Extending the Random-Utility-Based Multiregional Input-Output Model: Incorporating Land-Use Constraints, Domestic Demand and Network Congestion in a Model of Texas Trade

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ABSTRACT

This study describes the applications and extensions of an existing random-utility-based multiregional input-output (RUBMRIO) model, applied to Texas trade patterns. The new model simulates labor and commodity trade patterns among zones (counties), as motivated by foreign and domestic export demands. The trade impedance, represented by travel cost on a two-mode transportation network, can be iteratively updated to capture congestion impacts on the highway network. To achieve this, the extended model estimates truck, work and shopping trips, all of which are predicted to remain largely intercounty.

Modeling results suggest that Chemical and Allied Products, Mining, Manufacturing and Agriculture sectors generate most of the State's truck trips, consistent with information from the Vehicle Inventory and Use Survey. The new version can limit production levels and housing – and thus zonal development – according to local land availability. Incorporation of domestic demands, in addition to foreign demands for Texas goods, resulted in relatively close approximation of production found by the U.S. Commodity Flow Survey.

Simulation of different demand and production-technology scenarios highlighted the importance of Agriculture, Machinery and Equipment, and Fabricated Metal Products sectors for the State's economy, as well as the State's relative dependence on demands by New England and Middle Atlantic States. Improved production technologies reduce the need for intermediate trading but have a larger positive impact if applied in appropriate sectors and counties.

Key Words: Trade Models, Integrated Transportation-Land Use Models, State Economy

1. INTRODUCTION

Integrated modeling of transportation-land use interactions enhances planning, policy and investment decisions. Transportation system features affect household and firm location choices, production levels, and trade patterns. And these choices manifest themselves in various forms of travel demand, impacting the operational performance of the transportation system.

Input-Output (IO) models have been widely used to simulate the linkages between industries, and between producers and consumers. (Leontief 1963) These models are demand-driven, in the sense that production levels are adjusted to meet both final and intermediate demands. Traditional IO models have been extended to incorporate spatial disaggregation. The application of random utility principles, in the form of logit models for location choices, gave rise to several operational models, including MEPLAN (Echenique, 1985; Hunt and Echenique, 1993; Hunt and Simmonds, 1993; Abraham and Hunt, 1999), TRANUS (de la Barra, 1995) and others (Kim, 1989; and Ham et al., 2000).

Most recently, Hunt and Abraham's Production Exchange and Consumption Allocation System (PECAS) model (Hunt and Abraham, 2002; and Abraham and Hunt, 2002) provides a framework to incorporate variable technical coefficients, and uses "exchange zones" to clear all markets. When run as a component of an larger integrated land use-transport model, PECAS aims to account for congestion by updating the travel-time variables in each time step. Restrictions on land use are incorporated, using logit model predictions of land development changes over time. Even though the PECAS structure has been incorporated in several valuable applied models (Hunt and Abraham2002), data acquisition for both model calibration and application can be overwhelming.

This paper builds on Jin et al.'s work (2003), which developed a Random-Utility-Based Multiregional Input-Output (RUBMRIO) model of Texas trade. Their RUBMRIO model describes the production and trade patterns of 18 social-economic sectors (including households and government) across Texas' 254 counties. Production and trade typically are driven by export demands at 31 key ports, while specific trade patterns respond to prices, measured in utility units and based on expected minimum transportation costs (represented by distance on a two-mode highway/railway network). Their applications consider network and corridor congestion and the multiplier effects of shifts in demand, by port and sector. Zhao and Kockelman (2003) have shown that the general RUBMRIO formulation converges for most any set of parameter and factor inputs.

In the present paper, the RUBMRIO model is extended to recognize land use constraints on production (and residence), to incorporate "domestic demands" by other U.S. states, to estimate vehicle trips resulting from monetary trades, and to capture the effects of the network congestion on trade and production decisions.

After describing the original RUBMRIO model structure, the first section of this paper details each of the model extensions, including data acquisition and calibration of new parameters. The second section examines the trade and location choices resulting from a variety of scenarios, including changes in demands for Texas' products and production technologies by industry and location.

2. THE ORIGINAL RUBMRIO MODEL STRUCTURE

The RUBMRIO model derives from IO-type productive dependencies across economic and social sectors and logit models of input origin and transportation mode choice. It relies on an iterative algorithm (Zhao and Kockelman 2003) for solution of trade flows among zones, and production within zones. It applies random utility theory for input purchase decisions, which requires computing the disutility of acquiring commodity *m* from every possible provider zone *i*, by transporting the commodity via rail, highway, and any other permitted modes. The disutility is a calibrated function of transport distance (or travel cost, depending on the data used for calibration) plus commodity sales price at the origin. Jin et al. (2003) calibrated their mode- and origin-choice parameters by industry using nested logit models and the 1997 Commodity Flow Survey data (BTS 2001).

The standard RUBMRIO algorithm begins by assuming some set of sales prices across production zones and commodity types. As Figure 1 suggests, it distributes export demand (at export zones) across the production zones, according to relative trade (dis)utilities, which are comprised of transport costs and production zone sales prices. Production in each county is computed in order to meet this export demand plus any intermediate demands arising from such production (in other sectors and counties). Intermediate consumption also is distributed across counties, and the networks that unite them, using relative trade utilities. Average intermediate input prices (in utility units) are computed as a purchase-weighted averages of trade utilities across counties; coupled with technical coefficients, these provide average output sales prices. These newly computed sales price estimates feedback for a new iteration. Figure 1 illustrates the procedure, and the model inputs and outputs.

Table 1 lists the economic sectors considered in this work's Texas application. The regions or zones are represented by Texas' 254 counties. The 18 foreign export ports[1] range from Midland's International Airport, with just $33,260 in foreign exports in 2000, to Houston's maritime port, with $21.7 billion in exports that same year (Please refer to Table 2 in Jin et al. [2003] for further information.).

3. MODEL EXTENSIONS

This section describes the RUBMRIO application's extensions, which include: recognizing the effect of land use constraints on production (and residence), considering domestic demand (by other U.S. states), and estimating vehicle trips in order to capture congestion's effects on trade patterns.

To incorporate domestic demands, every non-Texas state is regarded as a port that demands commodities, and the basic structure of the model is not modified. On the other hand, the recognition of land use constraints involves a modification in model structure, so that production in over-developed counties is reassigned. It requires data on (or estimates of) the number of workers per unit of production, number of workers per household, usable land per region, and maximum residential and employment densities.

The model derives truck and personal (work and shop) trips from the simulated commodity trade flows. Truck-trip derivation requires estimates of value per commodity ton and tonnage carried per truck trip. To transform labor expenditures into work trips, IMPLAN (MiG, 1997) estimates of production per worker are used. Work trips are then distributed according to a logit model, calibrated using Census commute data. Shopping trips are generated by household purchases from each industry, based on assumptions about the average purchase value that motivates a round trip. These trips then are allocated among counties via a logit model, calibrated based on Austin Travel Survey (ATS) data. The total number of trips can be loaded into Texas highway network.

3.1 Domestic Demands

In this work's enhancements to the RUBMRIO model, domestic demands were added, as an exogenous factor. Since trade data (in the form of the CFS) are available primarily at the state level (BTS 2001), the model assigns state-level demands across Texas counties using the random utility principles defined by Eqs. 1 and 2 and based on Jin et al.'s (2003) parameters. Eq. 3 illustrates how the model's production function incorporates a new, third term (Z_{is}^{m}), in order to account for domestic demands.

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

$$Z_{is}^{m} = Z_s^m \frac{\exp(U_{is}^m)}{\sum_i \exp(U_{is}^m)} \quad [2]$$

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

where U_{is}^{m} is the (systematic) utility of acquiring commodity *m* in zone *i* and transporting it to U.S. state *s*, p_{im} is the price paid for commodity *m* in zone *i* (assumed to equal its average production cost[2]), the β's and λ's and are logit model parameters (calibrated from CFS data), and $d_{is,highway(railway)}$ is the distance between zones *i* and s, by highway or railway. (For more information on parameter calibration, please see Jin et al. [2003]) The Z_{is}^{m} are the interstate flows of commodity type *m* from zone *i* to state *s*, and x_i^m is the production of commodity *m* in zone *i*.

The CFS data set (BTS 1997) provided the information on the demand by the 50 U.S. states (plus the District of Columbia), for products of various industries. Table 1 bridges the CFS commodity codes with the IMPLAN categories adopted here. Table 2 summarizes these domestic demands. The $129 billion in exports to other U.S. states represents just over half (52%) of the total final demand that drives the Texas economy in this study[3]. As Table 2 indicates, these exports account for all Sector 6 exports (Primary Metals) and most of Sectors 4 and 9 exports.

Distances between the 50 non-Texas U.S. states (including the District of Columbia) and Texas' 254 counties, over both the highway and railway networks, were estimated using TransCAD software's (Caliper 2002) shortest-path routine, based on national rail and highway networks. The highway network use for this and all other TransCad applications is the National Highway Planning Network (NHPN V2.2), supplied by the Federal Highway Administration. It represents current and planned interstates, principal arterials and minor rural arterials (FHWA 2003).

In order to simplify the following trade computations, the states were then simply linked to Texas' actual highway and railway networks using dummy connectors. These centroid connectors are fictitious links that unite state centroids to the closest node on the corresponding Texas transportation network.

Incorporation of domestic demands (which are 55% of total final demand) increased model's predictions of intermediate trade flows by a whopping $625 billion (106%). Labor expenditures increased 95%, reaching a total of $375 billion[4]. Overall, 83% of consumption (including labor expenditures) is predicted to derive from intermediate trading (both inter- and intra-county), including trades/sales of labor. (Without labor, the intermediate trading percentage falls to 53%.)

Hidalgo and Dallas Counties are among the those for which the model predicts the highest levels of value added (at 2.61% and 2.36%, respectively)[5], and this result is consistent with the 2000 Census County-to County Work flow files (U.S Census Bureau 2003), which position them among the top ten Texas counties for job attraction.

3.2. Vehicle Trips

The results of the original RUBMRIO model, after convergence of the iterative solution process, are annual trade flows among counties and between counties and export zones, by commodity sector, expressed in dollar values. In order to explore the relationship between network performance and trade patterns, it is necessary to generate vehicle trips from the dollar flows. This section describes the extended model's incorporation of truck trips, work trips and household shopping trips. These trips are computed separately (as total daily trips among zones), and then are combined to generate a representative single hour of total trip demand via percentages, according to Eq. 4.

$$Veh_{ij} = 0.05SHTrips_{ij} + 0.20WRKTrips_{ij} + 0.08PCE \times TTrips_{ij} \qquad [4]$$

where $SHTrips_{ij}, WRKTrips_{ij}$ and $TTrips_{ij}$ represent the number of shop, work and truck trips between zones *i* and *j*, respectively[6], and *PCE* is the passenger-car equivalent of each truck. The representative hour was chosen to be a work–trip peak hour, and the percentages (5%, 20%, and 8%) were approximated from different sources. The Census data suggest that 20% of the home-based work trips occur during a representative peak hour (8:00AM to 9:00AM). The ATS shows that a 5% of Austin's home-based shop trips depart at this time. And the *Highway Capacity Manual* (TRB 2001) suggests the use of 10% AADT to create a representative hourly flow volume. This percentage was reduced to 8% based on observed distributions of daily volumes for rural highways, exhibited on the HCM (TRB, 2001).

The extended model results in trade patterns wherein most predicted trips (95%) are intrazonal. Intrazonal trip predictions account for 83% of truck trips, 23% of work trips, and 95% of shopping trips. This striking result may be moderated by more accurate estimates of intrazonal distances and travel times. It certainly will disappear as zone sizes fall.

As a check the resulting predicted vehicle volumes were compared to the FHWA Freight Analysis Framework (FAF) data on flows by network link. The FAF network (FHWA,2003) is The FAF network is a reduced version of the NHPN (NHPN V2.2, FHWA) used in this work (containing approximately 54% of the NHPN lane-miles). The estimation of vehicle-miles traveled provided by this model was compared to the vehicle-miles that result from the traffic volumes and link lengths contained in the FAF network, after appropriate adjustment (scaling) to account for the differences in both networks' coverage. The comparison suggested that the applied RUBMRIO model overestimates the number of daily trips[7]. To account for this, the TCF were adjusted to match the AADT from the FAF network.

3.2.1. *Commodity Trips*

Commodity trips derive from the percentage of annual trade between counties, by industry sector, that relies on highways. This is computed based on the original model's nested logit mode choice parameters, as calibrated by Jin et al. (2003):

$$P^m_{ij,HIGHWAY} = \frac{\exp(V^m_{ij,HIGHWAY})}{\exp(V^m_{ij,HIGHWAY}) + \exp(V^m_{ij,RAILWAY})} \qquad [5]$$

$$V^m_{ij,HIGHWAY} = \beta_{0,t} + \beta_t d_{ij,HIGHWAY} \qquad [6]$$

$$V^m_{ij,RAILWAY} = \beta_r d_{ij,RAILWAY} \qquad [7]$$

where $P^m_{ij,HIGHWAY}$ is the proportion of commodity *m*'s flow from zone *i* to zone *j* that is transported by highway. The Mining sector (commodity group 2), receives special treatment here, since it is dominated by shipments of crude petroleum and natural gas, which are mostly transported by pipeline, rather than highway or railway. Therefore, the $X^2_{ij,HIGHWAY}$ have been reduced in proportion to the IMPLAN based amounts of natural gas and crude petroleum in the Mining sector.

Given these proportions, estimated commodity highway flows between all zones are converted to daily trips, according to Eq. 11 (This equation is equally valid for *i,j*, *i,k* and *i,s* pairs.)

$$TTrips_{ij} = \sum_m P^n_{ij,HIGHWAY} \times TCF^m \times PCE \qquad [8]$$

where $TTrips_{ij}$ is the number of vehicle trips between *i* and *j*, TCF^m is the Truck Conversion Factor (from annual 2000 dollars of commodity *m* to daily trucks) and *PCE* is the truck-to-car equivalency factor, needed to match the usual units of road capacity. In this work, an assumption of 2 vehicles per truck unit was made, based averaging HCM-suggested values for rolling and plain terrain.

The TCF^m essentially converts from dollars to tons, tons to trucks and from annual to yearly flows. Even though all sectors generate some form of travel, the TCU, wholesale trade, retail trade, FIRE, services, and government sectors (sectors 12 through 16 and 18, in Table 1) are absent in the CFS. Thus, they are assumed to generate negligible truck trips here, and only passenger-car travel, in the formal of household shopping trips.

For the other sectors, conversion from dollars to tons is rather straightforward. The 1997 CFS tables provide trade volumes in 1997 dollars, in tons and in ton-miles, permitting calculation of tons-to-dollars ratios (as weighted averages across sub-sectors). All dollar factors then were inflated at a 3% annual rate (to the year 2000).

Conversion on tonnage to vehicle trips is not so straightforward and has been pursued in different ways in the literature, depending mostly on data availability. (See, for example, Figliozzi et al. 2000, Figliozzi and Harrison 2001 Fischer 2000, Memmot 1995). One also must account for empty trips (see, e.g., JFA 1999, and Holguín-Veras 2002 and 2003). For the purpose of this conversion, the Vehicle Inventory and Use Survey (VIUS) (U.S.Census Bureau, 2002) micro-data sample was used, as described here now.

The 2,181 Texas records in the 2002 VIUS dataset (weighted by shipment expansion factors) contain information on operational and usage characteristics of trucks owned by private and public companies throughout the United States. Such data includes average empty weight, average gross weight, annual miles traveled, empty miles traveled, miles traveled while carrying different commodity types, and miles traveled per trip by each of five distance categories[8]. The average payload estimates result from the division of weighted average ton-mileage by weighted average mileage, for every commodity type in every distance category. As one might expect, shorter-distance shipments tend to be carried in smaller units (Cambridge Systematic Inc., 2002). Since most CFS shipments are in the Medium/Short range (100-200 miles), these sector-specific average payload values were used here. Based on these VIUS data, empty trips were assumed to require another 8% of trip-making.[9] Yearly flows or trip-volumes were converted to daily flows based on the HCM's (TRB 2000) recommended assumption of 300 working days per year; this assumption accounts for 5 full working days per week, plus 2 days working at 44% of fleet capacity.

The model suggests that Chemical and Allied Products, Mining, Manufacturing and Agriculture sectors generate most of the truck trips. Table 6 notes that this trend is consistent with the percentage of total miles that trucks travel in Texas carrying each commodity type (computed from the 1997 Vehicle Inventory and Use survey data). It also highlights those sectors for which further refinement in the conversion factors is needed, in order to capture better the trip generating patterns.

3.2.2. *Work Trips*

Work trips in this model are a consequence of the demand for labor by different industries, using IMPLAN commodity tables' (MiG 1997) estimates of average industry output per worker, for each zone and industry[10] (Eq. 12). For each zone, the numbers of predicted jobs per industry are added (Eq. 9).

$$jobs_j^m = x_j^m \times wpd_j^m \qquad [9]$$

$$W_j = \sum_m jobs_j^m \qquad [10]$$

where $jobs_j^m$ is the number of jobs generated by industry *m* in zone *j*, x_j^m is the production of industry *m* in zone *j*, wpd_j^m is workers per dollar of output (the inverse of output per worker) in industry *m*, zone *j*., and W_j is the daily number of work trips to zone *j*.

The model permits a distribution of labor (and thus households) across counties of residence, using a commute-distance sensitivity factor (Eq. 11).

$$WRKTtrip_{ij} = W_j \frac{\exp(\gamma \times d_{ij})}{\sum_i \exp(\gamma \times d_{ij})} \qquad [11]$$

where W_j is the daily number of work trips to zone *j* (Eq.10), $WRKTrip_{ij}$ is the number of daily round work trips from county *i* to county *j*, and γ is the logit-model distance-sensitivity parameter.

This logit-model factor was calibrated based on inter- (and intra-) county commute counts from the Census 2000 County-to-County Worker Flow Files (U.S Census Bureau 2003). In this model employers choose their workers (or at least choose the counties from which they draw their workers), much like any other input to production. Inter-county distances (computed using TransCAD's [Caliper 2002] shortest path algorithm) constitute the model's independent variables, and only the highway mode is modeled for congestion[11]. To meet LimDep V7.0 (Econometric Software Inc. -1997) software limitations on choice set size, each destination-county record was randomly assigned a 10-choice subset, out of the 254 origin options. These subsets included the destination county, and McFadden (1978) has shown this to provide consistent parameter estimates.. The extended RUBMRIO model results predict 10.8 million daily work (round-) trips by Texans, which is reasonably close to the 9.1 million Census-recorded work trips. In addition, the predicted cross-county commuting percentage of 23% is close to the 21% Census value.

3.2.3. *Shopping Trips*

Beyond businesses trading with one another and purchasing household labor in the form of workers, households purchase goods from businesses, particularly from those in the retail trade and services sectors. In these transactions, household members usually undertake the requisite transport and a round-trip is generated.

Shopping (round) trips generated per zone are derived from household consumption (Eq. 12), assuming an average purchase value per, as well as an even year-round trip distribution (Eq.13) and a single available mode (highway).

$$ch_j = \sum_n (X_j^n \times a(n,17,j)) \qquad [12]$$

$$hhtrip_j = ch_j \times TPD/365 \qquad [13]$$

where ch_j is the households' consumption in zone j, X_j^n is the production of commodity *n* in zone *j*, and *a (m,17,j)* is the appropriate technical coefficient (where sector 17 corresponds to households). In Eq. 17, *TPD* is the number of trips per dollar (inverse of the average purchase value per trip, which is estimated to be $44[12]), and $hhtrip_j$ is the number of daily household shopping (round) trips generated by those residing in zone *j.*

As noted on Eq. 14, shop trips are allocated to different counties using a logit model. This model was calibrated with Austin Travel Survey (ATS) data on home-based non work trips, and shortest path distances provided by TransCAD (Calipper Corp. 2000).

$$HHTrip_{ij} = hhtrip_i \times \frac{\exp(\delta \times d_{ij})}{\sum_j \exp(\delta \times d_{ij})} \qquad [14]$$

$HHTrip_{ij}$ is the number of shop trips between zones i and j, d_{ij} is interzonal distance, and δ is the logit-model distance-sensitivity parameter. According to these assumptions, most predicted shop trips (95%) are intrazonal. This is a sensible result, considering that the ATS data indicate 92% of shop trips to be under 20 miles, and 99% to be under 40 miles (and Texas counties average 1040 square miles in area).

3.3. Congestive Feedbacks

In order to consider the trade-pattern impacts of roadway congestion, an iterative feedback with TransCAD (Caliper Corp. 2002) was performed. The linkage consists in an update of the table originally containing the free-flow shortest path distances between all zones. A distance "updating factor" results from the predicted changes in the shortest path travel times after the network is loaded with the trips generated by the RUBMRIO model. TransCAD performs the route assignment, and computes the new (shortest path) travel times; the ratios of these to the original (free-flow) times are the updating factors. All distances are scaled up by these factors, and the RUBMRIO model is re-run with the "congested" distances. Most of the updating is performed by TransCAD, and coded in GISDK, a feature that automates procedures in such software. The process is repeated until convergence.

The NHPN (FHWA, V7.0) was used for every TransCAD Step. The network link capacities were estimated according to HCM procedures (FHWA 2000). Free-flow speeds were computed based on speed limits, according to the NCHRP Report 387. Speed limits were approximated according to link characteristics, such as road surface type, presence of medians, and access control, using values suggested by the FHWA (FHWA, 2002 [Table 4.4]). Dummy connectors with infinity capacity were created to link county and non-Texas state centroids, and to link the locations of export ports to the main network. When computing the shortest path times, intrazonal travel times (t_{ii}) were obtained as a percentage of the average of the travel times to three bordering zones.[13]

The applied procedure leads to general congestion and other interesting results. The ability to obtain more accurate results is primarily impacted by two factors: (1) Most of the trips generated by the RUBMRIO model are intrazonal (intracounty) trips, and TransCAD does not assign these trips to the network. Therefore, even when the intrazonal travel times change due to network traffic loads that impact routes to the nearest three zones, the intrazonal trips do not contribute to local congestion. Clearly, this is not a realistic assumption, particularly at the scale of counties. (2) The use of dummy connectors generates substantial congestion on nearby links, distorting the congestion pattern. (3) All zonal production (or port/state consumption) leaves (or reaches) the county via a single point, augmenting the previous effect.

3.2. Land Use Constraints

The original RUBMRIO model allowed for any level of production, which then may exceed production zone capabilities. This work explores the process for limiting production and housing via land availability. Land use constraints in many forms can enhance the model's conceptual approximation of a real behavior, and some interesting results may arise.

The proposed approach compares available land to production and local labor needs, based on maximum land use intensities, for industries and households. Zonal land requirements for the specified production levels can be computed according to the right side of Equation 15:

$$Area_j \geq \sum_m \left(\frac{jobs_j^m}{WD_{\max}{}^m} + \frac{\phi \times w_j}{HD_{\max}} \right) \qquad [15]$$

Where $Area_j$ is the county area, $WD_{\max}^m$ is the maximum allowable job density for industry *m*, $HD_{\max}$ is the maximum allowable household density, and ϕ is the number of households per worker. $jobs_j^m$ is the number of jobs generated by industry *m* in zone *j* (as noted on Eq.9), and w_j is the number of workers residing in zone *j*, computed as $w_j = \sum_{i,m} worktrips_{ij}^m$

County land areas can be obtained from TransCAD (Caliper Corp. 2002). The number of workers per household was set to 0.808, based on 2000 Census data. Krishnamurthy and Kockelman's (2003) examination of ultimate densities for Austin, Texas suggests maximum densities of 50 jobs per acre and 15 households per acre (assuming pure industrial and residential uses, respectively). However, these maximum densities were developed for traffic analysis zones, and it is likely that lower densities apply at the level of an entire county[14], and further research is needed. The model code can permit industry-specific density capacities.The proposed algorithm modification for land constraints is based on Zhao and Kockelman's (2003) proof of the RUBMRIO model's price and flow solution independence. This result allows one to incorporate land-use constraints as an iterative re-distribution of trade flows and production levels, given the final model prices.

The presence of counties for which Eq. 15's inequality is not satisfied (i.e., the presence of overloaded zones) indicates an infeasible predicted trade pattern. New trade patterns can be generated using an iterative process, which retains the equilibrium prices and the commodity flows originating in the overloaded zones, after proportionally reducing the latter to meet the area constraint (Eq. 16).

As noted, all flows originating in the overloaded zones are proportionally reduced (Eqs. 17a, 17b and 17c), and the flows from non-overloaded zones to export ports and other states are re-computed (Eq. 18a and 18b). The iterative solution of Eqs. 19 and 20 produces new interzonal trade patterns. (These are consistent with Zhao and Kockelman's (2003) fixed-point RUBMRIO algorithm formulation).

$$\frac{A_j}{\sum_m w_j^m \left(\frac{1}{WD_{\max}{}^m} + \frac{F}{HD_{\max}} \right)} = R_j \qquad [16]$$

$$Y_{ik}^m (\forall i \in \mathrm{Max}O) = R_j \times Y_{ik}^m \qquad [17a]$$

$$Z_{is}^m (\forall i \in \mathrm{Max}O) = R_j \times Z_{is}^m \qquad [17b]$$

$$X_{ij}^m (\forall i \in \mathrm{Max}O) = R_j \times X_{ij}^m \qquad [17c]$$

$$Y_{ik}^{m}(\forall i \notin \mathrm{Max}O) = \left(Y_k^m - \sum_{j \in MaxO} Y_{jk}^m \right) \frac{\exp(U_{ik}^m)}{\sum_i \exp(U_{ik}^m)} \quad [18a]$$

$$Z_{is}^{m}(\forall i \notin \mathrm{Max}O) = \left(Z_s^m - \sum_{j \in MaxO} Z_{js}^m \right) \frac{\exp(U_{is}^m)}{\sum_i \exp(U_{is}^m)} \quad [18b]$$

$$X_{ij}^{m}(\forall i \notin \mathrm{Max}O) = P_{ij}^m \sum_r X_{ij}^m \quad [19]$$

$$X_{ij}^{m}(\forall i \notin \mathrm{MaxO}) = P_{ij}^m \times (\sum_n (a_j^{mn} \sum_r X_{jr}^n) + \sum_k Y_{jk}^m + \sum_s Z_{js}^m) \quad [20]$$

where m and n index industries, i, j and r index zones, and k and s index export ports and other states, respectively. P_{ij}^m is the probability of acquiring commodity m in zone i and consuming it in zone j, computed as $P_{ij}^m = \dfrac{\exp(U_{ij}^m)}{\sum_i \exp(U_{ij}^m)}$

If the new trade pattern solution contains new overloaded zones, the procedure is repeated, adding these overloaded zones to the previous set.

4. APPLICATION SCENARIOS

This study applies the extended RUBMRIO model to simulate the effects of changes in demand for Texas products and supply of transportation infrastructure, as well as changes in technology. The resulting production levels and trade flow patterns are computed, and the revised and base cases are compared.

4.1. Domestic Demands Effects

Domestic demands account for 52% of the final demand that drives Texas economy in this study framework. Changes in the amounts and nature of these demands can impact the Texas economy in a variety of ways.

The effects of different domestic export types were examined by changing demands across sector and location. Eqs. 21 and 22 were used to compute and compare the marginal differences in internal trade values and labor expenditures per dollar change in domestic export demand.

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

$$= \frac{\sum_{i,j,m} x_{ij}^{m'} - \sum_{i,j,m} x_{ij}^{m0}}{Y_k^{m'} - Y_k^{m0}} \quad [21]$$

$$\text{Value Added Multiplier} = \frac{\text{change in labor expenditures (\$)}}{\text{change in a specific commodity's export (\$)}}$$

$$= \frac{\sum_{i,j} x_{ij}^{HH'} - \sum_{i,j} x_{ij}^{HH^0}}{Y_k^{m'} - Y_k^{m^0}} \qquad [22]$$

4.1.1. ***Commodity Type Effects***

The simulated scenarios effectively consider the effect of a $1 increase in demand for each commodity group represented in the CFS. Total flow multipliers ranged from $4.2 to $5.3 across sectors (Table 3), with greatest impacts resulting from changes in demand for Sector 1, 7, and 8 commodities (Agriculture, Industrial Machinery and Equipment, and Fabricated Metal Products). The value-added multipliers follow the same trend, with values ranging from $1.1 to $1.7. These results are consistent with Jin et al.'s (2003) identification of the most vital economic sectors.

4.1.2. ***Demand Location Effects***

Instead of allowing demands to vary across each of 49 states, nine different state groups were examined, according a CFS classification. Total demand was increased by $1000 for each commodity group, and the resulting trade-based and value-added multipliers (exhibited on table 3) ranged from 3.9 to 5.8 and from 0.5 to 2.1 respectively. New England and Middle Atlantic States were found to exert the greatest total effects, sharing values of $5.8 and $2.1 for trade-based and value-added multipliers, respectively.

4.2 The Effects of Variations in Technical Coefficients

To simulate possible *improvements in production* technologies, all technical coefficients expect for those on labor were reduced by 20%. Leakages through purchases of goods from other states were held constant. In order to maintain a constant 1.0 column sum (of technical coefficients), such reductions in input purchase requirements require that the share of labor expenditures then increase. This type of scenario represents a situation in which new technologies allow for a more efficient use of the available resources, increasing industry profits (which are included in the value-added). Thus, technical coefficients were reduced across all industries and counties, and the effects of the changes were compared in terms of the percent modifications in the amount of internal trade and total value added. These are shown in Tables 4 and 5. Clearly, trading falls, as inputs become less necessary, with the northern and eastern regions benefiting through profits (which may be distributed in the form of wages).

Improvements (reductions) in technical coefficients were also made industry-specific and their results examined. These simulations indicated that the effects differ across industries. Sectors 9, 5 and 10 (Electronic and Electric Equipment, Chemical and Allied Products and Industrial Machinery and Equipment) exhibited the greatest impacts, with predicted value-added increases of 3.14%, 2.49% and 2.05%, respectively. The total intermediate trade flows follow a similar trend, increasing a 1.39% and a 0.99% when the technology improves in just sectors 5 and 8, respectively. Even though such industries are consuming fewer intermediate inputs, the results suggest that the resulting increases in labor expenditures/value added can propel certain sectors of the State economy.

A scenario also was examined where technical coefficients were reduced by county group/State region. The resulting impacts differ notably in magnitude and direction. These results can be explained by original values of the technical coefficients as well as by the production levels on the counties (which are in turn affected by their location). For example, technology improvements in the northern and western regions resulted in increases in total value added (5.3% and 7.6%) and internal trade (0.4% and 0.6%). These counties originally had low value-added technical coefficients (with values ranging from just 0.025 to 0.054, compared to 0.76 in other county groups). An increase on the value added per unit results in a larger economy.

Southern, eastern and north-eastern counties exhibited a decrease in both total value added and total internal trade when more efficient technologies were applied there. This apparently inconsistent result can be explained by the fact that these counties provide most of the total final demand, so changes in their technology result in major reductions in intermediate demand, which is not counteracted by increases in household purchases (through increases in values added). Moreover, the percent increase in the value-added technical coefficient is small, because the original values of this coefficient are already so large for these counties.

5. CONCLUSIONS

Integrated land-use and transportation system modeling is a highly complex endeavor, but it can provide a very valuable project and trade assessment tool for decision makers. This paper explored the application of a RUBMRIO model to Texas's 254 counties, with trade and production driven by commodity export demands. The extended RUBMRIO model developed here considers domestic demands (from other U.S. states) and loads the highway network with truck, commute, and shopping trips; it recognizes how to limit regional development according to land availability, and to feedback congestion information to influence trade patterns.

The inclusion of domestic demand as a driver of the Texas economy considerably improved model estimation of Texas production, relative to a scenario where the State economy was driven purely by foreign export demand. The model responds to shifts in domestic demand levels by both product and location. Impacts are consistent with simpler trends noted by Jin et al. (2003), regarding the influence of different commodity types on production, labor expenditures and trade flows. Effects differed substantially depending on the location of the demand changes.

If more detailed data becomes available, regarding county of origin and mode of transport for meeting domestic export demands, more precise results can be achieved. Consideration of the entire U.S highway and railway networks, in order to link others states to Texas' networks, also may be desired, along with the explicit incorporation of other transportation modes (such as pipeline and air).

The model resulted in sensible predictions of the impacts of technology changes. The outcomes reinforce the stature of Texas' most important industries. And they illuminate the differences in production technologies across Texas' counties, providing interesting insights on the possible implications of such differences.

This work provides a solid framework to capture congestion impacts on trade patterns due to transportation cost increases. The resulting work trips estimates are remarkably close to Census data, and shopping trip distances traveled are consistent with the ATS data. Better estimates of the commodity truck trips should be possible when using a finer subdivision of the economy (at least in the trip-generating stage); this would allow the analyst to recognize fundamental differences in trip generation by industries currently included in the same category.

It also should be helpful to apply the value-to-truck conversion factors based on shipped-distance. Estimates of network use by the Service, Transportation and FIRE sectors are needed as well.

Network refinements in the vicinity of county centroids, and allowance for several centriods per county should enhance prediction of congestion patterns. And a finer spatial zoning system is needed to evlalute the impacts of specific network modifications, such as changes in cost and infrastructure availability.

The present paper also provides a structure for recognizing land use limitations on development and production. Further research to compute better estimates of land availability and land-use intensity values (recognizing the differences among industries) is desirable.

In summary, RUBMRIO models can prove a powerful tool for policy makers, transportation planners, economists, and developers. And several extensions adopted here incorporate new capabilities, permitting greater realism in behavioral results. The next step is to make the model even more realistic. Given appropriate data sets (for calibration) and more flexible production technology specifications (for trade-offs between various factors of production), one can make wages, rents, profits and final demands truly endogenous to the model, responsive to prices for substitute goods and service throughout Texas – and beyond the State's borders.

ENDNOTES

[1] In the present work, Ling et al's (2003) zone system and economic sector classification are used; however, ports representing less than one percent of total foreign export demand were excluded.
[2] If fixed price increases (to generate profits, for example) are included in sales prices, across each industry, model calibrations and applications will not be affected.
[3] The other 48%, as mentioned earlier, comes from exports to foreign countries.
[4] The U.S. Bureau of Economic Analysis (BEA 2003) estimated Texas GSP to be $742 million in the year 2000. This is roughly twice the labor expenditures (which include profits) predicted by the model. In addition to human capital contributions, GSP includes the value of any raw materials used in production and found in Texas, such as oil, gas, minerals, forests, and soil nutrients (which contribute to agricultural production).
[5] Bowie and Webb Counties also exhibit a high production level, according to the model predictions (18% and 8% respectively). This may be a consequence of being located very close to points where the dummy connectors to other U.S. States meet the Texas highway network.
[6] Trucks are converted by a factor of 2.0 to equivalent passenger car units.
[7] The difference may be due to at least two factors: (1) The *TCF* s are not completely accurate, because they are computed for aggregate sectors. This can be overcome by subdividing sectors into more diverse commodity groups. (2) The conversion process assumes that the entire industry's output translates into truck trips, which may be inaccurate for certain industries.
[8] These distance categories are the following: Local (< than 50 miles), Short distance (50 to 100 miles), Medium/Short Distance (100 to 200 miles), Medium/Long Distance (200 to 500 miles) and Long distance (over 500 miles).
[9] Work by Figliozzi (2002) suggests a higher percentage (12%) of empty trips, but VIUS results were used here, in order to maintain data consistency.
[10] For simplicity, the Texas application of this model refers to 5 zone groups. Within each of these five groups, the same factors apply to every zone. See Jin et al. (2003) for further details.
[11] Other trade flows in this model have railway as a transportation option. However, this mode and network would not be realistic for Texas commuters. Of course, transit and other personal modes of travel may be realistically added, particularly for intra-county travel choices. Overall, the result of this simplification is probably minimal: The automobile mode dominates personal travel in Texas, however, claiming 96% of such commutes in the 2000 Census.
[12] This $44-per-trip value was estimated by dividing total Personal Consumption Expenditures in 1990 (Bureau of Economic Analysis[BEA], 2001) by the number of U.S. households that same year (U.S. Census Bureau, 2001), and by the yearly number of shopping and personal/family business trips per household (as provided by the Nationwide Personal Transportation Survey or NPTS [FHWA,1999].)
[13] This is one of two TransCAD intrazonal travel time options. The other is a constant travel time option, which neglects congestion.
[14] Entire counties need better land use balance than small neighborhood zones. For example, open space, schools, and civil infrastructure are needed to support human communities, and cannot be located too far away. In contrast, a small zone may be completely developed as a single use.

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FIGURE 1. The RUBMRIO Model

Utility of purchasing commodity *m* from zone *i* and transporting it to *j*

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

Initial values of p_i^m are set to equal zero.

Flow of *m* from zone *j* to export zone *k*

$$Y_{ik}^{m} = Y_k^m \frac{\exp(U_{ik}^m)}{\sum_i \exp(U_{ik}^m)}$$

Production of *m* in zone *i*

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

Initial values of X_{ij}^m are set to zero.

Consumption of *m* in zone *j*

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

Flow of *m* (as an intermediate input) from zone *i* to zone *j*

$$X_{ij}^{m} = C_j^m \frac{\exp(U_{ij}^m)}{\sum_i \exp(U_{ij}^m)}$$

Average **Input Cost** for commodity *m* in zone *j*

$$c_j^m = \frac{\sum_i X_{ij}^m \times U_{ij}^m}{\sum_i X_{ij}^m}$$

Output Price of commodity *n* in zone *j*

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

Note: *i*,j are indices for zones/counties; *k* is the index for export zones and *m,n* stand for economic sectors. $\lambda^m, \beta_0^m, \beta_{highway}^m, \beta_{railway}^m$ are the Logit model parameters, A_j^{mn} and A_{0j}^{mn} are the technical coefficients with and without import considerations (see Jin et al.,2002) respectively. $d_{ik,railway}, d_{ik,highway}$ are the distances between counties.

TABLE 1: Description of Economic Sectors in the Model

Sectors	Description	IMPLAN Code	SIC Code (2-digit)	SCTG Code
1	Agriculture, Forestry, & 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 & Kindred Products	58~103	20	2, 5~9
5	Chemicals & 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 & Equipment	307~354	35	34
9	Electronic & Electric Equipment	355~383	36	35
10	Transportation Equipment	384~399	37	36 & 37
11	Other Durable & 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, & Real Estate)	456~462	60~65	
16	Services	463~509	70~87	
17	Households			
18	Government			

Note: SIC stands for Satandard Industrial Classification, and SCTG stands for Standard Classification of Transported Goods.

TABLE 2. Domestic Demands

Sector Number & Name		Domestic Demand ($2000)
1	Agriculture, Forestry, & Fisheries	$746,332,541
3	Mining	2013895861
4	Food & Kindred Products	6906034640
5	Chemicals & Allied Products	33273537150
6	Primary Metals Industries	6877623738
7	Fabricated Metal Products	5662511314
8	Industrial Machinery & Equipment	8695921466
9	Electronic & Electric Equipment	52085925182
10	Transportation Equipment	4425544350
16	Other Durable & Non-Durable Manufacturing	8239161580
		$1.28926E+11

Note: The 1997 CFS trade values have been inflated to 1997 values (in order to match the foreign export data year) based on an assumed 3% yearly inflation rate.

TABLE 3. Multiplier Effects of Domestic Demands by State Groupings

State Group	Number of States in Group	Trade-based Multiplier	Value-added Multiplier
New England States	6	**5.8**	**2.1**
Middle Atlantic States	3	**5.8**	**2.1**
East North Central States	5	5.4	1.8
West North Central States	7	4.1	0.7
South Atlantic States	9	5.7	**2.1**
East South Central States	4	5.5	2.0
West South Central States	3	5.1	1.6
Mountain States	8	3.9	0.4
Pacific States	5	3.9	0.5

TABLE 4. Effects of Changes in Production Technologies by County Groupings

County Group	%Change in Total Value Added	%Change in Intra-Texas Trade
North	5.33%	0.42%
East	7.59%	0.64%
North-West	-12.57%	-13.19%
West	0.75%	-3.47%
South	-6.10%	-7.43%

TABLE 5. Effects of Changes in Production Technologies by Industry

INDUSTRY GROUP	%Change in Total Value Added	%Change in Intra-Texas Trade
Agriculture, Forestry, and Fisheries	0.20%	0.07%
Mining	1.33%	0.66%
Construction	1.24%	0.31%
Food and Kindred Products	0.93%	0.32%
Chemicals and Allied Products	2.79%	0.99%
Primary Metals Industries	0.30%	0.11%
Fabricated Metal Products	0.40%	0.69%
Industrial Machinery and Equipment	2.05%	1.35%
Electronic and Electric Equipment	3.14%	0.14%
Transportation Equipment	0.69%	0.30%
Other Durable and Non-Durable Manufacturing	2.82%	1.04%
Transportation, Communications, & Utilities	4.78%	1.69%
Wholesale Trade	3.92%	1.44%
Retail Trade	1.95%	0.74%
FIRE (Finance, Insurance, and Real Estate)	4.77%	1.71%
Services	6.21%	2.21%

TABLE 6. Truck Trip Generation by Industry

Sector # & Name		VIUS	RUBMRIO
1	Agriculture, Forestry, & Fisheries	11.17%	12%
3	Mining	34.36%	13%
4	Food & Kindred Products	7.44%	16%
5	Chemicals & Allied Products	15.27%	15%
6	Primary Metals Industries	0.87%	5%
7	Fabricated Metal Products	0.49%	3%
8	Industrial Machinery & Equipment	1.61%	12%
9	Electronic & Electric Equipment	1.20%	5%
10	Transportation Equipment	0.19%	5%
16	Other Durable & Non-Durable Manufacturing	27.39%	13%