6

The Location Effects of Alternative Road-Pricing Policies

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Since the early 1970s, urban economists have recognized the importance of a general equilibrium model of the urban economy. Initially, however, they developed such models only for monocentric cities in which all jobs were assumed to stay in a central business district (CBD). Thus, although the analytical solution of the monocentric city model yielded many theoretical insights, it remained empirically inappropriate and difficult to justify in policy application. Early contributions to the general equilibrium model of a monocentric city included Mills (1972), Dixit (1973), and Sullivan (1986), who developed the most complete models all solved numerically.

A parallel line of developments that started in the early 1970s led to the National Bureau of Economic Research (NBER) urban simulation model (Ingram, Kain, and Ginn 1972; Kain and Apgar 1985; Kain, Apgar, and Ginn 1976, 1977, 1982) and the Urban Institute Model (Struyk and Turner 1986; Turner and Struyk 1983; Vanski and Ozanne 1978). These two urban simulation models were applied primarily to the study of housing market issues, but they did not

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treat in sufficient detail and microeconomic depth employment location, the relationships among industries and interindustry trade, the redevelopment of the building stock and the complexity of trip making, or the interaction between labor and housing markets. They also did not treat traffic congestion.

The general equilibrium theory of a polycentric city with dispersed employment is more recent. Such models have been developed for linearly shaped hypothetical cities, with jobs endogenously located anywhere in the city. The earliest version of such models, by Anas and Kim (1996), included traffic congestion and agglomeration economies: the weaker the agglomeration economies or the higher the traffic congestion, the larger the number of places to which jobs disperse in equilibrium. The effects of congestion pricing on job and residence location were studied by Anas and Xu (1999), and tolls and the urban growth boundary were compared in Anas and Rhee (2006). Cordon tolls have been studied numerically by Fujishima (2011), who applied the Anas-Xu model to a stylized version of Osaka, and by Anas and Hiramatsu (2012a), who applied the RELU-TRAN2 model to the Chicago metropolitan statistical area (MSA).

The RELU-TRAN computable general equilibrium (CGE) model (Anas and Liu 2007) is an empirically applicable model that is well grounded in microeconomics based on the theoretical structure of the Anas-Xu model. It includes real estate development and redevelopment under perfect foresight based on Anas and Arnott (1991, 1993, 1997). RELU-TRAN2 is an extension that includes gasoline consumption and the choice of vehicle type. Using RELU-TRAN2, the effects of the gas price on the urban economy were studied in Anas and Hiramatsu (2012b) and the effect of cordon tolling policies for the Chicago MSA in Anas and Hiramatsu (2012a). The purpose of this chapter is to report an empirical application of RELU-TRAN2 to the analysis of alternative road-pricing policies other than cordon tolling to reduce traffic congestion in the Chicago MSA. The model and its calibration are described and some simulation results are presented from the application of RELU-TRAN2 to assess the impacts of hypothetical road-pricing policies in the Chicago MSA.

Tolling the traffic congestion externality has two major effects on location patterns. First, workers are induced to move closer to employment centers to reduce travel distances over which the toll must be paid. Second, employers may decentralize and move closer to employees or customers to avoid paying higher wages to attract workers. Because job and residence locations are interdependent, the net effect is ambiguous. An important question, therefore, is how the net effect varies according to the specifics of a road-pricing policy. In the presence of public transit, these locational responses become relatively milder to the extent that drivers can avoid road charges by switching to transit.

This chapter focuses on the quasi-Pigouvian tolling of all major roads only, and of major and local roads only. Against these benchmarks, it compares the effects of a tax on gasoline that is revenue neutral with respect to each quasi-Pigouvian tolling. These policies are introduced and discussed in more detail, and the results of the simulations are presented.

The main focus is to understand the effect of road-pricing policies on the location of jobs and residences within the Chicago MSA, on urban wages and rents, and on real estate prices and land development. The issue is relevant to the inquiry about the impact of road pricing on central city revitalization and whether pricing centralizes or decentralizes land use, jobs, and population. Almost two decades ago, in 1994, a special report of the National Research Council debated the issue and concluded:

> Neither theory nor research on the relationship between the cost of transportation and urban development provides compelling evidence to support whether congestion pricing would have a centralizing or decentralizing effect. (Deakin 1994)

The Chicago simulations show that quasi-Pigouvian tolls can both centralize and decentralize the location of jobs and residences but that fuel taxes much more strongly centralize the location of jobs and residences. Under the quasi-Pigouvian tolling of only the major roads, jobs are weakly centralized in the CBD while a much stronger movement of jobs to the outer suburbs is also observed. Average wages, rents, and real estate prices increase under all of these policies. Urban sprawl, measured as the depletion of undeveloped land, increases under all policies, but there are significant differences among the policies. A conclusion that emerges from these results is that the road-pricing policies, and especially the fuel tax, can indeed help significantly concentrate jobs and population in the central city and toward the downtown and thus may help central city revitalization and the reduction of urban sprawl. This conclusion provides at least a first tentative answer to the 20-year-old controversy.

The following section explains the structure and calibration of the CGE model with a heavier focus on consumer behavior, including travel. More detailed descriptions of the model can be found in Anas and Liu (2007), and its calibration is covered in Anas and Hiramatsu (2012a, 2012b). The next sections of the chapter describe the road-pricing policies to be tested by simulation and discuss the results of the policy tests.

The RELU-TRAN CGE Model

RELU-TRAN is a CGE model, calibrated and tested for the Chicago MSA, described in Anas and Liu (2007).[1] In RELU-TRAN2, an extension of RELU-TRAN, the travel behavior of the consumer has been enriched by treating the choice of automobile type by fuel economy level and by adding equations that calculate gasoline consumption and carbon dioxide (CO_2) emissions from automobile travel (Hiramatsu 2010). In the model, the Chicago area is represented by

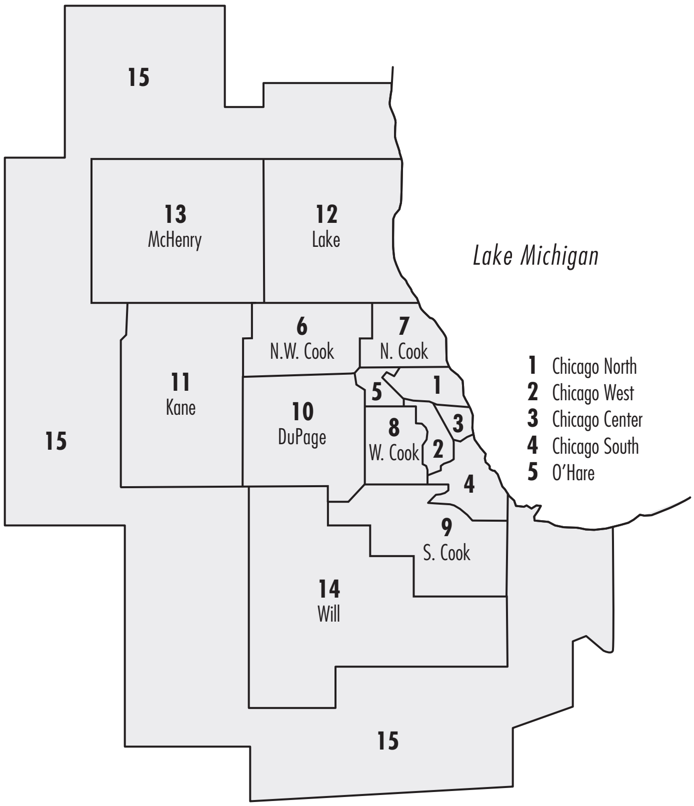
1. This section describes the structure of the model and its calibration, and thus borrows heavily from corresponding sections in Anas and Hiramatsu (2012a, 2012b).

a system of 15 zones covering the entire area and by an aggregation of the major road network and of local roads.

REPRESENTING THE CHICAGO MSA

Figure 6.1 shows the 15-zone Chicago MSA used in the model. The zones can be grouped into five concentric rings. Ring 1 consists of zone 3, the major employment center in the region, which we will refer to as the CBD. Ring 2 includes zones 1, 2, 4, and 5, which together with the CBD make up the city of Chicago. Ring 3 consists of zones 6 to 10, which include all of the inner suburbs encircling the city. Ring 4 (zones 11 to 14) covers the outer suburbs, and zone 15, a single peripheral zone, represents the exurban areas, which are primarily rural

Figure 6.1
RELU-TRAN Zones for Chicago MSA



Source: Anas and Liu (2007).

in character and include some parts of northwestern Indiana and southeastern Wisconsin.

All 15 zones are included as possible locations for consumers, but those who choose either a residence or a job in the peripheral zone 15 are treated as having partially exited the region. Such consumers can still choose a job or residence in one of the 14 zones, but the wages they earn or the rents they pay in zone 15 are taken as exogenous and are not adjusted in the general equilibrium that the model calculates for the 14 nonperipheral zones. In the base simulation reported in this chapter, residents located in peripheral zone 15 are only 5 percent of the total.

All trips that originate and terminate within the same zone utilize a *local road*, which is an abstract aggregation of the underlying system of streets and minor roads. Trips originating in one zone and terminating in another utilize a path over the interzonal road links shown in figure 6.2, a crude aggregation of major roads and highways, but they also use the intrazonal roads to access and egress from the interzonal road network. Figure 6.2 shows the aggregated interzonal road network consisting of 34 two-way (68 one-way) interzonal road links connecting the zone system. In the model, each local road, each one-way interzonal link, and each intrazonal road is represented by a capacity that is crucial in calculating congestion. The model calculates an equilibrium congested travel time for each local road and each one-way interzonal link, as discussed below.

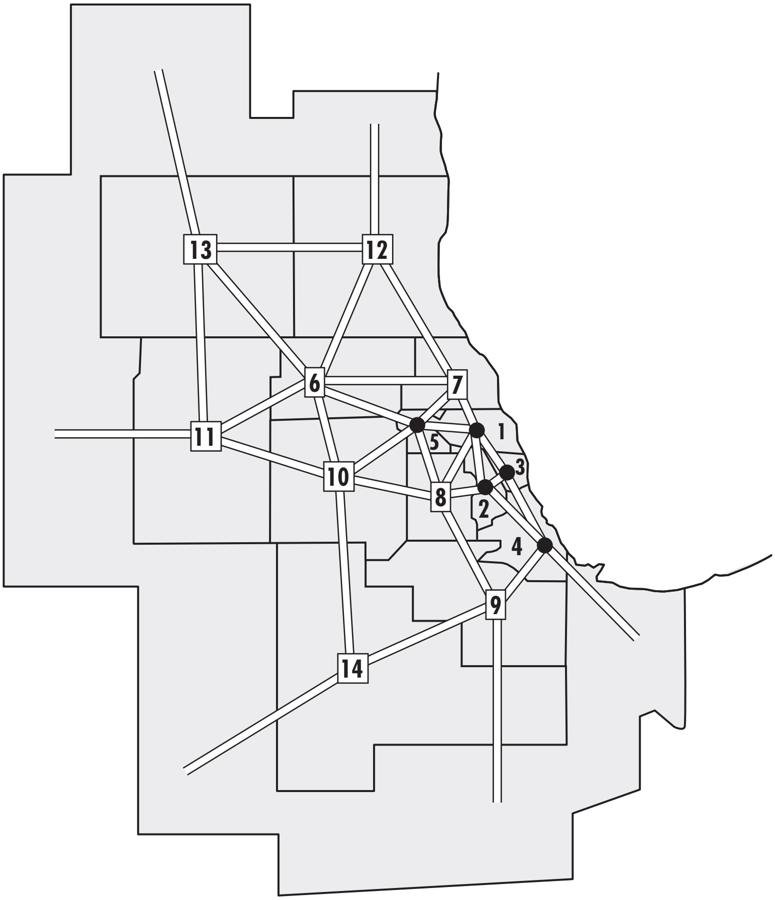
MODEL STRUCTURE: CONSUMERS, FIRMS, AND DEVELOPERS

The model is microeconomic in structure and consists of consumers, firms, real estate developers, and an abstract public sector that sets road tolls or other taxes and may or may not redistribute the revenues generated by various policies.

Consumers, firms, and developers in the RELU model are treated in submodels that correspond to different markets: the housing market, the labor market, and the markets for industrial output. In all of these markets, consumers and firms are perfectly competitive (price-takers). All consumer decisions involving travel mode and the choice of a travel route on the road network are treated in TRAN, the transportation submodel. RELU and TRAN are linked sequentially but are iterated to a fully simultaneous equilibrium (see Anas and Liu [2007] for the algorithm).

Consumers in RELU Consumers in RELU are adults, potentially active in the labor market. Each is either a whole or fractional household. Conclusions about households can be drawn only by pasting together the consumption or other decisions of consumers. Consumers are divided into four groups representing skill levels in the labor market that correspond to quartiles of the income distribution in the calibration of the model. Each consumer makes a set of simultaneously determined utility-maximizing decisions consisting of discrete and continuous choices. Consumers are myopic, spending the income of each period during that period, neither saving nor borrowing.

Figure 6.2
Network of Major Roads in RELU-TRAN2



Source: Anas and Liu (2007).

The highest-level decision of a consumer is whether to enter the labor market or remain outside the labor market (voluntary unemployment). An unemployed consumer has an exogenous unearned income that is constant, increasing by skill level. The exogenous unearned income of an employed consumer is supplemented by wage income. An unemployed consumer chooses a fictitious job location (zone 0) and incurs no commuting travel time or cost. Should wages increase (decrease), then consumers are more (less) likely to choose work, rather than unemployment. Both employed and unemployed consumers make shopping trips to all model zones. The number of such trips depends on the gross-of-transport cost unit price, which attenuates with distance and congestion.

Three discrete decisions are common to all consumers:

1. *Job-residence location*. Consumers choose any two of the MSA's zones as a place of work and a place of residence. Each zone is an imperfect substitute in the labor and housing markets. Thus, each consumer has an idiosyncratic preference for each one of the job-residence pairs. Wages in each zone are determined by the skill level of the consumer (not by industry of employment). The choice of a residence-job location pair (i, j) by an employed consumer also determines the consumer's commute, as will be discussed in more detail below.
2. *Housing type*. There are two housing types representing floor space in single-family housing or in a multiple-family housing structure. Housing choices are treated as renting.
3. *Car type*. Five discrete car types differ by fuel economy. Fuel-inefficient vehicles are larger, are more comfortable, and have higher acquisition and maintenance costs. The consumer's utility function has a systematic preference that increases with the comfort, safety, and size of the vehicle and an idiosyncratic component for each car type. Thus, the choice of a car type involves a trade-off between the marginal utility of owning a larger and less-fuel-efficient vehicle and the higher acquisition, maintenance, and fuel costs for such a vehicle. Thus, less-fuel-efficient vehicles are on average owned by higher-skill and higher-income consumers with idiosyncratic variation within each skill-income group.

Choice of continuous variables depends on the discrete choices (i, j, k, c), where $i = 1, \ldots, 15$ are zones of residence, $j = 1, \ldots, 15$ are zones of job location, $k = 1,2$ are the housing types, and $c = 1, \ldots, 5$ are the car types. Thus, a working consumer faces 2,250 discrete bundles to choose from, whereas a nonworking consumer faces 150 discrete bundles. The conditional choices of the continuous variables depend on the discrete choices as follows:

1. *Housing quantity*: Given (i, k), how much housing floor space to rent.
2. *Labor hours*: Given (i, j), how many hours to supply at j.
3. *Shopping trips*: Given i, the quantity of retailed goods to buy at $z = 1, \ldots, 14$ and the number of trips required to make those purchases at fixed rates per unit of the good. Goods purchased at alternative locations are imperfect substitutes, and all locations are patronized because the consumer's utility incorporates a taste for location variety in shopping.

An important aspect for the consumer is the trade-off in the utility function between work, leisure, and travel. In the model, leisure is fixed and the remaining time is allocated between work and travel, including commuting (once per workday) and endogenous shopping trips. Time is valued at the wage rate since it is assumed that an extra hour of travel means that the consumer will have one hour less to earn wages. It is also assumed that commuting time creates some disutility. Thus, the marginal rate of substitution between disposable income and commuting time exceeds the wage.

Formally, each consumer of skill/income f maximizes utility in the continuous variables $\mathbf{Z} = [Z_1, Z_2, \ldots, Z_{14}]$ and b; and the discrete bundles (i, j, k, c), where i is residence location, j is job location, k is housing, and c is car type:

(1)

$$\underset{\forall(i,j,k,c)}{Max}\left\{\begin{array}{l} \underset{\forall Z_z, b}{Max}\, U_{ijkc|f} = \ln\left[\left(\sum_{\forall z} \iota_{z|ijf}(Z_z)^{\eta f}\right)^{\frac{\alpha f}{\eta f}} b^{1-\alpha_f} \exp\left(-\gamma_{1f} G_{ijcf} + \gamma_{2f}\, m_c + \Lambda_{ijkc|f} + u_{ijkc|f}\right)\right] \\ subject\ to\text{:} \sum_{\forall z}\left(p_{\Re z} + s_{ijf}\, g_{izcf}\right) Z_z + bR_{ik} + \Delta_j d g_{ijcf} \\ +K(m_c) = \Delta_j\, w_{jf}\left(H - dG_{ijcf} - \sum_{\forall z} s_{ijf}\, Z_z G_{izcf}\right) + M_f \\ and\ H - \Delta_j dG_{ijcf} - \sum_{\forall z} s_{ijf}\, Z_z G_{izcf} \geq 0\ \ for\ j > 0. \end{array}\right\}$$

Given are the prices of goods in z, $p_{\Re z}$; the rent of residential floor space, R_{ik}; the wage rate, w_{jf}; nonwage income, M_f; mode- and route-composite shopping travel times, G_{izcf}, and commuting times, G_{ijcf}; mode- and route-composite monetary costs of commuting and shopping trips, g_{ijcf} and g_{ijzf}; the quantity shopped per trip, s_{ijf}; the fuel inefficiencies (gallons per mile) of the available car types, m_c; the annual time endowment available for work and travel, H; and the number of days per year, d, for which a commute is required. $\Lambda_{ijkc|f}$ are constant effects associated with the discrete choice bundle (i, j, k, c) and $u_{ijkc|f}$ are the idiosyncratic tastes. $\iota_{z|ijf}$ are constant effects that reflect the attractiveness of a retail location z to consumers of type f located at residence-job locations i, j. η_f in the CES subutility defined over retail locations is related to the elasticity of substitution among the retail locations, and α_f is the share of the disposable income spent on purchasing retailed goods, and $1 - \alpha_f$ the share that will be spent on renting housing. γ_{1f} is the marginal disutility of commuting time, and γ_{2f} the marginal utility of a larger, safer, but less-fuel-efficient car. The right side of the budget constraint is the money income of the consumer who is paid a wage per hour of labor supplied after all travel time (for commuting plus shopping). If the consumer chooses not to work by choosing $j = 0$ in the outer stage, then $\Delta_j = 0$, and the consumer has no wage income. Otherwise, for any $j > 0$, $\Delta_j = 1$. The left side of the budget is the monetary expenditure on retail goods, commuting and housing space, and annual car-ownership costs, $K(m_c)$. The prices of the retail goods are the prices at the retail location plus the monetary cost of the travel from home to the retail location.

In the inner stage (inside { }), given the discrete choice bundle (i, j, k, c) determined at the outer stage, the consumer chooses the optimal quantities of the retailed composite goods to shop from each retail location z, (vector $\mathbf{Z} = [Z_1, Z_2, \ldots, Z_{14}]$); and the residential floor space b to rent. This gives Marshallian demands $Z^*_{ijkc|f}$ and $b^*_{ijkc|f}$. At the outer stage, the consumer chooses the most preferred (i, j, k, c), given the indirect utility function $U^*_{ijkc|f} + u_{ijkc|f}$ from the inner stage. The discrete choice probabilities have the nested-logit structure, where a marginal probability describes the binary choice of entering the labor market versus not participating in the labor market. The conditional multinomial logit probability, $P^*_{i,j>0,kc|f}$, describes the distribution of employed consumers of type f among the bundles (i, $j > 0$, k, c).

RELU connects with TRAN via the mode- and route-composite trip times and monetary costs, which are the matrices $\left[G_{ijc|f}\right], \left[g_{ijc|f}\right]$. RELU-TRAN2 does not treat traffic congestion by time of day, so all who use a road experience the same congestion. The monetary cost, on the other hand, does depend on car type since gasoline consumption depends on traffic speed determined by congestion and since car type is a discrete choice that depends on car acquisition and operating costs and on car preferences, which vary with income.

Consumers in TRAN In the TRAN submodel, each consumer chooses the mode of travel for each trip and the routing of that trip over the road network if the mode is car.

1. *Mode choice*. For each residence-job-car bundle (i, j, c), the consumer of type f chooses a travel mode for each trip (whether for commuting or for shopping) that is determined in RELU. There are three modes of travel: $m = 1$ (car), $m = 2$ (public transit), and $m = 3$ (nonmotorized). The third applies largely to intrazonal trips, especially in the suburbs. When the choice is car, it is assumed that the chosen car type, c, is used. Systematic and idiosyncratic generalized costs are treated in the choice of mode.
2. *Route choice*. For car trips, the consumer chooses the route from trip-origin zone i to trip-destination zone j with the minimum round-trip generalized cost over the road network. As in mode choice, the systematic and idiosyncratic generalized costs of the available routes are considered. The consumer takes as given the speed of travel on each road link on that route since speed is determined by traffic congestion. As congestion increases, traffic slows down. The speed and time on each link is endogenously determined at equilibrium. All car types are assumed to cause the same congestion on one another. The generalized cost of travel on a link is a weighted sum of the monetary cost and the value of travel time.

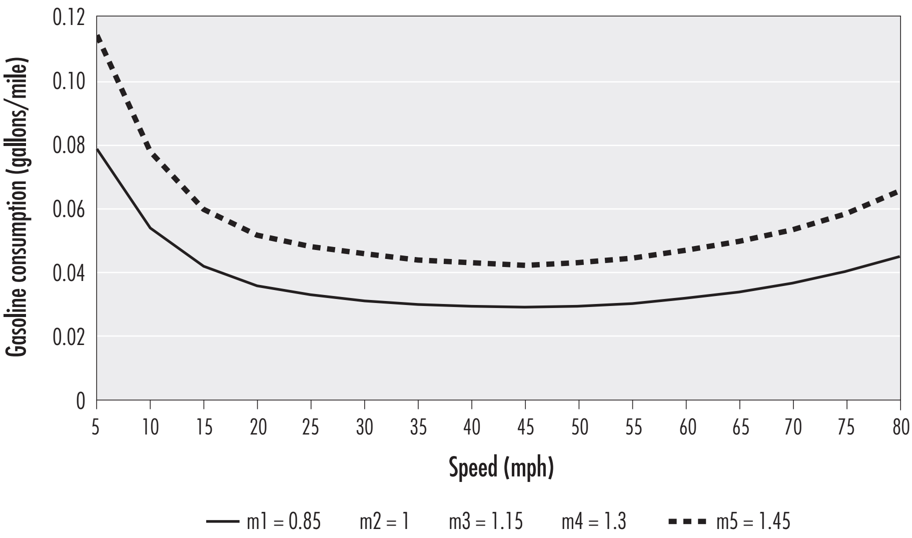
This value of time is exogenous and increasing by skill-income group. The monetary cost depends on vehicle type (fuel economy) and on the cost of gasoline. Figure 6.3 plots the U-shaped speed versus fuel consumption curves based by smoothing those estimated by Davis and Diegel (2004) for nine actual car models.

These relationships were obtained by fitting a polynomial curve to the Geo Prizm and then multiplicatively shifting this polynomial. Consumers determine their monetary expenditure on operating a car by choosing their car type in RELU (as we saw) and by choosing routes that are faster or slower in TRAN. Consumers with lower (higher) values of time are more likely to prefer cheaper (faster) routes, and this, together with their preference for car size and the level of car-acquisition costs relative to their income, determines fuel economy and gasoline consumption.

The gallons/mile versus miles/hour U-shaped polynomial curve is $f(s)m_c$, where:

(2) $$f(s) = 0.12262 - 1.172 \times s + 6.413 \times 10^{-4}s^2 - 1.8732 \times 10^{-5}s^3 + 3.0 \times 10^{-7}s^4 - 2.472 \times 10^{-9}s^5 + 8.233 \times 10^{-12}s^6$$

Figure 6.3
Fuel Intensity Versus Speed



Source: Anas and Hiramatsu (2012a).

$p_F f(s) m_c d$ is the fuel cost of driving a road distance d at speed s using a car of fuel efficiency level m_c when the price of a gallon of fuel is p_F. The speed is $s = \frac{1}{Time}$, where d is the road distance and *Time* the congested time to travel one mile. *Time* is given by a Bureau of Public Roads (BPR)-type congestion function $Time = c_0 \left(1 + c_1 \left(\frac{Flow}{CAP}\right)^{c_2}\right)$. *Flow* is the aggregate volume of traffic on the road, and *CAP* is the road's capacity (constant all along the road). The generalized cost of traveling a road of length d is $gcost_{fc} = (vot_f)\left(\frac{d}{s}\right) + p_F f(s) m_c d$, where vot_f is the value of time in route choice that depends on the consumer's income, indicated by f.

Firms RELU includes four industries: (1) agriculture; (2) manufacturing; (3) business services; and (4) retail. Production functions are constant returns, and all firms producing in the same zone and industry are perfectly competitive profit maximizers in input and output markets, charging the same price and paying the same wages and rents. Goods in the same industry produced in different zones are variants of the same good. As explained earlier, consumers buy only the retail good by shopping it in every zone. All location variants of a good are also used as intermediate inputs in the production of the other goods except for the retail good, which is produced by the input of the other goods but is not itself an input in the production of other goods. In addition, each industry uses primary inputs, which are business capital, space in commercial and industrial buildings, and labor from each of the skill groups (income quartiles) of the working consumers. All outputs can be exported to other regions from any zone where they are produced.

Developers The treatment of developer behavior in this model is based on Anas and Arnott (1991, 1993, 1997). Developers are agents who incorporate the activities of landlords, who rent out floor space and collect rents on it; investors, who buy and sell real estate; and contractors, who construct or demolish. Unlike the model's firms and consumers, who are myopic, developers operate with perfect foresight and are risk-neutral profit maximizers. In this chapter, the model is implemented as a stationary-state or long-run equilibrium model, and developers therefore operate with perfect foresight of this stationary state. Time is in discrete periods of five years in duration. There are no transaction costs in buying and selling. In the beginning of each period, a developer is the owner of vacant land or of residential or commercial or industrial buildings. Developers in the same zone who own vacant land face a common cost of construction but are horizontally differentiated by idiosyncratic costs. The idiosyncratic cost draw of each developer for constructing each type of building and for just keeping the land vacant is determined toward the end of each period.

When these costs are determined, the developer decides whether to continue to hold the land vacant or to construct a particular building type, given the construction cost per square foot of floor space. At the beginning of the period, when the uncertainty has not been resolved, the developer values the vacant land asset at the expected maximum profit the land would fetch from the most profitable construction or from doing nothing at the end of the period. Similarly, developers who start the period owning a particular type of building decide whether to demolish it at the end of the period, while in the beginning of the period they value the building asset knowing only the expected value of the profit-maximizing action. Since developers are perfectly competitive, asset prices for vacant land and for each type of building are determined in the beginning of each period.

Since the developers' behavior is assumed to be stationary in the aggregate in each zone and for each type of building and vacant land, the asset prices for building and land make all expected economic profits zero so that developers earn only normal profits, while stocks, rents, and values are stationary because the construction flow of the floor space of each building type equals the demolition flow of the floor space of the same building type. An exogenous change would alter the long-run equilibrium stocks that prevailed but would also change the rates of demolition and construction necessary to maintain the stocks at a stationary level (Anas and Arnott 1993).

MODEL STRUCTURE: GENERAL EQUILIBRIUM

The model includes four markets: (1) the labor market for each labor skill level in each zone (56 equations of 14 zones by 4 skill levels); (2) the rental market for each residential building type (single-family and multiple-family) in each zone (28 equations of 14 zones by 2 housing types); (3) the business rental market for commercial and industrial buildings (28 equations of 14 zones by 2 building types); and (4) the goods markets for each industry and zone (56 equations of 14 zones by 4 industries). Solving these equations determines the rental prices per square foot, the hourly wages for each skill level, and the output prices for each industry. Real estate values are then calculated from rents and construction costs, and the stocks of each building type in each zone are adjusted to the new equilibrium.

CALIBRATION OF THE MODEL

The model's calibration is evaluated by key elasticity measures and the marginal rate of substitution between commuting time and disposable income. The values of these relationships are for the year 2000 Chicago MSA data and are shown in table 6.1. It is important to put these numbers in the context of the literature, where the same relationships have been estimated by others.

The elasticity of location demand with respect to commuting time was estimated in the 1970s by Charles River Associates (1972), Lerman (1977), Atherton, Suhrbier, and Jessiman (1975), and Train (1976). A survey of the literature,

Table 6.1
Calibrated Elasticities in RELU-TRAN2 (Chicago MSA)

Consumers	Income Quartiles			
	1	2	3	4
MRS (disposable income, commute time), ($/hour/day)	12.295	21.056	36.204	93.215
Elasticity of location demand with respect to commuting time	–0.619	–0.602	–0.607	–0.544
Elasticity of housing demand with respect to rent	–1.95	–1.76	–1.57	–1.38
Elasticity of labor supply with respect to wage	3.83	2.93	2.1	1.32
Developers	**Building Type**			
	1 Single family	2 Multifamily	3 Commercial	4 Industrial
Elasticity of floor space supply with respect to rent (short-run)	0.0991	0.23	0.268	0.138
Elasticity of construction flow with respect to asset value				
Overall	0.0521	0.421	0.420	0.0744
City	0.0335	0.0564	0.261	0.0396
Suburbs	0.0526	0.681	0.452	0.0785
Elasticity of demolition flow with respect to asset value				
Overall	–1.612	–0.982	–0.176	–0.523
City	–0.0550	–0.528	–0.346	–0.667
Suburbs	–1.719	–1.375	–0.073	–0.465
Elasticity of floor space stock with respect to asset value				
Overall	0.0535	0.0147	0.00542	0.00872
City	0.00102	0.0068	0.00643	0.00786
Suburbs	0.0672	0.0218	0.00480	0.00922
Driving				
Gasoline consumption (CO_2 emissions) with respect to fuel price (base fuel price is $1.90)	–0.0899			
VMT with respect to fuel price	–0.0721			
MPG with respect to fuel price	–0.0180			

which includes their own estimates, is given by Anas and Chu (1984). They reported:

> The in-vehicle time elasticity ranges from –0.36 to –1.40 for transit and from –0.55 to –1.77 for the drive-alone mode. Out-of-vehicle time elasticities range from –0.23 to –2.7 for transit and are –0.42 in the CSI model. Train and CRA do not report out-of-vehicle time elasticities for the auto mode.

As shown in table 6.1, the workers' travel time elasticity of location demand in RELU-TRAN2 ranges from –0.544 to –0.619 and is in the range of the above estimates.

It is reported in Anas and Arnott (1993) that the average rent elasticity of housing demand, the rent elasticity of white households, and the rent elasticity of nonwhite households in the Chicago MSA for 1970 to 1980 are –0.554, –0.516, and –0.683, respectively. In our model, the rent elasticity of housing demand cannot be larger than –1 because of the functional form of the utility function, and it ranges from –1.38 to –1.95. Our elasticity combines two aspects of the demand for housing: the demand for housing size as floor space, which has elasticity of –1, and the number of consumers who demand housing at a particular location, which has elasticity that ranges from –0.38 to –0.95. Housing demand at a particular location is the product of these two quantities. Thus, our elasticity is higher than that in Anas and Arnott (1993), who estimate a model in which the housing size effect is fixed.

Kimmel and Kniesner (1998) studied U.S. household data for the period from 1983 to 1986. Their wage elasticity of labor supply (hours worked) is +0.51. In our model, the consumer makes more nonwork trips when the wage increases (because of the income effect for shopping normal goods), and this reduces the labor supply.

In Anas and Arnott (1993), the elasticity of housing floor space supply with respect to rent is +0.1016 and +0.1136 for single-family and multifamily housing, respectively. In our model, the corresponding values are +0.0991 and +0.23. Thus, the elasticity of our single-family housing is similar to theirs, but our multifamily housing supply is more elastic than theirs. This elasticity measures the percentage of existing housing stock that will be put on the market to be rented (rather than being kept vacant) by the landlords. Our +0.23 estimate for multifamily housing is almost the same as that reported by Anas (1982) for the Chicago MSA using 1970 data.

DiPasquale and Wheaton (1994) report that the long-run price elasticity of the aggregate housing stock is in the +1.2 to +1.4 range. Blackley (1999) reports that the construction elasticity ranges from +1.0 to +1.2 and that the long-run price elasticity of new housing supply (supply measured in value terms) in the United States for 1950 to 1994 ranges from +1.6 to +3.7. Green, Malpezzi, and Mayo (2005) report a price elasticity of housing supply in the Chicago MSA for the period from 1979 to 1996 as +2.48, but their estimate is not significantly different from zero. Their housing supply is defined as the number of housing units for which building permits were issued, multiplied by 2.5 (the average household size), divided by the population. Our elasticity of housing construction measures what percentage of the land available for construction will be developed into type *k* building (housing) if the asset price of type *k* building rises. This elasticity ranges from +0.03 (for single-family housing in the city) to +0.68 (for multifamily housing in the suburbs).

There are a few reasons why our elasticity of construction is so small. First, many of our modeled zones are urbanized and there is not much land left to be developed. The area covered by the Chicago MSA in Green, Malpezzi, and Mayo (2005) is broader than in our modeled zones. Second, by the year 2000, our modeled zones had become more developed than they were during their period, and the available land had decreased significantly. Finally, the definition of our elasticity of construction is different from theirs because they measure how much an increase in asset price would increase building permits multiplied by the population that would use the newly constructed housing, whereas our elasticity measures the percentage by which the developed land would increase.

Two additional assumptions could be affecting our elasticity in real estate variables. First, our building structural density (in floor space per unit of land) is constant by building type and zone. However, average structural density in our model zones is not constant and can change over time by demolishing low structural density buildings and constructing higher structural density buildings, for example. If the developer could directly choose the building's floor space amount, the stock could be more elastic when the building value increases. This would be especially true in the zones where vacant land is scarce. Smith (1976) reports that the price elasticity of density is +5.27, where Smith's density is the number of dwelling units built on a unit land area, from Chicago MSA cross-section data between 1971 and 1972. The second assumption that could be affecting our low elasticity of stock is the condition that the construction and demolition flow of each building stock in each zone is equalized by the real estate market being in stationary equilibrium. In reality, the construction flow would be larger than demolition and stock in a growing economy.

The above discussion suggests that the methodology used in the literature to estimate the supply elasticity of housing is not robust. There are important data-driven or definitional differences between any two studies. Hence, it might be better to evaluate the reasonableness of our housing supply elasticity by actually simulating the model in a comparative statics exercise and observing how the housing stock responds in quantity. In such a comparative statics exercise, Hiramatsu (2010) simulated a simple urban growth scenario in which he increased the total population and the net exports by 10 percent. The vacant land stock decreases in both the city and the suburbs. The single-family housing stock decreases in the city and increases in the suburbs. The multifamily housing stock increases in both the city and the suburbs, increasing more in the suburbs than in the city. Both single-family and multifamily housing stocks increase by less than the 10 percent population growth, and the average floor space per person decreases. The industrial and commercial buildings also increase in the city and in the suburbs. The rate of increase is more in the city than in the suburbs but is not as high as the rate of increase of the housing stock. In the city, where the available land is limited, some single-family housing is demolished and multifamily housing, industrial buildings, and commercial buildings are constructed. In the suburbs, where there is plenty of land, both single- and multifamily housing is constructed, as well as industrial and commercial buildings. Thus, the building stocks respond reasonably with respect to the increase of the population and net exports. Accordingly, the rents and values of each building type change in a normal way. In the city, the rent of single-family housing increases by more than 10 percent because the supply decreases. The other building rents also increase since demand increases by more than supply does. Both rent and value increase more for those building types and locations where the demand increases more and the supply increases less. In this way, we conclude that the building markets—including stocks, rents, and values—respond reasonably under the calibrated elasticities of the model.

Road-Pricing Policies: Congestion Tolls and Fuel Taxes

The model calculates two externalities of traffic congestion. One is the delay caused by the volume of traffic on each road. The other is the excess fuel consumption induced by the traffic: when traffic moves more slowly, vehicles consume more gasoline per mile, as shown in figure 6.3. These two externalities are calculated on each major (interzonal) and local (intrazonal) road, but the model does not distinguish between different times of the day, thus implying that all the travel occurs over a relatively wide rush hour.

The policies examined in this chapter directly or indirectly target these two congestion externalities caused by driving. The following alternative policies are considered:

- A quasi-Pigouvian congestion toll that varies by type of road and is charged on each road link. There are two versions of this: QP1, under which only the major (interzonal) roads are tolled and local (intrazonal) roads remain untolled, and QP2, under which all roads (interzonal and intrazonal) are tolled.
- A per-gallon fuel tax, the rate of which is calculated so that the aggregate fuel tax revenues match the revenues of QP1 or QP2.

QUASI-PIGOUVIAN TOLLS

In theory, first-best Pigouvian tolling would perfectly internalize both externalities over the entire network. The first-best Pigouvian tolls measure the excess time delay plus the excess fuel consumption imposed by each car trip on all other car trips.

This chapter refers to tolls as quasi-Pigouvian because they deviate in three ways from first-best Pigouvian tolls, which would be very difficult to implement in reality.

First, every mile of road is shared by travelers with different values of time. The first-best Pigouvian toll would be calculated by multiplying the marginal time delay experienced by each traveler on each road by the traveler's marginal rate of substitution between travel time and disposable income and then adding these up over all travelers on the road. Instead, we assume that the road authorities know only the average value of time of the drivers on each road, which is exogenously given according to the income level of the traveler.

The second reason why congestion tolls in RELU are quasi-Pigouvian is that consumers can save fuel not only by traveling faster (see figure 6.3), but also by switching to vehicles with higher fuel economy. The first-best policy might vary the part of the Pigouvian toll aimed to capture the fuel externality, not only according to route, but also according to the car types on the road. We assume that road authorities know only the average car on each road and set a toll that is common to all vehicles.

The third and final reason is that RELU-TRAN2 treats heterogeneity among consumers, and when such heterogeneity is present, toll revenue should in general be distributed unequally among the consumers. However, doing so would be difficult in practice since road authorities would need to know how the marginal utility of income varied in the driver population. RELU-TRAN2 assumes that toll revenue is equally distributed among all consumers, including nondrivers.

FUEL TAXES

The fuel tax also acts globally over the entire network, but it is a lower-best instrument since it targets only fuel consumption, thus working on the congestion only indirectly. In fact, the fuel tax is, a priori, a crude instrument because it is paid for the fuel consumed on each mile of road regardless of the congestion level on the road. Although figure 6.3 shows that fuel consumption indeed rises with congestion (that is, with lower traffic speed), the fuel tax would be paid even on a road with zero congestion.

The fuel tax is very easy to implement since all car traffic pays the same fuel tax per gallon of gasoline. Cars with lower fuel economy consume more gasoline and pay higher fuel taxes. Thus, on the one hand, the fuel tax creates an incentive for using vehicles that have higher fuel efficiency. On the other hand, the fuel tax may do a poor job of internalizing the delay externality of congestion. It affects congestion only indirectly by raising the fuel cost of travel and thus reducing travel volume and improving speed. In contrast, our quasi-Pigouvian toll is directly proportional to the delay caused by congestion and reduces the time-delay externality more efficiently by differentially pricing the externality on each road.

TAX-AVOIDANCE BEHAVIOR UNDER THE POLICIES

In our general equilibrium model, the effects of the policies will differ according to the way the market agents (consumers and firms) exercise tax-avoidance behavior directly or become influenced by changing travel times, prices, rents, and wages indirectly. Since the model entails many margins of adjustment, the overall effects are complex and require netting out the various changes across all margins.

The most immediate form of adjustment would be in the choice of route. For example, a commuter who passes through the CBD could be induced to travel around it to avoid the higher tolls that would prevail on the highly congested roads terminating in the CBD. As many travelers do this, roads circumventing the CBD would become more congested, and the roads going into the CBD would become less congested. Another example is that a quasi-Pigouvian congestion toll would increase the monetary cost of travel, inducing consumers with low values of time to choose longer but less congested routes with lower tolls. Commuters with higher time values would prefer to pay higher tolls and travel on the faster routes. These adjustments would not work as well under fuel taxation; in that case, fuel taxes would be more correlated with distance traveled than with congestion. Hence, under fuel taxation, shortening the distance traveled would be a more dominant response.

A second margin of adjustment concerns the fuel efficiency of the car. The higher monetary cost of the fuel tax, for example, would induce consumers to switch to more-fuel-efficient cars. This effect, however, is small (Anas and Hiramatsu 2012b).

A third margin of adjustment entails switching between car and mass transit. Higher tolls or taxes would induce consumers with lower values of time to switch to the slower but cheaper transit mode. As tolls or fuel taxes reduce congestion and speed up driving, some consumers with high values of time would switch from transit to car.

A fourth margin of adjustment would be to change the destination, number, and length of nonwork trips from the locations that involved a high tax or toll layout to other locations that involved less. All of these effects are treated in the model.

Changing job or residence locations requires longer-term adjustments. Some examples of residence location changes would be for a worker who commutes into the congested CBD to move his residence into the CBD, reducing housing size at the same time in response to the higher CBD rents. Such a choice would be favored by workers who dislike transit or who reside in suburban areas in which transit is inaccessible. Others may indeed switch to transit, but to do so they may have to move from the suburbs to the city, where transit is more easily accessed. Still others may reject these options and prefer to switch to a suburban job from one in the CBD.

Firms, meanwhile, would also respond to tolls or taxes. For example, a firm located inside the CBD that employs many employees who drive into the CBD but dislike switching to transit or moving their residences into the CBD faces a choice: pay higher wages to induce employees to keep their CBD jobs or relocate outside the CBD to lower the tolls and taxes that employees incur. However, the CBD may attract more firms if enough consumers are willing to locate their residences within it or to switch to transit and if such shifts increased the supply of labor within the CBD enough to lower wages. Such shifts could also induce developers to replace commercial real estate with residential housing.

In realistic schemes, only major roads may be proposed for tolling. If the quasi-Pigouvian toll is levied on major roads only, the differences between quasi-Pigouvian tolling and gasoline taxation are magnified because drivers on local roads (i.e., those traveling intrazonally) would not be charged under quasi-Pigouvian tolling but would pay the fuel tax. Under such quasi-Pigouvian tolling, interzonal trips and congestion would decrease while intrazonal trips and congestion would increase as consumers and firms relocate to avoid using the major roads and rely more on local roads.

The quasi-Pigouvian toll paid will be higher than the fuel tax on highly congested roads, while the fuel tax paid would be higher on the less congested roads. Hence, drivers would feel that the fuel tax is too high on long-distance and slower routes since fuel consumption increases with distance and falls with speed. Because the fuel tax affects all roads, it would not be very helpful for drivers to make detours.

The Impacts of the Policies

The salient results of the road-pricing policy simulations are presented in tables 6.2 to 6.4. Table 6.2 shows the effects of the policies on driving-related aggregates such as fuel consumption and CO_2, vehicle miles traveled (VMT), gallons per mile (GPM), and total travel time. Table 6.3 juxtaposes the effects of the policies on the distribution of jobs and residences and on land development

Table 6.2
Percent Changes in Driving-Related Aggregates Under Road-Pricing Policies

	Quasi-Pigouvian Toll, QP1, on Major Roads	Revenue-Neutral Fuel Tax at 55.5%	Quasi-Pigouvian Toll, QP2, on All Roads	Revenue-Neutral Fuel Tax at 287%
Gasoline and CO_2	–4.64	–2.65	–12.52	–13.35
Vehicle miles traveled (VMT)	–3.93	–2.11	–9.93	–11.10
Gallons per mile (GPM)	–0.67	–0.56	–2.66	–2.40
Total travel time	–2.45	–1.30	–5.34	–5.45
Total travel monetary cost (including tolls or taxes)	23.96	24.61	114.65	112.91

Table 6.3
Effects of the Pricing Policies on Jobs, Residences, and Undeveloped Land

Changes in:	Location	Base Level	Quasi-Pigouvian Toll, QP1, on Major Roads	Revenue-Neutral Fuel Tax at 55.5%	Quasi-Pigouvian Toll, QP2, on All Roads	Revenue-Neutral Fuel Tax at 287%
Jobs	CBD	537,861	+747	+2,385	+6,215	+10,987
	City ex-CBD	793,798	–4,058	+2,314	+2,275	+10,713
	Inner suburbs	1,720,045	–5,027	–2,526	–12,385	–15,081
	Outer suburbs	693,578	+9,475	–1,759	+5,064	–5,198
	Total		+1,137	+414	+1,169	+1,621
Residences	CBD	39,688	+535	+781	+3,237	+3,755
	City ex-CBD	1,413,312	–5,940	+8,117	+14,272	+40,296
	Inner suburbs	2,157,789	–10,768	–3,713	–27,253	–28,106
	Outer suburbs	1,080,057	+16,174	–5,184	+9,745	–15,944
Undeveloped Land (sq. feet and % changes)	CBD	79,357,608	–4.50%	–1.94%	–6.99%	–7.92%
	City ex-CBD	664,730,392	–2.68%	–1.24%	–4.23%	–5.06%
	Inner suburbs	6,368,076,040	–7.92%	–3.35%	–10.72%	–12.25%
	Outer suburbs	44,984,268,688	–1.90%	–0.67%	–2.63%	–2.64%

by geographic ring within the MSA: the CBD, the rest of the city of Chicago, the inner suburbs, and the outer suburbs. Table 6.4 shows how consumer utility, revenue from the policy, real estate values, wages, and rents change under the alternative policies.

REVENUE AND WELFARE

A first observation from these tables (see table 6.4) is that the revenue raised by the quasi-Pigouvian tolling of all roads (QP2) is 4.6 times the revenue raised from the tolling of the major roads only. The revenue-neutral per-gallon fuel tax rate that corresponds to QP1 is 55.5 percent and that which corresponds to QP2 is 287 percent. The former increases the after-tax gasoline price by about one-half, while the latter would almost quadruple it.

Next (also from table 6.4), the total welfare change is positive. The average tax revenue change per consumer is redistributed back equally among the consumers. Hence, the welfare per consumer consists of two parts: (1) the change in compensating variation (CV), which measures how much the average consumer would be willing to pay to accept the policy; plus (2) the average annualized

Table 6.4
Changes in Welfare Components, Wages, and Rents Under Pricing Policies

	Quasi-Pigouvian Toll, QP1, on Major Roads	Revenue-Neutral Fuel Tax at 55.5%	Quasi-Pigouvian Toll, QP2, on All Roads	Revenue-Neutral Fuel Tax at 287%
Revenue/consumer ($/year)	284	284	1,306	1,306
(a) CV[a] per consumer ($/year)	244	14	264	97
(b) Annualized real estate income per consumer ($/year)	1,149	485	1,701	1,967
Total welfare/consumer ($/year) = (a)+(b)	1,393	499	1,965	2,064
CV/consumer of workers by income level ($/year)				
1	349.22	90.41	379.86	405.11
2	410.85	107.16	377.49	427.65
3	550.22	136.27	516.02	515.81
4	1,388.13	351.02	1,741.03	1,440.95
CV/consumer of nonworkers by income level ($/year)				
1	–902.78	–273.19	–616.18	–900.41
2	–1,416.71	–523.95	–1,503.94	–1,914.12
3	–1,938.02	–761.93	–2,327.90	–2,873.74
4	–4,189.55	–1,801.55	–5,950.33	–7,056.66
Change in average wages	+8.6%	+3.4%	+11.14%	+13.03%
Change in average rents by building type				
Single-family homes	+4.55%	+1.97%	+6.72%	+7.57%
Apartments	+3.62%	+1.66%	+5.50%	+6.41%
Commercial	+5.97%	+2.49%	+8.49%	+9.67%
Industrial	+5.78%	+2.45%	+8.30%	+9.50%

[a]CV = compensating variation.

change in real estate values per consumer. Real estate developers make zero expected profits, as explained earlier. However, the introduction of a road-pricing policy causes the holders of land and buildings in the pre-tax equilibrium to experience windfall gains and losses in the values of their assets. An annualized income stream is calculated from these aggregated net gains, but this is not redistributed to the consumers. Thus, implicitly, all consumers are treated as renters, and all real estate asset owners are treated as absentee. Welfare gains therefore consist of the two parts above, which are aggregated.

The welfare change numbers of table 6.4 suggest several observations. One is that consumers are better off under Pigouvian tolling than under the equivalent fuel taxation. Tolling removes the negative externality where it is present, but fuel taxation removes it imperfectly while also inefficiently penalizing those who create little or no congestion (and overpenalizing them for the pollution they create).[2]

EQUITY UNDER THE ALTERNATIVE POLICIES

Table 6.4 also shows how CV gains or losses are distributed among the various consumer groups. In the model's baseline, four income groups correspond roughly to the quartiles of the 2000 personal income distribution. In each income group, the model divides the population endogenously into consumers who are and are not working. Employed consumers experience a disutility from commuting time and forego wage income when allocating more time to work and nonwork travel. The marginal rate of substitution between commuting time and the disposable income allocated to buying goods and services increases with the income of the employed consumer. Nonworking consumers in the model have a low value of time from traveling for nonwork trips. A property of consumer behavior in the model is that nonwork trips are made to acquire goods and services, which are normal goods. Therefore, richer consumers make more nonwork trips, and this holds true for both working and nonworking consumers. Then, road pricing reduces the CV of a richer nonworking consumer by more since such a consumer makes more nonwork trips but cannot allocate time saved from less congestion to earn more income. Table 6.4 shows that, among consumers who are employed, the CV gain increases with income since time saved is valued more the higher the income/wage of the working consumer. Among those who are not working, the low values of time but the higher monetary cost of travel after road pricing cause the opposite result: CV is negative and becomes more negative with income since the higher the income the greater the number of trips made for shopping normal goods and, therefore, the higher the exposure to the higher monetary cost of travel under tolling or fuel taxes. Note that wages are endogenous in the model and increase under all scenarios (the reasons for which will be discussed later), and this causes an increase in the value of time in RELU, which affects location decisions and trip making.

AGGREGATES RELATED TO DRIVING

Not surprisingly, fuel and emissions of CO_2, vehicle miles traveled, gallons per mile, and total travel time all decrease as the monetary cost of travel, including

2. Note, however, that the total welfare increase under the gas tax is 2,064 per consumer, which is larger than the corresponding 1,965 under QP2. This is a minor anomaly due to the fact that our realistic congestion tolls are quasi-Pigouvian and not first-best for the reasons explained earlier.

tolls or fuel taxes, increases under each policy (see table 6.2). The 55.5 percent increase in the cost of fuel causes travel monetary cost to increase by 24.61 percent, and the 287 percent increase in the cost of fuel causes travel monetary cost to increase by 112.91 percent. These percentage increases are similar to those that occur under quasi-Pigouvian tolling.

Importantly, the percentage increases in monetary cost are less than half of the percentage increases in the cost of fuel, which points to the adjustments consumers and firms undertake to blunt the impact on their budgets of the road-pricing policies. These adjustments may be grouped into two broad categories: switching to transit, which is the biggest effect (transit ridership increases by 13 percent or more), and making fewer and shorter car trips. There are, of course, rebound effects in fuel, CO_2, VMT, GPM, and travel time induced by reduced congestion, which in turn is caused by fewer and shorter car trips.

CENTRALIZATION OR DECENTRALIZATION OF JOBS AND RESIDENCES

Table 6.3 shows how the spatial distribution of jobs and residences and of undeveloped land changes under each policy. In the model, the total number of consumers is fixed, and they may choose whether to work. Therefore, in addition to changes in job locations, the model also indicates whether a particular policy increases or decreases the number of consumers in the labor force. That is why the positive and negative job changes do not sum to zero. Note, however, that all consumers have housing whether they are in the labor force or not. Therefore, the consumer increases and decreases by residential location do sum to zero (net of rounding). Why does the total number of jobs increase (though very slightly) under each policy? It is directly related to the result in table 6.4 that shows an increase in wages. While the increase in wages is explained below, note for now that the higher wages cause some residents who are initially not in the labor force to choose to enter the labor force (the extensive margin of labor supply).

Several additional results are seen from a systematic examination of table 6.3. Under the quasi-Pigouvian tolling of the major roads only (QP1), jobs and residences move similarly, decreasing in the city of Chicago ex-CBD and the inner suburbs and increasing in the outer suburbs and only slightly in the CBD. Since only major roads are taxed, two important toll-avoidance margins are at work. One of these is that some residents who previously drove on major roads now switch to mass transit, and doing so may entail moving their residences to the city, where transit is more available than in the suburbs. The other margin is that some outer suburban residents who commuted downtown from the suburbs by car and who would thus be greatly affected by the tolls on major roads, now want to work in the suburbs, preferably in their zone of residence. Doing so, they avoid driving on the major roads and paying the tolls. This creates an abundance of labor supply in the outer suburbs, and firms from the city are then attracted to relocating to the suburbs.

Next, also from table 6.3, consider the effects of the fuel tax that achieves revenue neutrality with QP1. Because the fuel tax is paid by all car travel, whether on major roads or not, it is much harder to avoid using the second margin of intrazonal location of job and residence that was important under QP1. Under the fuel tax that is 1.5 times higher, the margin of switching to transit becomes much more important, and there is a strong trend toward moving residences from the inner and outer suburbs to the city, including the CBD. Of course, some consumers prefer to continue driving but to shorten the length of their trips, and this means that some of those who worked in the city but resided in the suburbs would move to the city.

Now, still from table 6.3, look at QP2, the quasi-Pigouvian tolling of all roads (major and local), and its revenue-neutral fuel tax. Note that comparing QP2 tolling and QP1 tolling, the job and residence changes are qualitatively similar but quantitatively different. Under QP2, as under QP1, jobs leave the inner suburbs and increase rather significantly in the city ex-CBD and CBD but increase less in the outer suburbs than they did under QP1. The suburbanization effect is weaker and the centralization effect is stronger under QP2 because the margin of intrazonal location is less effective under QP2 since intrazonal as well as interzonal roads are tolled. So the margin of central relocation to make better use of transit is relatively stronger. Under the QP2 revenue-neutral fuel tax, the effects are qualitatively identical to those under the QP1 neutral fuel tax but larger in magnitude, and the reason is simply that the fuel tax is a lot higher under the QP2 revenue-neutral scenario.

WAGES AND RENTS

As shown in table 6.4, the average Chicago MSA wages and rents increase by significant percentages under each of the policies. Furthermore, wages increase by a higher percentage than rents do.

The wage increase results from the need of most firms to entice their workers to continue commuting to the same jobs despite the higher monetary cost of transportation caused by the tolls or the fuel taxes. At the margin, firms and consumers adjust by relocating closer to each other, though infra-marginally most firms and consumers stay put. In the new equilibrium—after the fuel tax or the tolls—firms must pay higher wages.

Rents increase primarily because of two effects, one that operates in the floor space for business use and the other in residential demand for housing. In the case of the business, labor and building space are substitutes in the production functions. As labor becomes more expensive (wages increase), its substitute also becomes more expensive. In the residential case, consumers want to live closer to their jobs and to shops at the margin. This intensifies the demand for housing, causing housing rents to increase. Meanwhile, the higher wages also have an income effect that operates in the housing market, by raising the demand for housing, a normal good.

The higher rents cause higher prices for each type of real estate floor space (since real estate prices are the discounted sum of rents plus expected capital gains). These higher floor space prices cause real estate construction that expands each type of developed stock and depletes some of the initially undeveloped land (table 6.3), increasing, at the margin, both infill development in the CBD, city, and inner suburbs and sprawl development in the outer suburbs.

Conclusions and Extensions

This chapter showed that road-pricing policies—and especially those applied broadly, such as fuel taxation or the Pigouvian tolling of all roads—would indeed cause the centralization of jobs and residences to the city of Chicago from the suburbs. This result, however, does come with some important qualifications. One is that Pigouvian tolling of only the major roads could very well cause centralization of jobs and residences to the CBD *or* their decentralization to the outer suburbs.

Cordon tolling was not discussed in this chapter but has been examined in greater detail in Anas and Hiramatsu (2012a). That article looked at the location of three cordons for Chicago and calculated the optimal cordon toll level for each cordon location.[3] By consulting that article as a companion to this chapter, we learn that London-type cordons that circumscribe the CBD and Stockholm-type cordons that circumscribe a much larger area that includes most or all of the inner city cause jobs and residences to move out of the cordon. This reduces real economic output inside the cordon, increasing it outside the cordon. The combined nominal output, however, increases for the MSA. A counterfactual outer cordon that circumscribes the perimeter of the outer suburbs has the opposite effect. Cordon toll avoidance in this case concentrates residences and jobs within the cordoned area. Real output increases within and decreases outside the cordon, while aggregate nominal output again increases. The cordon policies are not nearly as efficient as fuel taxes or congestion tolls in correcting the externalities of congestion, and the CBD and inner-city cordons captured about 65 percent of the total welfare gains of quasi-Pigouvian tolling. The outer cordon was the least efficient, capturing about half of the efficiency gains of the narrower cordons. But planners interested in the economic revitalization of the central areas would find a meaningful trade-off between the location effects and the efficiency gains of this outer cordon. Similarly, the simulations presented in this chapter suggest that planners interested in the vitalization of the central city should favor the gasoline tax over Pigouvian tolling since the gasoline tax caused greater centralization of jobs and residences.

3. A toll is paid every time a car crosses the cordon in the inbound direction.

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