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Marginal Social Cost Pricing on a Transportation Network

A Comparison of Second-Best Policies

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Abstract

In this paper we evaluate and compare long-run economic effects of six road-pricing schemes aimed at internalizing social costs of transportation. In order to conduct this analysis, we employ a spatially disaggregated general equilibrium model of a regional economy that incorporates decisions of residents, firms, and developers, integrated with a spatially-disaggregated strategic transportation planning model that features mode, time period, and route choice. The model is calibrated to the greater Washington, DC metropolitan area. We compare two social cost functions: one restricted to congestion alone and another that accounts for other external effects of transportation. We find that when the ultimate policy goal is a reduction in the complete set of motor vehicle externalities, cordon-like policies and variable-toll policies lose some attractiveness compared to policies based primarily on mileage. We also find that full social cost pricing requires very high toll levels and therefore is bound to be controversial.

Key Words: traffic congestion, social cost pricing, land use, welfare analysis, road pricing, general equilibrium, simulation, Washington DC

JEL Classification Numbers: Q53, Q54, R13, R41, R48

Contents

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1. Introduction

In the past two decades, analysts and policymakers have become increasingly interested in the full social costs of motor vehicle use (Quinet 2004; Delucchi 2000; Lee 1993; Litman 2003). In most accounts, the social costs of transportation include external, non-market, or unpriced costs (such as air pollution), as well as private or market costs (such as the transportation costs faced by the traveler). A social-costs analysis can provide data, functions, and estimates that can help analysts and policymakers evaluate the costs of transportation policies, establish efficient prices for transportation services and commodities, and prioritize research and funding (Murphy and Delucchi 1998).

Not surprisingly, there is little agreement about precisely which costs should be counted in a social cost analysis. Methods used to estimate those costs also vary widely and often produce very different numerical estimates. The externalities most commonly included on the list are those associated with congestion, traffic accidents, local air pollution, global air pollution and oil dependency, and noise. However, several studies include other external costs, such as those related to highway maintenance costs, urban sprawl, parking, and the like (Parry et al. 2007).

Historically, there has been no effort to use pricing to mitigate the external costs of motor vehicle use. The main fiscal instrument affecting motor vehicle use is the gasoline tax, which is currently intended to raise revenue. Except for congestion, which is discussed below, the policies presently addressing motor vehicle externalities are regulatory, including federal emissions standards, corporate average fuel economy (CAFE) standards, as well as state and local traffic laws. Such regulations reduce but do not eliminate or internalize the externalities. Fully internalizing these negative externalities is difficult, because monitoring and measuring them is difficult or impossible. For example, with current technology at least, vehicle emissions are impossible to measure in real time on ordinary vehicles in use. Quantifying noise, oil

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dependency, or accident externalities is even more problematic. However, with these regulations already in place, most observers have concluded that the remaining externalities are approximately proportional either to fuel consumption (greenhouse gas emissions, oil dependency) or VMT (accidents, local emissions, noise) (Parry and Small 2005). Of course, the rates of proportionality are highly localized.

Until recently, no policy (save road construction) has attempted to deal with traffic congestion, which by most estimates is by far the most important externality of motor vehicle use. Congestion is also worsening rapidly as road construction has failed to keep up with growth in the demand for travel on a global level. Thus congestion depends on VMT, but it also depends on the time and place, for road use is emphatically a peak-period phenomenon. Today, peak-period pricing of roads to deal with congestion is becoming a reality, thanks to recent improvements in technology, together with apparently growing public acceptance of the concept. As with the other externalities, measurement of congestion is problematic. Ideally, the first-best system would involve marginal social cost pricing on every link of an urban network, but as noted above, such a system is likely to be excessively information-intensive as the optimal charges would be subject to rapid changes. Even if that difficulty can be overcome as technology improves, it is not clear that it will be capable of leading to conscious changes in travel behavior as a response to pricing. Presently, most congestion pricing schemes, both implemented and proposed, are confined to a set of simple policies. In Europe, the favorite pricing scheme is a cordon (or area) toll, while in the United States, high-occupancy toll (HOT) lanes have been a predominant form of pricing up to date.

The two studies in the literature that are closest to our approach are Proost and van Dender (2004) and Santos et al. (2000). Both of them use transportation modeling frameworks that are somewhat different from ours and therefore an immediate comparison of the results is difficult. Proost and van Dender (2004) use a multi-modal partial equilibrium transportation model, TRENEN, which describes the market equilibrium for all transportation markets simultaneously. They calibrate TRENEN to several cities in Germany and the UK and test several pricing schemes—average cost pricing, Ramsey social cost pricing and marginal social costs pricing. It should be noted that TRENEN is a non-network aggregate model that assumes that all travel is aggregated on a single link. It is also a medium-run static model, where there is only one type of representative households. The model demonstrated that the issue of tax interactions plays an important role in determining the welfare effects of a particular pricing scheme for various cities. The study by Santos et al. (2000) simulated cordon-type pricing for eight English towns and computed social benefits, both from reductions in congestion and air pollution, resulting from various toll levels. Santos et al. (2000) used the SATTAX-SATURN modeling platform, a complex network transportation model with a very simple demand side. They suggested that given a high uncertainty in the estimation of environmental costs, congestion tolls alone could be successfully used to reduce environmental externalities.

In this paper, we model and compare six road pricing instruments that can be used to internalize, even if partially, transportation-related externalities and by doing so improve travelers' welfare and reduce social costs of transportation. The instruments are three types of cordon pricing schemes, a distance-based toll charged on all freeways, a distance-based toll charged on all metro area roads, and a gasoline tax. All instruments, except for the VMT tax perhaps, are initially designed to internalize only the congestion externality. In our simulations we observe how these instruments can be used as second-best policies internalizing not only the congestion externality, but also all other major external costs of motor vehicle use.

The rest of the paper is structured as follows. In the next section, we briefly describe the LUSTRE model, the welfare measure used, and how various transportation externalities are represented in this framework. Section three outlines the policies we simulated in this paper in a more precise technical manner. Section four reports and discusses the results. In particular, we point out how each policy affects individual types of external costs. The last section concludes and lays out future agenda.

2. The LUSTRE Model

This section presents the salient features of LUSTRE, the modeling platform used in the simulations. Due to space limitations, we cannot provide many modeling details; for a more detailed discussion the reader is referred to Safirova et al. (2006).

LUSTRE integrates RELU—a spatially disaggregated general equilibrium model of a regional economy and land use that incorporates decisions of residents, firms, landlords and developers—with START, a spatially disaggregated strategic transportation planning model that features mode, time period, and route choice. The integrated model features a rather detailed representation of the local economy, with features including agents of different skill levels, real estate and income taxes, and a detailed transportation network combining roads and a congestible transit system.

2.1 RELU

In RELU, 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 combination consisting of their zone of residence and employment and their type of housing (single versus multifamily). Conditional on these discrete choices, individual agents decide how much housing to rent and the quantity of retail goods and services to purchase at each available retail location. Commuting and shopping trips are linked to individual's labor supply, work and residential locations, and consumption level. Travel demands are therefore completely endogenized.

2.2 START

START computes the generalized cost of travel, taking into account the time and monetary elements of traveling. Time elements range from the time spent traveling and transit waiting time to parking search time and transit crowding penalties. Monetary elements include car operating costs (fuel and oil consumption, fuel taxes, maintenance), car depreciation costs, tolls, and parking and transit fares. The value of time is a function of the travelers' wage rate, and varies by trip purpose. The transportation network is disaggregated in 40 travel zones (START's travel zones correspond to RELU's economic zones). 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 on each link is determined by a speed/flow•distance curve. The rail network of the region, which combines the Washington Metrorail system and suburban heavy rail systems [Maryland Rail Commuter (MARC) and Virginia Railway Express (VRE)], and the bus network are represented. Agents choose, mode, time of day, and route[1]. Trip generation and choice of origin and destination are delegated to RELU.

2.3 Equilibrium

Unlike many other land-use transportation models, the integration in LUSTRE is achieved at the behavioral level of individual agents, not at the aggregate level. As shown in Figure 1, wages (determinant of the value of travel time) and the trip demands of each RELU agent to meet journey-to-work and shopping needs are summed and loaded onto the START

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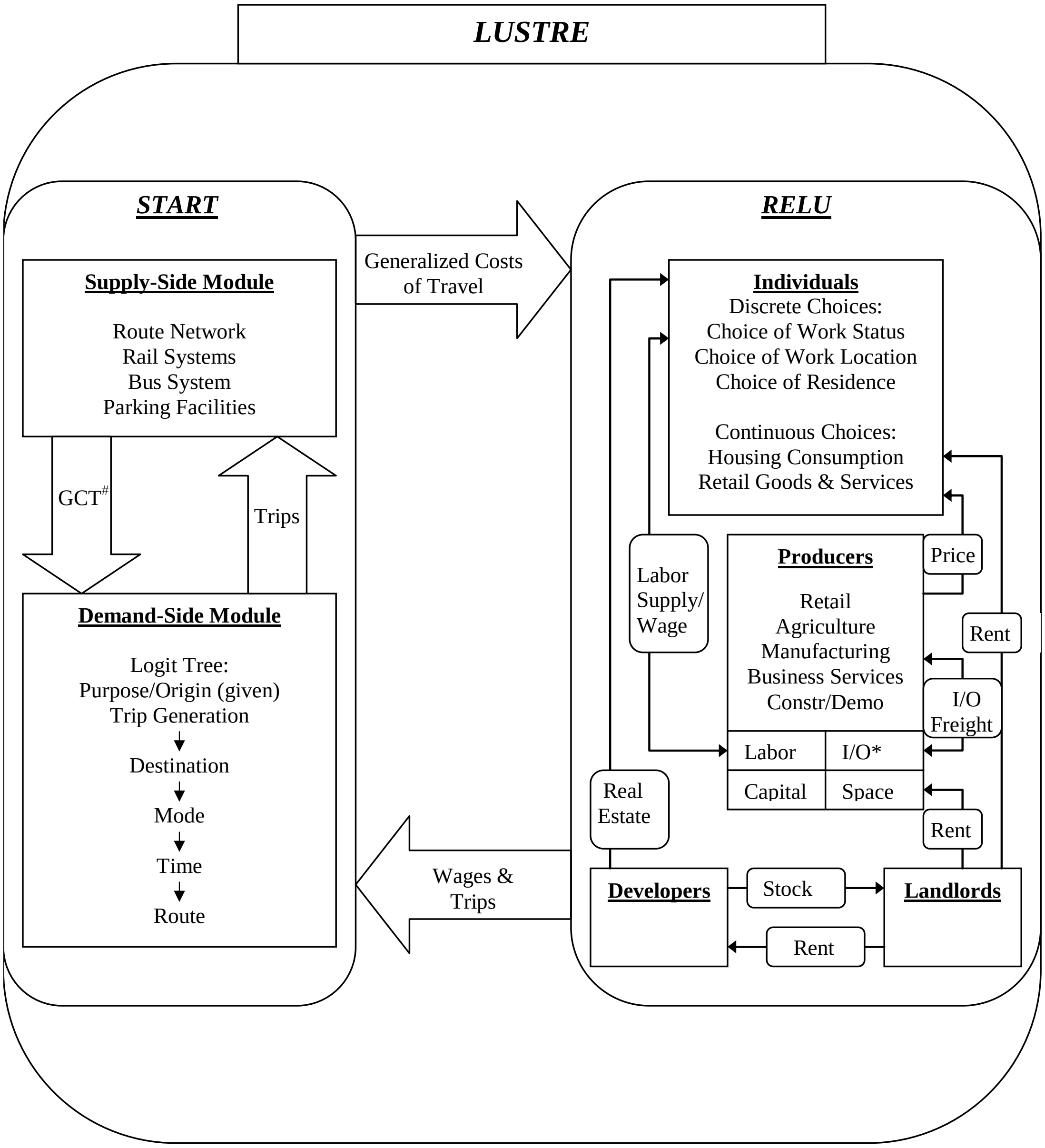
[1] The order of choices varies with the trip purpose.

transport network, which computes equilibrium generalized costs for each pair of zones, by mode and time of day, and passes those costs to RELU.

Figure 1. Flow Diagram of LUSTRE



Generalized Costs of Travel

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

Using the updated travel costs, RELU finds a new equilibrium prices (rents, wages and goods prices) and quantities (employment, travel demands, goods purchases, land allocations and housing types) by zone. The updated travel demands are passed back to RELU, and the system iterates until a fixed point is reached. The model is calibrated for the greater Washington, DC metropolitan area for the year 2000. More details can be found in the mathematical appendix in Safirova et al. (2006).

It should also be noted that while LUSTRE is an equilibrium model, so that all markets clear, it is not a fully dynamic model. In the real world, the various markets represented in LUSTRE clear at vastly different rates, from the daily clearance of the transportation route and mode choice "market" to the decades-long clearance of the land-use market. In the current version, the evaluation of various policies is achieved by comparison of a long-run equilibrium to the baseline.[2]

2.4 Data

LUSTRE is calibrated for the Washington, DC metropolitan region of for the year 2000; the transportation network and characteristics of the economy both are specific to this region (see Figure 2). To calibrate the model, a variety of data sources have been used. Data on residential and workplace patterns, wages, and incomes were extracted from the Census Transportation Planning Package (CTPP) and supplemented by the Consumer Expenditure Survey. Prices and production volumes are based on data obtained from the Bureau of Labor Statistics; housing consumption data and residential rents came from the American Housing Survey; and land-use data were collected from the local and county governments in the metropolitan area. On the transportation side, we merged the data from the CTPP with data from the 1994 Travel Survey, scaled up to the 2000 levels of travel demand. The Metropolitan Washington Council of Governments (COG) Version 1 transportation planning model and the data from aerial photography (COG 1999) were used to calibrate road link speeds.

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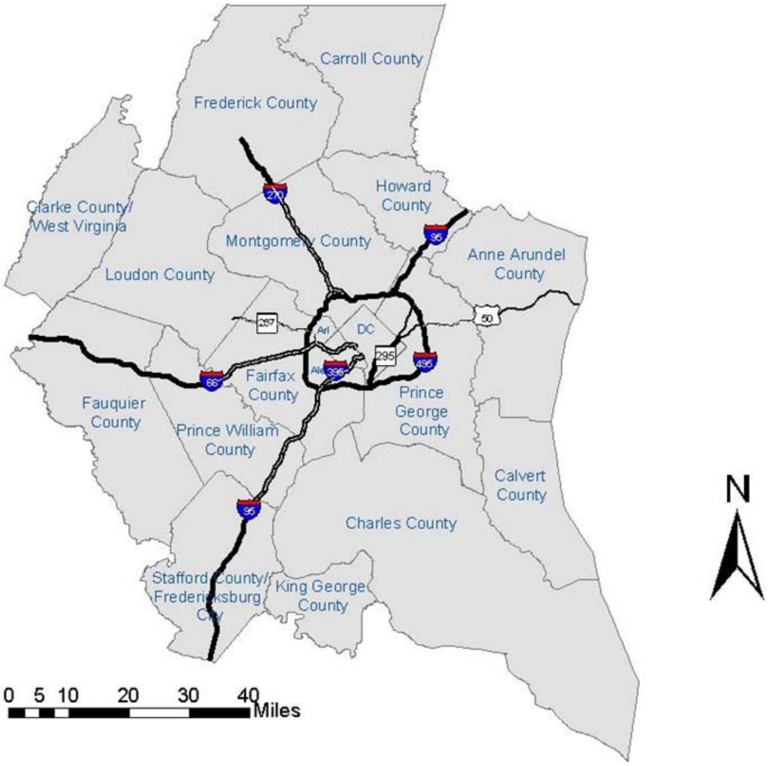
[2] As is customary when dealing with the static long-run equilibria, we do not account for the capital costs of setting up pricing equipment

Figure 2. Metropolitan Washington, DC, with Zones Used in the Model

Zone Number	Description
1	DC Downtown
2	DC Northwest
3	DC Northeast
4	DC Southeast
5	Montgomery Co. Southwest
6	Montgomery Co. Southeast
7	Montgomery Co. West
8	Montgomery Co. East
9	Montgomery Co. Northeast
10	Prince George Co. Northwest
11	Prince George Co. Southwest
12	Prince George Co. Northeast
13	Prince George Co. Southeast
14	Frederick Co.
15	Carroll Co.
16	Howard Co.
17	Anne Arundel Co.
18	Calvert Co.
19	Charles Co.
20	Arlington East
21	Arlington South
22	Arlington West
23	Alexandria
24	Fairfax Co. East
25	Fairfax Co. Northeast
26	Fairfax Co. South
27	Fairfax Co. Northwest
28	Loudon Co. East
29	Loudon Co. West
30	Prince William Co. South
31	Prince William Co. North
32	Stafford/Fredericksburg Co. North
33	Fauquier Co.
34	Clarke Co.
35	Stafford/Fredericksburg Co. South
36	King George Co.
37	External Zone, South
38	External Zone Southwest
39	External Zone, Northwest
40	External Zone, East



2.5 Welfare

One of LUSTRE's strengths resides in its ability to compute a welfare measure that accounts for the changes in transportation as economic variables. LUSTRE's welfare measure is based on RELU utility function. In RELU, utility is agent-based and therefore all changes in transportation and economic conditions affecting individuals are incorporated in the welfare measure.

Since the discrete consumer choices in RELU are characterized by a multinomial nested logit, the aggregate indirect utility takes a well-known analytical form. Aggregate indirect utility is, however, not well suited for policy evaluation because this is an ordinal measure of welfare. A more meaningful measure is the change in consumer surplus, a monetized value of welfare change. As in Anas and Rhee (2006), the change in consumer surplus (*CS*) in this framework can be approximated by:

$$CS_f = \frac{\left(W_f^1 - W_f^0\right)}{AMUI_f}$$

where W is the aggregate indirect utility of an individual of skill level f, with superscript 1 referring to the equilibrium post policy implementation and 0 to the baseline equilibrium; and $AMUI_f$ is the average marginal utility of income.

Now we will move away from the technical description and summarize which costs and benefits of transportation are captured in the consumer surplus computed in LUSTRE and which ones are excluded.

The consumer surplus includes any changes in time of travel, including the delays imposed by others (or the reduction of such delays) and car operating costs. Note that in START, operating costs are a function of VMT and speeds. Travel time and car operating costs associated with congestion are therefore implicitly included. For transit users, changes in travel time and monetary costs are also fully accounted for. The interactions between transit usage and traffic quality are incorporated and accounted for as well. In RELU, real estate and income taxes are present. Furthermore, revenues from transportation policies are recycled back to the economy. Issues of tax interaction between existing taxes and transportation policies are present and consequently included. Also, changes in economic conditions, such as wages, retails prices and rents, are naturally evaluated. Finally, a subtler potential source of changes in the consumer surplus is an inherent attractiveness of consumption packages to the individuals that is not captured in prices, wages, and rents. Indeed, in LUSTRE, it is assumed that individuals have preferences over certain choice packages for reasons other than purely economic reasons. These preferences are implicitly represented in the consumer surplus.

At the same time, the maintenance and operating costs of transportation infrastructure (road and transit) are excluded from the consumer surplus. More importantly, the following transportation externalities are excluded: accidents, air pollution, climate change, oil dependency, noise, transportation related crimes, and other environmental damages such as water pollution.

In sum, LUSTRE has a detailed representation of private travel demands[3] and marginal private costs. On the other hand, most of the external costs of transportation are missing; only congestion and issues of tax interactions are considered. In the following, we present a simple methodology to account for additional transportation externalities in LUSTRE.

2.6 Transportation Externalities in LUSTRE

Being a rather detailed transportation and economic model, LUSTRE provides a useful framework to represent and measure the congestion externality. The empirical literature suggests that the most important transportation externalities, apart from the congestion externality, are: air pollution, accidents, climate change, oil dependency and noise (Delucchi 1997; Quinet 2004). In this paper, we focus on those externalities.

For all these externalities, we compute the aggregate costs by assuming a linear relationship between the level of damages, in monetary terms, and VMT. This is an important simplification because vehicular emissions (CO, VOC, NOx, CO_2), oil consumption, accidents, and noise are not only a function of the VMT but also of speeds, vehicle type, maintenance, and driver’s behavior. Moreover, the true relationships between most of those variables are likely non-monotonous and not well-behaved. For example, the formation of local air pollution is a complex, non-linear process. Furthermore, it is not clear if the health effects and their associated costs increase linearly in stocks of pollutants. Regarding this point, Small and Kazimi (1995) conclude that a linear relationship might be appropriated for low levels of chemical

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[3] Freight trips are present in LUSTRE. They are tied to the activity of the firms. The level of sophistication is, however, far lower than that for private trips.

concentrations and when costs are aggregated over population. Similarly, we justify the use of a linear relationship by the fact that we are interested in obtaining aggregate costs. Since we are averaging over a large population (around 4 million) and over different trip characteristics, various non-linearities in the causality chain will be significantly smoothed out.

For each externality, the aggregate costs are computed by multiplying the average marginal costs by the total VMT. We use average marginal costs values cited in the review by Parry et al. (2007).

Table 1. Central values for marginal external costs

External Costs	Cents/mile (2000)	Studies Reviewed
Air Pollution	2.02	Small and Kazimi (1995) McCubbin and Delucchi (1999) US Federal Highway Administration (FHWA) (2000)
Accidents	2.64	US FHWA 1997, Miller et al. 1998, Parry 2004
Climate Change	0.35	Nordhaus and Boyer (2000) Tol (2005) Pearce (2005)
Oil Dependency	0.53	Leiby et al. (1997) NRC 2002 CEC 2003
Noise	0.053	Delucchi and Shi-Lang (1998) US FHWA (1997)
Congestion	3.08	Small and Parry (2005) US FHWA (1997, 2000)

Source: Parry et al. 2007.

2.7 Emission Scenarios

The level of detail of the transportation module in LUSTRE allows for a further advance of modeling techniques for emissions scenarios. In particular, it is possible to take into account the effects of different speeds and vehicle types. Note that emissions scenarios are produced by integrating LUSTRE with EPA’s model MOBILE6.2. For a detailed description of the methodology, we refer the reader to Harrington et al. (2007). A subsequent step in our model development would be to link the emission scenarios with the computation of the transportation externalities, when appropriate.

3. Policy Description

First, for the six transportation pricing policy instruments, we compute the monetary levels of the second-best transportation policies that internalize the congestion externality and, to a certain extent, the tax interaction externality[4]. Afterward, for the same six instruments, we compute the levels of second-best policies that also internalize the other transportation externalities as computed in LUSTRE.

For all six instruments, the revenue collected as tolls, VMT tax and additional transit fares[5] are redistributed in lump-sum fashion to all individuals.[6] We do not explicitly include the costs associated with operating toll-collection mechanisms.[7] Here our goal is not to be realistic, but to minimize issues of tax interactions, a complex topic that is beyond the scope of this paper. The six instruments are:

- A small cordon, levying a toll on all vehicles entering the downtown core during morning rush hour (Downtown cordon);
- A big cordon, levying a toll on all vehicles entering the area surrounded by the Washington Beltway during morning rush hour (Beltway cordon);
- A double cordon, combining the two cordons above (Double cordon);
- A road toll, charging users by distance and time of day for travel on all freeways and Potomac bridges in the metropolitan area (Freeway toll);
- A road toll, charging users by distance and time of day for travel on all links in the metropolitan area (Comprehensive toll);
- A VMT tax[8].

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[4] In LUSTRE, government is not represented explicitly. The effects of the transportation policies on the revenue collected from income and property taxes are not taken into account. Issues of tax interactions are therefore not fully accounted. However, the presence of taxes distorts an agent's behavior; some of these distortions are captured by the model (for example, the decision to be employed or unemployed). The interactions between taxes and the new transportation policies are therefore represented only partially.

[5] In effect, we assume that the transit fares are used to reduce local transit operating subsidies.

[6] Although a lump-sum distribution of the revenue is usually reserved for theoretical literature, recently a credit-based pricing scheme has been proposed to improve public acceptance of congestion pricing (Kalmanje and Kockelman 2004). On the revenue distribution side, it resembles the lump-sum scheme.

[7] Based on the calculations by Gulipalli and Kockelman (2006), we estimate the operating costs of a small cordon to be in the range of $10 million annually, and the costs of other policies might be perhaps as high as $100 million. However, one can expect significant cost reduction in the near future as congestion pricing and other electronic toll collection (ETC) applications become more widespread.

[8] A VMT tax is often described as a promising alternative to gasoline tax. The State of Oregon is currently working on the implementation issues surrounding gas tax [19] **.**

For the cordon tolls, by second best, we mean that each of these pricing policies is optimized within the constraints imposed by the instrument to achieve the highest gain in consumer surplus, with and without the additional transportation externalities as computed by LUSTRE. The consumer surplus net of the costs of the additional transportation externalities is thereafter referred as social welfare. For each cordon, the toll is the same at all entry points. Cordon locations are not necessarily optimal but are chosen for convenience of administration and compatibility with our modeling structure.

For the road tolls, the second best policy that internalizes the congestion externality only corresponds to the marginal cost of congestion (MCC) on each applicable link in each of the three time periods:

$$MCC_k = \left(\frac{1}{S_{k1}} - \frac{1}{S_{k0}} \right) \times FD_k \times VOT_k \, ,$$

where S_{k0} and S_{k1} are correspondingly the initial and resulting speed levels on the link k after adding one VMT to the link, FD_k is the number of link users, and VOT_k is the average value of time. For the freeway toll, the charge only applies to freeway travel, while for the comprehensive toll, all links of the network are charged.[9] The second-best policy that internalizes congestion and the other transportation externalities is equated to the MCC plus the average marginal value of the external costs. Excluding congestion, the sum of the external costs is 5.6 cents per mile (see Table 1). In this case, the comprehensive toll is probably close to a first-best optimum with respect to the full social costs of transportation. However, it still fails to internalize the effects of the pricing scheme on the alternative mode (transit) and the recycling of revenues is not optimized.

The sixth policy is the optimal VMT tax for the entire area. It is assumed that the VMT tax is imposed on top of existing federal and state gas taxes and is adjusted until the overall consumer surplus, again with and without the transportation externalities, for the entire study area is maximized. In LUSTRE, motorists can reduce VMT in numerous ways: by choosing different routes, by switching to transit or carpool modes, by shopping less or choosing closer

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[9] Note that the $MCCs$ for all tolled links are computed simultaneously and account for the network effects (see Safirova et al. [17] for a discussion of the network effects caused by road pricing). To do so, LUSTRE is run iteratively, where drivers are charged tolls equal to $MCCs$ as computed at the previous iteration, until the $MCCs$ converge.

shopping locations, by switching employment or residential locations, or by leaving the labor force altogether.

4. Results

Table 2 contains some information on the scale and scope of each policy and its anticipated effects on total travel. The second column gives the percent of VMT affected by the policy after the implementation. The changes in VMT are also reported.

Table 2. Six Second-best Transportation Policies: Optimal fees and effects on VMT

		Congestion Pricing			*Social Cost Pricing*		
Policy	Percent of VMT affected	Toll/Tax rates, where charged	Average cost per VMT (¢/mi)	Total estimated VMT (million miles per day)	Toll/Tax rates, where charged	Average cost per VMT (¢/mi)	Total estimated VMT (million miles per day)
Base Case	-	-	-	172.7	-	-	172.7
VMT Tax	100%	9.00 ¢/mi	9.00	-18.8	14.59 ¢/mi	14.59	-26.2
Comprehensive Tolls	100%	Variable	3.04	-6.9	Variable	9.30	-19.4
Freeway Tolls	26%	Variable	0.67	-2.1	Variable	2.02	-6.3
Double Cordon	7%a	D: $3.43 B: $2.18	0.35	-1.2	D: $4.29 B: $2.57	0.37	-1.4
Beltway Cordon	7%a	Beltway 2.84	0.29	-0.9	Beltway 3.34	0.30	-1.0
Downtown Cordon	1.1%a	Downtown 4.70	0.14	-0.7	Downtown 5.80	0.14	-0.8

a. A percentage of the number of trips, not VMT.

For each policy instrument, it is possible to compare by how much the optimal toll charge(s) or tax rate should be increased to account for the full social costs of transportation. For the cordon policies, applying the principles of social cost pricing rather than congestion pricing has rather small impacts on the toll level and the transportation outcomes of the policies. The new optimal cordon tolls would require an increase of about one dollar per car, leaving the average cost of the policies per VMT almost unchanged. For all three policies, the slight increases in tolls bring further reductions in VMT. The changes are small. It was to be expected, given that the cordon pricing affects only a small proportion of the total VMT. Nevertheless, from the point of view of policy evaluation, taking into account the full costs of transportation raises the social welfare by a substantial amount, around $20 million annually or an increase of one-third, relative to the case in which only congestion is internalized (see Table 3). We can interpret these increases as efficiency gains due to internalizing transportation externalities.

While cordon policies are now closer to the policy arena, other, more aggressive policies promise to be more effective to internalize the transportation externalities. Our simulations show that freeway tolls bring more significant VMT reductions and simultaneously raise social welfare compared to the cordon tolls. But the comprehensive tolls and the high VMT tax are the two policies that really differentiate themselves from the others. For both policies, the VMT reductions are drastic and the welfare gains are large.

As mentioned earlier, when comprehensive tolls are set to internalize all the transportation externalities, this policy becomes a proxy to a first-best policy; the annual efficiency gains reach more than 900 million. The results differ greatly if social costs pricing is used in place of congestion pricing. The average cost per mile of the policy increases by more than a factor of three (see Table 2). Consequently, the reductions in VMT change by almost the same factor (a reduction of 20 percent versus 7 percent). Table 4 shows the implications of such reductions for vehicular emissions. The social welfare gains are almost twice as large (see Table 3, column 2) and the costs of the different transportation externalities are about 15 percent lower with social cost pricing relative to congestion pricing (see Table 3).

As modeled here, the VMT tax is similar in design to the comprehensive tolls. The only difference is that the VMT tax corresponds to a toll fixed at the same level on all links during all time periods. This is an important departure from optimality because congestion varies substantially by location and time. It is therefore not surprising that the VMT tax induces higher VMT reduction than the comprehensive tolls (see Table 2), but meanwhile brings lower social welfare gains (see Table 3). The VMT tax is a coarser instrument.

Table 3. Consumer Surplus, Social Welfare, and Costs of Transportation Externalities for Six Second-best Transportation Policies

	Change in Consumer Surplus, Only Congestion Internalized (millions of 2000$)	Change in Social Welfare with Additional External Costs (millions of 2000$)	Congestion Costs (millions of 2000$)	Average MCC (¢/mi)	Air Pollution Costs (millions of 2000$)	Accident Costs (millions of 2000$)	Climate Change Costs (millions of 2000$)	Oil Depen-dency Costs (millions of 2000$)	Noise Costs (millions of 2000$)
Base Case	-	-	3182.2	7.45	874.0	1139.9	152.0	228.0	22.8
VMT Tax (Congestion Pricing)	333.6	788.4	2281.0	6.59	709.5	925.4	123.4	185.1	18.5
VMT Tax (Social Cost Pricing)	250.0	883.5	1877.0	5.96	644.9	841.1	112.2	168.2	16.8
Comprehensive Toll (Congestion Pricing)	391.5	557.6	1353.1	3.42	813.9	1061.6	141.5	212.3	21.2
Comprehensive Toll (Social Cost Pricing)	452.0	919.9	1155.5	3.37	704.7	919.2	122.6	183.8	18.4
Freeway Toll (Congestion Pricing)	174.8	225.3	2436.4	5.82	855.7	1116.1	148.8	223.2	22.3
Freeway Toll (Social Cost Pricing)	243.7	395.0	2378.9	5.94	819.2	1068.6	142.5	213.7	21.4
Double Cordon (Congestion Pricing)	86.3	116.5	3003.3	7.12	863.0	1125.7	150.1	225.1	22.5
Double Cordon (Social Cost Pricing)	85.0	118.1	2985.2	7.08	862.0	1124.3	149.9	224.9	22.5
Beltway Cordon (Congestion Pricing)	59.0	82.7	3020.7	7.16	865.4	1128.8	150.5	225.8	22.6
Beltway Cordon (Social Cost Pricing)	60.0	81.7	3033.8	7.14	866.1	1129.7	150.6	225.9	22.6
Downtown Cordon (Congestion Pricing)	51.5	68.9	3087.8	7.45	867.7	1131.7	150.9	226.3	22.6
Downtown Cordon (Social Cost Pricing)	50.6	69.8	3077.4	7.45	867.0	1130.9	150.8	226.2	22.6

Table 4. Emissions and Energy Scenarios for Six Second-best Transportation Policies

	Reduction in Vehicular Emissions (Ton Per Day)		
	VOC	CO	NOx
Base Case	173.5	2154.5	393.4
VMT Tax (Congestion Pricing)	-17.8%	-17.8%	-18.5%
VMT Tax (Social Cost Pricing)	-25.1%	-25.0%	-25.8%
Comprehensive Toll (Congestion Pricing)	-7.7%	-4.9%	-5.6%
Comprehensive Toll (Social Cost Pricing)	-18.7%	-16.8%	-17.7%
Freeway Toll (Congestion Pricing)	-2.2%	-1.1%	-1.4%
Freeway Toll (Social Cost Pricing)	-5.7%	-5.8%	-6.4%
Double Cordon (Congestion Pricing)	-1.5%	-1.0%	-1.1%
Double Cordon (Social Cost Pricing)	-1.6%	-1.1%	-1.2%
Beltway Cordon (Congestion Pricing)	-1.0%	-0.7%	-0.8%
Beltway Cordon (Social Cost Pricing)	-1.1%	-0.7%	-0.7%
Downtown Cordon (Congestion Pricing)	-0.9%	-0.6%	-0.7%
Downtown Cordon (Social Cost Pricing)	-1.0%	-0.6%	-0.7%

If the VMT tax internalizes the congestion externality only, we estimate that its optimal rate would be 9 cents per mile, which is in line with some European countries[10]. However, if the VMT tax is adjusted to internalize the full range of transportation externalities, we found that its optimal level would be as a high as 14.6 cents per mile. This estimate is much higher than other estimates, notably the one by Parry and Small (2005) that used similar cost estimates to quantify the transportation externalities. As a justification for our higher estimate we have two explanations. First, it is because we consider a VMT tax and therefore individuals cannot switch to more fuel-efficient vehicles. Second, our estimate is for the Washington, DC metro area, a region that suffers more from congestion than the average American city considered by Parry and Small (2005). As a result, they consider a marginal cost of congestion of 3.5 cents per mile, while in our case the cost of congestion is more than two times higher, 7.5 cents per mile at the baseline (see Table 3).

In all cases, the important conclusion to retain from our simulations is that a VMT tax designed to internalize the full social costs of transportation will be high, and about twice higher than the level designed to account for congestion only.

In the rest of this section, we further explain the sources of the social welfare gains. We first focus on the VMT reductions, given that they are crucial to explain the size of the costs of the transportation externalities. Thereafter, we summarize the land-use and economic effects. We use the comprehensive tolls with social cost pricing as a case study simply because this is the policy closer to a first-best optimum. Note that the explanations for the other policies would be similar.

4.1 VMT Reductions

As mentioned earlier, LUSTRE captures VMT reductions due to route choice, mode switch, and changes in shopping behavior, employment and residential locations, and work status.

The comprehensive tolls with social cost pricing reduce VMT by 33.4 million miles per day (19.4 percent). Let’s first investigate how a traveler’s route choice might have contributed to this reduction. In LUSTRE, for each origin, destination, and time of the day triplet, different routes varying in length, average speed of travel, congestion level, and toll level (if present) are

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[10] See, for example, Kalmanje and Kockelman 2006.

available[11]. The portion of the comprehensive tolls that charge for congestion induces travelers to take shorter and least-congested routes. However, there is potentially an arbitrage. Indeed, it is possible that the shorter routes are also the most congested and then have the highest charge per mile; traveling on longer but less-congested routes might then end up being cheaper. On the other hand, the remaining portion of the comprehensive toll that accounts for the other externalities is a fixed charge per mile. It unambiguously encourages shorter trips. For our simulations, we observe that for most origin, destination, and time of the day combinations, travelers substitute toward shorter routes. Overall, however, it contributes to a small share of the total reduction in VMT, around 0.6 million of VMT per day.

Modal shift is the next source of VMT reduction and by far the most important. The comprehensive tolls reduce the number of car trips by more than 2 million daily (about 14 percent). As a result, train and bus ridership increase by, respectively, 40 percent and 28 percent, which might raise issues of capacity constraints, notably for the Metro system. We estimate that the modal shift leads to a reduction of 31.5 million of VMT per day, making the bulk (94 percent) of the total reduction.

Changes in shopping behavior and residential and employment locations contribute to a reduction of 0.9 million of VMT. As we will see below, there is a clear pattern in population and employment movement toward the center of the region.

Finally, the last and a quite subtle source of VMT change in LUSTRE is the change in work status. In our framework, individuals can voluntarily choose to leave the labor force. We found that the comprehensive tolls induce 16 thousand workers to quit the labor force. The explanation behind this change is first due to the tolls and the corresponding increase in commuting costs. The lump-sum redistribution of the toll revenue also plays a role. In sum, the high commuting costs discourage individuals from making the journey to work, while additional unearned income compensate for the loss of salary. In this simulation, voluntary long-term unemployment contributes to a reduction of 0.4 million of VMT.

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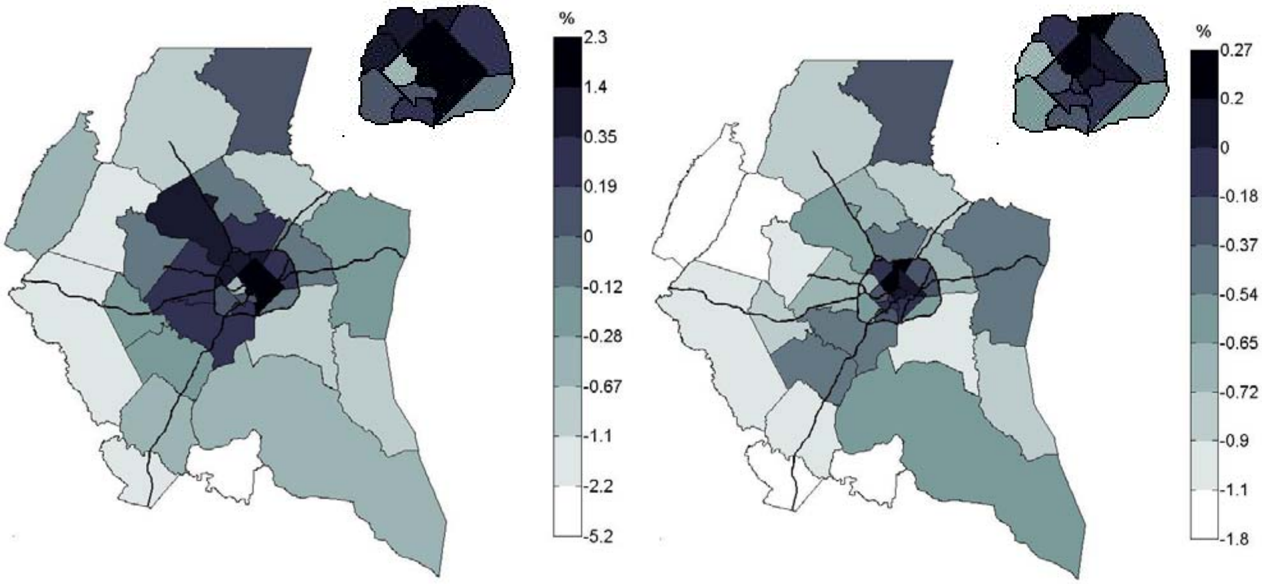
[11] More specifically, route choice is made in START sub-model. Travelers optimize route choice by minimizing their generalized costs of travel.

4.2 Land Use and Economic Effects

Regarding the change in land use, we observe that residents move toward the center of the region (see Figure 3a). Residents move for a better access to transit, a shorter journey to work, and a higher density of retail locations, which all help mitigate the burden of the tolls.

Figure 3. Changes in Residential and Employment Locations in the Long Run due to Comprehensive Policy



a) Residential

b) Employment

While LUSTRE computes a long-term equilibrium, but does not explicitly represent the path toward it, we can theorize that employment and retailers follow the change in population distribution. Indeed, at the long-term equilibrium, we observe that employment displacement has a similar pattern as for population. The changes are smaller, however. To sum up, the present simulation suggests that a substantial increase in transportation costs can contribute to the agglomeration of the population and economic activity in the downtown area and close suburbs of the region.

The effects of the tolls on the local economy are the following. We first find that employers have an incentive to slightly increase wages to compensate for the tolls paid by their employees. One might think that employees' benefits are adjusted to account for the tolls, as it is often the case for parking fees. The burden of the tolls is then partially shifted to the employers.

The movement of the population toward the downtown area and suburbs of Washington, DC, which already has a rather high density, contributes to increasing rents and the value of the real estate. The increases are, however, within a two percent range. Note that these variations exclude the effect of long-term demographic growth, which is anticipated to be important in the region. It is unclear for us if new migrants would respond differently to the tolls than the established population. For example, in our framework, we consider that individuals have inherent preferences for the place they live, creating a certain inertia to move. New migrants might not have such preferences and might be more sensitive to other factors, in this case travel costs, when they choose their residency location.

In all cases, the impacts of the comprehensive tolls on the economic activity and land-use changes are small. It suggests that the tolls can improve traffic quality, without having too much secondary economic and land-use effects.

5. Conclusion

In this paper we have used LUSTRE, an integrated model of land use, transportation, and economic activity, to simulate six second-best road pricing policies. The policies modeled are three different cordon-based policies, road pricing implemented on highways only, comprehensive road pricing on all metro area roads, and a VMT tax. For each policy, we find the policy level that maximizes residents' welfare. In the first set of simulations we account only for the congestion externality, and in the second set we also take into account other major external costs of transportation. Our results are consistent with the externality theory, which says that policies designed to internalize a broader set of externalities are more efficient. Our contribution is to quantify by how much the transport externalities are reduced when a broader set of externalities is internalized in a real world-like setting.

We find that using social cost pricing in place of congestion pricing makes an important difference when the transportation policies substantially affect VMT. Otherwise, for cordon tolls for example, the transportation outcomes of congestion pricing and social cost pricing are very similar. Nevertheless, accounting for a broader set of major external costs of transportation raises the expected benefits of the policy by a noticeable amount.

We also find that road-based charges can be highly effective at reducing both congestion externalities and other external costs of motor vehicles. The efficiency gains almost double when non-congestion related external costs are accounted for.

Comprehensive variable time-of-day pricing on the entire road network turns out to be by far the most effective and efficient policy when it comes to reducing congestion alone. However, when other social costs are factored in, the performance of the VMT tax is almost as efficient.

Since in this paper we attempted to conduct a long-term policy analysis based on present estimates of certain transportation externalities, a question arises about whether and how some developments in available technology can alter our results. In particular, it is reasonable to believe that congestion costs are likely to continue rising in the future, while air pollution costs related to motor vehicles would probably decline. It is hard to predict the direction of accident costs since they are affected by a variety of factors such as rising costs of health care, safer vehicle technologies, and congestion. Perhaps, better modeling of accidents should be the first priority to determine the balance between congestion and other motor vehicle externalities for years to come.

It should be noted that this analysis has been performed for one metro area using a specific modeling platform and may not serve as a generic example. More research is required to either corroborate or refute our findings. For practical purposes, it would be desirable to obtain local estimates of social costs, because several of them (for example, accident costs and air pollution costs) can significantly differ across metro areas.

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