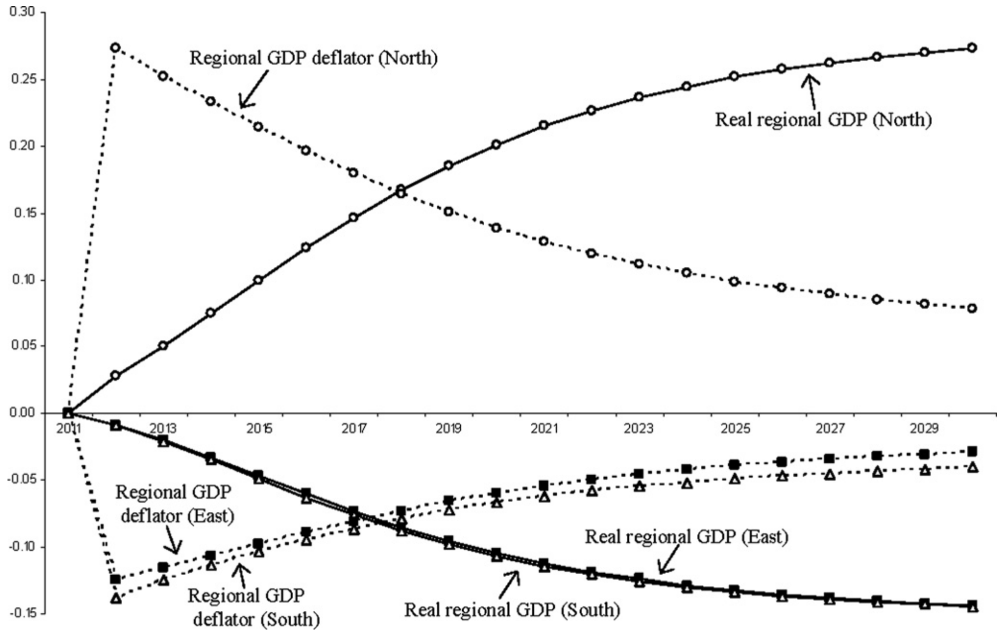

Figure 7.10 Simulating a twist towards Northern goods. Real GDP and GDP deflators, by region (percentage deviation from baseline).

In Section 7.6.3.2 we derived (7.42), a reduced form expression for short-run real investment. Using Table 7.4 to evaluate (7.42) for North provides:

$$i_{\mathrm{North}} = 4.17 y_{\mathrm{North}} + 0.50 p_{\mathrm{North}} - 1.25 \lambda_{\mathrm{North}}. \tag{7.84}$$

With deviations in North's real GDP and GDP deflator of 0.028 and 0.27%, respectively, in the simulation's first year, (7.84) predicts a real investment deviation of 0.25%, close to the MMRF result of 0.23% (Figure 7.11).

Using Table 7.4 to evaluate (7.39), North's short-run aggregate demand function can be presented as:

$$\begin{aligned} 0.81 y_{North} = {} & -2.13 p_{\mathrm{North}} + 0.61 apc_{\mathrm{North}} + 0.31 i_{\mathrm{North}} + 0.11 \lambda^{(\mathrm{S})}_{\mathrm{North}} + 0.06 \lambda^{(\mathrm{F})}_{\mathrm{North}} \\ & + 1.15 v_{\mathrm{North}} + 0.33 \xi_{\mathrm{North}}. \end{aligned} \tag{7.85}$$

Together, (7.83), (7.84) and (7.85) imply $y_{\mathrm{North}} = 0.0076 \xi_{\mathrm{North}}$ and $p_{\mathrm{North}} = 0.17 \xi_{\mathrm{North}}$. Since our shock is $\xi_{\mathrm{North}} = 1$, BOTE anticipates $p_{\mathrm{North}} = 0.17$ and $y_{\mathrm{North}} = 0.0076$. Via Figure 7.10 we see that the true outcomes are $p_{\mathrm{North}} = 0.27$ and $y_{\mathrm{North}} = 0.028$. While our short-run BOTE model does reasonably well at reproducing the signs and relative magnitudes of the Northern price and activity outcomes, it

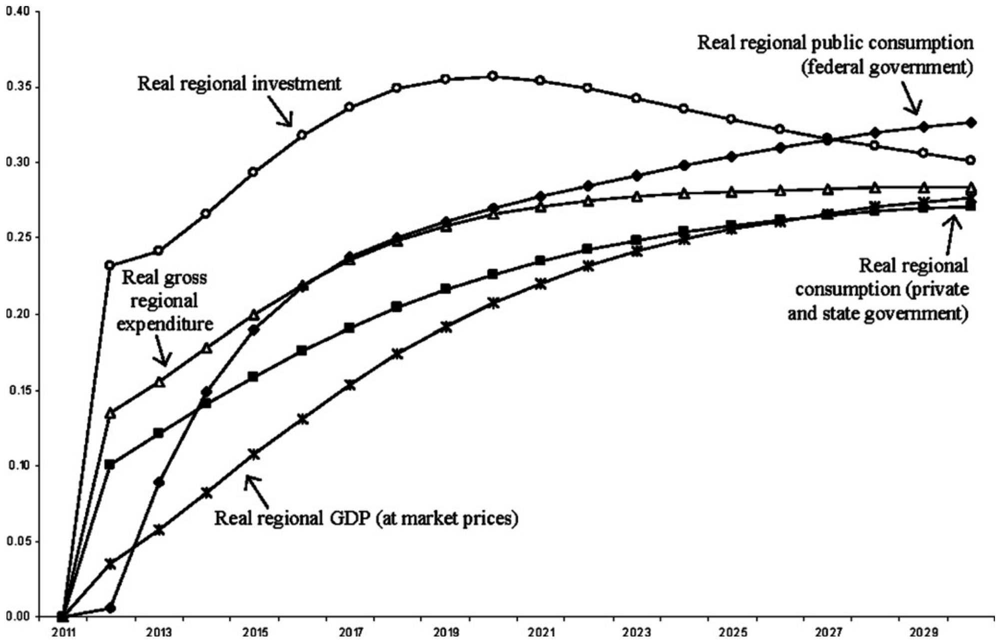

Figure 7.11 Simulating a twist towards Northern goods. Real regional GDP (at market prices), and real gross regional expenditure and its components, for the North region (percentage deviation from baseline).

has underestimated their absolute magnitudes. The underestimation of the real GDP outcome is due in part to BOTE's underestimation of the price elasticity of the short-run aggregate supply curve, as discussed earlier in reference to (B1) and (7.37). The underestimate of the price outcome is due in part to the absence in BOTE of terms-of-trade-induced aggregate demand expansion. To keep our BOTE model simple, we have suppressed terms-of-trade effects in (B8)'s description of real consumption. However, our twist shock generates an inter-regional terms-of-trade gain for North, because it raises demand for Northern goods while simultaneously depressing demand for goods produced in the rest of the country. In Figure 7.10 this is manifested as a large short-run rise in the Northern GDP deflator relative to the GDP deflators in the other two regions. Figure 7.12 goes further, reporting the deviation in North's average (interstate and foreign) terms of trade and its components. From Figure 7.12 it is clear that North's terms-of-trade improvement is due not only to a rise in its interstate export price relative to its interstate import price, but also to a rise in its foreign export price. It is the short-run positive deviation in North's terms of trade that explains why the deviations in real private consumption and real state government consumption lie above the deviation in real GDP in Figure 7.11.

We turn now to the behavior of the short-run regional labor market. Via (7.36), a 0.028% deviation in 2012 Northern real GDP requires a short-run positive deviation in

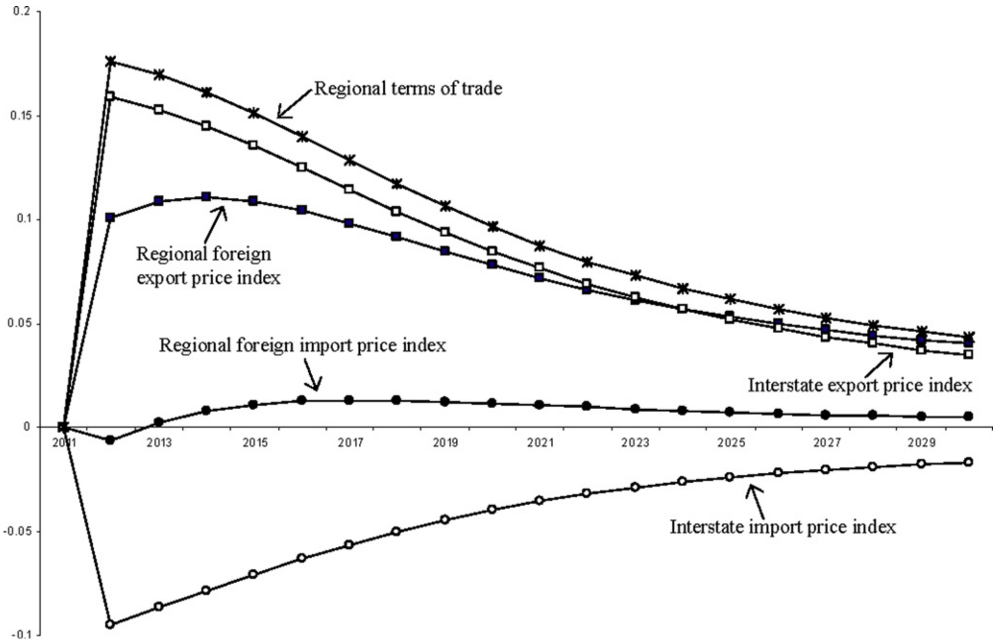

Figure 7.12 Simulating a twist towards Northern goods. Regional terms of trade and its components, for the North region (percentage deviation from baseline).

Northern employment of 0.06% (Figure 7.9).[97] Since North's participation rate and population are unchanged from baseline values in 2012, via (B20), North's 0.06% employment deviation requires a 0.06% deviation in the Northern employment rate (Figure 7.13). Substituting (B19) into (B18), BOTE suggests that the positive deviation in the regional employment rate, together with the positive deviation in the regional price level, requires a positive deviation in the 2012 regional wage of:

$$w_{\text{North}} = \alpha \cdot er_{\text{North}} + S^{(D)C}_{\text{North}} p_{\text{North}} = 0.5^{*}0.06 + 0.79^{*}0.27 = 0.24\%. \qquad (7.86)$$

which is close to the MMRF result of 0.25% (Figure 7.13).

(B21) is a stylized representation of the operation of MMRF Equations (7.12)–(7.14). Ceteris paribus, with $er_{\text{North}} = 0.06$ and $w_{\text{North}} = 0.25$, via (B21) we might anticipate a 2012 deviation in North's net immigration rate (φ_{North}) of $\phi_{\text{North}}(w_{\text{North}} + er_{\text{North}}) = 0.2^{*}0.31 = 0.064\%$. However, in Figure 7.9, we find the 2013 Northern population deviation is somewhat higher, at 0.09%. (B21)'s underestimate of North's immigration response can be traced to the fall in the migration income measure in the rest of Australia. Via (7.13), we see that $Y^{(\text{Diseq})}_{(o,d)}$ is a function of migration

97 $= \gamma_r / S^{L}_{r} = 0.028/0.48 = 0.06$

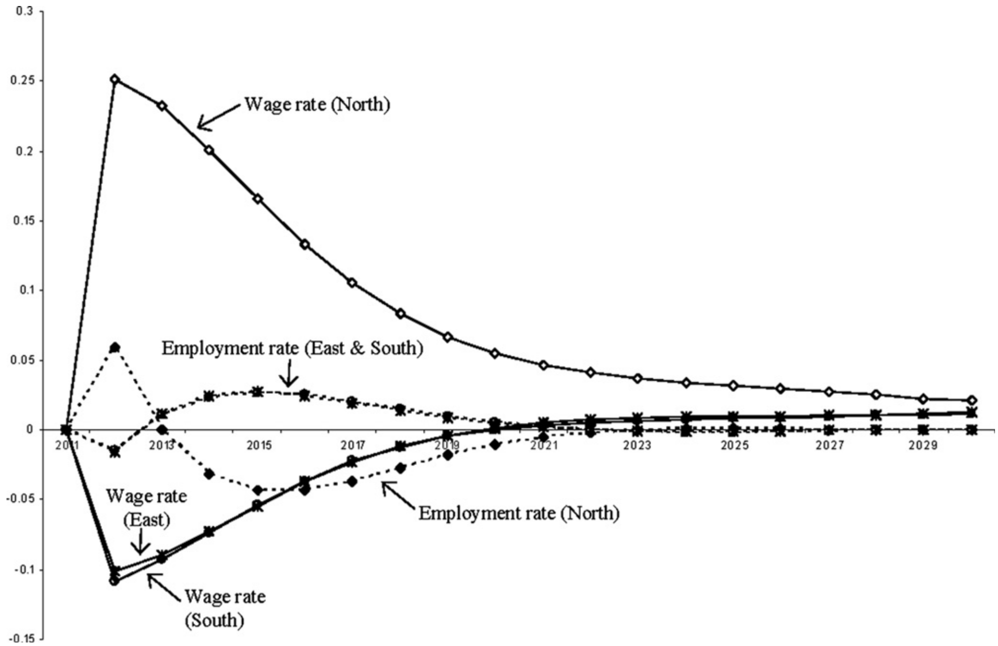

Figure 7.13 Simulating a twist towards Northern goods. Employment rates and wage rates by region (percentage deviation from baseline).

income in both destination and origin regions. The twist causes short-run labor market conditions to deteriorate in the rest of Australia: the 2012 deviations in the employment rate and wage rate outside of North are −0.015 and −0.11, respectively (Figure 7.13). In (B21), we can represent this by setting $f_r^{(SR)} = -0.015 - 0.11 = -0.125$. This contributes the remaining 0.025% (= 0.2 * 0.125) to our BOTE outcome for φ_{North}.

We conclude by using BOTE to describe the long-run outcomes of the shift in preferences towards Northern goods. We begin with (B5), (B23), and (B4). With rates of return, regional wage relativities, and region-specific productivity variables exogenous and unshocked, BOTE suggests little scope for long-run deviations in relative regional output prices. Figure 7.10 broadly confirms this expectation, revealing long-run attenuation of the large deviations in regional GDP deflators observed in the short run. Nevertheless, it is clear from Figure 7.10 that North's GDP deflator remains above baseline in the long-run, while the GDP deflators of the remaining two regions remain below baseline. The long-run persistence in the deviations in the regional GDP deflators is due to natural resource supply (n_r in BOTE), which is assumed to remain at baseline values throughout the policy simulation. The shift towards North in the spatial distribution of domestic demand places upward pressure on market clearing natural resource rental prices in North, while simultaneously depressing natural resource rental prices in the rest of the country. This is expressed as a small long-run positive deviation in the relative Northern regional GDP deflator (Figure 7.10).

With North's price level tending back towards baseline in the long-run, via (B14) we expect North's foreign exports to also tend back towards baseline in the long-run (Figure 7.8). Despite the gradual return of North's price level back to baseline, North's foreign import deviation remains positive (Figure 7.8). As described in (B15), foreign imports depend on both relative prices and regional activity. It is the long-run positive deviation in North's real GDP that keeps the foreign import volume deviation steady even as the long-run Northern price deviation declines.

We find that the long-run effects of the shift in regional preferences on North's real trade accounts is for a permanent rise in interstate export volumes, a permanent fall in interstate import volumes, a tendency towards little deviation in foreign export volumes, and an activity-induced positive deviation in foreign import volumes (Figure 7.8). In terms of (B13), the long-run deviation in the interstate trade balance is positive. With labor and capital in long-run elastic supply to the Northern economy, this causes long-run Northern real GDP to rise. This expansion in long-run regional GDP accounts for the long-run positive deviation in North's foreign import volumes.

Via (7.36), the long-run positive deviation in North's real GDP requires positive deviations in North's capital stock and employment. Via (B20), since long-run regional participation rates and employment rates do not deviate from baseline, the long-run positive deviation in North's employment requires an equivalent percentage deviation in North's population (Figure 7.9). Australia's total population is unaffected by the change in regional sourcing preferences. Hence, North's long-run population gain must be matched by long-run population loss in the rest of Australia (Figure 7.9). Again, with employment rates in all regions returning to baseline in the long-run, population loss in the rest of Australia requires employment in the rest of Australia to fall relative to baseline.

7.7 CONCLUDING REMARKS

Introducing a regional dimension to a CGE model comes at some cost in terms of such factors as increased data requirements that are not matched by data availability, increased model size and increased complexity in interpreting the subnational results. The imperative, however, for inter-regional and intraregional analysis is also considerable.

In this chapter, we aimed first to demonstrate the richness of analysis that can be undertaken with regional CGE models. Central to this are interpretations of model results that both reflect the underlying model mechanisms, but are explainable to policy makers outside the CGE field. It is our contention that without such explication of model results, their policy relevance is undermined. The capability of regional CGE models to produce useful results is of course dependent on the suitability of the model theory and database to the regional research question at hand. We thus review the major modeling issues particular to regional analysis and how the capacity to handle these issues has developed over time. In order to elucidate the above we summarize the general structure of large-scale multiregional CGE models, describing the range of regional attributes and inter-regional interactions treated in the regional CGE literature. We then proceed to conduct representative simulations with such a model, a variant of MMRF, in order to demonstrate the driving model mechanisms in determining regional CGE results. We interpret the results in a meticulous manner with the aid of miniature model techniques. While these techniques are now frequently used in national level modeling, their adoption in regional modeling has been quite rare.

In our discussion of regional CGE model applications we have shown three overall methods of analyzing results: (i) the BOTE technique, (ii) the use of regression analysis on model results to uncover in a step-wise fashion the driving factors underlying the key model results and (iii) sensitivity analysis. These three techniques are linked. For instance, Dixon *et al*. (2007) show that the long-run effects of a supply shock — a water buyback scheme — just depend on regional industry competitiveness. They show using regression analysis that this explains 90% of farm output results, deepening their understanding of their results as they refine their competitiveness indexes. That competitiveness indexes were the appropriate measure to use is signaled by our BOTE explanation of the effects on regional macro variables of regional supply shocks. Both regression and BOTE techniques identified the appropriate candidates for sensitivity analysis. For sensitivity analysis to be informative, it is important that it be limited to those parameters that are instrumental in determining results of the key variables.

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