A County Level Computable Geographical Equilibrium Model of the United States Economy

By

Thomas Cole Tanner

University of Georgia, Carl Vinson Institute of Government

Abstract

The fundamental goals of this paper are threefold. First, to lay out an alternative technique for managing and presenting regional economic accounts utilizing aspects of both input-output tables and social accounting matrices. Second, to implement an estimation technique that allows estimation of interregional trade flows, necessary for a multi-region model of the economy, without benefit of any trade flow data. Third, to establish a relatively simple set of "New Economic Geography" inspired behavioral equations, which can be used in conjunction with the regional accounts, to drive a county-level model of the United States economy including trade flows, demographics, and migration.

Introduction

Paul Krugman (1998) expressed a hope that the new economic geography research might one day develop "'computable geographical equilibrium' models, which can be used to predict the effects of policy changes, technological shocks, etc. on the economy's spatial structure in the same way that such models are currently used to predict the effects of changes in taxes and trade policy on the economy's industrial structure." However, he acknowledges that "preliminary efforts in this direction by several researchers, myself included, have found that such models are not at all easy to calibrate to actual data." It is the objective of this paper to unite several different threads of economic research to develop the framework for just such a regional "computable geographic equilibrium" model of the United States economy. Key tools and concepts that will be incorporated into the model will include: input-output analysis, Social Accounting Matrices, gravity modeling, and new economic geography. The model framework that is developed is extremely simple, at least by the standards of most computable general equilibrium models, yet is capable of generating a wide range of extremely complex economic behaviors/outcomes, can model these behaviors at an extremely fine level of geographic and sector detail, and can be calibrated to "real world" data.

The Industry-Commodity Relationships in the Model: A Merged IO-SAM Framework

The data framework for the model is based on blending the traditional input-output tables of Leontief (1941), Stone and Brown (1962), with the closely related Social Accounting Matrix (SAM) framework as formalized by Pyatt and Round (1985) based upon the earlier work of Stone that has become widely used in recent decades. The beauty of the IO framework originally developed by Leontief is its utter simplicity – each industry sells its output to itself, to other industries, or to final demanders. Therefore, on a single table, you can capture all the activity in an economy. Stone and Brown, however, observed that the Leontief IO table implicitly failed to recognize that every industry uses a mix of commodities, and that every industry makes a mix of commodities. The commodities are a necessary component to describe accurately and explicitly the system's behavior.

Mathematically, under the make and use table configuration of Stone and Brown, “industries” can be interpreted as a transformation system that converts a menu of commodities and factor inputs into a menu of commodities. Generally, the Stone and Brown IO tables can be used to model industry behavior using either Leontief or Cobb-Douglas production functions. The configuration is particularly well suited to Cobb-Douglas functions because all cells are simply a record of budget share, which is a constant in Cobb-Douglas production functions.

However, these traditional IO tables have very little to contribute when we attempt to examine or model anything beyond the industry-commodity-industry interactions. Particularly, the final demand components are simply floating out in the rightmost columns of the IO use table, and the factor components of the industrial process are hovering, detached, in the bottom rows of the use table. This points to the IO shortcoming that Social Accounting Matrices attempt to address – that there are a significant set of interactions that are not accounted for in the IO table format. Household, government, and capital markets are explicitly introduced under the SAM framework, and a host of behaviors such as taxation, intergovernmental transfers, etc., are included in this alternative data structure. In IO make and use tables, it is clear that there is a relationship between the value added rows and the final demand columns because the total of the value added cells in the use table must equal the total of the final demand cells in the use table, but the nature of the relationship is left to the imagination. The SAM framework has the advantage of being absolutely comprehensive because every transaction type is accounted for in some cell of a SAM matrix, and the matrix is potentially endlessly expandable, limited only by the data available and the needs of the researcher. One might imagine a comprehensive SAM in which every individual, every business, every government entity, in short, every agent, has its own row and column in the SAM. The result would be a matrix explicitly showing every financial interaction in the economy.

But the SAM is comprehensive at the expense of being incomprehensible, at least when one attempts to develop any interesting rules governing the behavior of the many agents implied by the SAM, a shortcoming introduced because non-industry entries are introduced in a single entry accounting framework. As such, SAMs are lovely for accounting work, and frustrating for economic geography work. As we shall see, the problem stems from the fact that, while a SAM is comprehensive from an accounting perspective (every transaction shows up in some cell in the matrix), it is not complete in an economic sense, in that each cell does not represent a unique exchange of a commodity for money, as it does in an IO make and use table. This model begins with an alternative framework that draws on the comprehensiveness of the SAM, and the simplicity and economic cohesion of the Make and Use IO table.

The model framework relies on taking the traditional economic concept of the circular flow diagram absolutely seriously, and on discarding the artificial primacy given to the idea of factor inputs to production. The proposed framework involves viewing the economy as a continuous process of converting menus of commodities into menus of commodities.

Businesses convert a menu of commodities into a menu of commodities, as is evident and explicit in the original Stone and Brown IO table structure. But labor can be viewed as an industry that converts “final goods” (a misleading term, as there is nothing “final” about them) into labor (a commodity behaviorally identical to any other). Even remittance cohorts (here meant to include not only the unemployed, but all individuals including the retired and others who receive government payments through transfers) can be considered as an entity that converts consumer goods into transfer payments. Government – this is perhaps the biggest conceptual hurdle – converts purchases of commodities (including, of course, labor, which is now just one more commodity) into government goods (“purchased” primarily through tax revenue). Throughout this discussion of our model development, we shall treat each entity’s consumption of government goods as proportional to their share of aggregate regional demand for government goods. This is a strong assumption, and the model can certainly be adjusted to an alternative assumption of the nature of government goods.

It is now possible to merge the IO and SAM methods of conceptualizing an economy into a unified system. The unified system’s row elements in the make table include all the various producer industries generally included in make tables. They also include rows for a “labor industry” (or industries), “remittance cohorts” (remembering that unemployed labor, retirees, and other transfer recipients are accounted for explicitly in this framework as an industry that converts consumer goods into transfer payments), and government rows. Finally, the make table adds "investor" rows to produce financial capital and "speculator" rows to produce physical capital as we will see in a moment.

The unified system also adds several columns to the traditional make table. The new columns include a "labor commodity" representing the wage bill produced by the labor industry added above as a make table row; a transfer payments commodity; and federal, state and local government commodities. They also include "financial capital" columns to represent commodities (dividends, interest, and rent) produced by the investor industry through the savings process; and "physical capital" columns to represent the residential and nonresidential capital commodity outputs of the speculator industries.

Several columns in the make table require additional discussion. A transfer payment column is added to represent the "commodity" produced by remittance cohorts such as unemployed labor and retirees. Conceptually, we are simply saying that unemployed labor and retirees are producing a commodity because the very fact that they are being compensated is evidence for the commodity itself. One might debate the wisdom or rationale behind the transfer payments, but what is beyond doubt is that unemployed labor and retirees are producing some commodity, which some entity or entities are purchasing, based upon some decision making criterion (optimizing function). This is all that matters from a modeling perspective. Similarly, additional make table columns include several government commodities, which are produced by the government "industries" rows added to the make table. Again, we can infer the presence of the commodity from the presence of the transaction (taxes). In a regional framework, we can comment later on the value of state and local government commodities by relying on a Tiebout-like behavior of "voting with one's feet." The make table also will include additional columns for residential and nonresidential physical capital, which will be the commodity produced by the speculator industries that were added as rows in the make table.

A use table can be constructed along similar lines. As with make table rows, the use table will add columns for a labor industry, remittance cohorts, government, investors, and speculators. The use table also will add rows for the commodities of labor; transfer payments, government taxes, and fees; financial capital; and residential and nonresidential physical capital. The labor industry will use a mix of commodities once relegated to the use table’s final demand portion. In the same manner, remittance cohorts and government also will use a mix of commodities from the final demand portion of the traditional use table.

The role of the proposed speculator industries deserves a brief explanation. Each speculator industry will use the mix of commodities identified in the traditional use table under investment final demand, in addition to the financial capital good, to produce the physical capital good(s) identified in the make table. The speculator industry is something of a “ghost in the machine” because it is a mechanism the model will use to insure that the presumably quite mobile financial capital commodity flows through speculator intermediaries to purchase presumably relatively immobile physical capital. For example, while it may be that money I invest in Georgia goes to purchase a conveyor belt for use in a California assembly plant, the likely mechanism is that I (or my bank, or my broker, or some other financial intermediary) furnished my mobile financial capital to a California speculator (which may be the business itself, or a California bank, or a real estate speculator) who then purchased the conveyor belt in California. That is, my Georgia financial capital was used in California to purchase a conveyor belt in California. What decidedly I did not do was use my savings to purchase a conveyor belt in Georgia for shipment to California. As we develop an economic geography model of the United States, it is critical accurately to model where demand actually occurs, and introducing the speculator intermediary helps facilitate this. Finally, producer industries, in addition to using the commodities identified in a traditional IO table, also use labor, government, and physical capital commodities, which traditionally are identified as value added components in the use table.

Two industries receive very special treatment in the model, as they will both figure prominently in the behavioral equations and in the ultimate geographic equilibrium: the “real estate” industry (NAICS code 531) and the “owner occupied dwellings” industry, which is not identified in the NAICS coding system, but is rather a constructed industry used in the BEA and BLS make and use tables to guarantee compatibility with NIPA. These industries are critical for the model, in that they include land values, which is the one fixed geographic commodity in our model. Land, as we shall see shortly, is the only completely immobile commodity in the model, and land prices are the one factor that will invariably act to disperse economic activity. As such, the “other value added” components of these two industries are extracted, and are labeled as a separate land industry, producing a completely immobile land commodity. The only commodity used by the land industry is financial capital, specifically the rent (real or imputed) paid to landowners.

Figure 1 outlines the framework for the proposed comprehensive SAM/IO data structure. Note that the gray cells in the figure represent areas that are likely to contain either zeros or insignificantly small transactions. Note also that any given rows or columns could be expanded to fit any level of additional detail; the basic structure is limited only by the data that would be available to support it. This framework will be explored in more detail as we begin to develop the model that will flesh out the data structure.

Several data sources are used to estimate county-level employment for the merged IO-SAM at the NAICS five-digit detail level (709 industries). A complete description of the process used to populate the model can be found in Tanner (2005). The primary data sources are the County Business Patterns (CBP) from the Bureau of the Census, and the Regional Economic Information System (REIS) from the Bureau of Economic Analysis (BEA). Wage Bill (payroll) data, which will populate the regional “labor industry” output in the model and also determine output for many other industries, are derived with the same techniques and from the same sources as the employment data. Specifically, the CBP reports the total annual payroll for each NAICS code up to the five-digit level of detail for the United States and for every region, state, and county. However, total employment and total payroll data are subject to suppressions for privacy. Rather than rely strictly on the various RAS and statistical systems traditionally used to fill all data suppressions, we

MAKE TABLE

Commodities / Industries That Make Commodities	Producer Commodities	Labor	Transfer Payments	Government Goods	Financial Capital	Physical Capital	Land
Producers		▨	▨	▨	▨	▨	▨
Employed Labor	▨		▨	▨	▨	▨	▨
Remittance Cohorts	▨	▨		▨	▨	▨	▨
Government	▨	▨	▨		▨	▨	▨
Investors	▨	▨	▨	▨		▨	▨
Speculators	▨	▨	▨	▨	▨		▨
Land	▨	▨	▨	▨	▨	▨	

USE TABLE

Industries / Commodities Used by Industries	Producers	Employed Labor	Remittance Cohorts	Government	Investors	Speculators	Land
Producer Commodities							▨
Labor		▨	▨		▨		▨
Tran Pmts/Taxes/Fees	▨	▨	▨		▨	▨	▨
Government Goods							▨
Financial Capital	▨	▨	▨	▨	▨		
Physical Capital						▨	▨
Land							▨

Figure 1: A merged SAM/IO framework for the make and use tables.

developed a unique "range constraining" approach, which uses all information available in the CBP series and guarantees internal consistency with unsuppressed wage and employment data (Tanner 2005). All the furnished and estimated CBP wage bill and employment data are then totaled and scaled to match the wage bill and employment data reported in the BEA's REIS, which includes all county and state wages at the two-digit NAICS level of detail and all employment data at one-digit NAICS detail. The REIS directly provides wage bill and employment data for the government and agriculture sectors, and also disposable personal income data by county.

The process used to build a complete set of historical and forecast IO-SAMs is also outlined in greater detail in Tanner (2005). Annual IO tables are constructed using BEA

IO make and use tables, as well as biennial 11-year IO forecast tables from the Bureau of Labor Statistics (BLS). The very detailed BEA IO make and use tables are extended year-by-year to match the annual changes in make and use composition implied by the current 10-year BLS IO tables. This generates a detailed annual forecast series of national IO make and use tables. Next, each county's wage bill by industry is used to allocate each industry's national output to counties from the NIPA, and then the regional output by industry is allocated to commodities based on the national IO make table proportions. This assumes that the commodities produced by an industry are truly joint in the production process, as dictated by a nationally uniform production function for all firms in each industry based on competitive pressures to diffuse advantages quickly across all firms in an industry. Rather than relying upon the traditional matrix inversion technique used in most IO models (but unwieldy in a model with 3110 interacting regions), in baseline and simulation forecasting the model will apply the national IO tables to estimate a complete multi-regional supply response to indirect and induced demand, and to exogenous final demand, in a search cycle that looks for the suppliers of suppliers across industries and regions. Each cycle in the search process starts up in every region where the gravity-based production function's previous cycle estimated a supply output response, and so on, until the process reaches a minimum incremental output cutoff point.

The New Economic Geography Behavioral Assumptions

Regardless of the entity in question, in our model all will face a Dixit-Stiglitx (1977) constant elasticity of substitution (CES) nested Cobb-Douglas production function of the form:

$$\prod_{g=1}^{G}\left(\tilde{g}_{gmirt}\right)^{\theta_{\tilde{g}it}} = E_{it} + q_{mirt} \tag{1}$$

For manufacturer m, belonging to industry i, located in region r, at time t. G represents the total number of goods in the economy . $\tilde{g}_{gmirt}$ is the quantity of composite commodity good $\tilde{g}$ used by manufacturer m, in industry i, in region r, at time t. $\theta_{\tilde{g}it}$ is the share of composite commodity good $\tilde{g}$ used in industry i at time t. Note that the production function, at any point in time, is industry and time specific, but not region or manufacturer specific. E_{it} is the fixed cost of production for industry i at time t. Finally, q_{mirt} is the total output of manufacturer m, in industry i, in region r, at time t.

This behavioral equation will apply to all manufacturers, regardless of the "type" of entity in the traditional sense. For example, a labor manufacturer will use a mix of inputs to produce a labor commodity for sale to those manufacturers which demand such commodities. Implicitly, this amounts to the traditional cost minimization exercise for households and other "final demanders," but that distinction is artificial for purposes of this model.

Every manufacturer also faces the traditional constant returns to scale Cobb-Douglas budget share constraint given by

$$\sum_{g=1}^{G} \theta_{git} = 1 \tag{2}$$

This is completely consistent with agglomeration economies in the new economic geography framework, which is based on increasing returns at the industry level, but not at the firm level. In addition, a constant returns to scale technology is consistent with the input-output data structure used throughout the model.

Because we wish to allow for the possibility of joint production, as implied by our data structure described earlier, we must devise a mechanism for translating between industry production and commodity production. To that end, we specify:

$$q_{mirt} = \sum_{g=1}^{G} \vartheta_{git} q_{mirt} \tag{3}$$

Where

$$\sum_{g=1}^{G} \vartheta_{git} = 1 \tag{4}$$

Where ϑ_{git} is the output share of good g in industry i total output, at time t. For joint production, we shall calculate the U.S. average inputs for commodity g at time t, given by:

$$\theta_{\tilde{g}gt} = \sum_{i=1}^{I} \left(\theta_{\tilde{g}it} \frac{Q_{git}}{\sum_{i=1}^{I} Q_{git}} \right) \tag{5}$$

Where $\theta_{\tilde{g}gt}$ is the input share of commodity $\tilde{g}$ used in the production of commodity g at time t, and I is the total number of industries. To simplify the process of calculating prices across all regions and commodities in the model, we shall use these input shares in all price and trade calculations. Industries will only reenter the equation when we allow for industry expansion/contraction in a region in response to price changes in the various commodities across regions.

The model we are developing will not rely upon traditional iceberg costs. Instead, we will model the transportation component of the economy as an explicit subset of inputs into the Dixit-Stiglitz production function. The iceberg transportation cost assumption is so thoroughly embedded in the new economic geography literature, that it is identified by Krugman, Fujita and Venables (1999) as one of the three cornerstones of the literature. At the same time, Krugman (1998) says of iceberg transportation costs, “it’s too bad that actual transport costs look nothing like that.” Since tractability can be maintained with a more realistic transportation assumption, for this model, transportation cost will be given by:

$$\frac{P_{g\tilde{r}rt}}{P_{g\tilde{r}t}} = \prod_{\delta=1}^{\Delta} \gamma_{g\delta t} d_{\delta\tilde{r}rt}{}^{\theta_{\delta gt}} \tag{6}$$

Where the left hand side of the equation, $\frac{P_{g\tilde{r}rt}}{P_{g\tilde{r}t}}$, represents the ratio of the profit-maximizing price as delivered to region r to the profit-maximizing Ex Works (EXW) price for good g, produced in region $\tilde{r}$, at time t. Δ represents the number of modes of transportation. Each mode of transportation, as mentioned earlier, is a commodity in the overall economy, hence $\Delta \in G$. $d_{\delta\tilde{r}rt}$ represents the effective distance from region $\tilde{r}$ to region r by mode δ, at time t. $\theta_{\delta gt}$ is the share of transportation commodity δ, used in production of commodity g, at time t, and $\gamma_{g\delta t}$ represents the unit distance cost of shipping commodity g, by mode δ, at time t. In estimating NEG models, the concept of $d_{\delta\tilde{r}rt}$ is often approximated inclusively by straight-line distance or an average travel time between two regions.

Under this formulation of prices, and with the CES assumption of our Dixit-Stiglitz production function, the aggregate profit maximizing behavior of producers will lead to a trade relationship for every commodity-county-county combination of:

$$T_{g\tilde{r}rt} = \frac{Q_{g\tilde{r}t} \cdot P_{g\tilde{r}rt}^{-\sigma_g}}{\left(\sum_{\tilde{r}=1}^{R} Q_{g\tilde{r}t} \cdot P_{g\tilde{r}rt}^{-\sigma_g} \right)} \cdot D_{grt} \tag{7}$$

Where $T_{g\tilde{r}rt}$ represents the volume of trade in commodity g, from region $\tilde{r}$ to region r. $Q_{g\tilde{r}t}$ is the aggregate amount of commodity g, produced in region $\tilde{r}$, at time t, and D_{grt} is the aggregate demand for commodity g, in region r, at time t. Note that this is a completely traditional gravity model, in that the degree of interaction is a function of the relative size of the producer, the size of the demander, and the relative distance (shipping cost) between them. The specification encompasses any number of regions and commodities, and sheds the restrictive iceberg price assumption.

Estimating Price Elasticities and Trade Flows in the Model

The gravity model specified above is, by design, demand constrained. If we sum across all supplier regions $\tilde{r}$, we discover that

$$\sum_{\tilde{r}=1}^{R} T_{g\tilde{r}rt} = \sum_{\tilde{r}=1}^{R}\left(\frac{Q_{g\tilde{r}t}\cdot P_{g\tilde{r}rt}{}^{-\sigma_g}}{\left(\sum_{\tilde{r}=1}^{R} Q_{g\tilde{r}t}\cdot P_{g\tilde{r}rt}{}^{-\sigma_g}\right)}\cdot D_{grt}\right) \Rightarrow \sum_{\tilde{r}=1}^{R} T_{g\tilde{r}rt} = D_{grt}\forall g,r,t \tag{8}$$

That is, the total trade in commodity g from all regions, terminating in region r, is equal to the total demand for good g, in region r, an accounting condition that must be true by definition.

While theoretically complete, accurate empirical estimation of the above model requires one additional step: The addition of an explicit supply constraint to insure that every region in the model sells all output. As we wish to build an applied regional economic model of the United States economy, it is necessary to guarantee that our estimation process also meets the supply constraint that

$$\sum_{r=1}^{R} T_{g\tilde{r}rt} = Q_{g\tilde{r}t}\forall g,\tilde{r},t \tag{9}$$

If the model captured all trade perfectly, this would not be a concern, but in the presence of error in the estimation, we must transform equation (7) into a classic, doubly constrained gravity model following the form developed by Wilson (1970, 1974):

$$T_{g\tilde{r}rt} = \frac{Q_{g\tilde{r}t}\left(P_{g\tilde{r}t}\cdot\prod_{\tilde{\delta}=1}^{\Delta}\left(\gamma_{g\tilde{\delta}t}d_{\tilde{\delta}\tilde{r}rt}\right)^{\theta_{\delta gt}}\right)^{-\sigma_g}}{\sum_{\tilde{r}=1}^{R}\left(Q_{g\tilde{r}t}\left(P_{g\tilde{r}t}\cdot\prod_{\tilde{\delta}=1}^{\Delta}\left(\gamma_{g\tilde{\delta}t}d_{\tilde{\delta}\tilde{r}rt}\right)^{\theta_{\delta gt}}\right)^{-\sigma_g}\right)}\cdot D_{grt} \tag{10}$$

$$P_{g\tilde{r}t}{}^{-\sigma_g} = \left(\sum_{r=1}^{R} D_{grt} \left(B_{grt} \cdot \prod_{\tilde{\delta}=1}^{\Delta} \left(\gamma_{g\delta t} d_{\delta \tilde{r} r t} \right)^{\theta_{\delta g t}} \right)^{-\sigma_g} \right)^{-1} \tag{11}$$

$$B_{grt}{}^{-\sigma_g} = \left(\sum_{\tilde{r}=1}^{R} Q_{g\tilde{r}t} \left(P_{g\tilde{r}t} \cdot \prod_{\tilde{\delta}=1}^{\Delta} \left(\gamma_{g\delta t} d_{\delta \tilde{r} r t} \right)^{\theta_{\delta g t}} \right)^{-\sigma_g} \right)^{-1} \tag{12}$$

Where $P_{g\tilde{r}rt}$ is the profit maximizing price in region r of commodity g, produced in region $\tilde{r}$, at time t, which will drive the distance decay function in the gravity model. B_{grt} is a balancing factor that insures that all output is sold in all regions in the model; that is, that equation (11) is satisfied. As such, the model of trade flows will closely follow Alonso's (1973) General Theory of Movement, though applied to trade rather than migration, and built from an explicit microeconomic foundation.

Unfortunately, there is no reliable, comprehensive, and timely data source for regional trade flows within the United States. However, if we first difference the trade gravity equation, and are willing to make the simplifying assumption that $B_{grt} = B_{grt-1}$ then we arrive at the following trade relationship:

$$\frac{Q_{g\tilde{r}t}}{Q_{g\tilde{r}t-1}} = \frac{\sum_{r=1}^{R} D_{grt} \left(B_{grt-1} \cdot P_{g\tilde{r}rt} \right)^{-\sigma_g}}{\sum_{r=1}^{R} D_{grt-1} \left(B_{grt-1} \cdot P_{g\tilde{r}rt-1} \right)^{-\sigma_g}} \tag{13}$$

Where $Q_{g\tilde{r}t}$ and $Q_{g\tilde{r}t-1}$ represent the total quantities of commodity g produced in region $\tilde{r}$ at times t and $t-1$, B_{grt-1} is the demand-balancing term for commodity g in region r at time $t-1$, and D_{grt-1} represents total quantity of commodity g demanded in region r at time $t-1$. $P_{g\tilde{r}rt}$ and $P_{g\tilde{r}rt-1}$ are the profit-maximizing prices of commodity g in region r, produced in region $\tilde{r}$, at times t and $t-1$, and σ_g is the elasticity of substitution between individual varieties of commodity g. Derivation of the trade relationship can be found in Tanner (2005).

The estimated share of each transportation mode devoted to the shipment of each commodity will be estimated by:

$$\theta_{g\delta t} = \sum_{i=1}^{I} \left(\theta_{\delta it} \cdot \frac{\vartheta_{git} q_{it}}{\sum_{i=1}^{I} \vartheta_{git} q_{it}} \right) \tag{14}$$

Where I is the total number of industries, $\theta_{\delta it}$ is the budget share of industry i devoted to the purchase of transportation mode δ at time t (identified by the IO table for time t), q_{it} is the total national output of industry i at time t, and ϑ_{git} is the share of industry i output that is commodity g at time t. This equation enables the model to estimate the budget share of commodity g that is devoted to transportation mode δ as being the average of each industry's budget share devoted to transportation mode δ, weighted by the industry's total share of the output of commodity g. Note that most commodities are produced almost entirely by a single industry, and hence the commodity share is determined almost entirely by the production function of that industry.

The distance variables $d_{\tilde{\delta}\tilde{r}rt}$, $d_{\delta\tilde{r}rt}$, $d_{\delta\tilde{r}rt-1}$, and $d_{\delta\tilde{r}rt-1}$ are normally approximated by some inclusive straight-line distance or time measure, such that:

$$d_{\tilde{\delta}\tilde{r}rt} = d_{\delta\tilde{r}rt} = d_{\tilde{\delta}\tilde{r}rt-1} = d_{\delta\tilde{r}rt-1} = d_{\tilde{\delta}r\tilde{r}t} = d_{\delta r\tilde{r}t} = d_{\tilde{\delta}r\tilde{r}t-1} = d_{\delta r\tilde{r}t-1} \tag{15}$$

However, rather than using an inclusive straight-line distance or time measure, this model applies a unique and comprehensive database of transportation impedance measures developed by the Oak Ridge National Laboratories from impedance information for 1997 (Southworth, 1997 and Southworth, Peterson and Chin, 1998). Based on the Oak Ridge impedance database, the impedance in this model can differ between two regions both with the mode and with the direction of travel, but in the currently supported analysis,

$$d_{\delta\tilde{r}rt} = d_{\delta\tilde{r}rt-1} \tag{16}$$

As additional years of transportation data become available, impedance measures could be expanded to change over time, as well as with the mode and with the direction of travel.

Under the current assumptions, we can substitute the delivered price equation into our gravity equation and perform some simple algebra to get:

$$\frac{Q_{g\tilde{r}t}}{Q_{g\tilde{r}t-1}} = \frac{\sum_{r=1}^{R} D_{grt} \cdot \left(B_{grt} \cdot \prod_{\delta=1}^{\Delta} d_{\delta\tilde{r}rt}{}^{\theta_{\delta gt}} \right)^{-\sigma_g}}{\sum_{r=1}^{R} D_{grt-1} \left(B_{grt} \cdot \prod_{\delta=1}^{\Delta} d_{\delta\tilde{r}rt-1}{}^{\theta_{\delta gt-1}} \right)^{-\sigma_g}} \tag{17}$$

At this point we have an equation where the only unknowns are the elasticity of substitution σ_g and the balancing factor B_{grt}. Estimates of σ_g are calculated for each commodity g, using non-linear least squares. The estimation is made using data for all 3,110 regions in the U.S. database for the years 1999-2001.

Once σ_g has converged, we have effectively estimated the elasticities of substitution for each commodity in the model, subject to our initial condition that $P_{g\tilde{r}t}$ and B_{grt} are 1. These EXW balancing factors $P_{g\tilde{r}t}$ and B_{grt} are solved iteratively (of necessity, since they enter into the trade flow calculations nonlinearly), and the iterative estimation of $P_{g\tilde{r}t}$ and B_{grt} is followed by a re-estimation of σ_g. The entire process is repeated until convergence is achieved.

While trade flows are calculated for every commodity in our conjoined IO/SAM framework, some restrictions and assumptions will be imposed upon the various entities in the model to capture specific behavioral limitations. Specifically:

1. No local government commodity can be shipped across county lines. This, effectively, prevents the export of local government commodities across region borders, which means that local government is paid for entirely by those entities in

the region. Because this model will use counties as regions, this amounts to an assumption that local government does not cross county borders, but is provided uniformly within any given county; this is certainly a simplifying abstraction from reality, to the extent that some local government entities cross county borders, while others may have a footprint that does not cover an entire county.

2. No state government commodity can be shipped across state borders. This has the same effect for state government as our first assumption did for local government – state government does not cross state borders, but may be transported within the state, though such shipments are subject to the explicitly estimated transportation cost for the commodity.

3. Land cannot be shipped across county borders. Recall that the land area in a region fixes the supply of the land commodities in the region. This means that any region has a fixed supply of land, and this will act as the fundamental dispersing force in the model, counteracting any tendency toward catastrophic agglomeration that might occur in the presence of transportation costs alone.

Creating CGE and Dynamic Adjustment Paths for the Model

Recall from equation (6) that, under our explicit transportation cost assumption, the profit-maximizing price in region r of commodity g, produced in region $\tilde{r}$, at time t becomes:

$$P_{g\tilde{r}rt} = P_{g\tilde{r}t} \cdot \prod_{\delta=1}^{\Delta} \gamma_{g\delta t} d_{\delta\tilde{r}rt}{}^{\theta_{\delta gt}} \tag{18}$$

The next task is to define the vector of EXW profit-maximizing prices for all commodities manufactured in region $\tilde{r}$ at time t:

$$P_{g\tilde{r}t} = \frac{\sigma_g}{\sigma_g - 1} \Omega_{g\tilde{r}t} \tag{19}$$

Where σ_g represents the elasticity of substitution between individual varieties of commodity g, and $\Omega_{g\tilde{r}t}$ is the marginal cost function for producing commodity g in region $\tilde{r}$ at time t.

By working within price space (rather than quantity space), as dictated by the isomorphic discovery of Robert-Nicoud (2004), the EXW marginal cost function Ω_{grt} is in turn given by:

$$\Omega_{grt} = \prod_{\tilde{g}=1}^{G-\Delta} \left(P_{\tilde{g}rt}\right)^{\theta_{\tilde{g}gt}} \tag{20}$$

Where $G-\Delta$ is the number of non-transportation commodities, $P_{\tilde{g}rt}$ is the price index of commodity $\tilde{g}$, in region r, at time t, and $\theta_{\tilde{g}gt}$ is the share of commodity $\tilde{g}$ used in production of commodity g at time t. This vastly simplifies the marginal cost functions used by others (e.g. Fan, Treyz & Treyz, 2000) in developing multi-industry NEG models.

The price index $P_{\tilde{g}rt}$ is given by:

$$P_{\tilde{g}rt} = \sum_{\tilde{r}=1}^{R} \left(\frac{T_{\tilde{g}\tilde{r}rt}}{\sum_{\tilde{r}=1}^{R} T_{\tilde{g}\tilde{r}rt}} P_{\tilde{g}\tilde{r}rt} \right) \cdot \frac{\sum_{r=1}^{R} D_{\tilde{g}rt}}{\sum_{\tilde{r}=1}^{R} Q_{\tilde{g}\tilde{r}t}} \tag{21}$$

Where R represents the total number of regions in the model. $T_{\tilde{g}\tilde{r}rt}$ is the total trade in commodity $\tilde{g}$, originating in region $\tilde{r}$ and sold to region r, at time t, and $P_{\tilde{g}\tilde{r}rt}$ is the profit-maximizing price in region r of commodity $\tilde{g}$, produced in region $\tilde{r}$, at time t. The ratio of total demand in all markets, $\sum_{r=1}^{R} D_{\tilde{g}rt}$ to total supply in all markets $\sum_{\tilde{r}=1}^{R} Q_{\tilde{g}\tilde{r}t}$, might seem superfluous. Remember that the national IO tables are balanced by design, and hence, this ratio should equal 1 and be irrelevant to the calculation – and indeed, for most commodities, this is the case. However, in the case of the state and local government commodities and, critically, the land commodity, markets are not national in scope, and this ratio is likely not going to be 1.

To generate our dynamic new economic geography model of the economy, it is critical that we unwrap the concept of the EXW price of good g. Within a new economic geography framework, the EXW price can be decomposed as:

$$P_{grt} = \frac{\sum_{r=1}^{R} D_{grt}}{\sum_{r=1}^{R} Q_{grt}} \cdot \prod_{\tilde{g}=1}^{G-\Delta} \left(P_{\tilde{g}rt}\right)^{\theta_{\tilde{g}gt}} \cdot A_{gr} \tag{22}$$

That is, the EXW price P_{grt}, is equal to the demand to supply ratio of the commodity in the market times the production function weighted price index for all non-transportation intermediate inputs. The refinement that we must introduce at this point is the variable A_{gr}, which is the first nature production cost of commodity g in region r, and is calibrated from the EXW price equation (19). The EXW price equation (19) is correct, only if there are no location-specific price differences in production for any region, except those originating from the price of intermediate inputs. However, in the real world, regions are intrinsically heterogeneous. For example, coal mining is intrinsically more profitable in Wyoming than in Delaware, not because market access is better in Wyoming than in Delaware, but because Wyoming is intrinsically different than Delaware – Wyoming has lots of rich coal deposits, and Delaware does not. Likewise, boat building will tend to be more profitable when there is a body of water in the region, agriculture will be more profitable for regions that have the appropriate soil, etc. In a completely homogenous world, there would be no such first nature differences, all A_{gr} values would be expected to equal 1, and the only other force driving the location decision would be market access. But with our CGE behavioral equations, and with our trade flow calculations from the previous section, we can estimate a completely new economic geography model.

For each origin region $\tilde{r}$ and destination region r, for each good g, we calculate the delivered price equation (18) for the last history year using our calculated EXW price $P_{g\tilde{r}t}$ from equations (19) and (20). Once we have calculated the delivered price for all regions and commodities in the last history year, we can use equation (21) to calculate the price index for every commodity and region in the last history year. Finally, the EXW price for every commodity is decomposed into its respective elements, per equation (22), specifically to calibrate the first nature differences, A_{gr}, for each good and region in the last history year. We shall assume that these first nature differences do not fluctuate over time.

Once these calculations are made, there is certainly no guarantee that profits of all industries, in all regions, will be equal. Given the monopolistic competition configuration of the model, any potential for profit will be realized in regions that can produce and deliver output at a low relative price within the various markets they serve. As such, given the behavioral equations outlined in the previous section, we can estimate an index of relative profitability for firms in industry i in region r at time t as:

$$\pi_{irt} = \sum_{\tilde{g}=1}^{G} \left(\vartheta_{\tilde{g}it} \cdot \sum_{r=1}^{R} \left(\frac{T_{\tilde{g}\tilde{r}rt}}{\sum_{r=1}^{R} T_{\tilde{g}\tilde{r}rt}} \cdot \frac{P_{\tilde{g}rt}}{P_{\tilde{g}\tilde{r}rt}} \right) \right) \tag{23}$$

Where π_{irt} is an index of relative profitability for industry i, in region r, at time t.

At this point, we must develop an output adjustment process for the CGE model in order to recognize that the adjustment to a stable, long run equilibrium is not an instantaneous process, but rather a series of myopic steps as each industry in each region makes adjustments, over time, in response to their profitability signals. An output adjustment process is estimated by

$$\frac{Q_{i\tilde{r}t+1}}{\sum_{\tilde{r}=1}^{R} Q_{i\tilde{r}t+1}} = \frac{Q_{i\tilde{r}t}}{\sum_{\tilde{r}=1}^{R} Q_{i\tilde{r}t}} + \lambda_i \cdot \left(\sum_{\tilde{g}=1}^{G} \left(\vartheta_{git+1} \cdot \sum_{r=1}^{R} \left(T_{\tilde{g}\tilde{r}rt} \cdot \frac{P_{\tilde{g}rt}}{P_{\tilde{g}\tilde{r}rt}} \right) \right) - 1 \right) \cdot \frac{Q_{i\tilde{r}t}}{\sum_{\tilde{r}=1}^{R} Q_{i\tilde{r}t}} \tag{24}$$

Where $Q_{i\tilde{r}t}$ and $Q_{i\tilde{r}t+1}$ are the quantity of output in industry i, in region $\tilde{r}$, at times t and $t+1$, respectively, and λ_i is the speed of adjustment of industry i to the relative profitability signal, and must be econometrically estimated.

Then, using our historical data, we can use equation (24) to calculate profitability response λ_i for each industry by least squares, using:

$$\frac{Q_{irt+1}}{\sum_{\tilde{r}=1}^{R} Q_{i\tilde{r}t+1}} \Bigg/ \frac{Q_{irt}}{\sum_{\tilde{r}=1}^{R} Q_{i\tilde{r}t}} = 1 + \lambda_i \left(\pi_{irt} - 1 \right) \tag{25}$$

Based upon the calculated profitability π_{irt} and profitability response λ_i, we can then calculate the expected market shares for the first forecast year, and allocate supply and demand accordingly. Based upon the new allocation of supply and demand, and the estimated elasticity of substitution, we can calculate a complete and balanced set of trade flows for the first forecast year.

Then, we calculate the EXW price for each commodity, in each region, in the first forecast year, by using equation (20) and the value of $P_{\tilde{g}rt-1}$ as an estimate of $P_{\tilde{g}rt}$. Using the EXW price we have just calculated, we use equation (19) to calculate the delivered price $P_{g\tilde{r}rt}$ for every good g, and for every origin region $\tilde{r}$, and destination region r.

Using this estimate of delivered price, we calculate the price index for each good g, and region r, in the first forecast year using equation (22). Once all price indices have been updated, we can recalculate the complete menu of EXW prices, to recalculate a complete set of delivered prices, then recalculate all price indices. This process is repeated until it converges completely. Because each iteration is capturing prices across a greater number of regions, the process necessarily converges very quickly.

With the delivered price and price index data for all regions and goods for the first forecast year, we can calculate industry i profitability for all industries in all regions, using equation (23). Based upon the calculated profitability π_{irt} and profitability response λ_i, we calculate the expected market shares for the second forecast year, and allocate supply and demand accordingly. The whole process is then repeated for each and every year of the forecast period, to build a complete county level CGE model of the United States Economy that is consistent with the new economic geography framework.

Characteristics and Behavior of the Model

Because of the switch from the SIC (Standard Industrial Classification) to NAICS (North American Industrial Classification System) system for coding industries and commodities that took place over the 1997-2000 time frame, and because the U.S. Bureau of Economic Analysis chose not to collect data in both formats for a single overlapping year, there exists no technique that will generate even a remotely useful county level time series that overlaps the two coding systems (Tanner & Hearn, 2005). Because the model we have developed ultimately is to be applied to regional planning activity, it has been built entirely in NAICS, which means that the data series cannot be extended before 1999. As such, the model is constructed using a complete historical database that covers only the years 1999-2001. The major shortcoming of this arrangement is that the model's forecasting capability cannot yet be tested against historical data; the estimation of trade flows in chapter 2 requires two years of historical data, and that leaves a measly one year of historical data that could be used to test the model. This is clearly insufficient to test a structural model. So, we are left to explore characteristics of the model forecast, while having to rely upon the integrity of the model logic, as opposed to its historical performance.

Because the model forecasts an enormous number of concepts, identifying data that will capture the overarching concepts of the New Economic Geography framework is a challenge. The challenge is intensified by the fact that the model forecasts the market share accruing to each county in every market, and hence, the U.S. aggregate forecast tells us nothing about the nature of the regional model. Because the NEG model is fundamentally driven by market shares and the amount of land available, it seems the single metric that best captures the model behavior is "relative total industry output per acre." That is, the total amount of output per acre in a county, relative to the total amount of output per acre in the United States. By this metric, a county with a relative total industry output per acre of 1, is producing exactly as much per acre as the U.S. as a whole. A county with a metric greater than 1 is, to some degree, a core county (a county that has experienced economic agglomeration), and a county with a metric smaller than one is, to some degree, a periphery county (a county that has experienced economic dispersion). If the metric for a county is increasing over time, this would reflect a county that is experiencing economic agglomeration, and if the metric is decreasing over time, this would reflect a county dominated by dispersion forces, the key features of the new economic geography literature.

To provide a frame of reference, in 2002 the "most peripheral" county in the United States was the Yukon-Koyukuk Census Area in Alaska. With a relative output per acre measure of 0.00031, this region had an "economic density" that was .031% of the national average. By this same metric, the five "most peripheral" counties in the United States in 2001 were: Yukon-Koyukuk Census Area, Alaska, Lake and Peninsula Borough, Alaska, Loving County, Texas, Petroleum County, Montana, and Yakutat City and Borough, Alaska.

At the other extreme, the most economically dense (or "most core") county in the United States was New York County, New York, with a relative economic density of 5803.38, meaning that output per acre in New York County is over 5800 times the national average output per acre. The top five "most core" counties in the United States in 2001 were: New York County, New York, San Francisco County, California, Suffolk County, Massachusetts, the District of Columbia, and Arlington, Virginia.

Under this measure of economic density, using what we know of the new economic geography structure of the model, we can begin to picture how various counties might be forecast to behave within this structure. We would expect that periphery regions like Yukon-Koyukuk, are likely to be very stable periphery counties, and that they are likely to see little change in their economic density over time. Likewise, we might expect the "most core" regions, like New York County, will be relatively stable in their market share. Between these two extremes, we have an array of regions that might, over the forecast period, be moving toward "greater coreness" or "greater peripheryness" if they are near their so-called "break point" (the point where the benefits of economic agglomeration outweigh the costs, and economic agglomeration/dispersion occurs). And we might have yet another group of midsize regions that are losing there "coreness" or "peripheryness" as they pass the sustain point for their particular equilibrium. If we look at the behavior of these counties in the aggregate, we expect to see a number of counties that are stable within their core, periphery, or dispersed equilibrium, and some counties that, across the forecast period, will be making the transition from core or periphery. We have compared our forecast to two alternative, naïve forecasts, and we see a result that is largely as expected. The first alternative forecast assumes the county share of U.S. output to remain constant throughout the forecast period, and a second assumes that the county share of U.S. output will grow at the average annual rate exhibited in the 1999-2001 historical period. Both of these forecasts would be expected to correspond well with the counties that do not approach a break or sustain point. The constant growth forecast is expected to perform comparatively well over the short term with counties that are in transition, but will likely perform very poorly as those counties approach their new core or periphery position. The constant share forecast will not accurately reflect the counties while they are in transition, but will not be wildly incorrect over time, as those counties approach their new equilibrium and settle into a more-or-less fixed output share. By examination of the correlation coefficients over the forecast period between our model, the constant shares model, and the constant growth model, we see results consistent with our intuition (see figure 2). For the first fifteen to twenty years of the forecast period, the forecasts of county level relative output per acre are very tightly correlated among the three forecast types. The correlation of the model forecast with the constant share forecast then begins to drop off, and by the close of the forecast period, the correlation between the constant growth forecast and the NEG model forecast is virtually zero. This is consistent with the idea that counties that are experiencing share growth are in transition, and not exhibiting a permanent relative growth behavior as suggested by the naïve model.

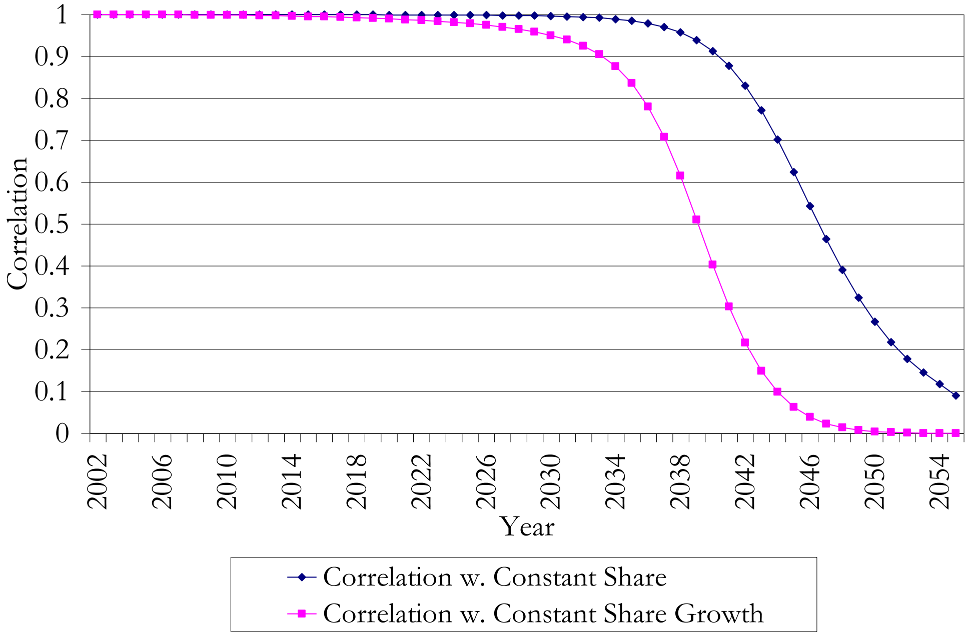

Figure 2: Correlation of the NEG model with the constant output share and constant output growth models.

The constant share forecast is much more tightly correlated with the NEG model forecast, for a much longer period of time. By the close of the forecast period, there is still approximately 9% correlation between the constant shares forecast and the NEG model forecast. Once again, this is consistent with our intuition regarding market behavior in an NEG format.

We can capture this behavior in another way, by looking at the behavior of our chosen metric, relative output per acre, within deciles. With a total of 3,110 counties, each year we divide these counties into ten groups of 311, based upon their relative output per acre. The 311 counties in the smallest decile are, in a sense, the “most peripheral,” and the 311 in the largest decile are the “most core.” Because our metric is a county aggregate, it necessarily abstracts from the more in depth model behavior, since every industry, in every county, can have any degree of “coreness” or “peripheryness.” Nonetheless, if we expect that movement toward core and periphery solutions fundamentally drive the economy, we can expect some specific behaviors to appear in the data. In an economy moving toward increasing heterogeneity, we would expect the average growth rate in the very smallest regions to be either constant (if they are as peripheral as they can get) or shrinking, and the growth rate of the very largest regions to be, in general, either constant (if they have reached a point of maximum "coreness") or growing. Somewhere in the middle of the distribution, we might expect to see counties that are in transition to a core position, or perhaps to a periphery position. A look at the growth rates by decile in Table 6.1 reveals some interesting patterns. First, the relative output of the smallest 311 counties is shrinking, and is shrinking slightly faster than it is for any other decile. Deciles 2 through 6 are shrinking slightly as well, though each successive decile is shrinking slightly less. The 622 regions in deciles 8 and 9 are actually growing in share of U.S. output, suggesting that they are moving toward becoming cores. The largest 311 regions, however, are exhibiting almost no growth in share of U.S. output, suggesting that the most core U.S. counties simply cannot get any more "core" than they already are. These counties are likely running into the model barrier created by land prices, which simply precludes further agglomeration.

Decile	Average Growth Rate	Decile	Average Growth Rate
Smallest	0.9814	6	0.9990
2	0.9883	7	0.9995
3	0.9913	8	1.0045
4	0.9923	9	1.0074
5	0.9950	Largest	1.0002

Table 1: County relative growth in share of US output, by decile, 2002-2055.

Agglomeration from a Homogeneous Economy

At this point, we have evidence that the model will maintain core/periphery economies when presented with a heterogeneous economy as a starting point; in this case, we started the model with our clearly heterogeneous 2001 economy, and allowed the model to go from there. However, it is interesting to test whether the model can develop a heterogeneous economy from a completely homogeneous starting point, and what characteristics this artificial economy might have. To that end, the forecasting model was adjusted in a few fundamental ways. First, the input-output matrix, which evolves over time in the forecasting model, is "locked down" as the 2001 input-output matrix, which means that changes in production technology will not take place, so the economy is evolving toward some fixed equilibrium, rather than an equilibrium that is, itself, changing due to input-output changes. Secondly, the total US output for every industry in the model was spread evenly across every county, in proportion to each county's share of total U.S. land area. So, a county that represents .1% of U.S. land area also was assigned .1% of total U.S. output of every industry. Thus, the model was starting from a truly dispersed "backyard capitalism" scenario.

With this starting point, a total of five alternative model specifications were built. In the first model specification, first difference values were set to 1 for all goods in all regions. That is, the model assumed that there were no first nature differences for any production activity in any region (so, coal mines, for example, could be located anywhere). Second, all impedance values, for all modes, for every region-region combination were set to 1. This means that there was also no transportation related advantage for any region in the model; any region would produce their output and sell it in every region (including there own) for the same price. All other characteristics of the model were left unchanged. This model was then allowed to run through 54 simulated years. It should come as absolutely no surprise that, under these restrictions, no agglomeration whatsoever takes place. The economy at the end of the 54 cycles remains completely homogeneous for the simple reason that, with no first nature price differences and no potential for second nature differences, there is no force to encourage any movement from the dispersed equilibrium.

For the second scenario, we reintroduce the first difference values , that were calculated for the model, but we continued to allow all goods to be shipped from any region, to any region, for the same price. This model effectively allows for first nature differences, but removes all second nature differences. When this model was allowed to cycle through 54 years, the result was spectacular agglomeration; agglomeration that is much greater than that actually seen in the U.S. economy in 2001 (as measured by the standard deviation in county output per acre). The reason for the spectacular level of agglomeration is simply that, with transportation costs not entering into the picture, all economic activity is strongly attracted to the places with the greatest first nature advantage in production. Many activities that we intuitively know are significantly constrained by transportation (restaurants, gas stations, grocery stores) will, nonetheless, cluster in a relatively small number of counties, even if the first nature price advantage is small, simply because the transportation effect has been removed.

The next incarnation of the model again removed the first nature differences, but this time the impedance values for every mode of transportation was set to equal the straight line distance between county centroids. Internal distances for every region were set equal to the square root of the region's land area. Under this configuration, we are removing any first nature differences among regions, and allowing second nature differences, but those second nature differences use the simplifying assumption that transportation costs are simply proportional to straight line distance. When this model is allowed to continue for 54 years, it generates economic agglomerations, though the agglomerations are much more modest than those created by the first nature difference model. The agglomeration is, of course, generated strictly through the second nature differences in this model.

The next incarnation of the model was very similar, except that the straight line distances were replaced with the Oak Ridge impedance data. Therefore, this model included all transportation infrastructure data for second nature differences, but still included no information about first nature differences. Not surprisingly, this model also generated economic agglomeration over the forecast period; the agglomeration was somewhat more pronounced then that generated by the straight line distance model, but still much less than the agglomeration generated by the first nature differences themselves. The agglomeration in this model is greater than that of the straight line distance model, simply because the transportation data is much more heterogeneous than the straight line distances. Two adjacent counties will face almost the same menu of straight line distances, and will, therefore, be almost equally preferable if that is the metric used for transportation costs. However, when a major highway, a rail line, and a port are located in one county and not the other, the difference between the two, from a profitability standpoint, becomes quite dramatic.

The final incarnation of the model included all of the transportation infrastructure data, and all of the first nature difference data. This version was simply the full model, but run on an initially homogenous distribution and with a constant IO table. This model exhibited somewhat more agglomeration than the model with transportation, but not first order differences. However, the model still showed much less agglomeration than the model of first nature differences alone.

The purpose of this experiment was not simply to look at the models compared to one another, but also to look at how the models might compare to the actual 2001 U.S. economy. We know that history matters, and that there are a near infinite number of potential equilibria in an NEG mode with this many regions and sectors. However, it seems reasonable that given the distribution of first nature differences, and given our heterogeneously distributed transportation infrastructure, we might gravitate to a similar spatial distribution of economic activity, even from very different starting points. In this case, we are taking our starting point of a homogeneous economy, with a fixed 2001 technology, and letting each of our alternative model specifications run for 54 years, to see how the resulting economy compares to the actual U.S. economy in 2001 (which obviously started from a very different starting point). Once again, we use our metric of relative output per acre for each county, and will see whether any of our model configurations are correlated with the actual 2001 economy. The summary results are reported in Table 2.

Forecast Method:	Correlation with 2001 Output per County:
No First Nature Difference	NA
First Nature Effect Only	.0593
Distance Effect Only	.1314
Transportation Effect Only	.5727
Transportation and First Nature Effects	.6502

Table 2: The degree of correlation between the distribution of economic activity in the U.S. in 2001 and the distribution of economic activity 54 years removed from a homogeneous distribution, for various model configurations.

The model with no first or second nature differences, of course, exhibits no heterogeneity at the end of 54 years, so there is no correlation to discuss. The model with first nature differences, but no transportation had a very high degree of agglomeration, but the agglomeration is only minimally correlated with the agglomeration in the actual economy. While the first nature model might perform very well for some industries, such as mining, which are clearly driven by location specific cost factors, it tells us little about industries that are more affected by market access, rather than by first nature differences.

The models that capture transportation (and hence shipping cost) are each much more strongly correlated with the actual U.S. 2001 data. The model that imbeds impedance data (but without first nature differences) generates a correlation of over 57%. Finally, the full model, with first nature differences and transportation infrastructure, manages to endogenously generate a heterogeneous economy that is over 65% correlated with the 2001 U.S. economy. These correlations are surprisingly high, and are no doubt driven largely by the fact that transportation generates economic agglomeration, which drives economic development, so the model is capturing the correlation between level of infrastructure and the size of the economy. In this way, the model is generating results very similar to Sutton, Roberts, Elvidge, and Meij (1997). They tested the simple correlation between the light levels from nighttime satellite photos of the United States, and the county level income data for the United States. Their analysis found a correlation of 84% to 93%, which is in line with the numbers found in this analysis.

While the exercise of building these alternative models has no immediate practical application, it is certainly reassuring to note the model's ability to spontaneously agglomerate a homogeneous economy in a manner consistent with NEG theory. In examining the degree of correlation between the model and the 2001 data, it also suggests a certain degree of inevitability in the specific pattern of heterogeneity observed in the U.S. economy.

While we do not yet have a sufficient historical record against which to test the model, these results can at least reassure us that the model is behaving as we would expect, given the theory.

Conclusions

In this paper, we have integrated concepts, theories, and data from a number of different areas into a comprehensive regional economic modeling methodology consistent with the theoretical New Economic Geography literature. The case for using this approach to develop a computable general equilibrium model appears compelling, and on that basis we believe the model takes several important steps forward in the field of applied regional economic modeling, forecasting, and impact analysis. While the model development effort has been significant, what has been built to this point only scratches the surface of what might be possible, as additional data, computing power, and theoretical work enable making increasingly simple models that can capture increasingly complex behaviors in an increasingly accurate manner.

References

Alonso, William. 1973. "National Interregional Demographic Accounts: A Prototype," Institute of Urban and Regional Development Monograph 17, http://www-iurd.ced.berkeley.edu/.

Batten, David and David Boyce. 1986. "Spatial Interaction, Transportation, and Interregional Commodity Flow Models," in *Handbook of Regional and Urban Economics*. Peter Nijkamp, Edwin Mills, P. C. Cheshire eds. Amsterdam: North-Holland, pp. 357-406.

Beaumont, Paul. 1990. "Supply and Demand Interaction in Integrated Econometric and Input-Output Models." *International Regional Science Review*, 13:2, pp. 167-81.

Bröcker, Johannes. 1990. "Derivatives of Flows in a Doubly Constrained Gravity Model." *Journal of Regional Science*, 30:2, pp. 259-268.

Ciccone, Antonio and Robert E. Hall. 1996. "Productivity and the Density of Economic Activity." *American Economic Review*, 86:1, pp. 54-70.

Dixit, Avinash K. and Joseph E. Stiglitz. 1977. "Monopolistic Competition and Optimum Product Diversity," *American Economic Review*, 67:3, pp. 297-308.

Fan, Wei, Frederick Treyz and George Treyz. 2000. "An Evolutionary New Economic Geography Model." *Journal of Regional Science*, 40:4, pp. 671-695.

Fotheringham, A. Stewart. and Morton O'Kelly. 1989. *Spatial Interaction Models: Formulations and Applications*. Dordrecht: Kluwer.

Fujita, Masahisa, Paul R. Krugman and Anthony Venables. 1999. *The Spatial Economy*. Cambridge, MA: MIT Press.

Hewings, Geoffery, Michael Sonis and David Boyce, Eds. 2002. *Trade, Networks and Hierarchies: Modeling Regional and Interregional Economies*. Berlin: Springer.

Jensen, Rodney. 1990. "Construction and Use of Regional Input-Output Models: Progress and Prospects." *International Regional Science Review*, 13:1, pp. 9-25.

Krugman, Paul R. 1980. "Scale Economies, Product Differentiation and the Pattern of Trade." *American Economic Review*, 70, pp. 950-9.

Krugman, Paul R. 1991. "Increasing Returns and Economic Geography." *Journal of Political Economy*, 99:3, pp. 483-99.

Krugman, Paul R. 1998. "Space: The Final Frontier." *Journal of Economic Perspectives*, 12:2, pp. 161-74.

Leontief, Wassily. 1941. *The Structure of the American Economy, 1919-1939*. New York: Oxford University Press.

Neary, J. Peter. 2001. "Of Hype and Hyperbolas: Introducing the New Economic Geography." *Journal of Economic Literature*, 39:2, pp. 536-561.

Pyatt, Graham and Jeffery Round. 1985. *Social Accounting Matrices: A Basis for Planning*. Washington, DC: The World Bank.

Robert-Nicoud, Frederic. 2004. "The Structure of Simple 'New Economic Geography' Models (or, On Identical Twins)." *Journal of Economic Geography*, 4, pp. 1–34.

Round, Jeffrey I. 2003. "Constructing SAMs for Development Policy Analysis: Lessons learned and Challenges Ahead." *Economic Systems Research*, 15:2, pp. 161-183.

Southworth, Frank. 1997. *Development of Data and Analysis Tools in Support of a National Intermodal Network Analysis Capability*. Washington, DC: US Department of Transportation Bureau of Transportation Statistics.

Southworth, Frank. 1998. Bruce E. Peterson and Shih-Miao Chin. 1998. *Methodology for Estimating Freight Shipment Distances for the 1997 Commodity Flow Survey*. Washington, DC: US Department of Transportation Bureau of Transportation Statistics.

Stone, Richard and Alan Brown. 1962. *A Programme for Growth, vol.1: A Computable Model of Economic Growth.* London: Chapman and Hall.

Tanner, Thomas. 2005. "Applications of New Economic Geography in Regional Economic Analysis and Forecasting." University of Georgia Dissertation.

Tanner, Thomas C. and Will Hearn. 2005. "Economic Impact Analysis," in *The Regional Economic Development Handbook*. Robert Pittman, ed. Washington, DC: International Economic Development Council, pp. 132-165.

Treyz, George Dan Rickman and Gang Shao. 1992. "The REMI Economic-Demographic Forecasting and Simulation Model." *International Regional Science Review*, 14:3, pp. 221-253.

Wilson, Alan. 1970. *Entropy in Urban and Regional Modeling*. London: Pion.

Wilson, Alan. 1974. Urban and Regional Models in Geography and Planning. Chichester: John Wiley.