RELU-TRAN: Applications and Challenges*

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Abstract

RELU-TRAN (Regional Economy Land Use and Transportation) is a spatial computable general equilibrium (CGE) model with endogenous road congestion, housing and labor markets and real estate development consistent with microeconomic theory. The model has been calibrated and used for the Chicago MSA and is currently being implemented for the Greater Los Angeles metropolitan area. So far the model has been used: (i) to examine the impact of an increase in the price of gasoline on travel and location decisions in the Chicago MSA; (ii) to study how travel time, gasoline consumption and automobile emissions would evolve over time as the area grows in population and land area and as employment continues to disperse into the suburbs. The model is also being used: (iii) to evaluate the effects of cordon tolling, of road congestion versus a tax on gasoline; and (iv) to examine the effects of an urban growth boundary. The main findings from these applications of RELU-TRAN are discussed and some challenges in the model's further application are identified.

Keywords： CGE, urban economics, policy

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1. Introduction

RELU-TRAN is a spatial computable general equilibrium (CGE) model. CGE models are structural as opposed to reduced form economic models. Hence, they are based solidly on microeconomic theory (Anas and Liu, 2007). RELU-TRAN simulates the workings of key urban markets and their interactions with each other in a manner that is defensible from the point-of-view of economic science. In the model, consumers choose their residential-workplace locations and the fuel economy of their cars, their housing space, labor supply and their consumption of goods and services which entail shopping trips. Consumers also choose their destination, mode and route for each work and non-work trip. The congestion is determined endogenously. Producers, developers and landlords are the other economic agents in the model.

The markets modeled are:

i) The market for land and existing (already built) floor space in each model zone, where the built floor space can be residential or commercial-industrial;

ii) The market for labor in each model zone;

iii) The "generalized retail" market in each model zone which is the market in which households acquire goods and services from the firms that provide these goods and services and also from government agencies;

iv) The markets in which goods and services are exchanged between firms engaged in production within the region, that is the procurement of intermediate inputs by firms in different industries from other firms within and by importing from beyond the region, and the export of their outputs beyond the region.

v) All of the above markets are connected by the regional mass transit and road networks. Therefore, the monetary cost and travel times that occur on these networks play key roles in determining how these markets clear, reaching a new equilibrium. Transportation is thus a key factor in determining indirectly the response of wages in the labor markets, prices in the goods markets and rents and market prices of real estate floor space and for developable land in the land markets. How all these markets interact and the structure of the RELU-TRAN solution algorithm are described in Anas and Liu (2007).

The purpose of this brief article is to summarize the economic and policy analytic results from the application of RELU-TRAN2 to the Chicago MSA. In the first of these studies (described in section 2), RELU-TRAN2 was used to examine the impact of an increase in the price of gasoline on travel and location decisions in the Chicago MSA (Anas and Hiramatsu, 2011). In section 3, a second study is described in which the model was used to study how travel time, gasoline consumption and automobile emissions would evolve over time to the year 2030 as the Chicago MSA grew in population and land area (Anas, 2010). In section 4, we describe the results of a study to evaluate the effects of cordon tolling and of tolls on road congestion versus a tax on gasoline in the Chicago MSA (Anas and Hiramatsu, 2010). In section 5, we describe a currently ongoing study in which the model is being applied to understand the effects of imposing an urban growth boundary to restrict aggregate land development in the outer suburban areas of the MSA.

2. Effects of the gasoline price

RELU-TRAN2, a spatial CGE model of the Chicago MSA was used to understand how gasoline use, car-VMT, on-the-road fuel intensity, trips and location patterns, housing, labor and product markets respond to a gas price increase. This application is described in detail in Anas and Hiramatsu (2011). For this purpose the model was calibrated to the base year of 2000. The approach in deciding on the model's parameters was a mixture of fixing some parameters at reasonable values and calibrating others in such a way that the model's elasticity relationships concerning location demand, housing demand and supply and the labor market are within reasonable ranges of estimates by various econometric studies in the literature.

Since RELU-TRAN2 is an extension of RELU-TRAN that includes choice among five car-types differing by TFI (recall Figure 2) and precise calculations of gasoline use, VMT, MPG and speed, it required a calibration adjustment that draws on additional data from the Illinois Travel Statistics on these aggregates (IDOT, 2000). In particular, data targets for RELU-TRAN2 to be matched by the calibration were constructed as follows: The data were used to target the number of jobs and residents by zone, the work-trip pattern by mode of commuting and the average travel speed. The vehicle miles traveled (VMT), gasoline consumed and miles per gallon (MPG) targets were constructed from the Illinois Travel Statistics (IDOT, 2000) as annual totals for the year 2000. This source gives region-wide VMT as 55,923 million miles/year composed of 15,820 million miles/year on interstates and 40,103 million miles/year on principal and minor arterials, collectors and local roads and streets. Using the same data set, we took 90% of these in an effort to exclude miles of travel generated by trucks (since they are not modeled in RELU-TRAN2). Then, our targets for total, major-road and local-road VMT per day were 137.9, 39.0 and 98.9 million miles, respectively. The calibrated model simulating an equilibrium for the base year predicts these as 132.51 (3.9% less), 32.71 (16.1% less) and 99.80 (0.9% more) respectively.

From the Illinois Travel Statistics, aggregate motor fuel consumption for the State of Illinois in the year 2000 was 4,329 million gallons. Chicago's consumption of fuel is estimated as 61% of this and 54.9% after the adjustment for trucks or 6.51 million gallons per day. The calibrated model predicts 6.17 million gallons per day or 5.2% less. The Illinois Travel Statistics also give the average miles per gallon that is the fuel economy that applies to cars in the region as 21.2 miles per gallon. The calibrated model predicts 21.48 or 1.3% more. The model's predictions were also evaluated by how well they fit the zonal location distribution pattern, by computing the average of absolute value percentage errors. Thus, for example, given equilibrium rents and wages and zone-to-zone travel times predicted by the model, the equilibrium distribution of employed residents by zone is predicted with an average error of 6.1%, and the distribution of jobs with 4.9%. The distribution of work trips is predicted with an average error of 5.9% and of trips by car with 6.1%. Car type choices are predicted with an average error of 5.3%.

We found a long-run elasticity (with congestion endogenous) of -0.081, keeping constant car prices and the technological fuel intensity of car types but allowing consumers to choose from available car types. By running the model in stages, we are able to decompose this elasticity into parts that are due to various market adjustment processes. So we found that 43.2% of this long run elasticity is from switches to public transit; 14.8% from trip, car-type and location switches; 38.3% from price, wage and rent equilibration, and 4% from building stock changes. 79.3% of the long run elasticity is from changes in car-VMT (the extensive margin of travel demand) and 20.7% from savings in gasoline per mile (the intensive margin); with 83% of this intensive margin from changes in congestion and 17% from the substitution of less fuel intensive cars. An exogenous trend-line improvement of the technological fuel intensities of the car-types available for choice raises the long-run response to a percent increase in the gas price from -0.081 to -0.251. Thus, only 1/3 of the long-run response to the gas price stems from consumer choices and 2/3 from progress in fuel intensity. These results are shown in Table 1 and Figure 1 which are borrowed from Anas and Hiramatsu (2011).

Table 1 : Compositional analysis of the long run elasticity (Anas and Hiramatsu, 2011)

Elasticity with respect to gasoline price of	**Base values**	**Elasticity by stage of adjustment (each stage includes earlier stages)**								
		Short-run				***Long-run***				
		1 *Routes*	**2** *Modes*	**3** *Trips*	**4** *Car fuel economy*	**5** *Resid. locat.*	**6** *Job locat.*	**7** *Price adjust.*	**8** *Stock adjust.*	**9** *TFI improves 2%*
GAS (*mill. gall./day*) **(a)**	6.169	−0.000046	−0.035	−0.042	−0.043	−0.046	−0.047	−0.078	−0.081	−0.251
VMT *(mill. mi./d)* **(b)**	132.5	−0.000084	−0.027	−0.033	−0.033	−0.036	−0.037	−0.061	−0.064	−0.041
GPM (gall./mi.) **(c)**	0.047	−0.000038	−0.008	−0.009	−0.010	−0.010	−0.009	−0.017	−0.017	−0.211
Speed (mi./hr)	21.7	0.000012	0.020	0.023	0.023	0.024	0.025	0.039	0.040	0.025
TFI index (*gall./mi.*) (VMT-weighted) **(d)**	0.0405	−0.000003	−0.001	−0.001	−0.002	−0.002	−0.002	−0.003	−0.003	−0.202
Fuel cost per mile (fuel price x GPM)	0.074	1.000041	0.991	0.990	0.989	0.989	0.990	0.981	0.981	0.768
Composition by extensive margin (VMT), intensive margin (GPM); composition of intensive margin by congestion and TFI										
VMT effect (extensive margin) in price elasticity of GAS **(b)/(a)**		1.826	0.777	0.785	0.760	0.786	0.797	0.784	0.793	0.163
GPM effect (intensive margin) in price elasticity of GAS **(c)/(a)**		−0.826	0.223	0.215	0.240	0.214	0.203	0.216	0.207	0.837
TFI effect in GPM **(d)/(c)**		−0.079	0.101	0.110	0.227	0.241	0.248	0.165	0.170	0.957
Congestion effect in GPM **[(c)-(d)]/(c)**		1.079	0.899	0.890	0.773	0.759	0.752	0.835	0.830	0.043

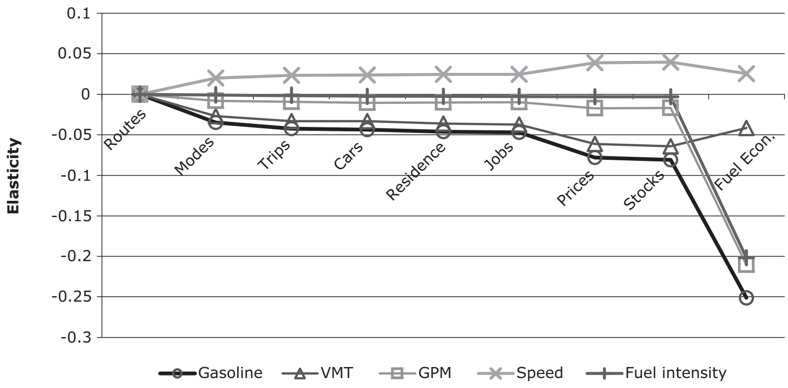


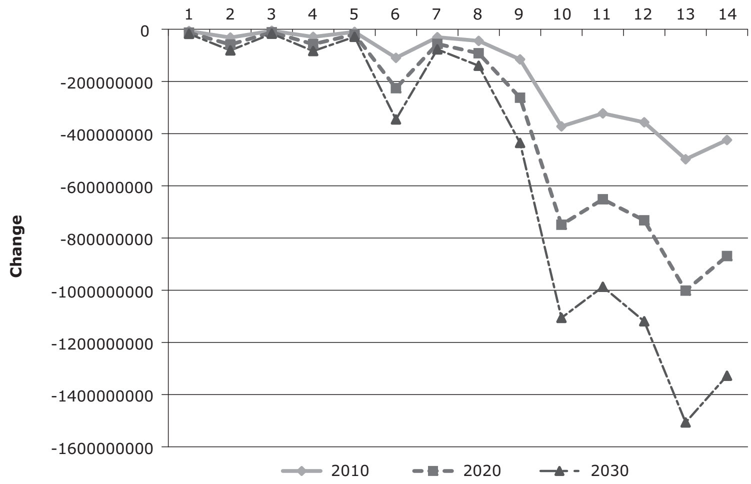
Figure 1: The elasticity of gasoline, VMT, GPM, speed and fuel intensity by stage of adjustment (Anas-Hiramatsu, 2011)

By running an additional simulation we captured the effects on gasoline demand, VMT, trips etc. from changes in the gasoline price in trend-line fuel intensity improvements and in the prices of cars in this period. In the period 2000-2007, real gasoline prices rose 53.7%, the average car fuel intensity improved 2.7% while car prices fell about 20%. The model predicts that from these changes, but keeping other things constant, gasoline consumption in this period would have fallen by 5.2%.

3. Sustainability of sprawl and travel time

In a second study RELU-TRAN2 was applied to simulate the growth of the Chicago MSA from 2000-2030 (Anas, 2010). As the metropolitan area grows from 2000 to 2030 according to the regional population forecasts supported by a forecast of growth in exports, in national wages, gasoline prices etc. the interdependent suburbanization of jobs and residences increases suburban land development and sprawl, but keeps the per-worker travel time in car commuting very stable. While congestion per road mile increases on average as more jobs and residences suburbanize, the average road distance traveled between job and residence and home and shop decrease as the decentralization of firms and workers' residences adjust to the higher congestion per mile. A number of sensitivity tests reported show that the results are robust in the face of changes in the baseline scenario. On the one hand, these results provide a theory based explanation of empirical observations made by others in the last twenty years. On the other hand, they provide the first empirical test of the predictions of theoretical models in which the locations of jobs and residences are interdependent and simultaneously determined. The results imply that suburban development in the U.S., contrary to popular expectations, is likely to remain sustainable in the face of additional metropolitan decentralization in the future.

These results are highlighted here in Figures 2-4. Figure 2 shows the progress of urban sprawl over the three decades whereas Figure 3 shows the slight decrease in per capita gasoline, per capita VMT etc. over the same time span and Figure 3 the stability of travel time per capita.



(Note: Horizontal axis numbers are model zones arranged roughly by distance from the center)

Figure 2: Decrease in undeveloped land or urban sprawl in the Baseline simulation 2000-2030 (Anas, 2010)

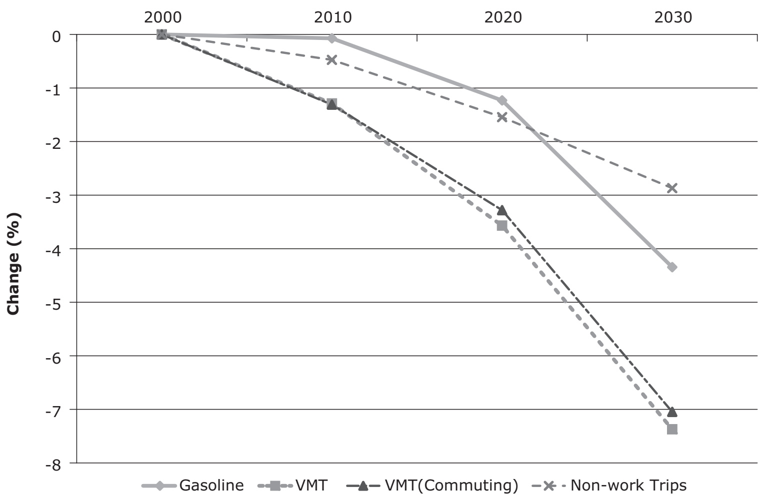


Figure 3: Percent change in per-capita driving-related variables in the Baseline simulation 2000-2030 (Anas, 2010)

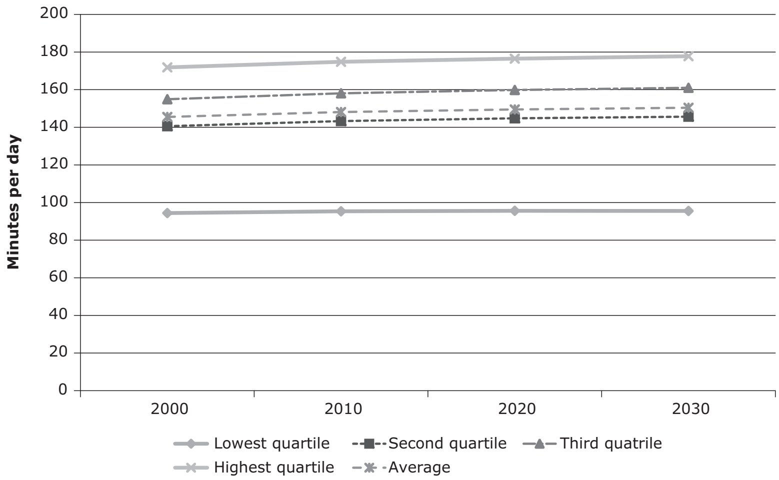


Figure 4: Per capita travel time in the Baseline 2000-2030 (Anas, 2010)

4. Congestion pricing policies

We have completed a third study. Preliminary results have been described in Anas and Hiramatsu (2010a). In this study, the impacts of anti-congestion policy on urban sprawl, fuel consumption and CO2 emission are analyzed using RELU-TRAN2, using the version calibrated to the Chicago MSA circa 2000 (see above). We model quasi-Pigouvian tolling of traffic congestion on all roads or only on major roads, versus (in each case) a revenue-neutral fuel tax per gallon of gasoline which increases the monetary cost of travel by 73% on average. The fuel tax reduces gasoline and CO2 by 18%, VMT by 15%, travel time by 11% and improves MPG by 3.3%. We also model a cordon toll for trips entering or crossing the CBD versus a CBD parking tax for trips terminating in the CBD.

Under the quasi-Pigouvian toll on all roads or the equivalent fuel tax, residential and job locations become more centralized in the CBD and the City of Chicago, but when only major roads are tolled there is a tendency for job and residence locations (and the implied commutes) to become more localized in the same zone. We find that when the cordon toll is low, jobs leave the CBD and relocate near suburban residences but some jobs move into the CBD under a revenue-equivalent tax on CBD parking. Under low levels of the fuel tax, residential and jobs locations are centralized in the CBD and the City of Chicago, but when the fuel tax becomes higher jobs and residences become more suburbanized.

We are currently refining this study specially with respect to cordon tolling. We are doing a comparison of three cordons of different sizes: a tight cordon around the Chicago CBD area (London style cordon), a cordon that encompasses the whole of the City of Chicago (Stockholm style cordon) and a cordon that encompasses both the city and the inner ring suburbs.

5. Urban growth boundaries

Urban growth boundaries (UGBs) are aimed at limiting the outward expansion of urban areas and are often proposed by planners as a means of containing urban sprawl, inducing urban compactness and intensifying the use of public transit. Economists have been critical of the impacts of UGBs, reasoning from basic principles that they raise rents and make housing within the boundary less affordable, that they increase traffic congestion within the boundary and might well cause economic activity to leave the urban area for other places. There exist some theoretical analyses of the effects of UGBs, but this paper is the first attempt to apply an empirical computable general equilibrium model, RELU-TRAN2, to a systematic analysis of the effects of UGBs. We use the model to evaluate the impacts of hypothetical UGBs imposed on the Chicago MSA's outer suburban ring. Varying the tightness of the UGB, that is increasing the amount of land excluded by the UGB from development, we can see how the UGB impacts the values of residential and non-residential buildings and their rents within the UGB. We can also see how wages, public transit use, road congestion, construction and demolition flows and commuting and other travel behavior within the MSA are affected. The tighter the UGB, the more negative the effect of the UGB on consumer welfare: the utility of each income quartile decreases monotonically with UGB tightness. The main reason for this is that the UGB increases rents significantly in the outer suburban ring, causing consumers to relocate inward in less attractive residence locations and in smaller housing units. From this preliminary investigation, we find that the UGB has negligible effects on transit use, congestion trip making and travel behavior, fuel consumption and CO2. These results are described in preliminary form in Anas and Hiramatsu (2010b). We are continuing to refine these results.

6. Challenges

The continual development of a model such as RELU-TRAN is challenging as there is a list of additional applications and methodological improvements that can be pursued. Here we will briefly discuss three that are on our agenda. These are: (i) the treatment of agglomeration economies; (ii) welfare analysis with taxation and redistribution; and (iii) dynamics.

6.1 Treatment of agglomeration economies

Agglomeration economies are cost reductions or productivity improvements that result from the spatial proximity of economic agents. A question that is frequently asked is whether RELU-TRAN treats agglomeration. The answer is that yes it does but there is more to do.

There are three layers of agglomeration. The first is that economic agents will locate in proximity to one another because they will seek to locate around natural or man-made in-homogeneities in space. In this case, a higher productivity may result because the spatial in-homogeneity imparts a benefit to each economic agent even though the agents may not benefit from being proximal to one another. An example, is exporting firms locating near a natural harbor or a man-made harbor facility. RELU-TRAN has two types of spatial in-homogeneities. One arises from the presence of transport networks which give rise to nodes of accessibility. A second arises from the fact that building space of one or another type is concentrated in various locations providing a reason why residential or business activity may also concentrate there.

The second layer of agglomeration arises from the fact that various economic agents engage in market interactions with one another. In RELU-TRAN various such interaction exist and are endogenous to the model. For example, consumer/workers locate close to firms which employ them and customers locate in good accessibility with respect to shops. Conversely, the firms need to be close to their workers and their customers. This interdependence between firms and consumers creates concentrations in space. Similarly, firms exchange inputs with one another, hence such firms must locate near others with which they interact and this in turn gives rise to spatial concentrations as well.

The third layer of agglomeration, not currently in RELU-TRAN, would arise from non-market interactions and externalities between firms and consumers, among consumer types and between firms. Anas and Kim (1996) which is a non-empirical spatial CGE model provided a framework for treating agglomerations arising from non-market interactions. As was well-demonstrated in that paper, multiple equilibria often arise from non-market interactions that are sufficiently strong. That is under the same parameter values there will be more than one equilibrium configuration of employment centers or any type of market concentration. It is on the agenda to add such interactions to RELU-TRAN and to explore whether the third layer of agglomeration is empirically significant on top of the first and second.

6.2 Welfare analysis with taxation and redistribution

The presence of taxes affect the performance in both equity and efficiency of the urban economy. In the applications discussed in sections 2-5 income, sales and property taxes were turned off. In the application of the model to congestion pricing (section 4), we imposed congestion tolls, cordon tolls or gas taxes in an environment free of other taxes. In addition, the revenues from these taxes were counted as part of the benefit of the anti-congestion policies. We are currently doing more thorough welfare analyses by redistributing the anti-congestion tax revenues but not necessarily in a first-best manner. It is in our agenda to do more thorough welfare analysis where the surplus or deficit from all taxes some of which are distortive and others such as Pigouvian taxes which are efficiency improving are redistributed optimally in either a first-best or a lower-best sense.

6.3 Dynamics

RELU-TRAN is a dynamic model. However, in the applications summarized in section1 and 3, 4 the dynamics occur in a stationary environment, a long run equilibrium. In this, the dynamics are limited to real estate development (Anas and Arnott, 1991, 1997). The developers build or demolish floor space under perfect foresight in the stationary state. The application of section 2 is not stationary but developers are treated as being myopic in their expectations of the future. In the future, we intend to treat in more detail dynamics in the non-stationary state under both myopic foresight and perfect foresight. Also, the addition of non-myopic behavior by consumers by the modeling, for example, of overlapping generations remains a challenge.

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