Tracking Land Use, Transport, and Industrial Production using Random-Utility Based Multiregional Input-Output Models: Applications for Texas Trade

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ABSTRACT

This study describes and applies a random-utility-based multiregional input-output (RUBMZIO) model of production, trade, and travel using Texas data. This model simulates trade patterns of labor and commodities among zones based on different export demands, production technologies, travel modes, and network routing options. The paper also describes the estimation of technical-coefficient tables based on IMPLAN transactions data and input-origin and mode-choice parameters based on nested logit models of trade using Commodity Flow Survey data. A variety of applications explore changes in location choices, production, and trade flow patterns due to different export demands, and travel costs.

Key Words: Random-utility-based multiregional input-output model; trade flow patterns; technical coefficients; nested logit model of input origin and mode choice

1. INTRODUCTION

Transportation systems are critical to regional economics and planning. They can dramatically affect household and firm location choices, production levels, and trade patterns. Robust models of transportation-land use interactions enhance planning, policy making, and public and private investment decisions.

Several integrated modeling efforts have been undertaken (e.g., DRAM/EMPAL, MEPLAN, TRANUS, ILUTE, IRPUD, and UrbanSim). DRAM and EMPAL are the most widely-used spatial allocation models in the United States today, and rely on gravity-type equations. Compared with other models, the data for DRAM/EMPAL are generally available. However, the model does not account for land market clearing processes and is quite aggregate in application (spatially and industrially). In MEPLAN, land and transport are two parallel and interacting markets. Behavior is modeled as a response to price or price-like signals in each system. One important feature of MEPLAN is that the demand coefficients can be treated as either fixed, factor-price sensitive, or factor-price and income sensitive. TRANUS shares many similarities with MEPLAN, though it is more restricted in its set of functional forms and modeling options. UrbanSim is based on microeconomic theory for individual urban actors. It is a disequilibrium model of building stock supply and demand with annual time increments. The model operates as a dynamic disequilibrium in each year, with the supply component developing and redeveloping individual land parcels on the basis of expected profit. UrbanSim is highly disaggregate relative to most other currently operational models.

The existing integrated transport and land use models that recognize business interactions rely on input-output (IO) models of inter-industry linkages (see, e.g, Echenique, 1985; Hunt and Echenique, 1993; Hunt and Simmonds, 1993; Abraham and Hunt, 1999; Barra, 1995; Kim, 1989; and Ham et al., 2000). Those IO based models are able to examine basic interactions among industrial activities in regional economies. Such methods bring freight flows to the fore while recognizing the basic drivers of human settlement: economic activities. This paper first examines the advantages and limitations of different IO models and then applies a random-utility-based multiregional IO (RUBMRIO) model for a study of economic interactions across Texas's 254 counties.

Essentially, IO models predict the flow of goods and services between different sectors of an economic system based on Leontief-type technology (where fixed input levels combine to provide one unit of output, in any sector). (See, e.g., Isard et al., 1998; Miller and Blair, 1985; and Davis, 1990) The basic concept was suggested by Keynes (Barra, 1995), who introduced the principle of effective demand, wherein the process of production is determined mainly by consumption. A key element of Keynes's theory is the idea of a multiplier effect, where increments in demand ripple their way through an economy, triggering additional demands. This was the basis for many later IO developments.

Leontief's (1941 and 1963) single-region model disaggregated Keynes's concept by economic sectors, to capture more detailed multiplier effects. Social accounting matrices (SAMs) later developed (Pyatt, 1976), to endogenize the "industries" of households and government. Leontief's single-region model was regularly applied on a national scale. To describe the economic interactions among regions, a model which recognized production by and trade across regions was needed.

With the development of random utility principles, a more behaviorally realistic multiregional IO framework emerged, to permit spatial disaggregation. (See de la Barra [1995] for a discussion.). A few operational models are to a large extent based on this framework. These include Echenique's MEPLAN (Echenique, 1985; Hunt and Echenique, 1993; Hunt and Simmonds, 1993; Abraham and Hunt, 1999), de la Barra's TRANUS (1996) and Kim's normative models (Kim, 1989 and 1983). In all these models, proper calibration is vital.

This study describes the calibration and application of a RUBMRIO model for Texas's 254 counties, across 18 social-economic sectors, and two modes of transport in order to meet foreign export demands at 31 key ports. The paper begins with a review of spatial distribution theories;

then describes the RUBMRIO structure, data acquisition, and model calibration; and ends with a discussion of results and further modeling opportunities.

2. LITERATURE REVIEW

The location of activities is the outcome of interactive market mechanisms involving three basic components: commodities, land and transport. Microeconomic theory, spatial interaction models and spatial accounting models are the leading theories that explain the spatial distribution of activities and interactions of households and businesses.

Microeconomic theories focus on individual consumers and/or suppliers. Chronologically, the theory essentially developed from Von Thünen's isolated state model (Von Thünen, 1966), Wingo's transportation and land use model (Wingo, 1961), Alonso's location and land use model (Alonso, 1964), and Mills' monocentric model (Mills, 1969). Von Thünen introduced the effect of transport costs on activity locations and land prices. Wingo and Alonso updated Von Thünen's proposition by adding household budget constraints. Alonso also introduced the concept of bid-price curve, an analogy to a demand price at constant utility. In 1995, de la Barra (1995) incorporated demand and land consumption elasticities. All these microeconomic models share a common feature: households and firms are assumed to maximize their utilities, resulting in an equilibrium and pattern of land rents.

Compared to microeconomic approaches, spatial interaction models provide an aggregate perspective, since both space and activities are grouped into discrete categories. The most basic form of a spatial interaction model is the gravity model, which states that interaction between any two zones is proportional to the number of activities in each zone, and inversely proportional to the frictions impeding movement between them. A general theoretical framework for gravity models is the entropy-maximizing method introduced by Wilson (1970). Lowry (1964) proposed the gravity-based urban land use Model of Metropolis for the City of Pittsburgh. His model specified the spatial distribution of population, employment, retailing, and land use within a compact iterative procedure. A well-known successor to Lowry's model is Putman's Disaggregate Residential Allocation Model (DRAM) and Employment Allocation Model (EMPAL) (Putman, 1995 and 1994). When compared to microeconomic models, spatial interaction models are considered more practical tools for the analysis of real cases as (1995).

The third line of development relies on input-output (IO) models to describe inter-industry productive relationships. A basic principle of IO models is that industry develops in order to meet some final – plus intermediate – demands. Early IO models represented national accounts. Leontief (1963) extended the classical IO model to include spatial disaggregation and provide a detailed account of multiplier effects across distinct economic sectors. IO theory is now proving central to complex integrated representations of spatial social and economic systems. There are a number of operational models making use the development of an IO framework, including MEPLAN, TRANUS and Kim's models (see, e.g, Echenique, 1985; Hunt and Echenique, 1993; Hunt and Simmonds, 1993; Abraham and Hunt, 1999; Barra, 1995; Kim, 1989; and Ham et al., 2000).

The heart of the MEPLAN framework is a social-accounting matrix (SAM). Spatial disaggregation is accomplished via production linkages which arise to satisfy local consumption and which are allocated across zones, according to discrete choice models, as a function of "prices" for such production (TCRP, 2002). More information can be found in Echenique (1985), Hunt and Echenique (1993), Hunt and Simmonds (1993), and Abraham and Hunt (1999).

Based on spatial IO theories, a random-utility-based multiregional IO (RUBMRIO) model was developed and applied to Texas. It recognizes multiple modes and industries, adjusts technical coefficient matrices for imports, and calibrates trade parameters using the latest Commodity Flow Survey data (organized for an origin-choice model of trade flows). Many applications are presented here, which explore changes in location choices, production, and trade flow patterns due to different export demands, and travel costs.

3. STRUCTURE OF THE RUBMRIO MODEL

Disutility Function

In the RUBMRIO model, both internal trade flows (among Texas's 254 counties) and external trade flows (from counties to export zones/customs districts) are based on the disutility of acquiring some commodity *m* from origin zone *i* and consuming it in zone *j* (or export zone *k*). The disutility function is composed of two items, as shown in Equation (1).

$$U_{ij}^{m} = -\left[p_i^m + \lambda^m \ln\left(\exp\left(\beta_0^m + \beta_{highway}^m \cdot d_{ij,highway}\right) + \exp\left(\beta_{railway}^m \cdot d_{ij,railway}\right)\right)\right] \quad (1)$$
$$U_{ik}^{m} = -\left[p_i^m + \lambda^m \ln\left(\exp\left(\beta_0^m + \beta_{highway}^m \cdot d_{ik,highway}\right) + \exp\left(\beta_{railway}^m \cdot d_{ik,railway}\right)\right)\right]$$

where p_i^m is the price of purchasing \$1 of commodity *m* in zone *i* (in units of utility), and λ^m and $\vec{\beta}$ are determined by a nested logit model put forward by Ben-Akiva and Lerman (1985) of input origin and shipping-mode choice by zone and sector.

Production Function

The behavior of land and transport markets are highly affected by the components' market prices, including land rents and transport costs, which in turn affect production, consumption and location decisions. The cost of producing one unit of commodity *n* in zone *i* is a function of the cost of inputs from other firms at other locations and the corresponding transport costs. The form of the overall manufacture cost and ultimate sales price is shown as Equation (2).

$$p_j^n = \sum_m (A_{0j}^{mn} \times c_j^m) \quad (2)$$

where A_{0j}^{mn} is the technical coefficient for zone *j* which defines the fractional amount of commodity *m* required to produce one unit[1] of commodity *n* in zone *j*, and c_j^m is the weighted-average cost of input *m* in zone *j*. These technical coefficients, A_{0j}^{mn}, come from the original IMPLAN transactions tables (Minnesota IMPLAN Group, 1997) for total purchases, both local and imported. IMPLAN (Impact Analysis for Planning) is a social accounting and impact analysis software, developed by the Minnesota IMPLAN Group. The input costs, c_j^m, are a weighted average of input purchase price for commodity *m* for all input zones *i* plus the associated transport costs (from each zone *i* to zone *j*), as shown in Equation 3. The weight factors are the interzonal trade flows (X_{ij}^m).

$$c_j^m = \frac{\sum_i X_{ij}^m (p_i^m + d_{ij}^m)}{\sum_i X_{ij}^m} \tag{3}$$

Trade Flows

Trade flows can be calculated when all the other values are given, including export demands, production costs, technical coefficients, and transport costs. Under an assumption of profit-maximizing/cost-minimizing behavior, with unobserved heterogeneity in alternatives, consumers (both final and intermediate) will buy from the producer(s) that can supply the lowest total price (including transport costs) of any input. Unobserved heterogeneity introduces the random elements, which, under an assumption of iid Gumbel distribution, leads to the multinomial logit model for origin and mode choices. Two kinds of trade flow are estimated in the current RUBMRIO model; these are the interzonal trade flows, X_{ij}^m, and the flows to export zones, Y_{ik}^m, as shown here:

$$X_{ij}^m = C_j^m \frac{\exp(V_{ij}^m)}{\sum_i \exp(V_{ij}^m)} \tag{4}$$

$$Y_{ik}^m = Y_k^m \frac{\exp(V_{ik}^m)}{\sum_i \exp(V_{ik}^m)} \tag{5}$$

where C_j^m is the total volume of *m* consumed in zone *j*, which can be calculated based on Equation (6):

$$C_j^m = \sum_n (x_j^n \times A_j^{mn}) \tag{6}$$

Here, A_j^{mn} is the technical coefficient matrix (following leakage considerations) for zone *j*, which defines the amount of commodity *m* required (from within the State) to produce one unit of commodity *n* in zone *j*. And x_i^m is the total production of commodity *n* in zone *i*, which is the sum of the trade flows leaving zone *i* to meet the demands of other producers and export zones.

$$x_i^m = \sum_j X_{ij}^m + \sum_k Y_{ik}^m \tag{7}$$

The solution process was divided into two steps. First, external flows (Y_{ik}^m) from Texas counties (internal zones) to export zones were estimated. Then, interzonal trade flows (X_{ij}^m) were calculated based on the resulting demands.

Equations 1 through 7 constitute the majority of the RUBMRIO model; these equations are solved iteratively to achieve an equilibrium trade pattern. To resolve this set of equations (and achieve a convergent solution), the iterations begin by setting all prices to zero, solving for trade-flow probabilities, and generating an initial pattern of trade. This alters the price structure, and thus the trade pattern. We continue updating prices and patterns until convergence. Zhao and Kockelman's current work (2002) describes this process.

4. DATA ACQUISITION AND PARAMETER ESTIMATION

Behavioral data (e.g., trade sensitivity to distance, mode preferences, and production technology) are required to calibrate the model. And various input data (such as export demands by port and network costs) are required to run the model. The trade flow patterns among 254 counties to meet exogenous demand for products at 31 export zones were modeled across 18 economic sectors. Primary data sets included IMPLAN's industry transaction tables by county (Minnesota IMPLAN Group, 1997) foreign export data for Texas's 31 custom districts, the 1997 Commodity Flow Survey (CFS) data set (Bureau of Transportation Statistics, 2001), and the shortest intercounty path distances by mode (U.S. Geographic Data for TransCAD 4.0) as calculated by TransCAD (Caliper Corp., 2001). The intrazonal travel distances are assumed to be the radii of the circles with same areas as the actual zones.

There are 254 counties in the State of Texas and these comprise the zones of production and intermediate consumption. According to U.S. Customs District data on file, there are 31 foreign-export zones within and bordering Texas. Figure 1 shows these zones/counties (across TxDOT's 25 formal districts) along with export zone locations.

To simplify the assortment of production technologies (in the form of 254 distinct technical coefficients tables), Texas' 254 counties were aggregated into 5 regions; and the IMPLAN technical coefficients table associated with the largest county in each region (i.e., Bexar, Dallas, El Paso, Harris, and Lubbock Counties) were used.

Technical Coefficient Estimation

Technical coefficients a_i^{mn} are very important parameters in the RUBMRIO model, reflecting productive technologies within zones. In the current study, the technical coefficients are assumed to be stable in the short run and therefore they are exogenous to the model. In the long run, or at the margin, these coefficients may differ, due to the changes in the technology of production.

To generate the technical coefficients, IMPLAN's industry-by-industry transaction tables at the State and county levels were used. The transaction tables derive from U.S. inter-industry accounts and estimate the values of purchases at finer levels of resolution. The original industry transaction tables include 528 industry sectors, which are also bridged to the Standard Industry Classification (SIC) code. In this study, an aggregated sector system is used to represent the whole economy in Texas. The 528 industry sectors are grouped into 16 industry sectors and two other economic sectors (Government and Households) according to the SIC codes. Table 1 shows the 16 industry sectors and their corresponding IMPLAN sector codes. Household and Government sectors were constructed by the value added table and final demand table generated by IMPLAN.

Due to imports, there are some "leakages" or consumption losses from counties and states across their borders. To recognize the effects of those out-of-state purchases, the industry transaction tables were multiplied by the regional purchase coefficients (RPC), which represent the proportion of local demand purchased from local (within-state) producers. IMPLAN generates RPCs automatically using a set of econometric equations (based on zone size and industry type, primarily). Aggregated transaction values (recognizing import leakages) were divided by the corresponding column total (including import expenditures) to get the following technical coefficients:

$$a^{mn} = \frac{X^{mn} \times RPC^{n}}{\sum_{m} X^{mn}} \quad (8)$$

Export Data

31 export zones are defined in this study as shown in Figure 1. Export data come from the 2000 custom records for Texas's custom districts (which include two New Mexico ports and one Oklahoma port). Table 2 describes the value of foreign exports by export zone (and as a percentage of total foreign exports). Laredo, Houston, and El Paso are the three largest export zones in Texas, accounting for 32%, 18%, and 15% of total foreign exports, respectively.

Estimation of Origin and Mode Choice Parameters

Transport cost is an important component of the disutility function (Equations 1 and 2). The cost to move commodity *m* from zone *i* to zone *j* depends on mode choices and interzonal distances. For each needed input *m*, buyers can choose the providers based on a random cost minimization. Their sensitivity to distance is reflected by the parameters λ^{m}. The mode choice parameters (β 's) were estimated based on two kinds of modes for each goods-moving sector: truck and rail.[2]

A nested logit model structure was used to determine where the origins and mode choices of trade flows, by commodity and destination. The lower level of the nest is mode choice, between truck and rail, while the upper level is origin choice. To estimate the origin and mode choices for each sector's flows, the 1997 Commodity Flow Survey data were used. These provide trade flows between states by dollar value for each type of commodity, as defined by the Standard Classification of Transported Goods (SCTG) codes. These commodity types were aggregated to the closest 10 economic sectors, according to the codes shown in Table 1. Since the SCTG codes do not match all SIC and IMPLAN codes and not all industries transport commodities, there were not enough categories in the CFS data to correspond to all 16 industry sectors. Sector 3's (Construction) parameters were assumed to be the same as sector 2's (Mining). Sector 12 (Transportation, Communications, and Utilities), sectors 13 and 14 (Wholesale and Retail Trade)'s parameters were assumed to be an average of all the other sectors' parameter values. Household and government purchases are assumed to be strictly local in the calculations.

In the lower layer of the nested logit model, mode choices were estimated for each sector *m*. Explanatory variables were highway and railway distances for each OD pair, based on shortest-path distances over the highway and railway networks, as generated by TransCAD (using U.S. Geographic Data for TransCAD 4.0) (Caliper Corp., 2001).[3] The states were represented by their geographic centroids. For sector *m*, the probability of choosing transport mode *t*, given the origin *i* and destination *j*, is as follows:

$$P_{t|ij}^{m} = \frac{\exp(V_{ij,t}^{m})}{\sum_{s} \exp(V_{ij,s}^{m})} \quad (9)$$

The systematic (non-random) conditional indirect utility $V_{ij,t}^{m}$ is given by:

$$V_{ij,t}^{m} = \beta_{0,t} + \beta_t d_{ij,t} \qquad (10)$$

where $d_{ij,t}$ is the distance from *i* to *j* by mode *t*; and β's are mode choice parameters to be estimated. ($\beta_{0,railway}$ was set to zero in order to permit statistical identification of the other parameters.)

In the upper layer, the probability that the buyers in state *j* will choose the sellers in zone *i* is:

$$P_{ij}^{m} = \frac{\exp(V_{ij}^{m})}{\sum_{k} \exp(V_{kj}^{m})} \qquad (11)$$

where V_{ij}^{m} (the expected maximum utility across mode alternatives) is as follows:

$$V_{ij}^{m} = \lambda^{m} \ln\left[\sum_{t} \exp\left(V_{ij,t}^{m}\right)\right] \qquad (12)$$

The estimated parameters for the origin and mode choice models for each commodity-moving sector are shown in Table 3.

5. APPLICATION RESULTS

Using the data and estimated parameters described above, this study applied the RUBMRIO model structure and examined the effects of export demand changes and travel cost changes on industry distributions (spatially and sectorally) and on total and regional trade flows.

Technical Coefficient Effects

Technical coefficients a_{i}^{mn} reflect Leontief-type production technology and use of inputs by area and sector. These values represent the amount of *m* needed to produce one unit of *n* in zone *i.* They are fundamental to production costs and consumption levels, and thus to trade flows and overall size of the state economy. Leakages through imports of inputs outside the State boundaries were introduced by regional purchase coefficients (RPCs). The resulting column totals of technical coefficients are less than one for all sectors.

Foreign Export Demand Effects

In this application of the RUBMRIO model, foreign exports are the only source of final demand, and these must be satisfied by Texas producers. Potentially, all zones and sectors can produce goods to satisfy these demands. Their distinct locations and technologies lead to different production levels by zone and a spatial distribution of trade.

As expected, the internal trades flows will vary with foreign export demands. To examine the effects of different commodities or export types on the State economy, different scenarios were run by changing export demands for the first 12 sectors. The marginal differences in internal trade values and labor expenditures (purchases from the household sector) per dollar change in exports were computed according to Equations 13 and 14.:

$$\text{Flow Multiplier} = \frac{\text{change in trade flows (\$)}}{\text{change in a specific commodity's export (\$)}}$$

$$= \frac{\sum_{i,j,m} x_{ij}^{m'} - \sum_{i,j,m} x_{ij}^{m0}}{Y_k^{m'} - Y_k^{m0}}$$

$$\text{Value Added Multiplier} = \frac{\text{change in purchases from household sector (\$)}}{\text{change in a specific commodity's export (\$)}}$$

$$= \frac{\sum_{i,j,m} x_{ij}^{HH'} - \sum_{i,j,m} x_{ij}^{HH0}}{Y_k^{m'} - Y_k^{m0}} \qquad (14)$$

The simulated outcomes show that the multiplier effects on both internal trade flows and labor expenditures, with respect to foreign export of different sectors, vary substantially by sector, as shown in Figure 2[4]. The multiplier values for trade flows ranged from \$4.5 to \$5.5 across export sectors.[5] Demand for Commodities 1 (Agriculture) and 8 (Industrial Machinery and Equipment) exhibit the greatest impacts/multipliers. These are where losses (or increases) could be most harmful (or beneficial) to intra-state sales. Such key commodities affect the state economy (and income) much more than other commodities.

The effects of foreign export demand also vary by export zone. Figure 3 shows the top multiplier estimates for "value added" (i.e., labor expenditures or personal income) and for trade flows due to a unit change in exports, across various export zones. These results reflect the importance of distinct export zones to the state economy, in terms of transactions and income. The Dallas-Ft. Worth export zone exerts the greatest total effect, with a flow-based multiplier of \$6.30 for every one dollar added to demand at that port. El Paso ranked among these top 8 export zones, with a flow multiplier of \$3.70.

Transport Cost Effects

A key component of the disutility functions, transport costs (proxied by network distances in this application) are expected to affect trade flow patterns. A specific corridor application was examined here, where highway transport costs were reduced 10% along Interstate Highway 35 (IH35, Figure 1), from Laredo (on Texas's southern border, with Mexico) to just north of Gainesville (bordering Oklahoma). This is a key trade corridor for the U.S. and Texas, particularly under the North American Free Trade Agreement. Following a 10% reduction in IH35 travel costs (which may be achieved through reduced congestion due to the addition of trucking lanes or a parallel highway, such as SH130, which is currently under construction), the trade from Austin to San Antonio was predicted to increase 1.1% and trade from San Antonio to Austin just 0.3%. Shipments to the Laredo Port by counties housing the IH35 cities of San Antonio, Austin, and Dallas also were predicted to increase (by 2%, 4%, and12%, respectively); these values probably would be larger if total export demand by that port could respond to transport-cost (and thus commodity price) reductions. (However, such a model requires an understanding of the dependence of foreign export demand on sales prices and travel costs.)

The highway travel costs on IH35 also were *in*creased 10% (under an increased-congestion scenario). The magnitudes of these impacts across counties differ. Tables 4 and 5 illustrate how *changes* in total production for the five most affected counties range from \$1.8 billion to \$764 million *more* per year (in the case of IH35 cost reductions), and from \$48 to \$880 million *less* per year (following IH35 cost increases). Thus, IH35 cost increases are predicted have a larger impact on production, while generating higher final demand demands from ports located along the IH35 corridor. These add to demand for intermediate inputs, which is met mainly by intra-county production in this model. Cost decreases reduce the final export demand to a lesser amount, since many counties continue to send final goods to their closest ports, even after the IH35 cost changes.

Production impacts appear to be felt most strongly in counties near the Texas borders and close to the I35 corridor, as depicted in Figure 5. This suggests that final export zone location is important, and that the I35 plays a relevant role in the connection of nearby counties. As illustrated by Figure 5, when costs rise, those counties located closer to the highway reduce the percent of the total trade with nearby counties along the corridor, while increasing the percent of trade allocated to other counties. An opposing set of results can be seen when costs are lowered. Income effects exhibit a similar pattern, and Tables 6 and 7 provide predicted changes for Texas' most income-impacted counties. These counties are impacted in all directions and are favorably located (since central counties have more intermediate trading opportunities than border counties) Evidently, the sectors most dependent on transport exhibit distinctive labor needs, relative to production and sales relationships.

In sum, the Texas case provides a complex web of production and travel dependencies, and the model highlights a variety of impacts that may otherwise be overlooked.

6. CONSIDERATION OF PRICE-ELASTIC TECHNICAL COEFFICIENTS

Each technical coefficient a_{ij}^{mn} is an important parameter in the model, representing the amount of product of sector *m* required to produce one unit of sector *n* product, thus reflecting the productive technology of any sector in any zone. However, there are a number of reasons to expect that fixed coefficients do not reflect reality. MEPLAN (Hunt and Echenique 1993) typically aspires to allow cost-sensitive technical coefficients, according to Equation 2.

$$a_j^{mn} = a_{j,\min}^{mn} + (a_{j,\max}^{mn} - a_{j,\min}^{mn}) \cdot \exp(-\alpha^{mn} \cdot c_j^m) \qquad (16)$$

where α^{mn} is an estimated parameter associated with the sensitivity of the demand for sector *n* with respect to price, and c_j^m is the cost of consuming a unit of sector *m* in zone *j*.

To explore how well this sort of allowance for price-elastic technical coefficients functions, two specific production technologies were compared here. These are the Cobb-Douglas and constant-elasticity-of-substitution (CES) specifications.

Rather interestingly, technical coefficients for input expenditures arising under Cobb-Douglas production technology truly are independent of both output, *y*, and prices, p_i. In other words, fixed proportions of expenditures will be spent on each input, no matter what set of prices producers face or what levels they produce at. If the budget is fixed, an increase in price p_i sector *i* will reduce x_i proportionally. Looking back at the literature, Klein and Goldberger (1955) were the first to demonstrate this, and El-Houdiri and Noruzad rediscovered it in 1988.

This fortunate results means that Cobb-Douglas technology, if used by all producers in a particular industry, will result in perfect IO estimates of expenditure shares. The key is that the technical coefficients be based on units of money (as in IMPLAN and as used here), rather than units of the actual goods (e.g., tons of agricultural products). Thus, the Cobb-Douglas in real input units translates to a fixed Leontief-style expenditure share in our IO approach! Unfortunately, the same cannot be said for CES-style production.

CES production assumptions are very common in computable general equilibrium (CGE) models (see, e.g., Sadoulet and Janvry, 1994; and Isard et al., 1998). It resembles the following:

$$y = A\left(\sum x_i^{\rho}\right)^{1/\rho} \tag{17}$$

In simulating expenditure shares under a variety of price conditions using CES technology, the average outcomes managed to closely track demand; however, recognition of other inputs' prices and more flexible functional approximations for the technical coefficients should improve the correspondence.

7. CONCLUSIONS

Urban regions are highly complex systems involving a variety of actors, markets, goods, resources, prices, and preferences. This paper provides detailed trade predictions following calibration and application of a RUBMRIO model to Texas. The simulated scenarios responded to shifts in various important inputs as expected, producing reasonable and interesting results. Such models can assist states and regions in appreciating trade flows, interactions, and dependencies.

Changes to final demands feed back through all levels of the trading system, impacting demand and trade flows everywhere. Certain commodities' export demands (e.g., Sectors 1 and 8) and certain ports affect trading levels more than others. Travel-cost increases result in trade localization, while reductions lead to greater interaction. Quantification of these effects is likely to be very helpful for trade, transport, and general investment policies by nations, states and regions. Changes in IH35 travel costs clearly will affect trade levels and flows; these results suggest that counties along the corridor and near State borders are most affected by such changes.

The current RUBMRIO models may be extended by expanding production process flexibility and price-responsiveness, rather than relying on fixed-coefficient production functions. Computable general equilibrium (CGE) concepts and techniques offer a key direction for further study in these regards (see, e.g., Zalai, 1982; Scarf and Shoven, 1984; Piggott and Whalley, 1985; Buckley, 1992; Sadoulet and Janvry, 1994; and Isard et al., 1998). Johansen (1960) introduced the CGE concept, as a combination of a dynamic input-output model with macroeconomic production and consumption functions. Thus, he extended the input-output model via relative, price-driven substitution possibilities. Within a CGE model framework, market equilibrium, variable prices, and flexible production are explicit and more realistic. CGE models can simultaneously determine changes in quantities of goods supplied and demanded, and their prices, in an aggregated multi-sectoral and multi-agent setup (Zalai, 1998). However, they require far more data (for calibration and application) than generally can be provided, in the form of product prices, wages, and sector-specific technology (over time and space, and across industries). Presently, they are applied to very limited (e.g., 10-region, 2-commodity, 1-mode) systems (Isard et al., 1998; Buckley, 1992).

Only two travel modes (highway and railway) were considered here, due to data limitations. If networks become available for calibration and application of mode choice across waterways and pipelines, model resolution will be enhanced. Additionally, land use limitations were not considered here, so assignment of production (including households) may exceed zone constraints. With more information, caps on zonal production can be applied. Moreover, congestive feedbacks may be incorporated in travel cost estimates (e.g., Zhao and Kockelman, 2003; Kim, Ham, and Boyce, 2002), if background flow values (from other network users) are known (or modeled endogenously), commodity flows are converted to truck and train flows, and origin and mode choice models are calibrated with respect to travel time and cost. (Travel time and cost variables are not available in the Commodity Flow Survey, but may be estimated or obtained for certain sectors based on others' research.) Of course, labor flows and household purchases may not be local (particularly at finer scales of spatial resolution than Texas counties); these can be calibrated and added in a reasonably straightforward fashion (after appropriate model calibrations). Additionally, trade information across state boundaries for non-foreign goods would be very helpful; such trade is largely unregulated, so the data are missing. However, with improved, coming versions of the Commodity Flow Survey, such information may soon be accessible.

In summary, the RUBMRIO model offers a valuable set of relationships to predict trade flows, location choices/production levels, and relative market prices. Predictive models of this type and their quantification of effects are very valuable for assessing regional transportation, land use, technology, and trade policies.

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ENDNOTES:

[1] Note that units of goods are all expressed in dollars. These mask actual prices, but they allow for common technology representations and cross-good aggregations (versus, for example, trying to specify tons of peaches and oranges in the same units).

[2] Waterway and pipeline modes are also important in the U.S. and in Texas. But networks for these modes were not available for model calibration.

[3] Unfortunately, travel times and costs by mode and OD pair are not available. However, one may be able to estimate costs and time as functions of distance and location, and apply network models with some acquired background traffic counts to allow for congestive feedbacks on the networks.

[4] Figure 2 only shows those sectors having foreign exports. There are no foreign exports for the other sectors.

[5] Export demand dollars were added in proportion to the current distribution across export zones.

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LIST OF TABLES AND FIGURES

TABLE 1. Description of Economic Sectors in RUBMRIO Model

Sectors	Description	IMPLAN Code	SIC Code (2-digit)	SCTG Code
1	Agriculture, Forestry, and Fisheries	1~27	01~09	1,3,4,5,6,25
2	Mining	28~47, 57	10~14	10~18
3	Construction	48~56	15~17	
4	Food and Kindred Products	58~103	20	2, 5~9
5	Chemicals and Allied Products	186~209	28	19~24
6	Primary Metals Industries	254~272	33	32
7	Fabricated Metal Products	273~306	34	33
8	Industrial Machinery and Equipment	307~354	35	34
9	Electronic and Electric Equipment	355~383	36	35
10	Transportation Equipment	384~399	37	36 & 37
11	Other Durable and Non-Durable Manufacturing	104~185, 210~253, 400~432	24~27, 29~32, 38~39	26~31
12	Transportation, Communications, & Utilities	433~446	40~49	
13	Wholesale Trade	447	50, 51	
14	Retail Trade	448~455	52~59	
15	FIRE (Finance, Insurance, and Real Estate)	456~462	60~65	
16	Services	463~509	70~87	
17	Households			
18	Government			

TABLE 2. Texas Export Zones and Foreign-Export Values ($/year)

#	Export Zone	Export Value	% of Total	#	Export Zone	Export Value	% of Total
1	Addison Airport, TX	1.078E+05	0.000%	17	Houston, TX	2.173E+10	18.510%
2	Albuquerque, NM	7.907E+06	0.010%	18	Houston Int. Airport, TX	5.007E+09	4.270%
3	Armstrong, TX	1.798E+05	0.000%	19	Laredo, TX	3.787E+10	32.260%
4	Austin, TX	3.107E+08	0.260%	20	Lubbock, TX	6.085E+04	0.000%
5	Brownsville, TX	6.671E+09	5.680%	21	Midland Intl Airport, TX	3.326E+04	0.000%
6	Columbus, NM	1.866E+07	0.020%	22	Oklahoma City, OK	7.373E+07	0.060%
7	Duval, TX	1.500E+09	1.280%	23	Port Lavaca, TX	1.883E+08	0.160%
8	DFW, TX	1.100E+10	9.370%	24	Presidio TX	8.379E+07	0.070%
9	Val Verde, TX	1.160E+09	0.990%	25	Progresso, TX	1.310E+08	0.110%
10	Eagle Pass, TX	4.271E+09	3.640%	26	Rio Grande City, TX	1.165E+08	0.100%
11	El Paso, TX	1.776E+10	15.130%	27	Roma, TX	8.950E+07	0.080%
12	Fabens, TX	4.776E+04	0.000%	28	San Antonio, TX	3.784E+08	0.320%
13	Ft. Worth Airport, TX	3.534E+06	0.000%	29	Santa Teresa Airport, NM	7.569E+07	0.060%
14	Freeport, TX	1.049E+09	0.890%	30	TX City, TX	1.052E+09	0.900%
15	Galveston, TX	3.641E+08	0.310%	31	Tulsa, OK	5.022E+07	0.040%
16	Hildago, TX	6.445E+09	5.490%	Total		1.174E+11	100.000%

* Some customs districts are on the State border and so can be located in neighboring states.

TABLE 3. Estimated Parameters for Nested Logit Models of Mode and Origin Choice

	Mode choice estimation				Origin choice estimation	
	$\beta_{0,truck}$	β_{truck}	β_{rail} *	# of observations (R-square)	λ	# of observation (R-square)
1	4.499	5.79E-10	-1.38E-04	830 (0.8170)	16212	49 (0.0007)
2	1.898	-1.07E-10	7.82E-10	288 (0.6225)	112.0	51 (0.0004)
4	3.856	-7.78E-04	8.91E-10	865 (0.7360)	6.926	49 (0.4499)
5	3.463	-6.97E-04	5.11E-10	1275 (0.6711)	5.507	49 (0.3039)
6	4.742	-1.16E-03	-1.38E-08	830 (0.8170)	3.096	48 (0.2892)
7	9.993	-2.15E-03	-1.16E-08	882 (*0.9898)*	1.723	49 (0.3086)
8	35.208	-2.79E-06	2.72E-12	919 (*1.0000)*	67293	48 (0.0005)
9	7.976	-1.77E-03	-9.35E-04	766 (*0.9877)*	155.7	49 (0.0009)
10	4.213	9.00E-03	1.14E-09	680 (*0.9877)*	3.976	48 (0.2859)
11	4.498	-1.12E-03	6.19E-10	1626 (*0.7487)*	3.334	49 (0.3025)

* In actual mode choice processes, cost is an important factor. For long-distance transport, the price of railway (in $/ton-mile) is likely to be much lower than that of truck transport on highway. This price distinction will cause shippers to choose the railway mode on longer trips. This negative correlation with the unobserved price variable is probably responsible for the positive coefficient estimates on railway distance in six of the ten estimated nested logit models.

TABLE 4. Five Counties with Largest Rise in Total Production when IH35 Transport Costs Fall by 10%

County name	Total Production (Original Transport Cost)	Total Production (Transport cost increase by 10%)	Percentage changes	Total Production Difference
Denton	$1.73e+10	$1.91e+10	10.7%	$1.85e+09
Ellis	1.67e+09	1.78e+09	6.3%	1.06e+08
Cooke	1.00e+09	1.1e+09	9.8%	9.80e+07
Williamson	2.03e+09	2.1e+09	3.8%	7.76e+07
Hill	1.67e+09	1.75e+09	4.6%	7.64e+07

TABLE 5. Five Counties with Largest Reduction in Total Production when IH35 Transport Costs Rise by 10%

County name	Total Production (Original Transport Cost)	Total Production (Transport cost increases by 10%)	Percentage changes	Total Production Difference
Tarrant	$2.14E+10	$2.05E+10	4.1%	$8.80E+08
Dallas	2.79E+10	2.72E+10	2.2%	6.26E+08
Zapata	3.39E+09	3.32E+09	2.0%	6.72E+07
Duval	3.15E+09	3.1E+09	1.6%	4.94E+07
Jim Hogg	3.02E+09	2.97E+09	1.6%	4.84E+07

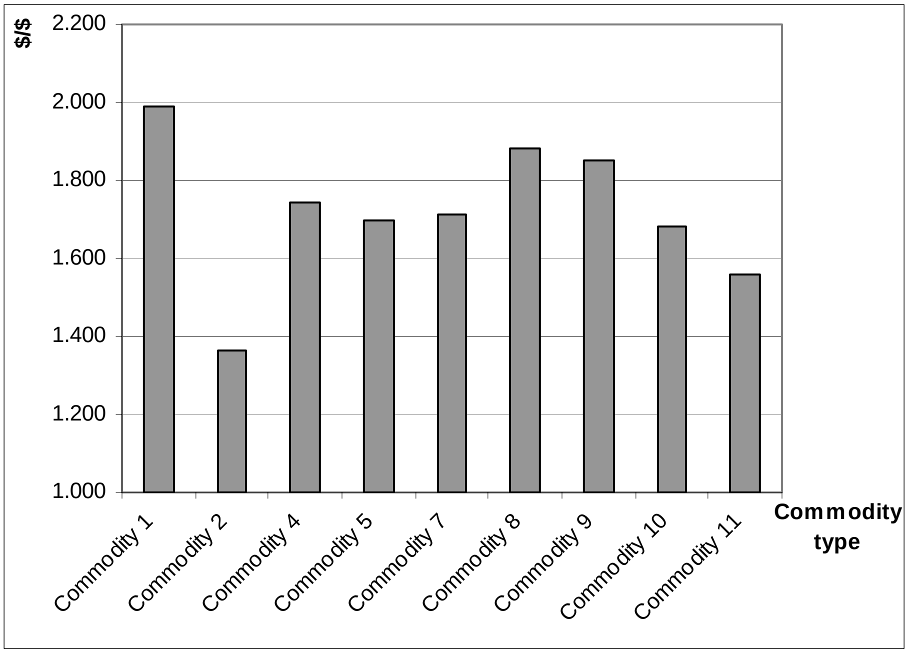
TABLE 6. Five Counties with Largest Rise in Personal Income when IH35 Transport Costs Fall by 10%

County name	Income (Original Transport Cost)	Income (Transport cost increase by 10%)	Percentage changes	Total Income Difference
Denton	$6.28E+09	$6.96E+09	10.83%	$6.80E+08
Cooke	1.18E+07	1.29E+07	9.3%	1.10E+06
Ellis	6.12E+08	6.51E+08	6.4%	3.90E+07
Hill	6.11E+08	6.39E+08	4.6%	2.80E+07
Fannin	4.59E+08	4.79E+08	4.4%	2.00E+07

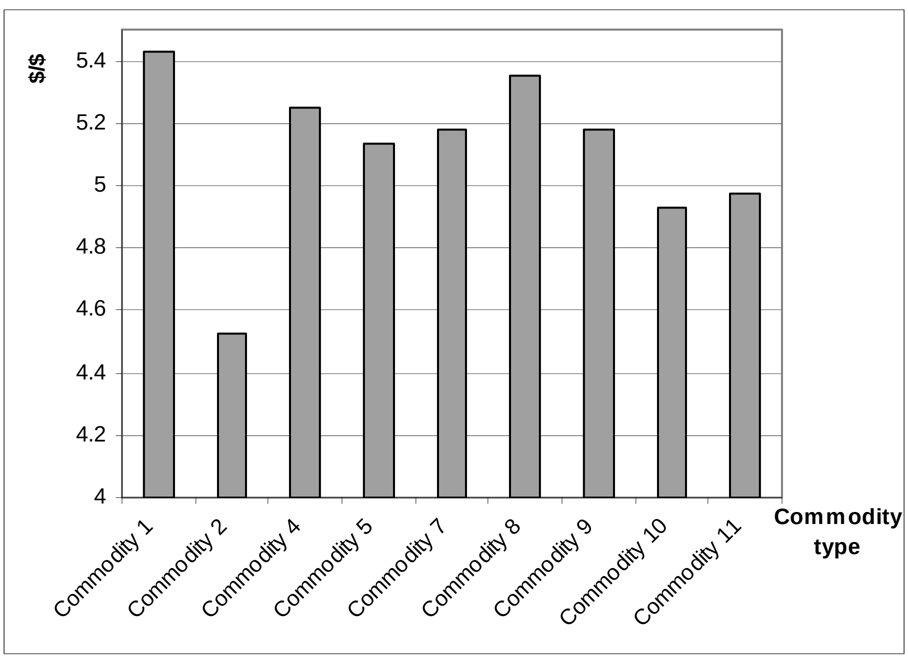
TABLE 7. Five Counties with Largest Reduction in Personal Income when IH35 Transport Costs Rise by 10%

County name	Income (Original Transport Cost)	Income (Transport cost increase by 10%)	Percentage changes	Total Income Difference
Starr	$1.06E+09	$1.04E+09	1.89%	$2.00E+07
Jim Hogg	1.09E+09	1.07E+09	1.8%	2.00E+07
Duval	1.13E+09	1.11E+09	1.8%	2.00E+07
Zapata	1.22E+09	1.20E+09	1.6%	2.00E+07
Mcmullen	9.39E+08	9.24E+08	1.6%	1.50E+07

FIGURE 1. Location of Texas Counties (production zones), Export Zones, and Highway Network, with IH35 Corridor Highlighted

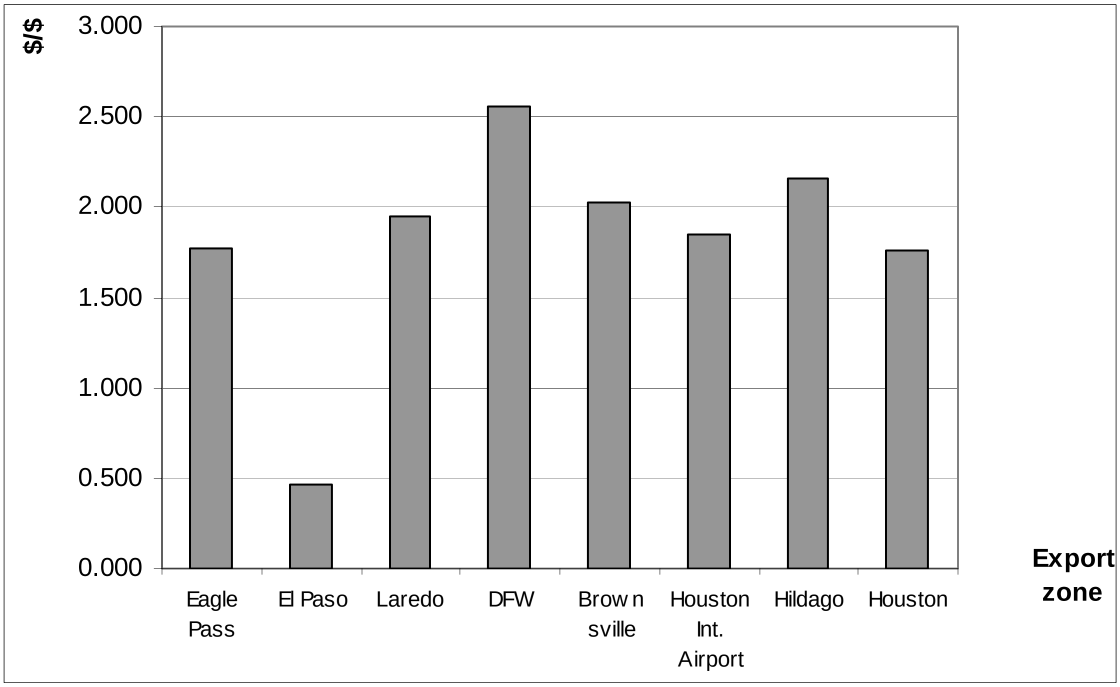


(a) Multipliers for total State labor expenditures across foreign export commodity types

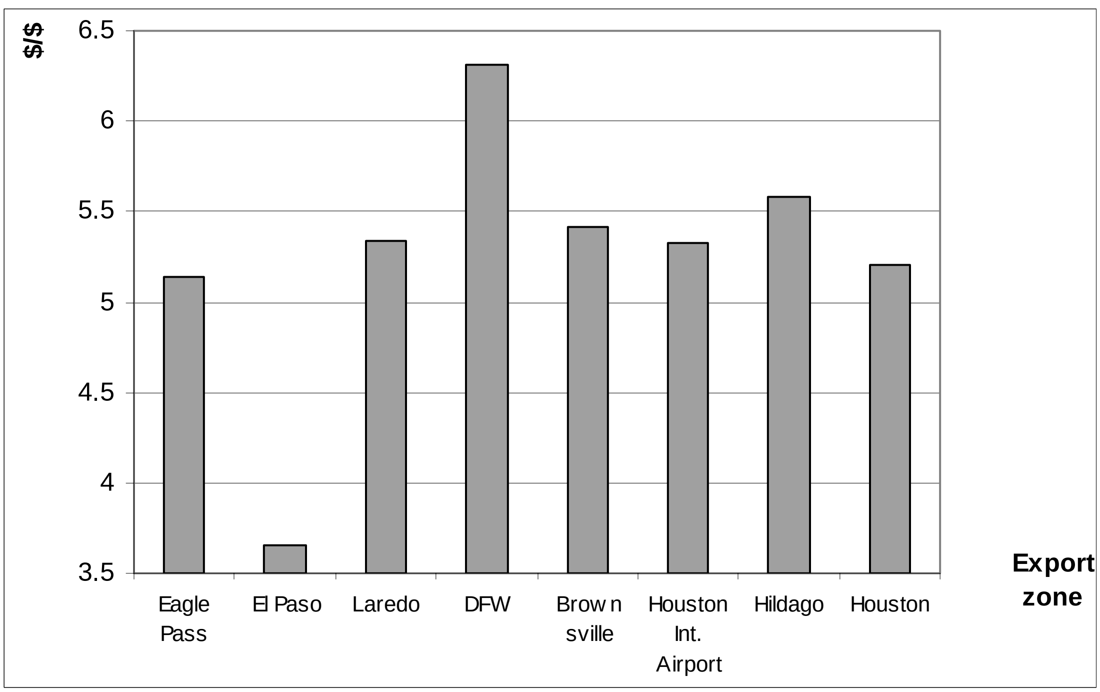


(b) Multipliers for total State transactions across foreign export commodity types

FIGURE 2. Changes in Labor Expenditures and Trade due to Changes in Export Demands, by Commodity Type



(a) Multipliers for total State labor expenditures across foreign export zones



(b) Multipliers for total State transactions across foreign export zones

FIGURE 3. Changes in Labor Expenditures and Trade due to Changes in Export Demands, by Export Zone

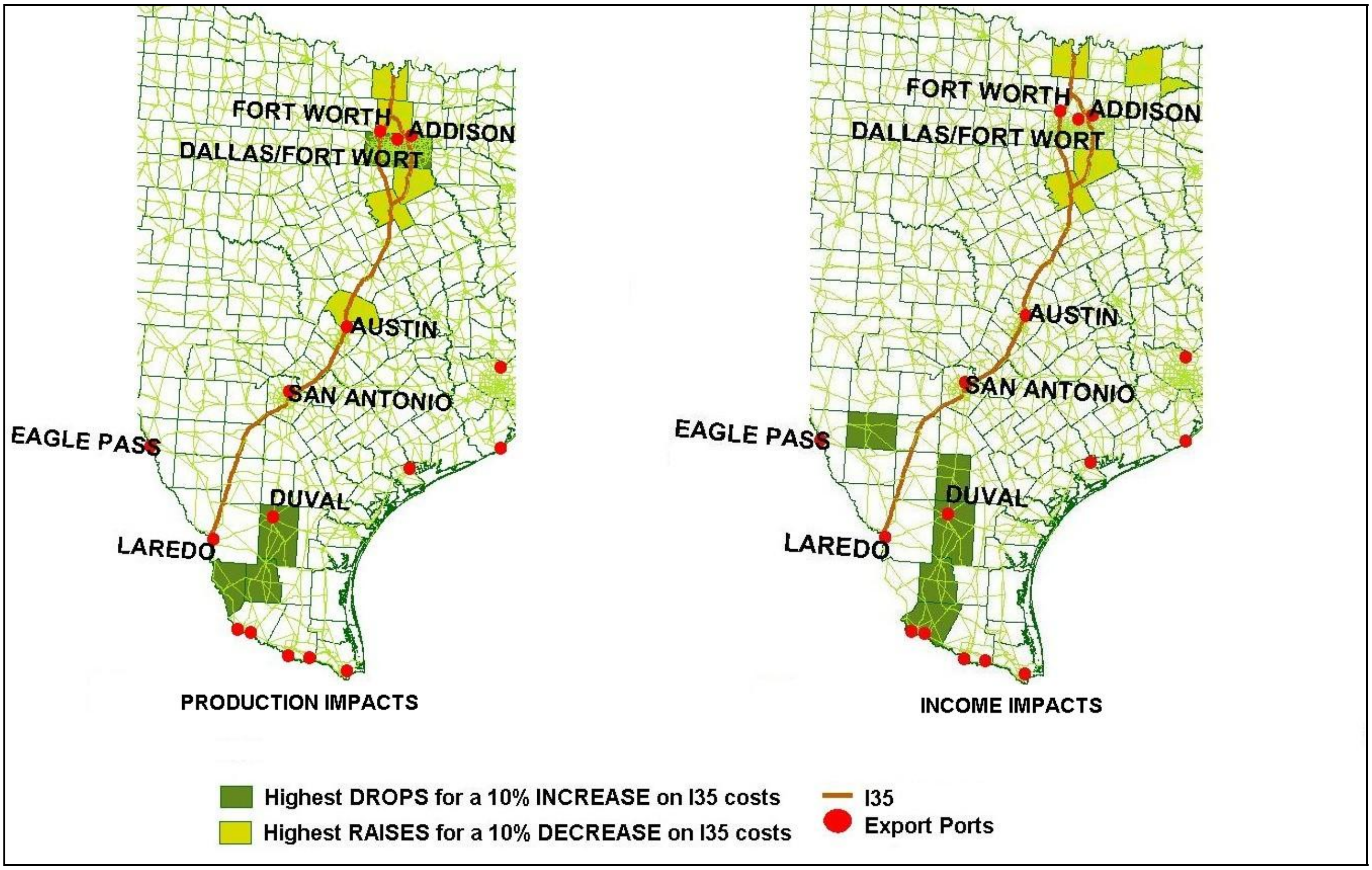


FIGURE 4. Most Affected County Locations, due to IH35 Transport Cost Changes

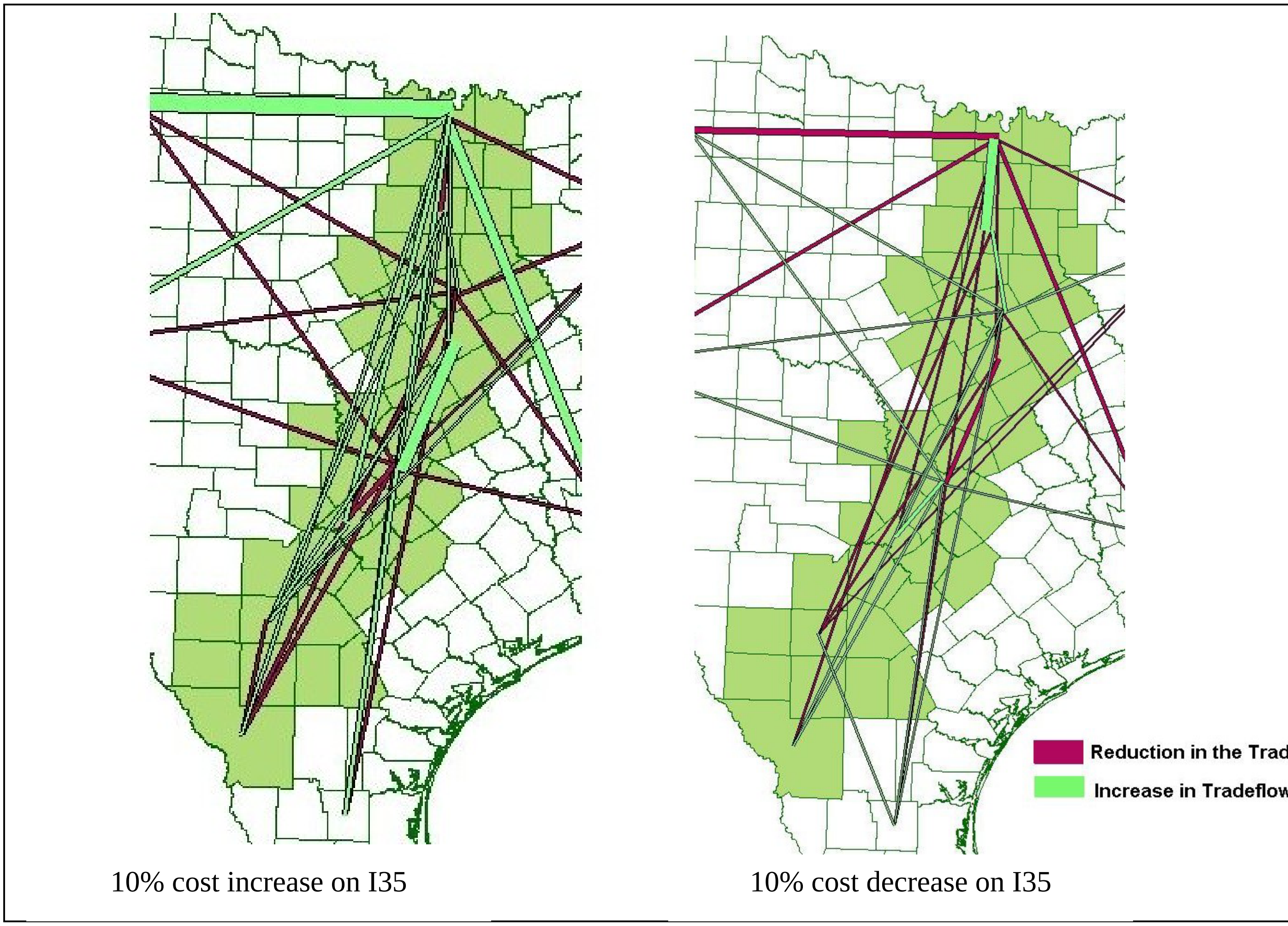


FIGURE 5. Changes Trade Flow Percentages, due to IH35 Transport Cost Changes