The Introduction of Dynamic Features in a Random-Utility-Based Multiregional Input-Output Model of Trade, Production, and Location Choice

by Tian Huang and Kara M. Kockelman

This study introduces dynamic features into the random-utility-based multiregional input-output (RUBMRIO) model. The RUBMRIO model predicts interzonal trade and travel patterns, as well as business and household location choices, using consumption and production process data. It equilibrates production and trade, labor markets, and transportation networks simultaneously. Multinomial logit models predict the origins of productive inputs, including commute behaviors (for the input of labor).

With household locations and expenditures/incomes relatively well-known for the very near future, one can predict current trade patterns by making household consumption, as well as (foreign and domestic) export demands, exogenous to the model, resulting in short-term predictions. The long-run equilibrium, wherein household locations and consumption patterns are endogenous, will differ from this short-term solution.

INTRODUCTION

Traffic conditions and transportation system investment decisions can and do impact land use decisions. And, of course, land development patterns drive much of travel demand. To this end, integrated transportation-land use models are valuable tools for planning and policymaking. Much effort has been devoted to developing such models, primarily for purposes of prediction. At the disaggregate level, Von Thünen's (1966) isolated state model was extended by Wingo (1961) and Alonso (1964), who both incorporated budget constraints. De la Barra (1995) incorporated elastic demand and land use intensities. In all these models, an equilibrium pattern is generated from the utility maximizing behavior of individuals under highly idealized settings (including a flat, featureless monocentric region).

Taking an aggregate and more practical perspective, Wilson's (1970) entropy-maximizing methods have been used to model spatial interactions. Putman's (1983 and 1995) Disaggregate Residential Allocation Model (DRAM) and Employment Allocation Model (EMPAL) are the well-known successors to Lowry's (1964) model. These are the most widely used spatial allocation models in the U.S. today.

Input-output (IO) theory also is widely used for describing inter-industry productive relationships. When coupled with random utility theory for the distribution of productive input, a spatial IO model emerges. MEPLAN (Echenique 1985; Hunt and Echenique 1993; Hunt and Simmonds 1993; Abraham and Hunt 1999), TRANUS (de la Barra 1995), PECAS (Hunt and Abraham 2003), and RUBMRIO (Kockelman et al. 2005; and Ruiz-Juri and Kockelman 2004 and 2006) are based on this theory. MEPLAN, TRANUS, and PECAS represent dynamics by allowing the travel costs associated with freight and person flows to affect land use decisions in the next iteration of the model, along with network system changes (e.g., roadway expansions) and exogenous economic shocks (e.g., increases in export demands).

Other spatial IO applications also exist. Kim et al. (2002a) developed such a model for estimating interregional commodity flows and transportation network flows to evaluate the indirect impacts of an unexpected event (an earthquake) on nine Midwest states. Canning and Wang (2005) tested an IO program for interregional, inter-industry transactions across four regions and 10 sectors using a global database documented in McDougall et al. (1998). Rey and Dev (1997) introduced a series of specifications for extra-regional linking of econometric and IO methods, thus extending multiregional IO models (which, traditionally, have fixed inter-zonal flow shares). Ham et al. (2005) estimated interregional, multimodal commodity shipments via an equivalent optimization adding interregional and modal dispersion functions to their system's objective function.

Also promising are computable general equilibrium (CGE) models (e.g. Buckley 1992; Bröcker 1998; Logfren and Robinson 1999; Kim et al. 2002b; and Kim and Hewings 2003). CGE models address three major limitations of IO models: they do not assume the fixed coefficients for productive relationships, they recognize price-expenditure interdependencies, and they allow for supply-side effects (rather than being solely demand driven). However, their intense data demands, including relative price information, are onerous if not impossible to adequately address, and system equilibration (for solution of factor and commodity markets) is complex and not necessarily convergent. Furthermore, most CGE models consider only a single region's trade and production decisions. Multiregional CGE models do exist; for example, Kim and Hewings (2003) developed a CGE model for four sectors and five metropolitan areas in Korea, and Logfren and Robinson (1999) simulated a four-region economy with five commodity-producing activities. Li and He (2005) extended a two-region CGE model into a three-region model for China to simulate interregional trade patterns and environmental impacts. However, major multi-regional examples remain rare, in large part due to data limitations (on prices and technology, as well as trade flows).

Recognizing constraints on data availability and the importance of inter-regional trading, this paper relies on spatial IO techniques to explain economic interactions. In order to recognize the dynamics of change, in land use, trade, and production, this study builds on the work of Ruiz-Juri and Kockelman (2004) and Kockelman et al. (2005), which developed a Random-Utility-Based Multiregional Input-Output (RUBMRIO) model of Texas trade. Their RUBMRIO model describes the production and trade patterns across Texas' 254 counties. Production is driven by Texas' 18 foreign exports and 49 other U.S. states, and trade flows are converted to vehicle trips, in order to capture the impact of network congestion on trade and production decisions. These earlier model versions are designed to reflect only a long-term, equilibrium solution, where trade and production of all inputs, outputs and other resources (e.g., labor, materials and final goods) are in balance, and all effective prices market clearing. In this paper, the RUBMRIO model is extended to characterize near-term production and trade patterns based on current settlement and earnings patterns, and to introduce dynamic features which forecast the evolution of a region's trade patterns – from a state of short-term disequilibrium to longer-run scenarios.

By specifying household moves as a dynamic feature of RUBMRIO, and by making household demands exogenous in near-term model applications, the new version of RUBMRIO tempers the equilibrium-based predictions, producing estimates that should prove closer to reality. Since long-term equilibrium will never be reached (thanks to system shocks, in terms of export demand levels, for example), this new dynamic model offers an evolutionary path which is valuable for both near- and long-term planning and policymaking.

The RUBMRIO model allows detailed evaluation of complex transportation networks and economic system interactions, across firms, households, regions, and travel modes. It provides behaviorally founded estimates of system wide and local impacts, and aspires to facilitate more reliable transportation investment decisions, land use strategies, and trade and transport policies.

THE ORIGINAL RUBMRIO MODEL

The RUBMRIO model was developed to predict trade patterns, as well as business and household locations, using production and consumption data. It derives from IO-type productive dependencies across economic and social sectors, using nested logit models for inputs and transportation mode choice. Driven by final export demands, the model relies on a production process characterized by fixed technical coefficients derived from IMpact analysis for PLANning (IMPLAN) data of industry expenditures across input types. The choice of input origins is determined using random utility theory, by estimating the utility of purchasing commodity m from every possible provider zone j via the set of available transportation modes t.

Recognizing that air and water modes carry only 3.3% and 2.5% of Texas' $589 billion of traded commodities (according to the *2002 Commodity Flow Survey* [BTS 2005]) and that these two modes generally require some surface transport (to and from their appropriate ports), the version of the RUBMRIO model used here does not predict such mode use. Moreover, since 10% of Texas' commodity trade (and 23% of its shipped tons) is carried via pipeline (in the form of mined gas and gasoline) [BTS 2005], RUBMRIO assigns only 55% of mining sector flows to the modeled road and railway networks.

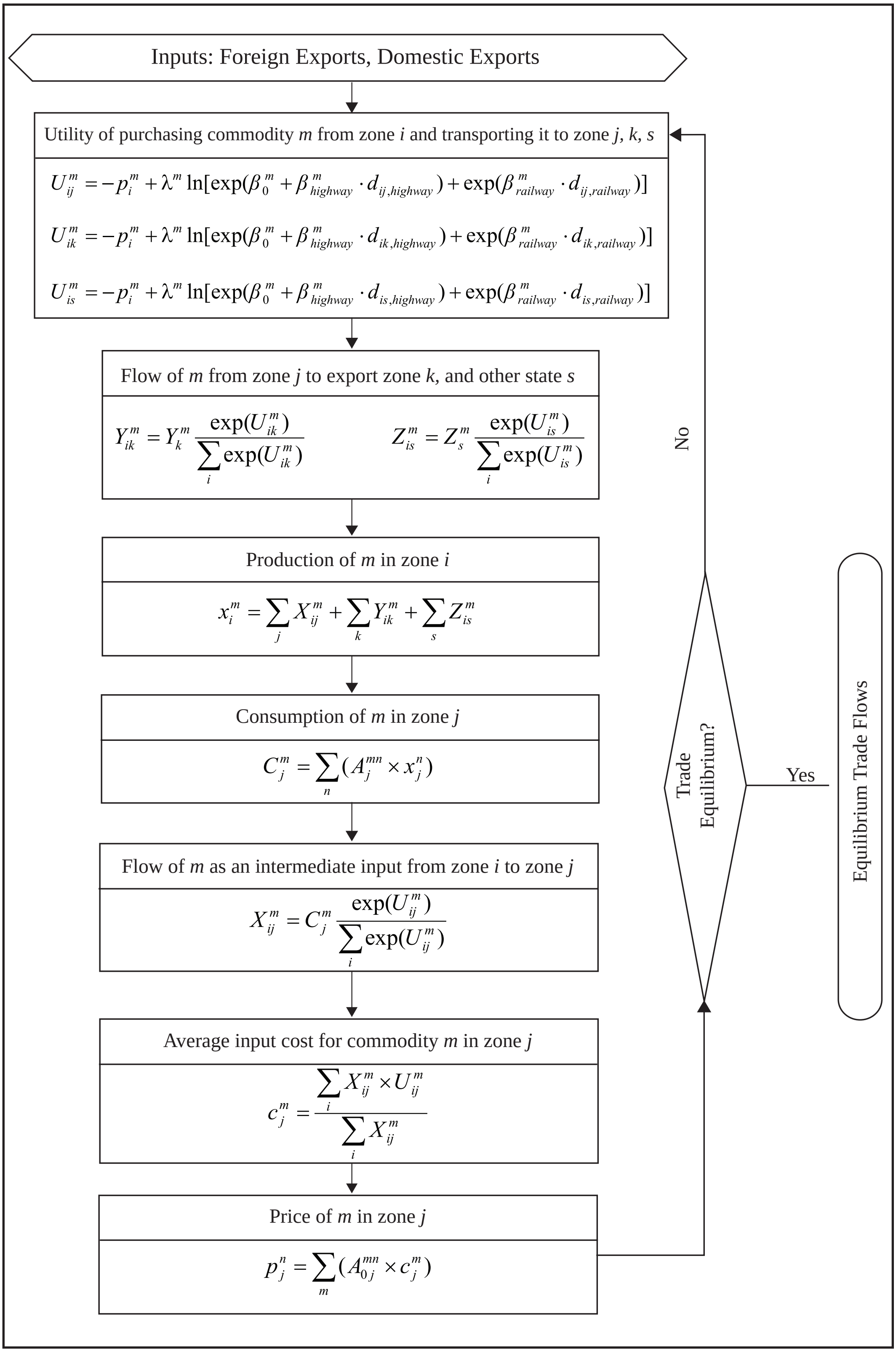
Currently, RUBMRIO utility functions are a function of transport distance, and linear functions of logsum (expected minimum cost) terms emerging from input acquisition decisions. Essentially, producers must decide how much of each input to purchase from each origin, based on relative transport costs and sales prices. Such decisions impact their own production costs and resulting sales prices. Purchase-weighted logsums of productive inputs serve as input sales prices, in utility-consistent units. Kockelman et al. (2005) calibrated the origin choice models using the *1997 Commodity Flow Survey* (CFS) data (BTS 2000), which do not offer travel cost information. Zhao and Kockelman (2004) applied fixed-point theory (i.e., the notion that a solution to $F(x) = x$ exists, under certain conditions) to examine existence and uniqueness conditions for RUBMRIO's model solutions. Under weak assumptions on output sales prices and spatial purchase probabilities, the solution prices and commodity flows were shown to be unique. Ruiz-Juri and Kockelman (2004) extended the base application by incorporating domestic demands from all other U.S. states (including the District of Columbia), wage relationships, and land use constraints. The model converts monetary trade flows into vehicle trips (by transforming monetary flows into tons and tons into trucks [using Vehicle Inventory and Use Survey data]), thus allowing for congestion feedbacks.

As shown in Figure 1, the model's original, long-run formulation is driven by final demand for exports, both foreign and domestic, by commodity type. Transport costs or distances, and network capacity and performance assumptions are also key inputs. By simply assuming initial commodity sales prices, the model runs iteratively to equilibrate trade and network traffic flows. In this way, exogenous final demands seek expected-cost-minimizing distributions of suppliers (across production zones). Intermediate production then is generated to meet these final demands (i.e., the sum of commodity purchases by regions outside the state of Texas), and distributed according to trade utilities. Average input prices (in units of utility) are purchase-weighted logsums, which generate (output) sales prices, via recognition of technical coefficients (the production process). The newly computed output prices feedback, into origin-choice utility functions, thus launching a new trade iteration.

Given information on (average) labor demand (per unit of industry output), the equilibrated production levels for each sector imply levels of demanded labor. These labor linkages result in work trips via Ruiz-Juri and Kockelman's (2006) multinomial logit model of origin choice. By converting monetary trade flows into vehicle flows, and applying deterministic user equilibrium to assign traffic flows to highway networks, the model recognizes congestion feedbacks via a distance updating factor. This factor is the ratio of congested (shortest–path) travel time to free-flow (shortest–path) travel time. This allows for a second, outer feedback loop, for a new iteration of trade and traffic, using the updated distance values, which serve as a proxy for travel times and cost.

The existing RUBMRIO model takes a long-term, equilibrium view of inter-regional interactions, and the household sector (see Table 1 for sector descriptions) is endogenous to the model. In Ruiz-Juri and Kockelman's (2004) implementation, state-level population was given and distributed based on wages that equilibrate labor supply and demand at the county level. In the short term, however, household locations and expenditures/incomes are relatively well-known, and one may better predict trade patterns by making household consumption, as well as (foreign and domestic) export demands, exogenous to the model. By dynamic adjustment of household consumption (as

Figure 1: Original RUBMRIO Model Structure



Note:

i, j are indices for zones/counties;

k, s index export zones and states, respectively;

m, n index economic sectors;

U_{ij}^{m} is the utility of acquiring commodity m in zone i and transporting it to zone j;

x_{i}^{m} is total monetary value of commodity m produced in county i;

Y_{k}^{m} is the value of commodity m demanded by export zone k;

Z_{s}^{m} is the value of commodity m demanded by state s;

X_{ij}^{m} is the total monetary flow of commodity m from county i to county j;

Y_{ik}^{m} is the flow of commodity m from county i to export zone k;

Z_{is}^{m} is the flow of commodity m from county i to state s;

C_{j}^{m} is the total monetary value of commodity m consumed in county j;

c_{j}^{m} is the weighted average cost of input m in zone j;

p_{j}^{n} is the overall manufacture cost and thus ultimate sales price;

A_{j}^{mn} are the technical coefficients with import considerations (see Kockelman et al. 2005);

A_{0j}^{mn} are the technical coefficients without import considerations (see Kockelman et al. 2005);

$d_{ij,railway}, d_{ij,highway}$ are railway and highway distances between counties;

$\lambda^{m}, \beta_{0}^{m}, \beta_{highway}^{m}, \beta_{railway}^{m}$ are the logit model parameters; and

initial values of p_{i}^{m} and X_{ij}^{m} are typically set to zero.

a function of county-level supply-demand imbalances), the model provides a prediction of each region's evolutionary path. This is the approach taken here.

SPECIFICATION OF THE DYNAMIC RUBMRIO MODEL

This section specifies a short-term RUBMRIO model for prediction of current trade patterns, as well as a transition mechanism from the short-term to the long-term model.

Short-Term vs. Long-Term Model Structures

The long-term model used here is the equilibrium state for inter-county and inter-sectoral interactions – including an endogenous household/labor sector. In reality, household locations and household expenditures are relatively fixed in the near term, which leads to what we refer to as the "short-term" model structure. As noted in Figure 2, final demand is assumed to be foreign and domestic exports in the long-run applications of the RUBMRIO model, and foreign and domestic exports *plus* household consumption in the short run. Essentially, in the short run households in every zone (i.e., every Texas county, for the application in question) can be regarded as residing in a port with an export demand for commodities. Any disequilibria of the supply and demand for labor in the zones motivate households to move, resulting in a corresponding change of household expenditures, thus moving the short-term prediction to a longer-term perspective. The basic structure of the model is unchanged, but short-term and long-term labor supply solutions are clearly distinguished, and form the basis for the transition mechanism. Figure 2 illustrates the connected procedures, and perspectives.

Thus, in this short-term model, household demands are exogenous to the model, and essentially added to the final demand which drives Texas's economy. Correspondingly, the household sector is removed from the IO table of productive sectors. As with any transaction in this spatial IO model, a zone's households' purchases may come from any of the other zones. Purchases are assigned using the random utility principles defined in Eqs. 1 and 2, using parameters estimated by Ruiz-Juri and Kockelman (2004). Eq. 3 illustrates the new, short-term production function that incorporates a fourth term (H_{ij}^m), in order to account for household demands.

$$(1)\quad Uh_{ij}^m = \delta^m \cdot d_{ij,highway}$$

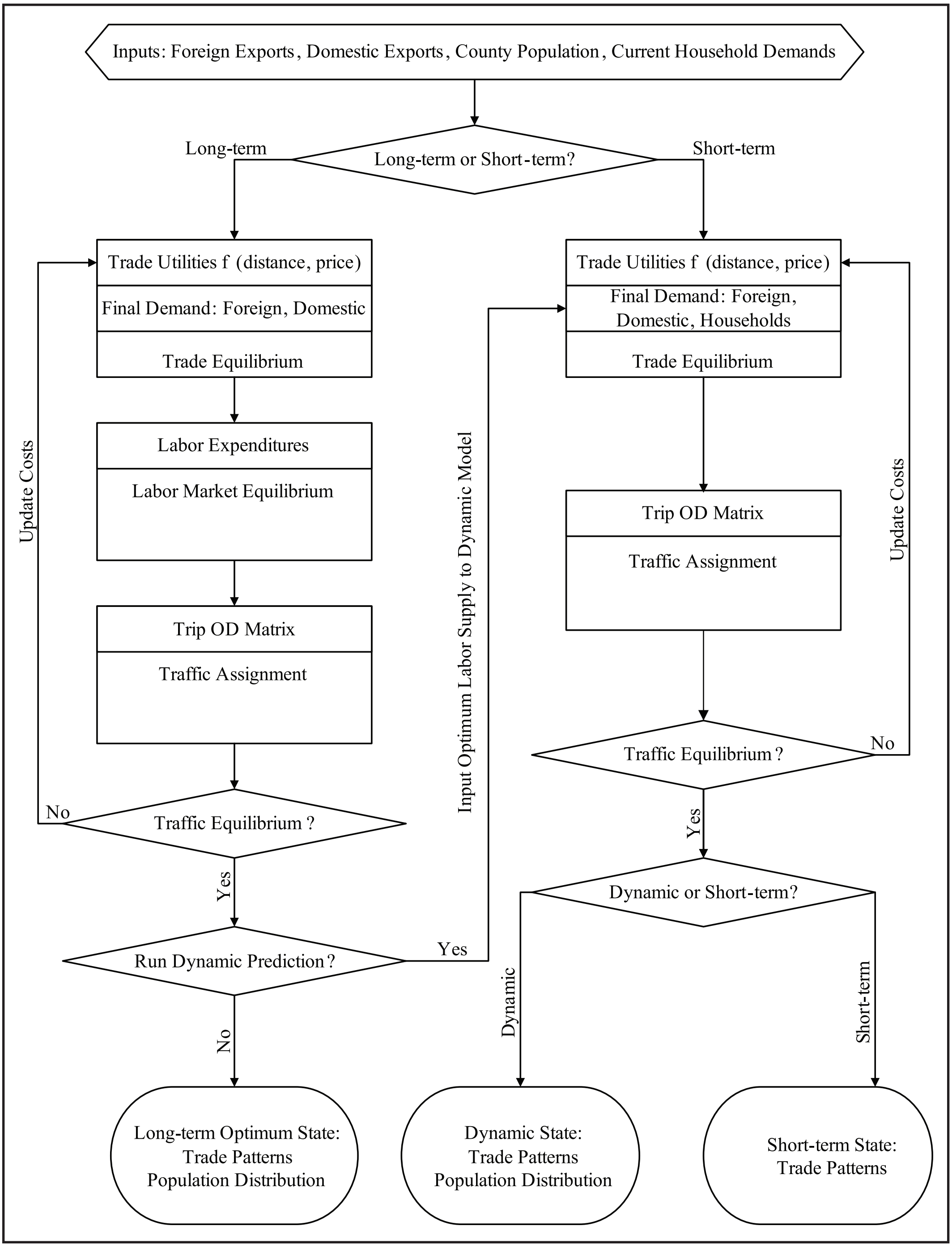
$$(2)\quad H_{ij}^m = H_j^m \frac{\exp(Uh_{ij}^m)}{\sum_i \exp(Uh_{ij}^m)}$$

$$(3)\quad x_i^m = \sum_j X_{ij}^m + \sum_k Y_{ik}^m + \sum_s Z_{is}^m + \sum_j H_{ij}^m$$

In Eq. 1, H_{ij}^m is the (systematic) utility of zone *j*'s households when purchasing goods from sector *m* in zone *i*, the δ^m,s are logit model parameters calibrated using Austin Travel Survey (ATS) data for home-based non-work trips (Ruiz-Juri and Kockelman 2004), and $d_{ij\ highway}$ is the road-network distance between zones *i* and *j*. In Eq. 2, H_j^m is zone *j*'s (total) household demand for commodity m, and H_{ij}^m is zone-*j* household purchases of commodity *m* from zone *i*. In Eq. 3, x_i^m is the production of commodity *m* in zone *i*, X_{ij}^m are interzonal flows of commodity *m* from zone *i* to zone *j*, Y_{ik}^m are flows of commodity *m* from producing zone *i* to foreign export zone *k*, and Z_{is}^m are domestic export flows from zones *i* to states *s*.

The 2002 IMPLAN data (Minnesota IMPLAN Group 2002) provide information on household expenditures by sector at the county level. Table 1 bridges the CFS commodity codes, NAICS and IMPLAN codes adopted here. Table 2 summarizes the household expenditures profile. The $418

Figure 2: Dynamic RUBMRIO Model Structure



billion annual expenditures by Texas households represent nearly 63% of the total final demand that drives the state economy in the short-term model. Household demands need to be met, and these clearly should be a major factor in near-term trade predictions.

Table 1: Description of Economic Sectors in the RUBMRIO Model

	Sector Description	IMPLAN	NAICS	SCTG
1	Agriculture, Forestry, Fishing and Hunting	1~18	11	1,3,4,25
2	Mining	19~29	21	10~18
3	Construction	33~45	23	--
4	Food Manufacturing	46~84	311	2, 5~9
5	Chemicals Manufacturing	147~171	325	19~24
6	Primary Metals Manufacturing	203~223	331	32
7	Fabricated Metals Manufacturing	224~256	332	33
8	Machinery Manufacturing	257~301	333	34
9	Electronic and Electric Equipment	302~343	334,335	35,38
10	Transportation Equipment	344~361	336	36, 37
11	Other Durable & Non-Durable Manufacturing	85~111, 112~146, 362~373, 374~389	312~316, 339, 321~324, 337	26~31, 39~43
12	Transportation, Communications & Utilities	391~397, 398~400, 413~424, 30~32	48, 49, 51, 22	--
13	Wholesale trade	390	42	--
14	Retail trade	401~408, 409~412	44, 45	--
15	FIRE (Finance, Insurance & Real Estate)	425~436	52, 53	--
16	Services	437~509	54~56, 61~62, 71~72, 81, 92	--
17	Households			
18	Government			

Note: This table provides the corresponding sector code in different data sources which were used in this study. IMPLAN stands for IMpact analysis for PLANning, NAICS stands for North America Industry Classification System, and SCTG stands for Standard Classification of Transported Goods.

Transitioning from Short- to Long-Term: Model Dynamics

By assumption, the main distinction between the short- and long-term models is treatment of the household sector. Household migration in response to trade pressures and demand/supply imbalances thus provides the mechanism for transitioning from short- to long-term. Many factors determine a county's attractiveness for population migrations, including environment and topography, wages and educational opportunities, risk of natural hazards and access to artistic and cultural institutions. While no model can control for all such factors explicitly, this work currently allows households to move in proportion to the long-run/equilibrium and short-run labor supply-demand imbalances.

Figure 2 illustrates the dynamic RUBMRIO model structure, which assumes that the labor force (and associated household members) moves toward zones of excess demand (for workers), increasing production and easing the local labor market imbalance (at least temporarily). Eq. 4 describes the change in labor supply, and Eq. 5 illustrates the proportionality assumed between labor and households.

$$(4)\ LabSupply_j^t = LabSupply_j^{t-1} + K \cdot (LabDemand_j^* - LabSupply_j^{t-1})$$

$$(5)\ H_j^t = H_j^{t-1} \cdot \frac{LabSupply_j^t}{LabSupply_j^{t-1}}$$

Here, $LabSupply_j^{t-1}$ and $LabSupply_j^t$ represent the number of workers supplied in zone *j* at time points *t-1* and *t*, respectively; is long-run equilibrium number of workers demanded by industries in zone *j* at time *t-1*; and *K* represents change in labor as a fraction of the current excess supply (or excess demand). Thus, *K* reflects the speed of evolution in worker and household locations toward the long-term equilibrium state. Based on intuition regarding flexibility in population movements, K was set equal to 0.05 per one-year $LabDemand_j^*$ interval in these applications of the dynamic RUBMRIO model. If imbalances are significant, predicted growth rates can be dramatic (e.g., over +100%, as well as approaching -100%). Nevertheless, it is useful to note that during the 1990-2000 period only four of Texas' 254 counties experienced an annualized population increase over 5%. A *K* factor of 0.05 is an important assumption, and future model extensions will focus on calibrating this parameter more rigorously.

In Eq. 5, H_j^{t-1} and H_j^t are total household demands across all sectors in zone *i* at time point *t*-1 and *t*, as in Eq. 2. These are assumed to be proportional to worker numbers (i.e., labor supply).

Table 2: Foreign, Domestic and Household Demands (in Billions of 2002$)

Sector Name	Foreign Exports	Domestic Demand	Household Demand
Agriculture, Forestry, Fishing and Hunting	3.010	0.931	0.299
Mining	7.182	1.034	1.719
Construction	0	0	0
Food Manufacturing	3.781	8.758	8.807
Chemicals Manufacturing	18.39	30.45	1.586
Primary Metals Manufacturing	0	5.026	negligible
Fabricated Metals Manufacturing	6.055	7.986	negligible
Machinery Manufacturing	37.95	27.90	0.502
Electronic and Electric Equipment	11.84	6.685	0.292
Transportation Equipment	12.00	1.421	0.074
Other Durable & Non-Durable Manufacturing	21.10	34.27	6.451
Transportation , Communications & Utilities	0	0	32.23
Wholesale trade	0	0	34.49
Retail trade	0	0	116.0
FIRE (Finance, Insurance & Real Estate)	0	0	91.68
Services	0	0	117.0
Households	0	0	0
Government	0	0	7.016
Total	121.3	124.5	418.1

Note: Foreign export levels are based on Ruiz-Juri's (2004) trend-line estimates, computed using data provided by the Texas Business and Industry Data Center, while domestic demand is calculated from the 2002 Commodity Flow Survey, and household demands come from Texas's 2002 IMPLAN data.

A Comparison of Model Dynamics

As spatial input-output models, MEPLAN and TRANUS model economic interactions and trade flows in a manner similar to RUBMRIO. Their dynamics are rather different, however. Three key things affect TRANUS and MEPLAN dynamics: changes to the transportation network (e.g., added capacity and pricing), changes in the location and levels of (exogenous) basic production (by a region's job- and income-generating industries whose demand is primarily external to the region), and land constraints (reflected through pricing signals). In MEPLAN, the "exogenous" production of basic goods is located via a separate model, based on Cobb-Douglas-like cost calculations and tempered by inertial terms (so that new levels are proportional to prior levels). The land use model keeps track of floor space availability and developable land constraints (Abraham and Hunt 1999). TRANUS is very similar in the sense that interactions rise to meet demand, while congesting the network and affecting contemporaneous accessibility measures. Transport system improvements may then be undertaken that affect accessibility measures in the following time steps (Donnelly et al. 1999).

Other techniques also may be useful for achieving robust dynamics. For example, a combination of average wage and land rent information could produce measures of zonal attractiveness for new entrants.

Incorporation of Domestic Import Traffic Flows

According to CFS 2002 data, Texas imports \$215.8 billion of commodities annually. Those import purchases are considered in the production process via an import parameter in the technical coefficients table, based on 2002 IMPLAN leakage values (which constitute purchases of inputs outside the region of study). However, their impacts on the transportation network need to be addressed explicitly. Each state *s* is assumed to sell each commodity *m* to every Texas county at the same price, which leads to the assumption that import levels solely depend on transportation costs between the origin (state) and destination (county). Therefore, import purchases are based on Eq. 6's utility specification, and generated trips are obtained using Eqs. 7 and 8 sequentially.

$$(6)\ Ui_{sj}^{m} = \lambda^{m} \log[\exp(\beta_{0,highway}^{m} + \beta_{highway}^{m} \cdot d_{sj,highway}) + \exp(\beta_{railway}^{m} \cdot d_{sj,railway})]$$

$$(7)\ I_{sj}^{m} = I_{s}^{m} \frac{\exp(Ui_{sj}^{m})}{\sum_{j} \exp(Ui_{sj}^{m})}$$

$$(8)\ ITrips_{sj} = \sum_{m} prop_{sj,highway}^{m} \cdot I_{sj}^{m} \cdot TCF^{m} \cdot PCE$$

In Eq. 6, Ui_{sj}^{m} is the import utility of acquiring commodity *m* in U.S. state *s* and transporting it to producing zone *j*. The *β*'s and *λ*'s are logit model parameters calibrated using CFS 1997 data (Kockelman et al. 2005), and $d_{sj,highway}$ and $d_{sj,railway}$ are the road- and railway-network distances between state *s* and zone *j*, respectively. In Eq. 7, I_{s}^{m} is state *s*' (total) export to Texas for commodity *m*, and I_{sj}^{m} is zone *j*'s purchase of commodity *m* from state *s*. In Eq. 8, $ITRIPS_{sj}$ is the total vehicle trips generated from transporting commodities from state *s* to zone *j*, $prop_{sj,highway}^{m}$ is the proportion of import flows of commodity *m* transported by highway from state *s* to producing zone *j*, TCF^{m} is the truck conversion factor for commodity *m* (Ruiz-Juri and Kockelman 2004), which converts annual monetary flows into daily truck flows (via dollar-per-ton and ton-per-truck assumptions), and *PCE* is the truck-to-car equivalency factor (assumed to be two vehicles per truck).

Data Sources

Distances between Texas' 254 county zones and all U.S. states, over both highway and railway networks, were estimated using TransCAD. The two networks are based on Caliper Corporation (2002) national railway network and the FHWA (2005) National Highway Planning Network. Foreign exports were derived from Texas Business and Industry Data Center (2004), and domestic demands were from the CFS 2002 data (BTS 2005). IMPLAN (Minnesota IMPLAN Group 2002) household and population values for Texas counties were used for the short-term population profile, and Texas Water Development Board (2006) state level population projections for 2010 and 2020 were applied for calibrating the new county population for short-term model application in 2010 and 2020. The state's population additions in 2010 and 2020 are allocated according to the long-term, equilibrium labor demand shares across counties. Due to the small number of data periods available and the limited accuracy for long-range projection, Texas' future foreign export demands are estimated based on trends derived from the 1997 and 2002 annual export data. Similarly, Texas' future domestic demands are estimated based on trends derived from the 1997 and 2002 CFS data by applying an exponential five-year growth rate to move the data forward from 2002 to 2010 and then 2020. Of course, the 1997-2000 period was a high-growth period, which capitalized on the North American Free Trade Agreement. Thus, actual rates of growth in export demand through 2020 may be quite a bit lower. Texas' future import data (not including foreign imports) are estimated in a similar way, based on the trends derived from CFS 1993, 1997, and 2002 data.

MODEL APPLICATION

Description of Scenarios

This study applies a dynamic version of the RUBMRIO model to anticipate changes in Texas trade patterns over the next 20 years. The base year for the application is 2002, based on Texas Business and Industry Data Center and IMPLAN demand data (for foreign and domestic exports, as well as county population and household expenditures). The equilibrium version of the RUBMRIO model was used to simulate the long-term optimal state of trade patterns and population distribution. When compared to current population numbers, these equilibrium estimates indicate locations of worker imbalance, thus providing the levels of dynamic adjustment (in workers and households, by county) for the subsequent time point. The model runs in one-year time steps for 18 years, until 2020.

Application Results

This section describes and compares the model outcomes of the three time points, in terms of production and population levels, and their associated trade flows.

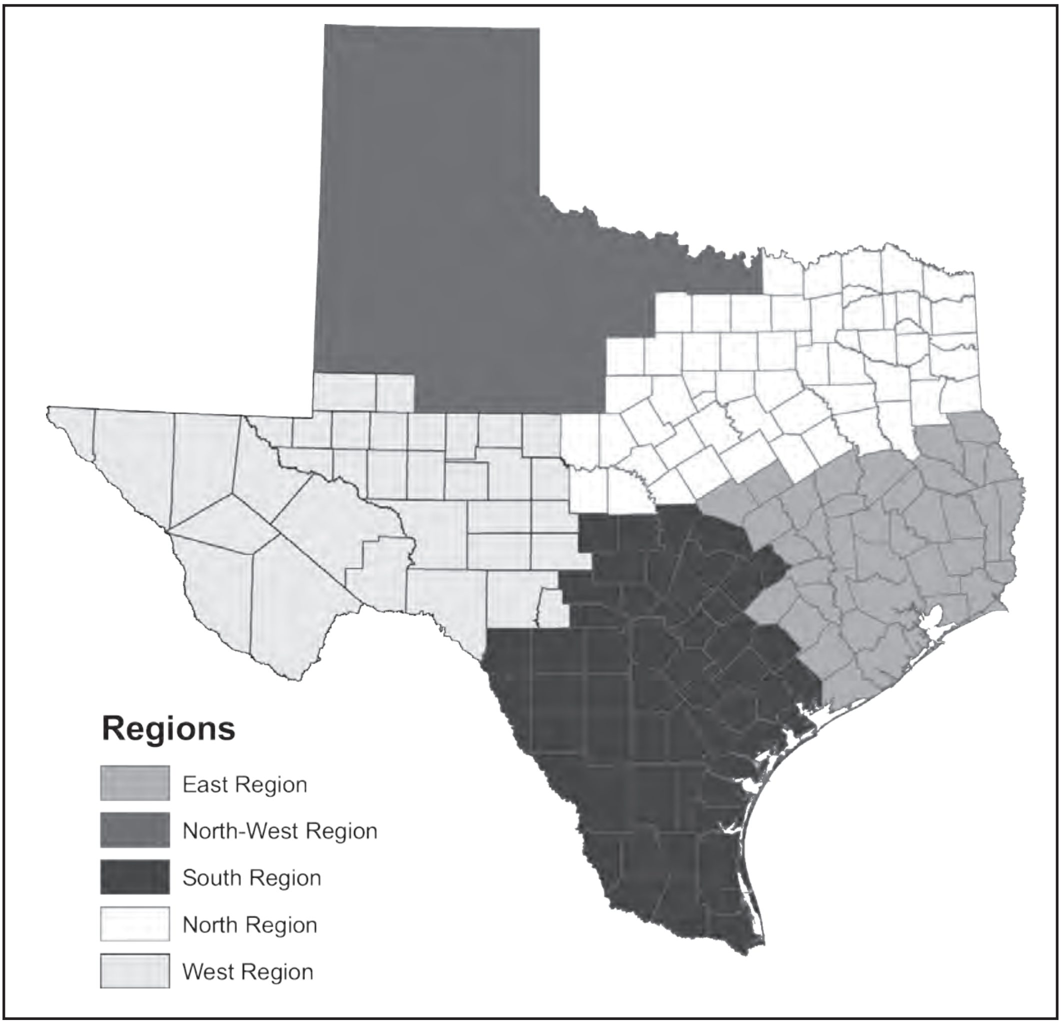
In the 2002 scenario, Texas' economy is driven by \$121 billion in foreign exports, \$124 billion in domestic demands, and \$418 billion in household expenditures. The short-term model generates \$1,238 billion of total trade flows (of which over 33% are value-added), while the long-term model generates \$1,366 billion total trade flows. The positive \$127 billion difference in the total trade flows is expected, considering that the long-term equilibrium tracks toward a more uniform distribution of household and firm location and production choices, spatially – due to use of logit model probabilities. In reality, of course, locations (and trade) may remain reasonably concentrated, since development decisions are reasonably discrete, even at the county level. Table 3 shows RUBMRIO predictions of truck trip generation by industry for the short and long terms, and these can be compared (by industry) to values implied by Texas Vehicle Inventory and Use Survey data (2002). These suggest that the mining, chemical manufacturing, other manufacturing, and agriculture sectors generated most of the truck trips, and short-term predictions are consistent with these survey data.

Texas' 254 counties can be grouped into five super-regions (Figure 3): north, west, northwest, east, and south. Figure 4 illustrates the trade patterns among these regions. The short-term model predicts that nearly 70% of total trades are intra–regional trades (Figure 4A), with trade flows declining with distance between regions (as expected).

Figure 4's comparison of equilibrium and dynamic disequilibrium predictions is quite dramatic. The long-term equilibrium approach predicts a relatively even distribution of trade (Figure 4B), with total intra-regional trades accounting for less than 22% of total trade flow values, and each region actively trading with all others. Essentially, the decision to model household demand endogenously or exogenously plays a major role in prediction. Households constitute a major consumption force in any economy, and their current, clustered locations strongly shape the future.

As time marches forward, current population and trade patterns are predicted to shift in response to market forces. During the 2002-2020 period, Texas' northwestern region is predicted to experience relatively rapid (short-term) growth, at an annual rate of 2.37%. The northern and eastern regions are predicted to continue their moderate growth (Figure 5A) at annual rates of 0.2% and 0.14%, respectively. The corresponding populations in these five regions are shown in Figure 5B. From 2002 to 2020, the northwest region is predicted to gain 2.8 million in population; the rapid population increase in the northwest region plays a major role in its trade growth. Since the long-term model does not take into account the effect of current population clusters and the northwest region is in a better location to trade with domestic markets, the northwest region's economy grows

Figure 3: Texas' Five County Groups



relatively fast, which attracts more population and results in the increase of household demand. The trade and population interaction causes the striking performance of the northwest region. The south region maintains the same population level and thus the same trade level. Population shifts (Figure 6) toward a long-term equilibrium in the 18-year time horizon modeled here tend to mirror the shifts in trading.

Since trade utilities are a function of transport distances and input prices, with commodity prices generated endogenously by the model, transport distance or cost is the fundamental factor affecting trade patterns in these models. Of course, productive technologies (in the form of somewhat distinction IO tables for the five regions) and export demands are also key. And, in the near term, as discussed above, meeting household demand is paramount, as this dominates final demand. In the longer term, the rates of growth in export demand ultimately tip the balance toward domestic trade (50% of the total demand expected in 2020), and labor and households are expected to shift to locations with greater demand for labor. In terms of producing exports, the northwestern and northern regions dominate trade with other U.S. states, and 16 of Texas' 31 major ports. The western and southern regions enjoy greater market shares in supplying foreign exports.

Table 3: Distribution of Truck Trips Generated in Texas, by Industry (2002)

Sector Name	VIUS	Short-Term RUBMRIO	Long-Term RUBMRIO
Agriculture, Forestry, Fishing and Hunting	11.17%	6.36%	6.88%
Mining	34.36%	37.13%	34.63%
Food Manufacturing	7.44%	7.37%	7.83%
Chemicals Manufacturing	15.27%	16.04%	18.46%
Primary Metals Manufacturing	0.87%	2.91%	3.86%
Fabricated Metals Manufacturing	0.49%	2.64%	2.81%
Machinery Manufacturing	1.61%	1.60%	1.49%
Electronic and Electric Equipment	1.20%	0.45%	0.98%
Transportation Equipment	0.19%	0.36%	0.48%
Other Durable & Non-Durable Manufacturing	27.39%	25.15%	22.59%

Note: VIUS (Vehicle Inventory and Use Survey) data were computed using the 2002 *Texas Vehicle Inventory and Use Survey*.

CONCLUSIONS

This paper introduces and applies a dynamic RUBMRIO model for Texas' 254 counties, with production, population, and trade patterns driven by foreign, domestic, and household demand. By removing the household sector from the spatial IO tables, and assuming stickiness in migration, the model recognizes the strong evolutionary impacts that existing populations have on the state's future.

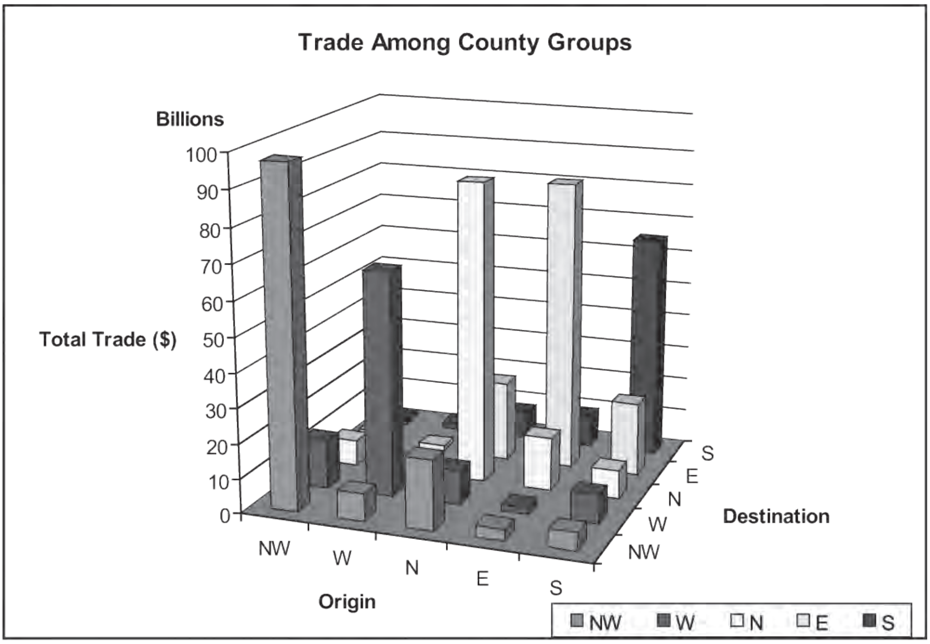
In addition, Texas' domestic imports are now recognized, via inbound goods movements, making predicted traffic patterns more realistic. All traffic assignment for congestion feedback is now accomplished using Microsoft Visual C++ codes, bypassing external assignment routines, speeding the overall model run times.

The dynamic RUBMRIO model described here can be further enhanced by introducing a size term for input origin, thus reinforcing the attractiveness of such centers (and their associated agglomeration economies) to recognize the supply power of existing centers of population and production. By recognizing the power of path dependence and historic advantage, such a specification would slow the system's evolution to any long-run "equilibrium" trade pattern, but may be far more realistic for prediction. A more formal calibration of population migration, in the presence of supply-demand imbalances and regional attraction factors, including market wages, also would be valuable. Finally, translation of trade distances to generalized cost values will permit roadway-pricing applications of the model. It is unfortunate that the CFS data do not offer information on such key variables. However, data from other sources (e.g., Reebie's TRANSEARCH estimates of trade) may fill this void, allowing reasonable parametric modifications to the current model coefficients.

In summary, the dynamic features of this model of spatial interaction and location choice offer valuable predictions of future trade patterns and assessment of regional transportation conditions. Such specifications should prove a powerful tool for policymakers, transportation planners, and developers, particularly for network level policies, including the coming Trans Texas Corridors (e.g., TTC69 and TTC35), as well as tolling and trade policies. It is clear that long-run equilibrium solutions can differ dramatically from their short-term, current-population constrained versions. It is critical to get the dynamics of trade patterns right – over time and space.

Figure 4: Short-term and Long-term (Equilibrium) RUBMRIO Model Predictions of Trade Patterns (2002)

A. Short-term Prediction



B. Long-term (Equilibrium) Prediction

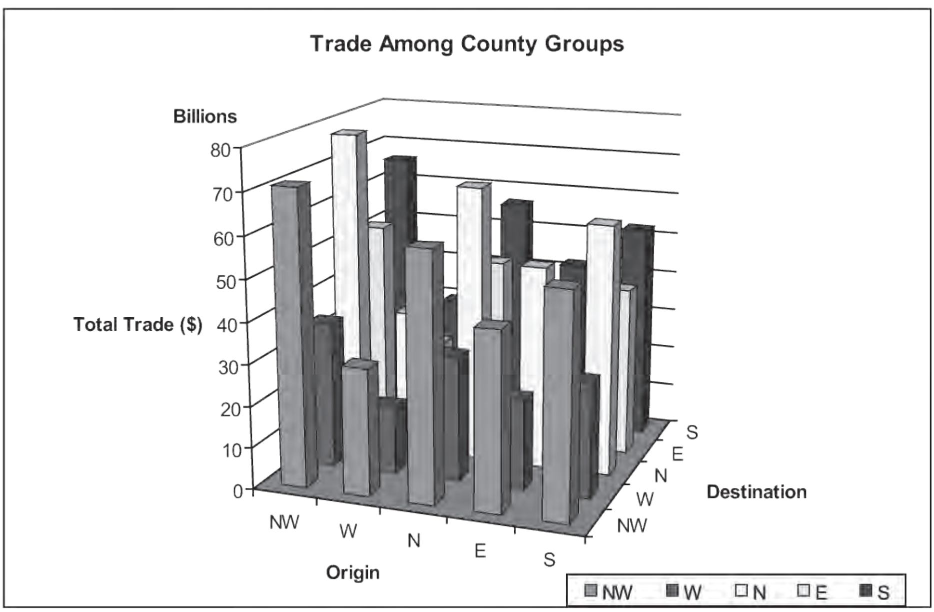
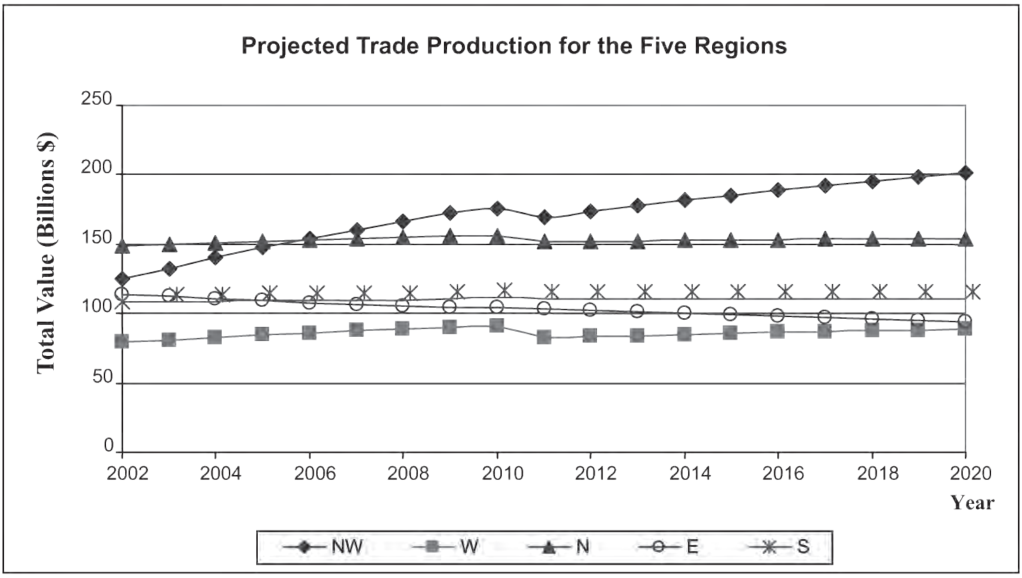


Figure 5: Model Predictions of Trade Patterns for 2002-2020

A. Trade Production



B. Population Change

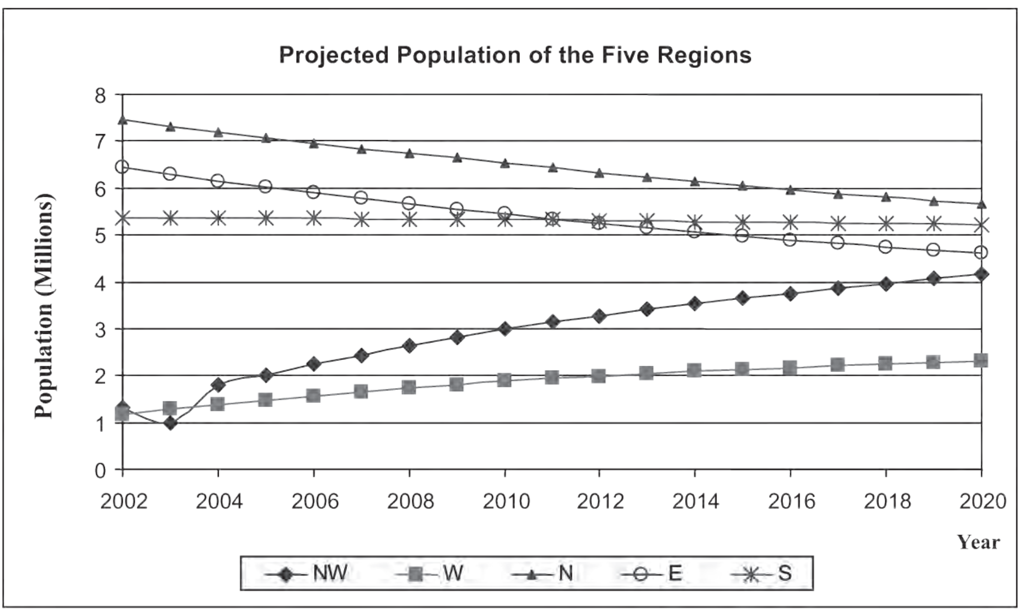
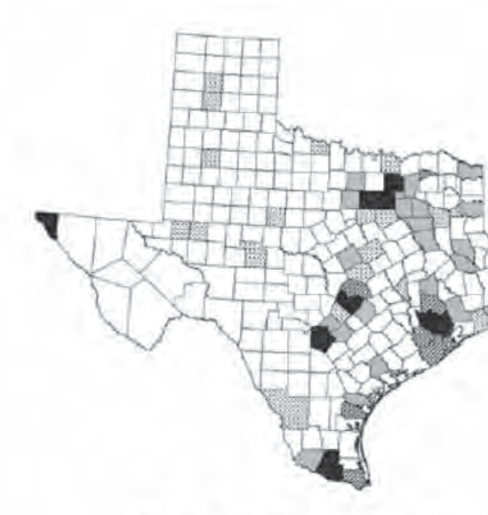
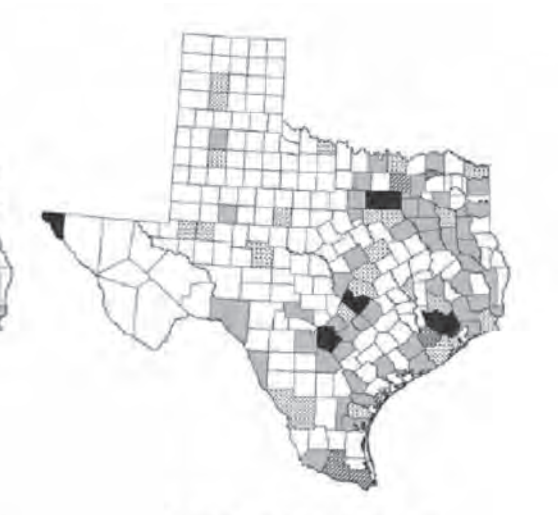


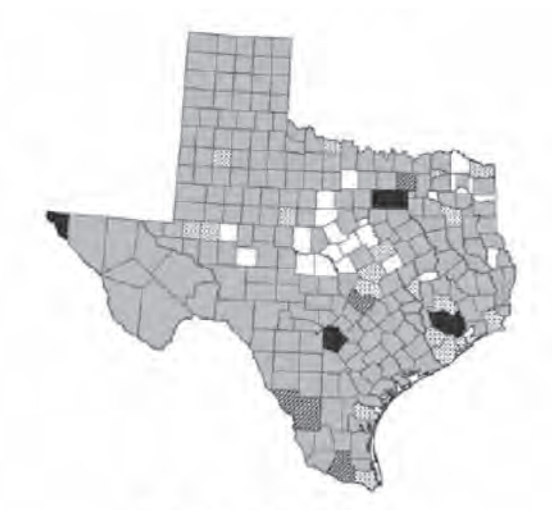
Figure 6: Model Predictions of Population Distribution for 2010 and 2020



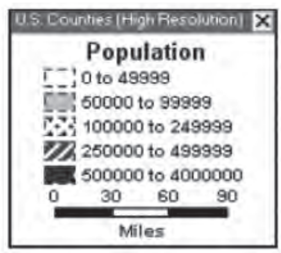
A. 2002 Texas County Populations



B. 2010 Population Predictions



C. 2020 Population Predictions



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