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# Long-Term Consequences of Congestion Pricing

*A Small Cordon in the Hand Is Worth  
Two in the Bush*

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## **Abstract**

We evaluate and compare the long-term economic effects of three cordon-based road pricing schemes applied to the Washington, DC, metropolitan area. To conduct this analysis, we employ a spatially disaggregated general equilibrium model of a regional economy that incorporates the decisions of residents, firms, and developers, integrated with a spatially disaggregated strategic transportation planning model that features mode, time period, and route choice.

We find that all cordon pricing schemes increase welfare of the residents, as well as lead to GDP growth. At the optimum, the larger cordon and a double cordon lead to higher benefits than the small cordon encompassing downtown core. Nevertheless, the small cordon seems to be a safer bet because when the toll charge is set suboptimally, the net benefits from the small cordon compared to the optimum change negligibly, while the net benefits from the larger cordon decline sharply as the charge deviates from the optimal level.

**Key Words:** traffic congestion, cordon tolls, land use, welfare analysis, road pricing, general equilibrium, simulation, Washington DC

**JEL Classification Numbers:** C68, D63, R13, R14, R41

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Elena Safirova, Sébastien Houde, Conrad Coleman, Winston Harrington,  
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## Introduction

The theory of road pricing goes back to Pigou (1920) and both ideas and practice have seen rapid recent developments (Small and Gómez-Ibáñez 1998; Lindsey and Verhoef 2001; Transportation Research Board 2003). While the first-best tolls are straightforward to derive for the simple theoretical cases, in real life there are significant complications, such as the availability of tolling technology, the heterogeneity of economic agents, and the interactions between the transportation sector and the rest of the economy.

Among the available second-best policies, cordon tolls have been widely studied (May, Liu, Shepherd, and Sumalee 2002; Shepherd and Sumalee 2004; Mun, Konishi, and Yoshikawa 2003; Zhang and Yang 2003). In a cordon toll scheme, travelers who want to drive into the charged area have to pay a toll that is levied at specific points of the road network located on the cordon. Cordon tolls provide a few advantages over other types of road pricing: they are transparent and easy to understand, they are relatively easy to implement, and the technology has been tested and is widely available. At the same time, cordon tolls have been criticized for being inflexible (the tolling locations cannot be easily changed), for being inefficient (because short and long trips that contribute differently to congestion are charged at the same rate), for causing increased congestion just outside the cordon, and for adversely affecting economic activity within the boundary. Although even single cordons have been demonstrated to perform close to first-best optima in simple theoretical models (Verhoef 2002; Akiyama, Mun, and Okushima 2002; Santos 2004), their remaining inefficiencies can be rectified further by the use of more complicated schemes, such as multiple cordons or cordons with fees varying by the time of day and direction.

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Several theoretical studies describe optimal cordon locations in addition to optimal cordon charges. In real cities, however, possible cordon locations are limited by network structure and other features of metropolitan organization. In practice, therefore, it is likely that the choice of the cordon will be highly discrete, allowing for a very limited number of locations. Nevertheless, it is desirable to compare the welfare and distributional effects of different policies to see the nature of trade-offs involved.

Economic evaluations of congestion pricing in general, and for London in particular, have predicted these schemes would be successful. These predictions, however, have been based on the evaluation of transportation effects alone; the wider economic effects of such schemes have remained uncertain (Vickerman 2005), as tolls will affect travelers' budget constraints and result not only in mode switching but also in broader changes in the economy that will be accompanied by the geographic redistribution of trips. Concerns that the London cordon may have negative effects on the economy of the central area, particularly on retail, have caused a reduction of the tolling window in response to complaints of retailers (Santos and Shaffer 2004). At present, the city of London is considering expanding the licensing area, and this measure is likely to result in higher toll collection. Very little is known, however, about the future effects of the cordon expansion on the city's businesses and residents.

In this paper, we model and compare the long-term effects of three cordon-based policies: a Downtown cordon (a small, London-type cordon encompassing the core downtown area); a large Beltway cordon (the boundary of which coincides with the "Beltway," Washington, DC's ring road); and a Double cordon (where Downtown and Beltway cordons are implemented simultaneously). Safirova et al. (2005) have addressed the question of cordon toll location using a transportation model calibrated to the Washington, DC, metropolitan region (the Washington-START model). They concluded that a cordon surrounding the downtown core of Washington, DC, would bring welfare gains similar to those of a much larger Beltway cordon. However, they found that the distributional effects of the two cordons are quite different and highly tied to the redistribution scheme employed.

This paper revisits the comparison of these two cordons for the Washington, DC, region and considers a third policy where the two cordons are implemented simultaneously. In this paper, however, comparisons are made using LUSTRE, an integrated model of Washington-START, and a land-use and economic model (RELU). Our motivation is to investigate how the long-term economic and land use effects vary with the location of the cordon tolls.

The rest of the paper is structured as follows. In the next section, we briefly describe the LUSTRE model, its components, the method of model integration, and the welfare measures used in this study. Section three outlines the policies we simulate in this paper in a more precise manner. Section four reports on the results, including geographical distribution of the welfare gains under the three policies. The last section concludes and lays out a future agenda.

## **LUSTRE Model Overview**

The LUSTRE model is an integrated model of land use, economic activity, and transportation. The model combines two pre-existing models: the Regional Economy and Land Use (RELU) model and the Strategic and Regional Transport (START) modeling suite.

The RELU model was developed by Alex Anas and Elena Safirova with the purpose of creating a theoretically sound modeling tool for the analysis of interactions between transportation, land use, and economic activity. The model is meant to be integrated with a detailed transportation model. The START modeling suite was developed by MVA Consultancy (May, Roberts, and Mason 1992). More recently, this model was calibrated for the Washington, DC, metropolitan area (referred to as Washington START) and used to conduct a wide range of policy simulations. LUSTRE is calibrated for the Washington, DC, metropolitan region for the year 2000; the transportation network and characteristics of the economy both are specific to this region.

## ***RELU Description***

RELU is a spatially disaggregated static computable general equilibrium model that represents the long-term economic equilibrium in a regional economy. For this paper, the spatial representation corresponds to the Washington, DC, metropolitan area divided in 36 economic zones, plus four outer zones that act as sinks (i.e., they attract economic activity but are not equilibrated together with the model zones). RELU follows the structure of Anas and Xu (1999) in its modeling philosophy, although several new features have been added. For an exposition of the model in greater detail, we refer the reader to Safirova et al. (2006). The following presents the salient features of the model.

RELU has seven types of economic agents that are explicitly represented. There are four types of individuals that correspond to a given skill level. These individuals are the consumers and the workforce in the regional economy; their total number is held fixed across simulations.

The three other agent types are producers, landlords, and developers. Although the government is not explicitly modeled, income and property taxes are present.

Individuals maximize their utility based on a series of discrete and continuous choices. After deciding whether to work or to be unemployed, individuals choose a triple corresponding to their residence, workplace, and type of housing. Conditional on these discrete choices, individuals decide how much housing to rent and how much retail goods and services to purchase at each available retail location. The costs of traveling to a given work or shopping destination are taken into account. Although leisure is not represented in the model, aggregate labor supply is elastic because of voluntary unemployment and the variation in time spent traveling to shop.

The production sector consists of four basic industries: agriculture, manufacturing, business services, and retail; construction/demolition industries are represented as well. The producers are perfectly competitive profit-maximizing agents, with a Cobb-Douglas production function between four groups of inputs: labor, capital, buildings, and intermediate inputs. At the same time, within input groups, substitution is characterized by a constant elasticity of substitution function. All primary industries, except retail, provide intermediate inputs to other sectors. Retail output is consumed by individuals only or exported out of the economic region. Prices of intermediate inputs include freight costs; hence, firm reallocation is affected by the cost of shipping goods.

Landlords manage floor space in a profit-maximizing way in a perfectly competitive market. Rents and operating costs are taken as given. Landlords decide whether or not to offer a unit amount of floor space on the rental market. Floor space in buildings is disaggregated into four types: single family housing, multi-family housing, commercial, and industrial use.

Developers, like landlords, are profit-maximizing agents. They determine how much vacant land should be converted into buildings or vice versa. Construction and demolition prices and other costs are taken as given. Potential rents for the building also affect developers' decisions. Each individual owns a certain share of the real estate.

### ***Washington START Description***

START contains two sub-models referred to as the supply-side and the demand-side. The supply-side consists of the transportation network disaggregated in 40 travel zones (START's travel zones correspond to RELU's economic zones, 36 + 4). Each zone has three stylized transportation links (inbound, outbound, and circumferential) and a number of other "special"

links that represent the principal highway segments and bridges of the region. The traffic quality for each link is characterized by a speed-flow curve. The rail network of the region combines the Washington Metrorail system and suburban heavy rail systems (Maryland Rail Commuter [MARC] and Virginia Railway Express [VRE]). The three rail systems are modeled. Bus travel is represented by a highly stylized route network, with bus accessibility in any zone determined by the density of stops, frequency of service, and reported bus travel times. Transit crowding costs and parking search costs are explicitly included in the model. The model also accounts for existing high-occupancy vehicle (HOV) lanes. The supply-side computes the generalized cost of travel taking into account the time and monetary elements of traveling. Time elements include the time spent traveling, transit waiting time, parking search time, and transit crowding penalties. Monetary elements include car operating costs, car depreciation costs, tolls, and transit fares. The value of time is a function of the travelers' wage rate and varies by trip purpose.

The demand-side is a strategic model with a nested logit structure. In START, trip purposes and origins are taken as given. Agents choose whether or not to generate a trip, destination, mode, time of day, and route (in LUSTRE, trip generation and destination is delegated to RELU). Nest order may be interchanged for different purposes. The model distinguishes four travel modes: single occupancy vehicle (SOV), HOV, transit (which has two sub-modes: bus and rail), and non-motorized (walk and bike). It also represents three time periods: morning peak, afternoon peak, and off-peak. Travelers maximize their utility of travel based on a generalized cost of travel that combines time and money costs explicitly modeled in the supply module, as well as idiosyncratic preferences.

The overall structure of START is iterative. The trips computed in the demand-side are loaded in to the supply-side network. The supply-side uses the loads to compute costs of travel, which are passed back to the demand module. This process iterates until the costs of travel converge to equilibrium values.

### ***Model Integration***

Figure 1 summarizes RELU and START and the integration procedure. First, RELU takes the time and monetary costs of travel as given. The RELU simulation yields (in addition to other land use and economic effects) trip demands, disaggregated by purpose and origin/destination pair, and wage rates. Trips are loaded into START and RELU-determined wage rates translate into value of time for START. Thereafter, START computes the generalized costs of travel. Any transportation policies are taken into account in this step. Computed

generalized costs are sent back to RELU. This iterative process between the two models continues until trip demands and costs converge.

### **Welfare**

The strength of LUSTRE resides in its ability to compute welfare measures that account for the changes in transportation as economic variables. LUSTRE's welfare measures are provided by RELU based on utility function for individuals. Since RELU's indirect utility function is a function of endogenous economic and transportation variables, we can decompose the welfare change to evaluate how each of those variables affects the welfare. The decomposition of the welfare gains is approximated using the first-order Taylor polynomial for the welfare measure (i.e., the sum of the partial derivatives of the welfare function, times the variation, from the baseline to the simulation, of the endogenous economic and transportation variables). Following this approach, we get the following formulation for the decomposition of the total welfare gain ( $\Delta W$ ):

$$\begin{aligned} \Delta W = & \Delta TRD \frac{\partial W}{\partial TRD} + \Delta RE \frac{\partial W}{\partial RE} + \Delta w \frac{\partial W}{\partial w} + \Delta p_{rz} \frac{\partial W}{\partial p_{rz}} + \\ & \Delta R_f \frac{\partial W}{\partial R} + \Delta G^{working} \frac{\partial W}{\partial G^{working}} + \Delta G^{shopping} \frac{\partial W}{\partial G^{shopping}} + \phi \end{aligned} \quad (1)$$

In equation (1), the first term represents welfare gains from the changes in toll revenues redistributed ( $TRD$ ) (surplus of transit fares is included); the second term accounts for changes in real estate value ( $RE$ ); the third term stands for changes in wages ( $w$ ); the fourth term accounts for changes in retail prices ( $p_{rz}$ ); the fifth term comes from the changes in rents ( $R$ ); the sixth term represents changes in commuting costs ( $G^{working}$ ); the seventh term stands for changes in costs of shopping trips ( $G^{shopping}$ ) and the last term is a correction term ( $\phi$ ) due the first-order approximation.

### **Policy Formulation**

The Washington, DC, metropolitan area has a number of features that dictate preferred locations of cordons. The public transportation system exists over the entire region but is concentrated in the downtown core. The Washington Metrorail system predominantly serves the area inside the Beltway. The economic activity in the region is centralized. Additionally, the transportation network developed in a way such that entry points to the cordon toll can be easily

identified by travelers and implemented by the city. Simulations consist of three cordons based on specific locations in the Washington, DC, metropolitan area that have been assessed as realistic for the implementation of such tolls (see Figure 2).

The first cordon circumscribes the downtown core of Washington, DC, hereafter referred to as the Downtown cordon. It covers an area of approximately 4 square miles. This area is the heart of economic activity for the region. More than 400,000 trips are made daily to the Washington, DC, downtown core, with 83.6 percent for commuting purpose. In relative terms, this corresponds to 8.6 percent of all trips and 14.1 percent of all commuting trips made over the study area. A majority of these trips (52.5 percent) are made by public transit, mostly by rail. Among those, 154,000 car trips are made with destinations in the downtown core. With the transportation network consisting of local streets and few arterials, it results in high congestion.

The location of the second cordon coincides with the Beltway; we will refer to this cordon as the Beltway cordon. The area encompassed by the cordon is approximately 170 square miles; an upper bound on the size of a tolled area as underlined by Safirova et al. (2005). This area is a mixture of residential sectors, working locations for both private business and for the public sector, and public areas, such as parks. The active population living within the Beltway was estimated at 1.16 million in 2000, which correspond to 28.1 percent of the active population of the entire study area. The metro system extends just beyond the Beltway and has park and ride facilities. Suburban light rail systems (MARC, VRE) also are available for travelers from more distant locations. Bus systems cover a large area and have fairly good frequency. There are 1.28 million daily trips from outside to inside the Beltway. Unlike the Downtown core, the vast majority of trips from outside to inside the Beltway are made by cars (87.8 percent). A Beltway cordon toll will generate substantial revenue because of the large area it covers and the large number of trips.

The third cordon toll policy is the combination of the Beltway and Downtown cordons, under which the two policies are implemented simultaneously. Travelers using their vehicle from outside the Beltway to the Washington, DC, downtown core will face two independent fees. We refer to this policy as the Double cordon.

The fee is uniform for the three policies and only charged to vehicles accessing the cordon area during the morning peak period, which begins at 6:30 a.m. and lasts until 9:30 a.m. The toll revenue and the additional transit fare revenue collected under the cordon are redistributed lump sum to all individuals. The implementation costs of the cordon are not taken into account because even if they can be substantial for a large cordon, such as the one defined

by the Beltway, we are interested in the long-term effects of the policy. For each of the three policies, we found the toll level that brings optimal welfare gains. Comparisons between policies are conducted at these toll levels.

## Results

Table 1 compares the overall results for the three policies. The total welfare gains are positive for the Beltway and Downtown cordons, as has been found in the earlier comparison using START only (2005). Therefore, accounting for the long-term economic and land use effects does not reverse the net effect of the policies. Note that although 2 dollars separates the optimal toll levels for the different cordons, the Beltway cordon provides welfare gains that are only 14 percent higher than the Downtown cordon (\$104 million versus \$91 million).

Figure 3 shows that the welfare gains under the Beltway cordon are much more sensitive to toll levels. For the Downtown cordon, welfare gains have a greater robustness, particularly if the charge happens to be higher than the optimal.

The optimal combination of the two cordons is a Beltway cordon of 218 cents with a Downtown cordon of 343 cents. At the optimum, the welfare gain is \$150.9 million, 65.4 percent and 44.7 percent higher, respectively, than those from the Downtown and Beltway cordons (Table 1). Thus, the Double cordon yields a substantial improvement in efficiency.

The sensitivity of the welfare gains under the larger cordon and their robustness under the smaller cordon is captured in the path to the optimal Double cordon. As shown on Figure 4, the optimal welfare gain is located at the highest point of a plateau that is circumscribed by a tight range of Beltway cordon charges and a wider range of Downtown cordon charges.

## ***Welfare Decomposition***

Table 2 presents the results of the welfare decomposition. The welfare per capita has been decomposed into several components representing effects of all transportation and economic variables that affect individuals. The welfare decomposition is reported for five large regions of the study area. The “Downtown core” region is defined as the region inside the Downtown cordon. The “Downtown” is the region at its exterior periphery. The “Close suburbs” is the region at the inside periphery of the Beltway. The “Distant suburbs” is the region tangent to the Beltway, but exterior to it. Finally, the “Exurbs” is the rest of the area. As we observe, the residents of the Downtown core gain the most across all three policies, followed by the residents

of the Exurbs. Residents living in the Downtown region and the Distant suburbs gain the least. The following analysis explains these results.

### **Redistribution Scheme**

The Beltway cordon, by virtue of the large area it covers, is a policy that generates substantial toll revenue: almost \$91 million annually. For the Downtown cordon, toll revenues are more modest: \$21.1 million annually. On the other hand, this small cordon collects \$45.8 million annually in additional transit fares; almost three times the amount for the larger cordon. This difference lies in the significant substitution toward public transportation that a small cordon induces. Unsurprisingly, the Double cordon is the policy that collects the most toll revenue: \$110.9 million annually. The lower toll in the downtown induces a smaller substitution toward public transit. The amount of additional transit fares collected under the Double cordon is between the two other policies: \$28 million annually.

In Table 2, the term “Toll Revenue” reflects the size of the welfare gains due solely to the lump-sum redistribution, in the form of extra unearned income, of the toll revenue and additional transit fares collected. The toll redistribution brought important welfare gains; residents of all five regions benefit similarly from the redistribution.

### **Transportation Effects**

As shown in Figure 5, the residents living near the exterior periphery of the cordons face the highest increase in their costs of travel. The number of economically active residents living just outside of the Downtown cordon is 486,000 and 1.2 million live immediately outside the Beltway. Therefore, a significantly larger number of individuals suffer from the travel cost increase induced by the larger cordon. On the other hand, residents inside the cordon see a decrease, or in the case of the Beltway, a very low increase, in travel costs. For these latter residents, the reduction in congestion brought by the cordons induces time savings, resulting in lower costs of travel relative to the baseline.

In Table 2, we observe that these changes in travel costs have important implications for the welfare gains within the regions. An important effect is that the changes in travel costs adversely affect all commuters, especially those residing just outside the cordons. The Beltway cordon impacts these commuters particularly negatively. This result might appear counterintuitive, since the toll level is lower than for the Downtown cordon. However, this result makes sense because the commuters around the Beltway rely more on cars as a mode of

transportation and travelers have fewer opportunities to find new routes to avoid the toll given its large area.

As for the costs of shopping trips, the effects on the welfare gains are less clear. For the residents living in the Downtown core, the changes in the costs of shopping bring significant welfare gains. The fact that shopping trips occur mainly during the off-peak and evening peak period means that shoppers living in the Downtown core are simultaneously less burdened by the toll and gaining from the relief of congestion. Interestingly, the changes in costs of shopping trips induce the larger welfare losses for the individuals living just inside the Beltway cordon.

### **Economic and Land-Use Effects**

Changes in rents, wages, prices, and real estate values are the explicit long-term economic and land use effects of the cordon policy that influence the welfare gains. These variables have a significant impact when we assess their contribution to the welfare gains (Table 2). While changes in real estate value and wages contribute to welfare gains, changes in the prices of retail goods and in residential rents lead to welfare losses.

*Rents.* Regarding the changes in residential patterns, the zones at the exterior periphery of the cordons (Distant suburbs) see a decrease of their active population. Migrants are moving inside the cordon and to a lesser extent into the Exurbs. Under the Beltway cordon, migrants prefer to reallocate to the very core of the cordon rather than to the interior periphery of the cordon (Close suburbs). This behavior is exacerbated under the Double cordon. As a result, changes in residential patterns create upward pressure on the residential rents in the Downtown core. Under the three policies, they increase by 0.23 percent, 0.30 percent, and 0.39 percent for the Beltway, Downtown, and Double cordons, respectively. These higher rents lead to welfare losses. On the other hand, residents of the Distant suburbs, whose population is declining, benefit from lower rents.

*Wages.* The degree of change in work status and location are reflected by the variations in average gross wage rates (Figure 6). Wages increase in all zones and especially inside the cordons. The Double cordon affects the labor market the most, followed by the Beltway cordon. These increases are induced by a labor scarcity that comes from both unemployment and relocation of the workers to certain zones. In this competitive characterization of the economy, the reduction of the labor supply in a given zone increases the marginal productivity of labor, which corresponds to higher wages. These changes in work status and location are primarily caused by the higher costs of commuting. The lump-sum redistribution of the toll revenue also leads to higher unemployment because it reduces the opportunity cost of unemployment. As a

result, we observe in Table 2 that the higher wages are an important contributor to the welfare gains, predominantly where labor becomes scarcer.

It should be noted that the welfare gains brought by higher wages partially are outweighed by the shift toward unemployment. Eventually for very high tolls the welfare losses caused by unemployment will dominate. This reversal between the two effects partly explains why the Beltway cordon is more sensitive to toll levels. The Beltway cordon affects a greater share of the active population; therefore, changes in toll levels induce a shift toward unemployment that eventually dominates.

*Prices.* The response of producers to the cordon policies is another factor affecting the welfare gains. More specifically, the response of producers is channeled to the welfare gains by the changes in the prices of retail goods and services they induce. These prices are a function of the demand of the shoppers and the costs of production. In the present simulations, the increases in wages impose enough pressure on the costs of production to result in higher retail prices. This inflationary pressure leads to welfare losses for individuals, as shown on Table 2. It is particularly true in the region inside the cordons, where the price increases are the highest. Note that individuals are more negatively affected by the changes in prices under a Beltway cordon relative to a Downtown cordon. This is another reason why the welfare gains under a Beltway cordon are more sensitive to the toll level.

The three policies increase the regional GDP over the whole study area. Overall, the Double cordon induces a \$420.9 million increase, the Beltway cordon induces a \$300.1 million increase, and the Downtown cordon induces a \$247.7 million increase. In Figure 7, we observe that under a Beltway or Double cordon, the GDP decreases the most around the interior periphery of the cordon and increases in the exurbs and to a lesser extent in the Downtown area. Under the Downtown cordon, the GDP is reduced more at the exterior periphery of the cordon. Thus, the smaller cordon adversely affects production in the area outside the cordon but it is no longer true as the size of the cordon increases

*Real Estate Values.* A shift in residence pattern and production results in higher rents on average over the whole study area (Double cordon: 0.058 percent, Beltway cordon: 0.042 percent and Downtown cordon: 0.033 percent). In turn, the higher rents increase the value of the buildings (housing, commercial, and industrial) provided by the developers. For individuals, who own a share of the real estate, the appreciation of real estate values translates into additional unearned income.

## Conclusions

In this paper, we have used an integrated model of land use, transportation, and economic activity (LUSTRE) to simulate the long-term effects of three cordon-based congestion pricing policies. Three policies have been modeled: a small Downtown cordon, a large Beltway cordon, and a Double cordon, combining the two other cordons. For each policy, we find the cordon level that maximizes residents' welfare and compare policies at the optimum toll level.

We find that all three policies result in modest but positive welfare gains, with the Double cordon being most effective. At the optimum, the welfare gain from the Double cordon amounts to \$150.9 million annually, 65.4 percent and 44.7 percent higher than those from the Downtown and Beltway cordons, respectively.

However, the welfare gains from the downtown toll are relatively insensitive to the charge level, while the gains from the other two policies decline sharply with deviation from the optimum. Therefore, even though the expected gains from the smaller cordon are lower, in practice smaller cordons are likely a safer bet. If the toll levels are set suboptimally, the tolling schemes with larger cordons might result in welfare gains significantly inferior to the optimal ones, but the small cordon will still be effective.

## References

- Akiyama, T., S. Mun, and M. Okushima. 2002. Second-Best Congestion Pricing in Urban Space: Cordon Pricing and its Alternatives. *The Review of Network Economics* 3(4): 401–414.
- Anas, A., and R. Xu. 1999. Congestion, Land Use and Job Dispersion: A General Equilibrium Model. *Journal of Urban Economics* 45: 451–473.
- Lindsey, R., and E. T. Verhoef. 2001. Traffic congestion and congestion pricing. In *Handbook of Transport Systems and Traffic Control*, edited by K. J. Button and D. A. Hensler. Oxford: Elsevier Science, 77–105.
- May, A. D., R. Liu, S. P. Shepherd, and A. Sumalee. 2002. The Impact of Cordon Design on the Performance of Road Pricing Schemes. *Transport Policy* 9: 209–220.
- May, A. D., M. Roberts, and P. Mason. 1992. The Development of Transport Strategies for Edinburgh. *Proceedings of the Institution of Civil Engineers: Transportation* 95: 51–59.
- Mun, S., K. Konishi, and K. Yoshikawa. 2003. Optimal Cordon Pricing. *Journal of Urban Economics* 54: 21–38.
- Pigou, A. C. 1920. *Wealth and Welfare*. London: Macmillan.
- Safirova, E., K. Gillingham, W. Harrington, P. Nelson, and D. Lipman. 2005. Choosing Congestion Pricing Policy: Cordon Tolls vs. Link-Based Tolls. *Transportation Research Record* 1932:169–177.
- Safirova, E., S. Houde, D. Lipman, W. Harrington, and A. Baglino. 2006. Congestion Pricing: Long-Term Economic and Land use Effects. Discussion paper 06-37. Washington, DC: Resources for the Future.
- Santos, G. 2004. Urban Congestion Charging: A Second-Best Alternative. *Journal of Transport Economics and Policy* 38(3): 345–369.
- Santos, G., and B. Shaffer. 2004. Preliminary Results of the London Congestion Charging Scheme. *Public Works, Management and Policy* 9(2): 164–181.
- Shepherd, S. P., and A. Sumalee. 2004. A Genetic Algorithm Based Approach to Optimal Toll Level and Location Problems. *Networks and Spatial Economics* 4(2): 161–179.
- Small, K. A., and J. A. Gómez-Ibáñez. 1998. Road Pricing for Congestion Management: The transition from theory to policy. In *Road Pricing, Traffic Congestion and the*

- Environment: Issue of Efficiency and Social Feasibility*, edited by K. J. Button and E. T. Verhoef. Cheltenham, UK: Edward Elgar, 213–246.
- Transportation Research Board. 2003. Road Value Pricing: Travelers Response to Transport System Changes. Transit Cooperative Research Program Report 95. Washington, DC: Transportation Research Board.
- Verhoef, E. T. 2002. Second-Best Congestion Charging in General Networks. Heuristic Algorithms of Finding Second-Best Optimal Toll Levels and Toll Point. *Transportation Research B* 36: 707–729.
- Vickerman, R. 2005. Evaluating the Wider Economic Impacts of Congestion Charging Schemes: the Limitations of Conventional Modeling Approaches. Paper presented at the 45<sup>th</sup> ERSA Congress, Amsterdam, The Netherlands, August 2005.
- Zhang, X., and H. Yang. The Optimal Cordon-Based Network Congestion Pricing Problem. *Transportation Research B* 38: 517–537.

## Tables and Figures

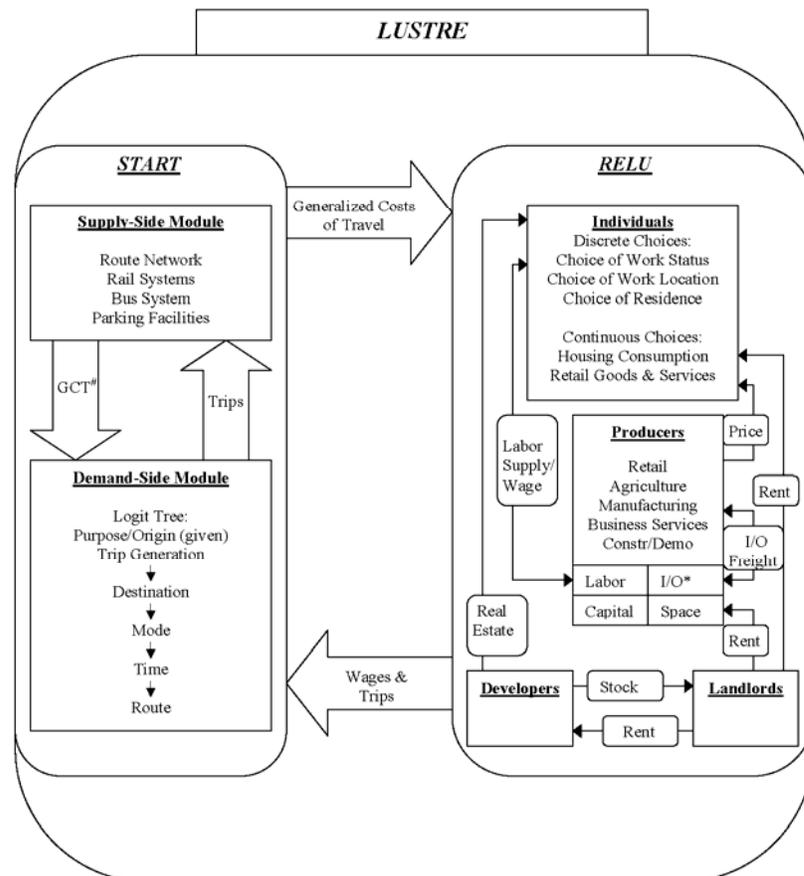
**Table 1. Welfare Gains and Revenue Collected under Three Cordon Policies**

	<i>Toll (2000 cents)</i>	<i>Total Welfare Gains (Thousands of 2000\$/year)</i>	<i>Cordon Toll Revenue (Thousands of 2000\$/year)</i>	<i>Additional Transit Fares Collected (Thousands of 2000\$/year)</i>
Beltway Cordon	277	104273	90967	16411
Downtown Cordon	470	91217	21131	45812
Double Cordon	Beltway: 218 Downtown: 343	150850	110932	28025

Table 2. Decomposition of LUSTRE's Welfare for Three Cordon Policies

		Welfare Gains per Capita (2000\$/year)	Welfare Decomposition (2000\$/year)							
			Wage	Toll Revenue	Real Estate Value	Price	Rent	Commuting Costs	Costs of Shopping Trips	Correction Term
Beltway Cordon 277 cents	Downtown core	50.0	37.9	51.6	10.9	-23.9	-15.9	-1.2	17.5	-27.0
	Downtown	42.4	39.0	52.2	11.0	-26.0	-13.5	-1.3	-5.9	-13.1
	Close Suburbs	36.0	41.8	48.8	10.3	-26.4	-9.0	-7.3	-18.6	-3.7
	Distant Suburbs	34.5	36.9	49.0	10.3	-17.0	6.1	-45.2	-5.1	-0.6
	Exurbs	43.4	24.6	44.5	9.4	-13.7	-3.8	-11.8	-0.49	-5.3
	All Area	39.6	32.8	47.5	10.0	-18.1	-2.9	-19.9	-4.9	-4.9
Downtown Cordon 470 cents	Downtown core	53.7	37.3	32.2	8.3	-18.8	-21.4	-1.8	54.6	-36.6
	Downtown	27.7	31.1	32.5	8.4	-15.3	3.9	-28.1	-8.2	3.4
	Close Suburbs	28.7	26.1	30.4	7.8	-12.3	1.3	-21.0	-0.45	-3.1
	Distant Suburbs	31.6	26.9	30.6	7.9	-13.7	-3.1	-11.3	0.32	-5.9
	Exurbs	33.7	20.6	27.2	7.1	-12.1	-3.6	-3.0	0.07	-3.2
	All Area	31.9	24.8	29.6	7.6	-13.1	-2.1	-11.0	-0.06	-3.8
Double Cordon: Beltway 218 cents, Downtown 343 cents	Downtown core	80.8	57.0	66.8	14.8	-32.8	-27.9	-2.2	49.6	-44.5
	Downtown	53.6	53.9	67.5	14.9	-32.1	-6.3	-24.2	-13.3	-6.5
	Close Suburbs	49.3	53.0	63.1	13.9	-30.5	-5.0	-23.9	-17.0	-4.3
	Distant Suburbs	51.4	49.6	63.4	14.0	-23.8	1.9	-43.9	-4.3	-5.6
	Exurbs	60.2	35.2	57.6	12.7	-20.0	-6.1	-11.4	-0.43	-7.2
	All Area	55.5	44.7	61.5	13.6	-24.3	-3.9	-24.5	-4.8	-6.8

Figure 1. Flow Diagram of LUSTRE



<sup>#</sup> Generalized Costs of Travel

\*Intermediate demand for finished goods and services, also referred as Input/Output (I/O) tables.

Figure 2. Policy Description

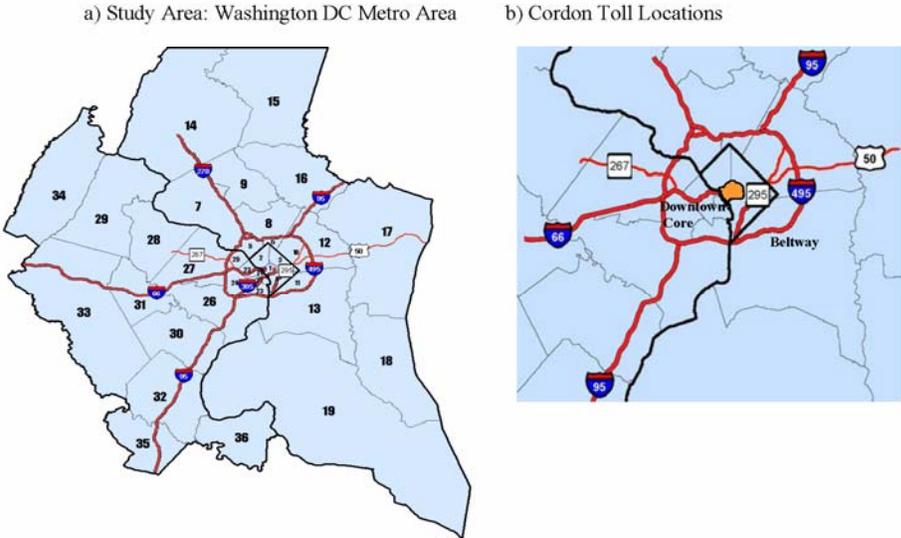


Figure 3. Total Welfare Gains under a Beltway Cordon vs. a Downtown Cordon

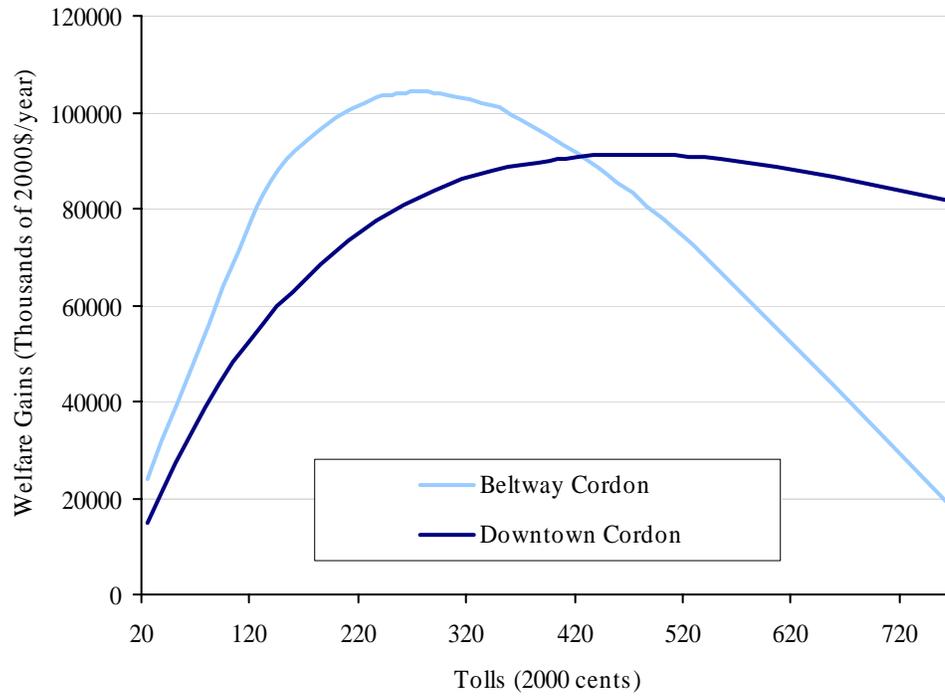
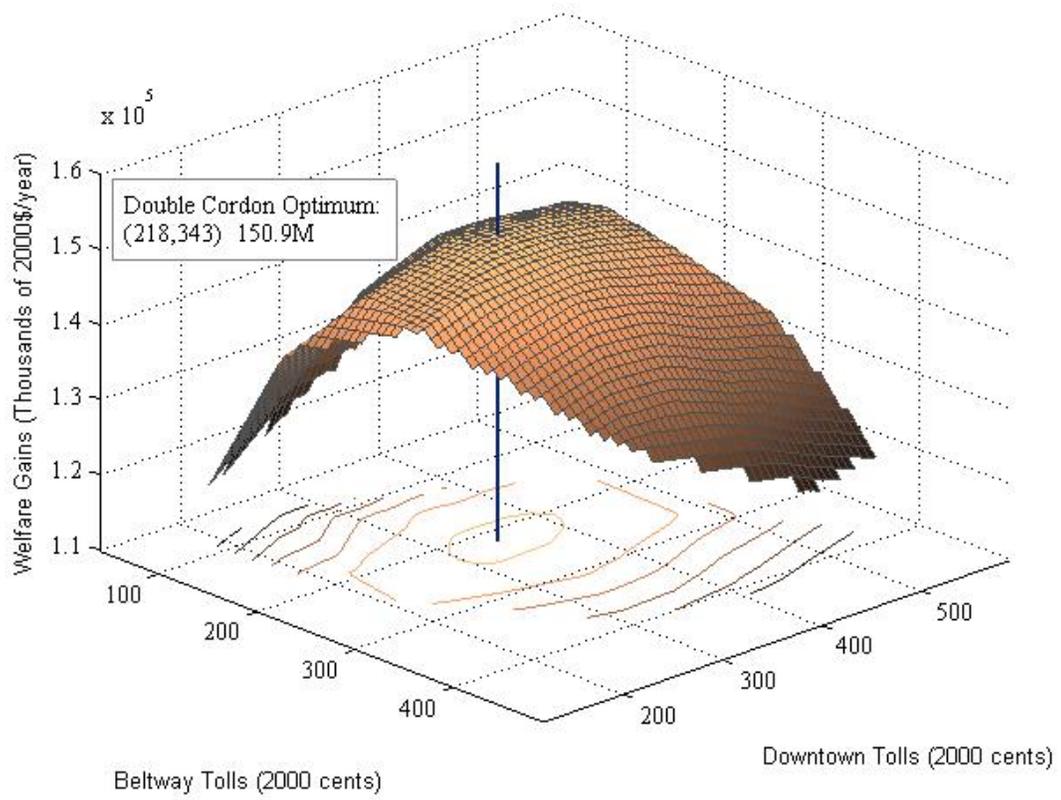
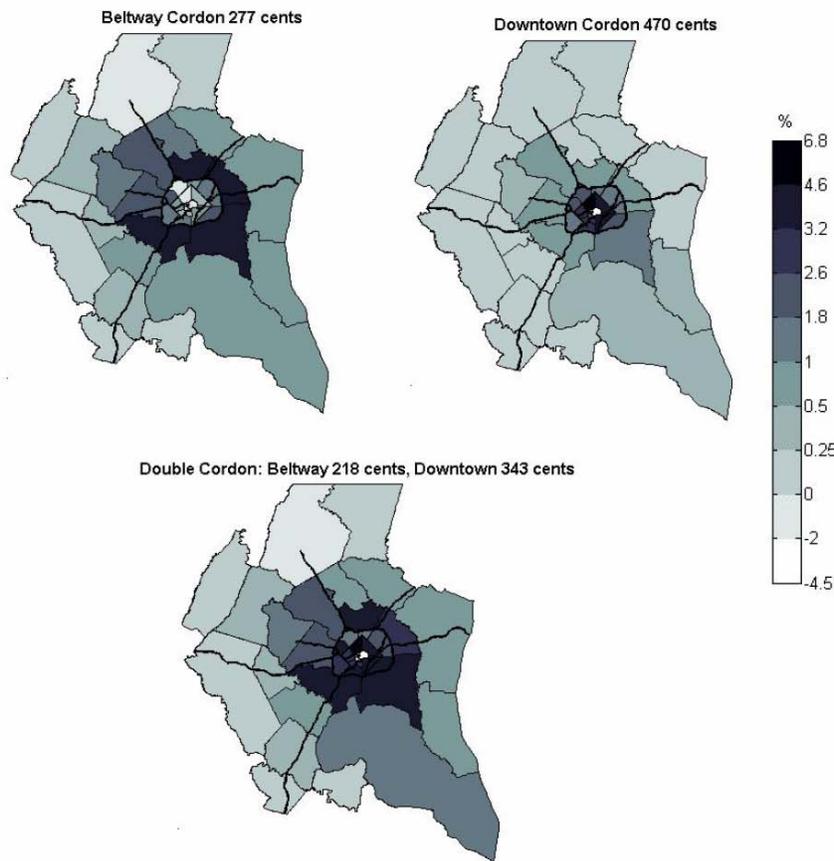


Figure 4. Total Welfare Gains under a Double Cordon



**Figure 5. Changes in Travel Costs by Zones of Origin for Three Cordon Policies, Simulation vs. Baseline**



**Figure 6. Changes in Average Gross Wages Rates for Three Cordon Policies, Simulation vs. Baseline**

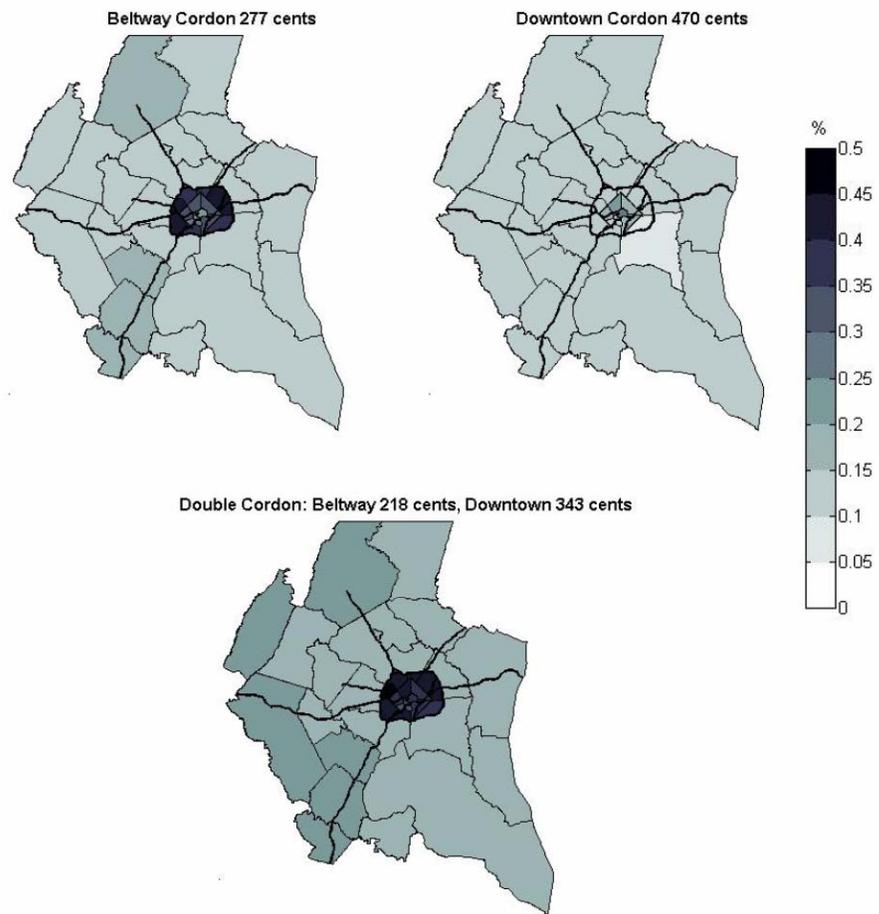


Figure 7. Changes in Regional GDP for Three Cordon Policies, Simulation vs. Baseline

