

# CGE Modeling for Regional Economic Development Analysis\*

by

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**Abstract:** Despite their long-standing use in economic policy analysis generally, and increasing popularity in regional policy analysis, CGE models have yet to become the dominant approach for analysis of regional economic development policies. This [review](#) discusses the likely reasons for the limited use of CGE models for regional economic development analysis, particularly for small regions. The paper also proposes methodological improvements that would likely lead to wider use of CGE models in economic development practice. A central theme is the need for a model that can be empirically-demonstrated to capture the relevant policy components and the structure of the region of study.

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## 1. INTRODUCTION

Following their extensive use in other areas, computable general equilibrium (CGE) models have become more widely used in regional policy analysis (see Partridge and Rickman, 1998 for an earlier survey of the regional CGE literature).<sup>1</sup> Although regional CGE models have provided numerous unique policy insights, they have yet to replace other regional models—such as input-output and econometric models—as the standard tool for regional economic development analysis. To be sure, an input-output model is most often the only option for planners in very small regions (West, 1995). Aside from their complexity, the limited use of regional CGE models in practice likely stems from deficiencies in their current formulation, implementation, and description. Therefore, this paper proposes a roadmap to help CGE models become more widely used in regional economic development policy analysis. A key aspect is discussion of features required for CGE models to become more useful in small-area economic impact and policy analysis.

The implicit structure of input-output and SAM models has been shown to bias regional impact and policy assessments. Rickman (1992) and Gillespie et al. (2001) show how input-output models overestimate economy-wide impacts of business assistance programs in the absence of pre-existing excess factor supplies. Because of their fixed-price and implicit perfectly elastic supply assumptions, input-output models are incapable of estimating the potential supply-induced displacement of other economic activity, which leads to overestimates of net benefits—particularly for job creation—of regional business assistance programs.<sup>2</sup> As Gillespie et al. (2001) note, this is of particular concern in short- to medium-run time frames. This concern led Koh, Schreiner and Shin (1993, p. 50) to remark, “Policy makers can be misled by fixed price multiplier analysis into thinking that certain actions of a structural nature can bring rapid results.” In fact, in comparison to a CGE model, Koh (1991) found the input-output framework

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<sup>1</sup>Several reviews of the literature exist for the varied applications of CGE models: analysis of tax and international trade issues (Shoven and Whalley, 1984); the study of developing economies (Decaluwé and Martens, 1988; Bandara, 1991); analysis of energy and environmental issues (Bhattacharyya, 1996), and estimation of the gains and losses associated with free trade agreements (Lloyd and MacLafren, 2004).

<sup>2</sup>Being extended versions of input-output models (Batey and Rose, 1990), SAM models possess the same limitations.

to perform poorly in explaining Oklahoma's economic adjustment to the energy boom and bust cycles during the 1977 to 1986 period. Likewise, in a short- and medium-run forecast comparison for all U.S. states in the 1980s, Rickman and Treyz (1993) found imperfectly elastic supply specifications, which included regional migration responses, to be more accurate than (input-output) perfectly elastic supply assumptions.

The absence of an explicit economic structure also limits the potential policy uses of input-output models. For example, input-output models cannot be used to evaluate policies related to increasing attractiveness of a region to firms and households such as regional fiscal policies. Similarly, because of the general paucity of time-series data for key regional economic variables, econometric models typically lack sufficient structure for complex policy analysis; this typically results in econometric models lacking required policy levers and makes them subject to the Lucas critique.<sup>3</sup>

CGE models incorporate both short-run supply constraints and less than instantaneous adjustment responses in investment, land supply, population, and (commodity and factor) prices. Thus, CGE models can capture both positive gross multiplier and negative displacement effects from exogenous stimuli. Yet, likely due to convenience, regional CGE models have typically been patterned after those used in national and international studies (Partridge and Rickman, 1998). As such, regional CGE models contain similar structure, many of the same simplifying assumptions, and the same vernacular used to describe economic behavior represented in the more geographically-aggregated models. One consequence is regional CGE modelers routinely use the same external substitution elasticities found in national or international models. Because the regional CGE models then appear more oriented toward uses in national or international applications, considerable skepticism often surrounds their usefulness in regional economic development analysis.

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<sup>3</sup>Although the REMI model contains detailed structure designed for policy analysis, including an input-output component (Treyz, Rickman, and Shao, 1992), it is not strictly an econometric model or a CGE model, and is better described as an eclectic model (Partridge and Rickman, 1998, p. 206, footnote 3).

Although some desirable features can be found scattered across various models, there is no current regional CGE model that is consistent with regional location theory, empirical evidence on the economic effects of regional economic development policies, and empirical evidence on the dynamics of regional adjustment processes. Admittedly, not all impact and policy analysis scenarios require all of these features, in which the CGE models are often tailored to the application at hand; yet, there is insufficient attention paid to what features are needed in various scenarios of applications. Therefore, in addition to reviewing the state-of-the-art in regional CGE modeling for economic development analysis, this paper proposes a framework to guide specification of regional CGE models to make them more widely used in practice. The framework includes: basis in regional location theory; multi-regional specification for small regions; heterogeneous labor classes and differential labor-supply responses; empirically-based specifications of unemployment and labor force participation outcomes for the region of study; commuting across regions and spatial differentiation of migration through multi-regional specification; and dynamic specification, which is consistent with known empirical regularities in regional data.

The next section discusses issues critical to specifying a CGE model for regional economic development analysis, which includes discussion of relevant existing regional CGE models and their applications. Section 3 then proposes and discusses a general framework for specification and implementation of a more “ideal” regional CGE model for use in regional economic development analysis. Although we do not suggest that all models must live up to this ideal, regional CGE methodology needs to be advanced such that the features of an ideal model are implemented where needed to make the CGE model more useful than current approaches. The final section contains a brief summary and conclusions.

## **2. CRITICAL ISSUES IN REGIONAL MODEL SPECIFICATION**

A reading of the regional economic development and CGE literature suggests several areas where regional CGE models might be improved for use in regional economic development analysis. First, the model needs to contain structure that is informed more by regional location

theory than by national or international CGE models. There are differing economic interactions among regions, particularly those in close proximity, than between nations. Second, a labor market specification is required that is capable of predicting the variety of potential outcomes of regional economic development efforts. Third, the model needs to contain a time element. Comparative static exercises very often find deaf ears among those interested in the timing of impacts—an interest that often derives from political necessity. Fourth, for smaller areas, the model should capture spatial linkages, such as inter-commuting, which affect growth benefits for existing residents, and spatial input-output linkages which may affect the generation and spread of agglomeration economies. Finally, to give the model builder and policy user greater confidence in the predictions of the model, it should be demonstrated, in a manner consistent with the underlying theory, to reflect the dynamic behavior of the economy of application.

## **2.1 Basis in Regional Economic Theory**

The development of the general structure of CGE models has been guided by their early uses in national and international policy analysis. Therefore, institutional detail, product market structure, factor market closures, and cross-economy interactions, contained in CGE models, often reflect national or international economic settings. Rather than being based on regional location theory, regional CGE models are more patterned after their national and international counterparts (Partridge and Rickman, 1998). This has led to model structure that is not completely representative of a regional economic setting, which likely causes inaccurate policy assessments, and precludes analysis of a wide range of commonly found economic development policies. As Wendner (1999, p. 267) remarks, “An applied model is useful only to the extent that its structure is appropriate to study the problem in question.”

A more appropriate framework would be the microeconomic regional equilibrium approach used in the quality-of-life literature (e.g., Roback, 1982). The theoretical underpinnings of this approach are the maximization of profits in firm location and utility in household location. Only policies that alter the relative attractiveness of regions to firms and households change the geographic distribution of economic activity. Yet, the standard uses of the approach in the

quality-of-life literature often invoke assumptions which are highly unlikely in regional economic development settings.<sup>4</sup> Regions are assumed to adjust instantaneously to external shocks, including instantaneous factor movement, so as to remain in continuous equilibrium.

In an attempt to adapt this approach to a growth context, Mathur and Stein (1993) extend the static equilibrium framework to a dynamic setting by allowing for sluggish interregional adjustment processes. Partridge and Rickman (2003a) demonstrate how this growth framework could be useful for regional economic development policy analysis. Besides incorporating sluggish labor supply adjustment, one modification relaxes the long-run assumption of perfect mobility for low-skilled labor, though high-skilled labor and capital are assumed to be perfectly mobile in the long run.

Empirical evidence exists that supports U.S. regions as possessing sluggish labor supply adjustment generally (Gallin, 2004; Partridge and Rickman, 2006) and imperfect long-run mobility of the low-skilled particularly (Bound and Holzer, 2000; Yankow, 2003). Similarly, regional labor market adjustment has been found to be comparable to the U.S. in Canada (e.g., Partridge and Rickman, forthcoming), while that for Europe has been reported to be more sluggish than in the U.S. or Canada (Obstfeld and Peri, 1998). Groenewold (1997) finds that only half of labor market adjustment to interstate unemployment disparities in Australia occurs within five years. Particularly sluggish regional labor market adjustment has been reported for regions in Spain by Jimeno and Bentolila (1995).

Factors affecting regional equilibrium levels of economic activity include tax and expenditure policies. Yet, following seminal national and international CGE tax incidence studies, early regional CGE models generally omitted the potential benefits of government expenditures in attracting firms and households, implicitly assuming that taxes only induce deadweight economic losses (Partridge and Rickman, 1998). Gyourko and Tracy (1989) and Dalenberg and Partridge (1997), however, show that local fiscal conditions, and the provision of public infrastructure, are important determinants of household location. A large empirical

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<sup>4</sup> For a recent review of the literature on estimating quality-of-life see Gyourko, Kahn and Tracy (1999).

literature also exists regarding whether the provision of public infrastructure influences regional economic growth.<sup>5</sup> In fact, in estimating a reduced-form econometric equation, Dalenberg, Partridge and Rickman (1998) found that taxes used to finance increased public infrastructure investment led to increased U.S. state employment growth.

Some recent extensions to the early regional CGE literature include Seung and Kraybill (2001) and Conrad and Heng (2002). Both of these studies examine the role of public infrastructure for regional economic growth. They find that even when accounting for negative effects of increased taxes to finance public infrastructure, the associated reduction in congestion provides offsetting positive effects on regional output. Yet, both studies omit the likely increased attractiveness of the region for households when congestion is reduced.<sup>6</sup> Indeed, public infrastructure may be more important to households in their location decision than it is to firms (Dalenberg and Partridge, 1997). In a dynamic CGE approach, Deepak, West and Spreen (2001) found that the largest local public policy impacts result from public infrastructure investments which reduce “bottlenecks” to regional growth.

A microeconomic regional location CGE approach also could be used to examine a wide range of regional economic development policies designed to increase regional productivity and competitiveness. Partridge and Rickman (1999) report that regional demand shocks in the U.S. during the 1980s and 1990s—which are identified by relative employment gains, wage gains, and population gains—are also associated with relative increases in productivity. Productivity may increase, for example, because of changing industry composition or a change in regulatory structure. Likewise, increased density (agglomeration) of regional economic activity may increase productivity (Ciccone and Hall, 1996; Ciccone, 2002).

Numerous theories have been developed to explain the agglomeration of economic activity, such as the New Economic Geography (NEG) (Rosenthal and Strange, 2001). Krugman (1998) discusses the desirability of having CGE models derived from NEG; yet he notes the

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<sup>5</sup>For a survey of the literature on public capital in a regional context see Mikelbank and Jackson (2000).

<sup>6</sup>Seung and Kraybill acknowledge this omission, suggesting that their result then provides a lower bound of the potential benefits of increased public infrastructure provision.

difficulties of constructing such models which are consistent with empirically-observed agglomeration economies. Nevertheless, Kilkenny (1998) developed a two-sector CGE model to test Krugman's NEG hypothesis concerning transport costs and rural development. NEG self-reinforcing agglomeration effects also have been incorporated into regional CGE models examining trade liberalization (Forslid et al., 2002) and transportation investment (Haddad and Hewings, 2005). Although NEG features may be necessary for examining trade or transportation policies, in practice agglomeration economies resulting from NEG pecuniary externalities are difficult to empirically distinguish from the wide variety of external externalities that can arise from the scale of the region (Head and Mayer, 2004). Thus, for many regional impact and policy analyses, incorporating agglomeration effects as a general productivity shifter within a microeconomic (constant-returns-to-scale) regional equilibrium framework may be sufficient and empirically defensible (Partridge et al., 2007).

Regional economic development efforts also often include attempts to increase regional quality of life—household amenity attractiveness—to stimulate in-migration of retirees and potential labor force participants. Yet, where labor is assumed regionally mobile, regional CGE models typically assume equalization of real wage rates (Partridge and Rickman, 1998), which implicitly omits the consumption of regional amenities. Incorporating amenities into residential location would allow for examination of policies that increase quality of life such as improved schools or recreation-related public infrastructure. An example of such a regional CGE policy study is McGregor, Swales and Yin (1995a). They consider the effects of an increase in household amenities—though they do not specify the source of the increased amenity attractiveness. If increased amenity attractiveness relates to increased public goods provision, a simultaneous tax increase or reduction in other expenditures would be necessary. To be sure, Seung and Kraybill (1999) report that assuming government expenditures either benefit firms, or households, lessens the predicted growth resulting from lowering state corporate income taxes. McGregor and Swales (2005) show how the attractiveness of public expenditures may govern

the sign of the balanced budget multiplier (where a demand stimulus occurs because government expenditures involve more labor and less imports, but taxes negatively affect factor supplies).

## **2.2 Spatial Linkages**

Most of the early regional CGE studies made insufficient effort to capture the greater degree of openness of regional economies (Partridge and Rickman, 1998). CGE studies concerned with multi-region issues tend to have more completely specified interregional linkages. Such linkages can be in the form of interregional flows of goods, factors, and payments. Multi-regional models can trace out the regional effects of international, national or regional policies and events. Because of the broad-region policy focus of most multi-regional studies, the regions specified are usually large (e.g., Gazel, Hewings and Sonis, 1995; Kim and Kim, 2002, 2003; Haddad and Hewings, 2005; Klepper and Peterson, 2006; Madden, 2006).

More common are models that simply contain a single atomistic region and an amorphous rest of the world. The region usually is assumed to be too small to affect the national or international aggregates. Yet, single region models can miss important interregional or nation-region feedbacks (Rickman and Schwer, 1993; Lofgren and Robinson, 2002), which are critical for small-region economic development analysis. And even where the *net* impacts of interregional interactions may be small because of offsetting effects, the predicted distribution of impacts depends on the interregional interactions (McGregor, Swales, and Yin, 1999).

For some regions, much of the benefits of growth dissipate outside the area of implementation because of in-commuting. A single-region model, absent a commuting linkage, would overestimate the growth benefits to residents of the region by assuming all new jobs are filled by local residents, and all wage payments remain in the area. Yet, a single-region model including in-commuting, but omitting feedback effects from the amorphous rest of the world, would underestimate the effects if some of the in-commuters spent their money locally, particularly if the area was a retail center. Likewise, regions linked through trade can impart relative competitiveness effects on their neighbors (McGregor, Swales, and Yin, 1999).

A multi-regional framework also would be an effective tool for demonstrating the economic interdependencies among neighboring localities for political purposes. The effects of a region's economic development policies extending beyond its boundaries suggest that there should be regional cooperation in economic development efforts (Quigley, 2002). The multi-regional model may convince a region's policymakers to pool their resources and undertake appropriate policies, with each area's contribution possibly based on its estimated benefit share.

An explicit spatial structure also would allow the model to address spatial mismatch outcomes. Distance-based frictions in firm location, household migration and commuting lead to spatial mismatch outcomes (Johnson, 2006). Specification of relevant spatial linkages could make the model capable of examining whether various place-based policies exacerbate or reduce spatial mismatch.

Recent exceptions to the single-area economic development policy model are studies by Schwarm and Cutler (2003; 2005), and Cutler and Strelnikova (2004), which use a multi-regional model of small economically-interdependent areas (U.S. cities/towns). The interdependencies include purchases across areas and commuting between place-of-work and place-of-residence, which vary by area. Cutler and Strelnikova (2004) note, for example, that if a region is a bedroom community, the elasticity of demand for locally produced goods and services is likely to be high, while that for a regional economic center is likely to be lower. Schwarm and Cutler (2003; 2005) demonstrate the importance of feedback effects at the small-area level. These studies assume an exogenous increase in manufacturing employment in the regional economic center, which through multiplier effects stimulates additional employment. Their model assesses the amount of income generated within the area, and the amount of income accruing to those from outside the area. They further estimate the amount of area expenditures, including spending from income paid to in-commuters. These studies show potential linkages between small areas, though because of the paucity of data, the parameterization was not empirically verified.

### **2.3 Regional Dynamics**

The absence of a time element in most regional CGE models has likely contributed to their limited use in economic development policy analysis. Obtaining the necessary resources for economic development efforts requires the support of local stakeholders, who are not necessarily satisfied with claims that positive results can be expected in some undetermined or abstract long-run time frame. To become more widely adopted, regional CGE models need to predict the time path of economic responses to policy changes. Policymakers want to know when initial impacts are expected and the required period for full responses to be realized. Moreover, policy makers also are often interested in the model producing a several-year baseline projection of economic growth for the region.

Input-output models are either considered to be comparative static, omitting the time dimension, or alternatively, their predicted outcomes assumed to be realized immediately, which is unrealistic (Gillespie et al., 2001). Likewise, static CGE models cannot be used to address the time path of regional economic adjustment to policy shocks. The emergence of dynamic versions of CGE models gives hope that these limitations can be overcome.

In the original dynamic formulations of country-level CGE models, in which markets clear each period, a series of equilibria were connected through movements in capital stocks that are determined by savings (Pereira and Shoven, 1988). The most common approach to producing a baseline projection has been that of specifying values for the state variables to produce a steady-state path (e.g., Ballard, Fullerton, Shoven, and Whalley, 1985; Ballard, 1987).<sup>7</sup> A policy shock then causes the economy to diverge from the baseline steady-state path, such that the differences between the new variable levels and the steady-state levels represent the policy effects. Models also have been constructed so as to produce non-steady-state, or “reasonable,” paths (e.g., Auerbach and Kotlikoff, 1987; Wendner, 1999). Either baseline path approach can be solved recursively unless perfectly forward-looking behavior is assumed, which produces an intertemporal feedback (Wendner, 1999). With forward-looking behavior, both the time path and

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<sup>7</sup> Rutherford and Tarr (2003) compare welfare estimates for a preferential trade area from comparative static and dynamic steady-state models.

base year must be solved simultaneously or with an iterative algorithm (Dixon and Rimmer, 2002, pp. 195-198).

In their earlier survey, Partridge and Rickman (1998) noted the virtual absence of dynamic regional CGE models. Again, following previous trends in other strands of the CGE literature, regional dynamic models have become more commonplace. Yet, the dynamic behavior of regions also can be expected to differ greatly from that of nations. For example, dynamic national models link capital formation with national savings, a link which is less likely to exist in regional economies. Although dynamic properties of a CGE model can be demonstrated through multi-period simulation, dynamic-regional CGE models that use national parameters also may produce adjustment periods inconsistent with empirical evidence on regional dynamic adjustment.

Following common practice elsewhere, dynamic regional CGE models typically assume myopic or backward-looking expectations and an initial steady-state path. Seung and Kraybill (1999; 2001) assume that labor, private capital, and public capital all grow at the same rate in the base steady-state path, which leads to stable prices and factor returns along the path. Price and quantity adjustments following a shock are assumed to eliminate excess demands within a year. The dynamic path results from the lagged adjustment processes of factor supplies: investment and migration.

McGregor, Swales and Yin (1996) and Gillespie et al. (2001) also assume an initial steady-state path and the absence of forward-looking expectations. They demonstrate how lagged adjustments of factor supplies constrain predicted economic growth responses to positive external stimuli in the short and medium run, and how the dynamic responses of the CGE model, in which perfectly elastic factor supplies were assumed in the long run, caused the CGE model to converge to those of an input-output model. The long-run period required for convergence, however, is too long to be relevant for most policy analyses. Kim and Kim (2002; 2003) similarly specify a dynamic multi-regional model characterized by a lack of forward-looking

behavior and a baseline steady-state path, though they assume fixed population growth rates, which preclude a primary source of interregional dynamic adjustment.

A somewhat different approach is taken in the FEDERAL-F dynamic multi-regional model of Tasmania and the rest of Australia (Giesecke, 2002; 2003; Giesecke and Madden, 2003a; 2003b). In FEDERAL-F, flows of investment, inter-regional migration, and government balances affect the stocks of capital, population and government debt, which then influence future endogenous variables. In contrast to generating a baseline steady-state scenario, however, FEDERAL-F is used to produce a baseline forecast. The model is first parameterized during historical simulation, allowing technical change, changes in household tastes, shifts in the positions of export demand curves, and rates of government taxation to vary, in historically fitting the model. These variables are extrapolated into the future based on their values during historical simulation. Thus, the model is examined for whether it was representative of the economy under study and could explain recent economic history of the region (Giesecke, 2002). A baseline forecast then could be produced to inform policymakers of the likely future economic path in the absence of additional policy action. Although wage adjustment returned regional unemployment to its baseline, they assumed short-run wage rigidity producing further dynamic adjustment.

Forward-looking expectations were incorporated into a combined dynamic CGE/optimal control model by Deepak, West, and Spreen (2001). Computational complexity led them to limit their model to ten variables, whereby when considering twenty periods a 200-variable simultaneous model resulted. Initial values of the endogenous variables were specified so as to produce a steady-state growth path. Control variables, corresponding to alternative local public policy regimes, were specified to examine what policies most enhanced regional growth.

## **2.4 Labor Market Specification**

Regional CGE models routinely contain assumptions of full employment, regardless of the labor-mobility assumptions (Partridge and Rickman, 1998). Assuming immobile labor likely leads to underestimates of growth, but overestimates of income growth (e.g., wage) benefits to

current residents. Incorporating perfectly mobile labor allows for another avenue of growth, but the full employment assumption precludes original residents of a region benefiting from reduced unemployment or increased labor force participation. This led McGregor, Swales and Yin (1995b) to question the usefulness of “natural rate” models for economic development analysis.

The assumptions of perfect mobility and full employment is inconsistent with empirical evidence that original residents benefit from employment growth through reduced unemployment and increased labor force participation (Bartik, 1991; 1993; Partridge and Rickman, 1999), and evidence that migration is not the sole long-run labor supply response to demand shocks (Decressin and Fatás, 1995; Jimeno and Bentolila, 1995; Partridge and Rickman, 2006). This suggests the need for regional CGE labor market specifications that allow for incomplete migration responses and permanent changes in employment rates.

The regional CGE literature contains few examples of imperfect labor mobility. Some studies specify imperfect regional labor mobility, but retain the assumption of homogeneous labor and long-run assumption of full employment (Rickman, 1992; Seung and Kraybill, 1999; 2001). Deepak, West, and Spreen (2001) specify high- and low-skilled labor with different migration propensities, wages fixed at national averages, and unemployment determined as the difference between labor demand and labor supply. A novel feature of their study is examination of both in- and out-migration in place of net migration. However, they do not allow for local wage responses, which is inconsistent with spatial equilibrium theories of regional economic activity. Notable regional exceptions also include Schwarm and Cutler (2003) and Cutler and Strelnikova (2004), which allow original residents to benefit through increased labor force participation and differential migration responses by household income class.

The assumption of a single homogenous labor market limits analysis of the economic development policy effects on a region’s income distribution. Yet, a possible argument for economic development policies is that they create jobs for the poor and reduce poverty (Bartik, 2001). Bartik (1994, 1996) reports that regional job growth disproportionately benefits low-skilled workers in the United States. Partridge and Rickman (2005) likewise find that

employment growth in U.S. local areas reduces their poverty, with the linkage partially transmitted through changes in unemployment and labor force participation. Akin to CGE models of developing nations (e.g., Decaluwé et al., 1999; Lofgren, Robinson and El-Said, 2003; Stifel and Thorbecke, 2003), regional labor market demand and supply can be specified in terms of skill or income level. This would incorporate different migration propensities and differential effects on employment rates by skill/income level, along with the corresponding links to poverty rates or income distribution.

In the DRAM model of California (Berck, Golan and Smith, 1997), the migration response to wage changes for high-skilled labor was estimated using Bartik's (1991) estimate that 77 percent of new jobs go to in-migrants. The low-skilled migrant elasticity of response was then assumed to be one-half that of the derived high-skilled response. The DRAM model also contained differential labor force participation rate responses. Yet, because the DRAM model is comparative static, short-run responses were not examined, and long-run labor market responses were not checked against empirical evidence.

## **2.5 Parameterization**

Parameterization of CGE models continues to be a contentious issue. CGE models have primarily been calibrated to a benchmark period dataset. Opponents of calibration argue that econometric estimation of CGE models is superior (e.g., McKittrick, 1998). Calibrating to a single observation for each variable makes CGE models heavily dependent on external elasticities, most of which are not estimated for the region under study, and often are out-dated (Partridge and Rickman, 1998). The advantage of calibration is that time series data are not needed, much of which are not available for key variables (Shoven and Whalley, 1992, p. 106). To address the lack of econometric basis of model parameters, many studies conduct extensive sensitivity analysis of key parameter values and model closures (Partridge and Rickman, 1998).<sup>8</sup>

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<sup>8</sup>According to Partridge and Rickman (1998), most studies only subjectively vary key parameter values and model closures, which may lead them to underestimate the uncertainty inherent in the models. More extensive- and systematic-sensitivity analysis has been proposed and implemented by Harrison and Vinod (1992) and DeVuyst and Preckel (1997). Examples of extensive sensitivity analysis include McGregor, Swales and Yin (1996), Abler, Rodríguez and Shortle (1999), and Haddad and Hewings (2005).

Partridge and Rickman (1998) argue for practical solutions that lie in-between the two extremes, and move beyond sensitivity analysis. As an example, they report that Adams and Higgs (1990) computed averages of several years of data for a key sector out of concern that the benchmark period was not representative of the underlying economic structure. Calibration also can be extended to using two points in time to see if the original calibration predicts the second point in time (e.g., Kehoe, Polo, and Sancho, 1995). Other practical approaches have begun to emerge.

Adkins, Rickman and Hameed (2003) used a Bayesian estimation approach to obtain production parameters for a regional CGE model of Oklahoma, in which regional data was sparse and judged to be of poor quality. Haddad and Hewings (2005) used data from a SAM to estimate “implicit regional trade elasticities.” Arndt, Robinson and Tarp (2002) used a maximum entropy approach to calibrate a CGE model of Mozambique to its recent history. In doing so, they incorporated prior information on parameter values, imposed general equilibrium constraints, and demonstrated that the model explains Mozambique’s recent history. Similarly, Liu, Arndt and Hertel (2004) used insights from the real business cycle literature to compare CGE model predictions and data available through time to evaluate the goodness-of-fit for the GTAP model and test hypotheses concerning values for key trade elasticities. Finally, the FEDERAL-F model is calibrated to recent history for its two regions, Tasmania and the rest of Australia (Giesecke, 2002; 2003; Giesecke and Madden, 2003a; 2003b). In Giesecke (2002), the time-series variation in the dynamically calibrated parameters was examined for its role in explaining Tasmania’s lower growth relative to the rest of Australia.

Despite increased attempts to incorporate time-series information into regional CGE parameter estimates, little if any attention has been given to whether CGE models capture the short-run regional adjustment dynamics. In dynamic sequencing, the assumption of one year elapsing between successive equilibria is for convenience, and may not be accurate. Gillespie et al. (2001, p. 128) note that given the absence of econometric estimation, the specification of one-year intervals is “suggestive, rather than definitive.” No attempts have been made to compare the

short-run dynamic properties of a regional CGE model against dynamic relationships obtained with other empirical approaches.<sup>9</sup>

### **3. A PROPOSED MODELING FRAMEWORK**

Outlined below is a general framework for formulating and implementing a regional CGE model that better addresses the needs of regional economic development policy analysis. The proposed model combines features currently found in various regional CGE models reviewed above, with new features and approaches to parameterization. Generalized mathematical expressions that correspond to the discussion appear in Table 1, with variable definitions provided in Table 2. It should be noted that, depending upon the historical, institutional, and policy context, each potential application would not require all these features. Since considerable regional heterogeneity likely exists, the approaches to addressing the issues listed below will likely vary. Thus, it is more of a checklist of issues to consider and a roadmap for how CGE methodology should be improved for it to become more useful for regional economic development analysis.

#### **3.1 Geographic Scope**

For large regions, like U.S. states or large metropolitan areas, Australian states, Brazilian states, Canadian provinces, and countries of the U.K., a single region model with links to a rest-of-the-world region may suffice for analysis of region-specific issues. However, for smaller geographical areas, the model should be multi-regional, encompassing the relevant labor market, which likely corresponds to the regional commuting zone. All economic interdependencies between the regions that can be measured should be specified. Yet, multi-regional linkages should be sufficiently flexible so that the model could be applied to a variety of small-region spatial settings.

For example, regions located adjacent to metropolitan areas likely possess significant commuting (though by definition in the U.S. commuting flows fall below the threshold for inclusion into the metropolitan area). Thus, their fortunes depend more on job growth in the

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<sup>9</sup>At the national level, Cooper and McLaren (1983) compare the temporal adjustments of a CGE model to a macro model.

metropolitan area and less on local job growth. So, a localized economic development policy may do little to improve the economic prospects of the original residents in the intended county, suggesting that rural regions adjacent to metropolitan areas should cooperate with them in economic development.

Following the discussion of agglomeration economies in Section 2, agglomeration economies from large urban areas may spread to geographically proximate regions or there may be generation of agglomeration economies of spatially-linked proximate comparably-sized regions. Pecuniary externalities underlying NEG can extend across proximate regions because of spatial input-output linkages, while knowledge externalities and lower trade costs for final goods also result from close proximity (Partridge et al., 2007). This suggests the need to more explicitly consider distance-based spatial interactions in regional CGE models, or at the very least consider the geographic scope of endogenous agglomeration effects (which could be captured by a region-wide productivity shifter).

Likewise, rural regions not adjacent to metro areas may be economically interdependent. For example, rural areas often contain a regional center for employment and retail, which suggests that it serve as the focal point of a multi-regional model. A properly specified multi-regional model could demonstrate the potential benefits of joint economic development efforts (Quigley, 2002). It may be better for communities peripheral to regional centers to support centralized economic-development efforts and commute to newly created jobs in the economic centers. Conversely, peripheral efforts to very-locally stimulate jobs will likely fail due to a lack of critical mass to sustain most economic development.

### **3.2 Commodity Markets**

As shown in Equation Block A of Table 1, local production depends on local household demand, local intermediate demand by firms, investment demand for local goods and exports. The Armington specification of price-responsive demand for products could be used for local versus import demand. Regarding export demand, an Armington specification can be used for demand by other regions in the model; whereas, for the rest-of-world region, an export function

could be specified. In a small-region context, besides the usual justification that goods are imperfectly substitutable (particularly at an aggregated level), or that markets are monopolistically competitive, small-area price-responsiveness is also likely justified by location considerations, including transportation costs.

The geographic scope of a regional market likely expands if local prices decrease, as declines in producer prices offset transportation costs for more distant potential markets. Lower producer prices increase local demand by households and firms, and correspondingly raise export demand outside the region. The different proximity of regional buyers and sellers versus that of international markets calls into question the simple use of international trade elasticities for regional price elasticities of demand. For example, because transportation costs are most likely a smaller portion of total regional product costs relatively small reductions in producer costs can lead to a significant expansion of a local firm/industry's regional market, suggesting larger regional trade elasticities. Yet, if transport margins are included (e.g., Haddad and Hewings, 2005), the elasticity of response will be with respect to purchase prices, which accounts for the transportation cost differential between regional and international trade.

Nevertheless, a broader range of goods and services is traded regionally. For example, haircuts are not internationally traded, but they are regionally traded when regions are small. Contrarily, because regions may be more specialized in production, regional commodity trade elasticities of substitution could be less than international trade elasticities (Bilgic et al., 2002). In short, in specifying commodity elasticities of substitution, there is a need to consider the regional context and to assess the relative prevalence of these factors.

### **3.3 Factor Markets**

Nested neoclassical production functions (e.g., the CES class of functions) (Perroni and Rutherford, 1995) for the major regional industries would include intermediate goods, capital, high-skilled labor, low-skilled labor, and land (Block B).<sup>10</sup> Although use of intermediate goods would likely be specified in fixed proportions for short- and medium-run analysis, they could be

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<sup>10</sup> For a review of the range of production elasticities available in the literature see Berck, Golan and Smith (1997).

made price responsive (Whalley and Trela, 1986). The nested function also allows for the import and local purchase proportions to be price responsive and different substitutability between pairs of primary factors. In the first tier of nesting of the primary factors, for example, land could be assumed to possess low substitutability with a composite of capital, high-skilled labor, and low-skilled labor. In the next tier, high-skilled labor could be assumed to possess low substitutability with a composite of capital and low-skilled labor. In a third and final tier, capital and low-skilled labor could be assumed highly substitutable.

A small region contains three sources of labor supply (Equation Block C) aside from natural labor supply growth. First, employment rates of current residents can increase, either through reduced unemployment, or increased labor force participation. Because regional unemployment rates more likely return to their long-run equilibrium rates (Partridge and Rickman, 1997a), employment-rate responses most likely result from changes in labor force participation. A second source is the change in net-commuting, in which commuters respond positively to higher wage rates and excess labor demand, relative to the nearby regions, which are denoted by subscript  $r$ . Thus, the benefits of local economic development efforts may be shown to extend beyond the boundaries of the policymaking entity. A third source is the in-migration of residents from other regions. In-migration primarily should occur from outside the commuting zone in response to increased wage rates and employment rates. Those inside the commuting zone are more likely to change their commuting destination than their residence, especially if they own their home, have school-age children, or their spouses also work. The benefit of a positive demand shock for current residents depends critically on how much their employment rate increases, which depends on the magnitude of the commuting and migration responses.

In terms of timing, the in-migration response is more likely to take longer. For the U.S., migration responses are dominant in labor market adjustment, with migration taking about five to seven years to fully adjust (Partridge and Rickman, 2006). Lesser and more sluggish migration responses might be expected elsewhere, such as in Europe where labor force participation has

been reported to be the dominant supply response (Decressin and Fatas, 1995). Conversely, commuting patterns and employment rates of current residents likely respond much quicker. A more sluggish migration response allows current residents to benefit for a longer period of time. However, as the migration response becomes more complete, wage rates get pushed down, with migrants comprising a larger share of new jobs. Nevertheless, to the extent that there is less than perfect long-run household mobility, in the aggregate, the original residents permanently gain from economic development successes.

Following the segmentation of labor in production, labor supply would be partitioned into high-skilled and low-skilled segments (e.g., Fane and Warr, 2002), with differential supply elasticities (e.g., using marginal income tax brackets as in Berck, Golan and Smith, 1997). For the United States, base-year commuting rates could be calculated using U.S. Census Bureau County-to-County Commuting Flows. Yet, these rates could be made responsive to changes in relative real wage rates (e.g., Schwarm and Cutler, 2003) and employment rates. Lower elasticities of migration would be assigned to low-skilled households as they have been observed to have lower propensities to migrate (e.g., Yankow, 2003). Since in-migration is most likely to be from those originating outside the commuting zone, elasticities at or near zero would be specified for migration between areas within the commuting zone. Sensitivity analysis could be conducted to assess the impact of these assumptions.

The inclusion of wage and employment rates in the migration equation follows the Harris-Todaro migration framework of Treyz et al. (1993), which has found its way into regional CGE models (e.g., Harrigan, McGregor, and Swales, 1996). Although the labor literature suggests that they have lower labor force participation responsiveness to wage rates, the low-skilled will more likely experience increased employment when labor demand increases.<sup>11</sup> Namely, low-skilled workers are the least likely to be employed prior to the demand stimulus, and the first to be terminated during a downturn.

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<sup>11</sup> See Berck, Golan and Smith (1997) for a discussion of the literature on various elasticity values.

A capital stock adjustment process captures firm location responses and adjustments in size to changes in regional competitiveness. For example, an increase in competitiveness, achieved through reduced production costs, increases demand for regional production and hence for capital. Because of greater mobility of firms across regions than nations, the regional capital adjustment process is more elastic than for the nation.

Short-run production responses are limited by the speed which new and existing firms can move capital to the region. The partial adjustment process occurs because of recognition, decision, and implementation lags regarding firm relocation and expansion. Each year a portion of the gap between the demand for local capital in production and supply would be eliminated as new firms relocate to the region and existing firms expand. The speed of response then needs to be based on empirical evidence regarding regional firm location rather than national or international evidence on capital adjustment.

Because capital and savings are not linked at the small-region level, savings can be omitted. The supply of land is allowed to respond positively to its rate of return and is mobile across industries within the region. For regions where there is little undeveloped land, the elasticity should be small.

### **3.4 Commodity and Factor Price Determination**

Short-run tightness in the regional and multi-regional labor market should increase the bargaining power of workers, increasing wage rates (Block D). In contrast to traditional wage curve (Blanchflower and Oswald, 1994) and Phillips curve specifications, the employment rate is used as the labor-tightness measure because it should better reflect tightness than the unemployment rate (Pannenberg and Schwarze, 1998; Boushey, 2002).<sup>12</sup> The equation may be specified in changes with lags to capture disequilibrium wage adjustment (Chiarini and Piselli, 1997; Iara and Traistaru, 2004).<sup>13</sup> Moreover, because wage rigidity likely differs across the labor

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<sup>12</sup> For example, Giesecke and Madden (2003b) incorporate discouraged workers rather than focus solely on the unemployed.

<sup>13</sup> U.S. labor market adjustment has been found to be more consistent with the Phillips curve than the wage curve (Dalenberg and Partridge, 2000; Partridge, 2001). A Phillips curve suggests the *change* in wage rates is related to the level of labor market tightness, while the wage curve suggests the wage *level* is related to the level of labor market tightness.

market, a separate wage equation is estimated for each class of laborers (Boushey, 2002).

Although the wage equation is expected to produce a short-run inverse relation between the wage rate and the employment rate, the migration equation produces a long-run positive relationship between the levels of the two variables as migrants will be attracted to areas with high wage rates (Partridge and Rickman, 1997b; Papps, 2001).<sup>14</sup>

Land prices equate the supply of developed land with total demand. And because of intersectoral mobility, land prices become equalized across sectors. Reflecting the capital stock adjustment process, the short-run regional capital returns can vary from the nation; deviation of regional capital returns from the nation reflects differential profitability for firms in the region. Investment responds positively to the higher rate of return in the region. In the longer run, as the capital stock adjusts, reflecting relocation and size adjustment of firms, the regional return to capital moves toward the national rate.

Unit cost functions determine commodity prices each period (Block B). But because the cost function includes the rate of return to capital, which might deviate from that of the nation, this allows for differential profitability across regions, particularly in the short run.

### **3.5 The Government Sector**

Although not shown in Table 1, the government sector could be added. The specification would depend critically on the particular application. The more the policy focus is on regional governmental policies, the greater the required detail in specification.

The price of factors to firms would then include the costs of taxes, with factor supplies responding to after-tax returns. Public capital could be added as affecting firm productivity, which affects unit costs. In addition, public capital could be included as a household amenity that affects migration. Low-skilled labor could be assumed transformed into high-skilled labor via tax expenditures on education. Non-capital-augmenting government expenditures financed by tax

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<sup>14</sup> An equation specified in wage changes with lags will produce a model in which there would be no period-by-period market clearing wage rate. However, the migration equation will produce the long-run equilibrium level of wages (Treyz et al., 1993). The AMOS model contains both a wage curve specification and a Harris-Todaro migration equation, producing differential wage-unemployment dynamics in the short run versus the long run.

revenues could be added explicitly, affecting the composition of factor demands (e.g., Morgan, Mutti, and Rickman, 1996).

Alternatively, tax revenue could be assumed spent by households on consumption goods, which implicitly assumes the pattern of production in the region is unaltered by government production and spending. This formulation would lead to an inability of the model to allow government to attract firms or households through provision of public amenities. Regional fiscal policy instruments also could be used as means to achieve environmental objectives (Ferguson et al., 2005). The importance of interactions between federal and regional tax policies in a multiregional CGE model was shown by Morgan, Mutti, and Rickman (1996). A final consideration is whether regional governments coordinate fiscal policy, or compete for fixed national factor supplies (McGregor and Swales, 2005). Petchey and Shapiro (2002) examine tax and policy competition among Australian states in terms of attracting mobile capital. Groenewold, Hagger, and Madden (2003) incorporate strategically-optimizing regional governments in a multi-regional CGE model and examine whether this undermines the effectiveness of federal inter-regional transfers.

### **3.6 Regional Income and Poverty**

Regional income derives from resident workers and owners of capital and land (Block F). Labor income includes that earned by residents working in the region plus that earned by those who commute to other regions. Capital income includes earnings from local ownership of both local capital and capital used in the rest-of-the-world. Landowners may be primarily local, though there is likely some nonresident ownership. All owners receive market returns for the use of developed land in production.

Consistent with SAM models, regional income in CGE models often include transfers to the regional government and households. In fact, in the absence of full employment assumptions in the labor market, transfer payments to households should be endogenous. Lower unemployment should reduce unemployment benefits, reducing induced consumption effects of exogenous demand stimuli and calculated multipliers (Van Dijk and Oosterhaven, 1986;

Rickman, 2002). In addition, if the model includes a demographic component, transfers could be associated with specific household classes, such as retirees; transfer payments are often an important source of basic income (Waters, Weber, and Holland, 1999; Roberts, 2003).

Besides transfers, poverty depends upon employment rates and wage rates among the low skilled. Employment rates account for labor force participation rates and unemployment rates among low skilled workers. The relevant employment rates can be either local or an aggregate of regional measures of the commuting zone. To the extent that poverty is concentrated among low-skilled workers, and their income is relatively homogenous, relative labor market outcomes for low-skilled workers likely explains poverty outcomes. Because the poverty rate also could be affected by within group movement of workers (Lofgren, Robinson and El-Said, 2003), which may take periods greater than one year to occur (Partridge and Rickman, 2005), the current-period poverty rate likely relates to past labor market outcomes.

The omission of capital and land returns is based on the belief that the low skilled generally have negligible ownership shares. If the data for the region suggest otherwise, capital returns, and particularly land returns, could be included. Low-skilled household ownership of capital and land most likely occurs in rural (agricultural) areas (Fane and Warr, 2002).

### **3.7 Dynamic Parameterization and Baseline Forecast**

The time dimension can be incorporated into the CGE model through dynamically-linking a series of successive model solutions. In contrast to conventional approaches, equilibrium is not necessarily assumed in each period. Rather, the partial adjustment equations determine the time path. The supply of capital partially adjusts to excess demand for capital. Migration responds gradually to labor market imbalances. Wage and land costs partially adjust to excess demands. When combined, the partial adjustment equations produce a disequilibrium path of regional growth that replaces the assumed instantaneous responses of input-output models, and the artificially created time path of a steady-state CGE model. The economy simply moves towards a microeconomic interregional equilibrium in the long run.

The model would be parameterized during simulation of the recent economic experience of the region. First, specification of labor market adjustment responses would be guided by estimates obtained from VAR or other empirical models (e.g., Partridge and Rickman, 2003b; 2006). The final proportions of a fixed increase in labor demand satisfied by the various supply components also could then be checked for consistency with dynamic empirical estimates. If needed, supply response parameters could be adjusted to make the CGE labor market responses consistent with available empirical evidence.

Share parameters for demand and production functions could be calibrated using expenditure shares during the recent historical period and external elasticity estimates. Unit cost functions and factor shares can be used to calibrate the fixed technology terms. Investment responsiveness would be based on empirical evidence on the timing of firm relocation or on the time required for the regional economy to adjust to external shocks.

The entire model could then be historically simulated to see how well the predictions fit the data. Key parameters could be adjusted to “fit” the model to the regional data. Hypothesis tests of key elasticities also could be conducted based on CGE model goodness-of-fit to the region’s data (Liu, Arndt, and Hertel, 2004).

Akin to Gisecke (2002), additional free parameters could be created to equate predicted employment levels in a year with their actual levels. Similar parameters could be created for wage rates and migration. Averages of these parameters could then be computed and extrapolated into the future. Combined with the estimated addition of national variables, this would form the basis for a baseline forecast several years into the future. The baseline forecast would be designed to capture the degree to which the interregional system is out of equilibrium at the end of the historical period, and includes known future equilibrium adjustments. This would then have advantages over simple trend forecasts from econometric or VAR models.

### **3.8 Illustration of Labor Market Dynamics**

Figure 1 shows the labor market dynamics of a positive shock to demand. Assume that the economy begins at long-run equilibrium wage rate,  $w_A$ , and employment level,  $L_A$ , which

corresponds to the intersection of the long-run demand ( $D_0^{LR}$ ) and supply ( $S^{LR}$ ) curves. Suppose a demand shock shifts the short- and long-run labor demand curves upward to  $D_1^{SR}$  and  $D_1^{LR}$ . Given the intra-nation mobility of firms and capital, a region's short-run labor demand curve is likely to be more elastic than the short-run aggregate national labor-demand curve. The regional labor demand curve is more elastic in the long run as it reflects labor demand after cumulative intra/inter-regional disequilibrium adjustments by firms, including changes in the stock of capital.

The new short-run equilibrium occurs where the short-run demand and supply curves intersect at the point where wages and employment equal  $w_B$  and  $L_B$ . Since  $w_B$  is above the long-run labor supply curve at  $L_B$ , the higher wage rate induces labor in-migration, shifting the short-run labor supply curve outward. Likewise, with  $w_B$  being below  $D_1^{LR}$ , firms accumulate capital and new firms relocate to the region. In other words, the region remains more competitive in production than the nation, inducing in-migration of firms, shifting the short-run labor demand curve out.

This adjustment process continues until the short-run demand and supply curves intersect at wage rate,  $w_C$ , and employment level,  $L_C$ , where a new long-run equilibrium is achieved. With migration assumed incomplete, the real wage rate remains above the pre-shock level, allowing the employment rate of original residents to permanently increase along the region's long-run labor supply curve. The CGE model then requires empirically-based estimates of the slopes of the long-run curves in addition to the speed with which the short-run curves shift.

#### **4. SUMMARY AND CONCLUSIONS**

This essay documents the recent growth in the use of CGE models for regional economic development policy analysis. While documenting recent advances in regional CGE modeling, the paper also discusses various characteristics of regional CGE models that have likely prevented them from becoming more widely used in the regional economic development arena. A central thesis is that many regional CGE inadequacies are holdovers from their origins in national and international policy applications. Regional CGE modelers have insufficiently adapted their

parameterization and conceptual framework from international (or national) economies to regional economic settings.

A framework is then put forth in the hope of making regional CGE modeling the preferred approach for examining the economic effects of proposed regional development policies. The proposed framework recommends: model structure informed by the vernacular of regional location theory to examine a wider range of regional policy issues parameterization; multi-regional specification for small areas, with explicit economic linkages between the areas; dynamic specification; allowance for permanent changes in unemployment and labor force participation as suggested by empirical economic development studies; heterogeneous labor classes and empirically-based linkages to poverty; model dynamics that reflect differences between regional and national/international economic settings; parameterization which captures known empirical regularities in the region's data.

The framework outlined only provides broad guidelines. The required features of a regional CGE model will always likely depend on its particular application. The plethora of current and likely future economic development policy alternatives also suggests possibilities for additional model features. In contrast to simpler regional models, a properly specified regional CGE model would be capable of integrating features required to address increasingly complex policy issues, while being significantly empirically-based to convince economic development practitioners to use it.

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**Table 1. Mathematical Expressions**

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*Representation for a given region, within a broader multiregion,  $r$ , and a rest-of-the-world region,  $row$ , containing industries,  $i$*

**A. Commodity Demands (for all industries  $i$ )**

*Household Commodity Demand*

$$(1) X_i^h = F_i^1(A_i^1, \mathbf{P}_i^1, Y)$$

*Household Imports*

$$(2) IM_i^h = F_i^2(A_i^2, \mathbf{P}_i^2, X_i^h)$$

*Household Consumption of Local Goods*

$$(3) C_i^h = F_i^3(A_i^3, \mathbf{P}_i^3, X_i^h)$$

*Intermediate Input Demands*

$$(4) X_i^f = F_i^4(A_i^4, \mathbf{P}_i^4, Q_i)$$

*Intermediate Input Imports*

$$(5) IM_i^f = F_i^5(A_i^5, \mathbf{P}_i^5, X_i^f)$$

*Intermediate Input Demands of Local Goods*

$$(6) M_i^f = F_i^6(A_i^6, \mathbf{P}_i^6, X_i^f)$$

*Investment Demand*

$$(7) I_i = F_i^7(A_i^7, \mathbf{P}_i^7, Q_i)$$

*Imports for Investment Demand*

$$(8) I_i^M = F_i^8(A_i^8, \mathbf{P}_i^8, I_i)$$

*Local Production for Investment Demand*

$$(9) I_i^L = F_i^9(A_i^9, \mathbf{P}_i^9, I_i)$$

*Export Demands*

$$(10) EX_i = F_i^{10}(A_i^{10}, \mathbf{P}_i^{10})$$

*Total Demand for Local Goods*

$$(11) D_i = C_i^h + M_i^f + I_i^L + EX_i$$

**B. Production (for all industries,  $i$ )**

$$(12) R_i = F^{12}_i(A_i^f, Q_i, w^s, w^u, r, q) \text{ for } R = L^s, L^u, K, T$$

### C. Factor Supplies

*Resident Labor Force*

$$(13) RLF^k = F^{13,k}(A^{LF,k}, w^k, w_r^k, POP^k) \text{ for } k=s,u$$

*Net Commuting*

$$(14) COM^k = F^{14,k}(A^{COM,k}, w^k/w_r^k, (L^k/POP^k)/(L_r^k/POP_r^k)) \text{ for } k=s,u$$

*Net Migration*

$$(15) MIG^k = F^{15,k}(A^{MIG,k}, w^k, L^k/POP^k, POP^k) \text{ for } k=s,u$$

*Total Labor Supply*

$$(16) L^{sup,k} = RLF^k + COM^k + MIG^k \text{ for } k=s,u$$

*Unemployed*

$$(17) UR^k = RLF^k - L^k + (ICOM^k - OCOM^k) \text{ for } k=s,u$$

*Capital Supply Adjustment (for all time periods t)*

$$(18) K^{sup}_t = (1-d) K^{sup}_{t-1} + I_{t-1}$$

$$I_{t-1} = F^{18}(r_{t-1})$$

*Supply of Developed Land (for all time periods t)*

$$(19) T^{sup}_t = T^{sup}_{t-1} + F^{13}(q_{t-1})$$

### D. Factor Price Determination

*Wage Adjustment Equation*

$$(20) w^k_t = F^{20,k}((L^k_t/POP^k_t - L^k_{t-1}/POP^k_{t-1}), (L_r^k_t/POP_r^k_t - L_r^k_{t-1}/POP_r^k_{t-1})) + w^k_{t-1}$$

for all t and k=s,u

*Market Clearing Equation for Developed Land*

$$(21) T^{sup} = \sum_i T_i$$

*Market Clearing Equation for Capital*

$$(22) K^{sup} = \sum_i K_i$$

### E. Commodity Price Determination

$$(23) P_i = F^{23}_i(A_i^f, w^s, w^u, r, q) \text{ for all industries } i$$

## F. Regional Income

$$(24) Y = w^u * (L^u - ICOM^u) + w^s * (L^s - ICOM^s) + w_r^u * OCOM^u + w_r^s * OCOM^s \\ + \phi r K^{sup} + \theta (r_{row} K^{row} + q_{row} T^{row}) + \delta q T^{sup} + tr(UR^u, UR^s)$$

## G. Poverty Rate

$$(25) POV = F^{25}(tr, w^u, UR^u/RLF^u, RLF^u/POP^u)$$

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**Table 2. Variable Definitions**

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$A^{\text{COM},k}$  net commuting shift parameter

$A_i^f$  multi-factor productivity

$A_i^j$   $j=1, \dots, 10$  taste parameters

$A^{\text{LF},k}$  labor force participation rate shift parameter

$A^{\text{MIG},k}$  migration shift parameter, likely reflecting regional amenity-attractiveness

$C_i^h$  household consumption of commodity  $i$  that is produced in the region

COM net commuting into the region

$d$  depreciation rate

$D_i$  total demand for commodity  $i$  produced in the region

$EX_i$  exports of commodity  $i$

$F_i^j$  general functional relationships

$I$  gross investment in the region

ICOM in-commuting to the region

$IM_i^f$  firm imports of commodity  $i$

$IM_i^h$  household imports of commodity  $i$

$K_i$  demand for capital by producing sector  $i$

$K^{\text{sup}}$  supply of capital in the region

$K^{\text{row}}$  supply of capital in the rest of the world

$L_i^s$  demand for high-skilled labor by producing sector  $i$

$L_i^u$  demand for low-skilled labor by producing sector  $i$

$L^s$  total demand for high-skilled labor

$L^u$  total demand for low-skilled labor

$L^{\text{sup},k}$  total supply of labor (including net commuting) for labor demand in the region

$M_i^f$  intermediate demand for local production of commodity  $i$

MIG net migration into the region

OCOM out-commuting from the region

$\mathbf{P}_i^j$  vector of relevant purchase prices of goods, including composite prices where appropriate

POP resident population

POV poverty rate measure

q regional rate of return to land

$q_{row}$  rate of return to land in the rest of the world

$Q_i$  output in producing sector i

r regional rate of return to capital

$r_{row}$  rate of return to capital in the rest of the world

RLF original resident labor force

$T_i$  demand for land by producing sector i

$T^{sup}$  supply of developed land in the region

$T^{row}$  supply of developed land in the rest of the world

tr transfers to households in the region

UR unemployment rate

$w^k$  wage rate in the region

$w_r^k$  wage rate in remainder of the multi-regional area

$X_i^f$  firm demand for commodity i

$X_i^h$  household demand for commodity i

Y regional income

$\theta, \varphi$  shares of national and regional capital supplies owned by residents in the region

$\delta$  local ownership share of developed land in the region

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Figure 1. Regional Labor Market Adjustment to Labor Demand Increase

