JTRF Volume 53 No. 1, Spring 2014

Road Supply in Central London: Addition of an Ignored Social Cost

by Omid M. Rouhani, Christopher R. Knittel, and Debbie Niemeier

Studies examining the social cost of driving usually ignore the opportunity cost of having roads in place: the associated land rents. Especially for geographic regions where land is valuable, including the rent costs may even lead governments to close some roads. By using the London congestion charging zone case, a more general long-run social cost curve is calculated with the addition of the rents. Based on the optimal road usage concept, this study found that including the rents in the cost/benefit analysis significantly affects the results and can increase the social cost by up to 200% and decrease the optimal road usage by 40%.

INTRODUCTION

Providing a partially charged service, as is the case with public roads, leads to more travel demand, which can result in wasteful consumption: the free-rider problem (Cornes 1986). The associated cost burden is enormous; Nash et al. (2008) estimated the costs of traffic congestion in the UK to be ₤15 billion per year, about 1.5% of GDP. Congestion pricing has been developed based on the notion that the users of roads, as public goods, should pay for the negative externalities they produce. Each additional user imposes a time cost burden on other users. The main idea involves charging users for this social cost (the difference between marginal social cost and marginal private cost) to reach a more efficient road usage (Pigou 1920; Vickrey 1963; Walters 1961; Yang and Huang 1998; Rouhani and Niemeier 2011).

Several cases of congestion pricing exist in Singapore (Olszewski and Xie 2005), London (Leape 2006), and Stockholm (Eliasson 2008). Various studies have analyzed different aspects of congestion pricing. Olszewski and Xie (2005) modeled the effects of the pricing on traffic flows in Singapore and found that time-variable road pricing or "shoulder pricing" method, increasing the charges before the peak and lowering them after, tends to transfer congestion to other periods and other routes and is an effective method of controlling congestion. Xie and Olszewski (2011) proposed a methodology for using the traffic data from the Singapore's Electronic Road Pricing (ERP) system to forecast the short-term impacts of trip rate adjustments on peak period traffic volumes.

Eliasson and Mattsson (2006) developed a method for quantitative assessment of equity effects of the Stockholm congestion pricing system. In another study, Eliasson (2009) set up a cost -benefit analysis for the case of the Stockholm congestion pricing and estimated that the Stockholm system yields a large social surplus, well enough to cover both investment and operating costs. Santos and Bhaka (2006) revised the standard approach to value travel time savings for the London congestion pricing system and showed that by switching to the bus, low-income users can gain from the system, when users account for the generalized costs of trips. Safirova et al. (2004) studied the welfare effects of various road pricing schemes for the Washington, D.C., metropolitan area. The study found that the aggregate social welfare gain from comprehensive pricing could reach $220 million, and most of this gain could also be achieved by using only HOT lanes (77%) and limited freeway pricing (82%).

In a controversial study, Prud'homme and Bocarejo (2005) constructed the demand and supply functions for the London congestion pricing scheme and determined the optimal road usage and optimal congestion toll for the system. They showed that the London congestion pricing is an economic failure despite its political success. Hamilton (2011) also indicated the unpredicted and excessive costs of congestion pricing in the case of Stockholm, Sweden. Nevertheless, Hamilton (2011) showed that by modifying insurance cost, recognizing the election's role, and informing the public it would be possible to establish a system, such as the Stockholm congestion charging system, for a considerably lower cost. For a review on methods and technologies available for congestion pricing, refer to de Palma and Lindsey (2011).

Studies on optimal road usage usually ignore some of the social costs that are associated with public roads (Rouhani et al. 2013*a*). Construction and maintenance costs are good examples (Verhoef and Mohring 2009). Although one can argue that users are paying for these costs through fuel taxes, the payments are not directly related to the usage. The users' cost burden should be based on the true total road costs and how much they use the road system. Users should not pay comparable amounts for a very expensive superhighway and a low-cost collector. And the payments should not be the same for roads with comparable construction and maintenance costs, but different levels of demand. One limitation in applying this concept is that part of the funding for roads comes from sources other than fuel taxes (revenue sources that are not related to road usage), for example, sales tax (Schweitzer and Taylor 2008).

Because it is difficult to find a defensible means of including construction and maintenance costs in optimal road usage analysis since they are partially paid by fuel taxes, one can replace these costs with the opportunity cost of having roads in place, which are the forgone rents of the land used for roads. If officials could close the roads, they could immediately lease the available land. But unlike other markets where supply and demand dynamics can drive products out of market, closing roads very rarely happens because not all the costs are considered (Rouhani 2009; Rouhani 2013; Rouhani et al. 2013*b*). As a result, once a road is constructed, the present calculation suggests that decision makers should use the land for roads, no matter if the future usage (benefits) is (are) really low. Nevertheless, studies show that decreasing capacity through blocking roads can even improve transportation network performance (Youn et al. 2008).

In old and well-developed cities, few new roads are being financed using current fuel taxes[1]. Most of the fuel taxes are used for road maintenance, alternative modes to cars, and purposes other than directly financing or paying for the rents. Even though existing old roads were financed through previously paid fuel taxes, one can argue that the forgone rents, at least partially, are not considered in individual users' current cost calculations, and so do not affect their current road usage. There exists a social (opportunity) cost associated with these rents. For geographic regions where land is valuable, like London (Cheshire and Hilber 2008), these ignored social costs may have significant impacts on the externalities associated with driving.

Previous research studies have examined the consideration of the opportunity cost of land in the context of curbside pricing (Shoup 2004 and 2005). For the road pricing concept, Roth (1967, page 67) makes the distinction between the cost of providing roads and the cost of using roads and concludes that the fixed costs of providing roads should not enter directly into congestion charges. Based on this distinction, one can argue that the fixed opportunity cost is not part of the marginal social cost of driving. However, the counter-argument is that 1) in the case of London, the rent costs are not paid by the individual costs of travel; the rent costs are even higher than all other social costs at some road usage levels, and 2) the rent costs are not fixed, but they depend on the amount of usage and vary from one time period to another (the change in the value of land). The total rent cost should be divided by the road usage. Therefore, a thorough calculation should consider (a portion of) the rents in addition to individual cost and congestion cost. Otherwise, these costs would be ignored.

In this study, these costs are added to the social costs typically considered and calculate a modified social cost curve. The model developed in this study is an extension of a previously calibrated model (Prud'homme and Bocarejo 2005) on the London congestion pricing zone.

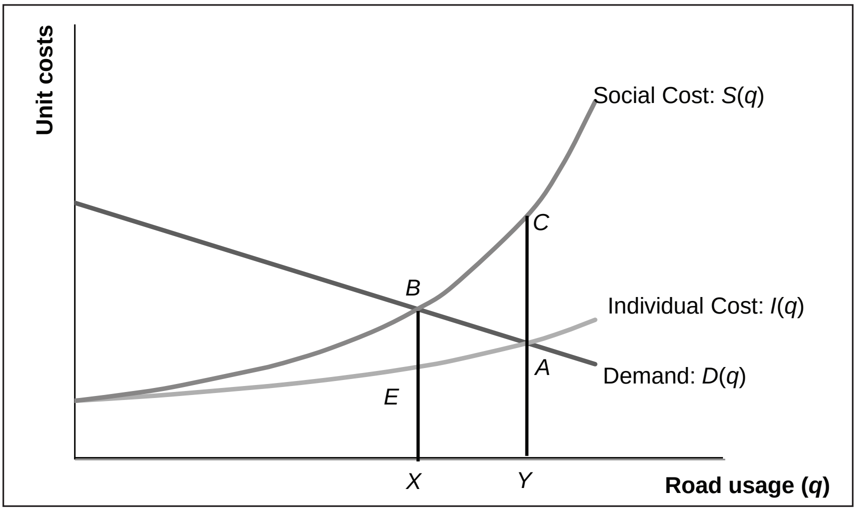
The next section begins by describing the basic model for the optimal road usage analysis. An extension to the model will be introduced by adding forgone rents to the social cost. The case study, the London congestion charge zone, will be described. A model developed in a previous study will be presented and then be modified taking the rents into account. Finally, the paper concludes with the results of modifying the social cost for the case study.

BACKGROUND

Figure 1 represents a simple model of road usage where $D(q)$ is the demand for road usage as a function of the unit cost of using roads (costs per km); $I(q)$ represents the unit individual cost (or marginal private cost), which is the per km cost borne by a motorist. As road usage (q) increases, the travel time as a part of the general cost of travel increases, and the cost born by motorists, $I(q)$, increases. An equilibrium is reached at point *A*, where $I(q)$ and $D(q)$ intersect, in which the cost of driving is equal to the benefit of driving, and the original road usage is *Y*.

But the unit social cost, $S(q)$, is different than $I(q)$. The social cost equals the individual cost plus the cost of additional time spent by all other vehicles because one extra vehicle is on the road (congestion externality). So the social optimal point (the optimal road usage) is at *B*, where $D(q)$ and $S(q)$ intersect, and the social optimal road usage will be *X*. To reach the optimal road usage, decision makers should impose a tax or congestion charge of *BE* as the optimal congestion charge. Without any charges, the deadweight loss (DWL) or congestion cost of the triangle *BCA* will be imposed on society.

Figure 1: The Optimal Road Usage and Congestion Concept



The original equilibrium, *A*, is sub-optimal because of the difference between the unit individual cost and the unit social cost. The original equilibrium of road usage is always greater than the social optimal usage because the social cost is greater than the individual cost. However, the optimal level of congestion is not zero. Therefore, policies should be aimed at ensuring the optimal level of congestion, not the elimination of congestion.

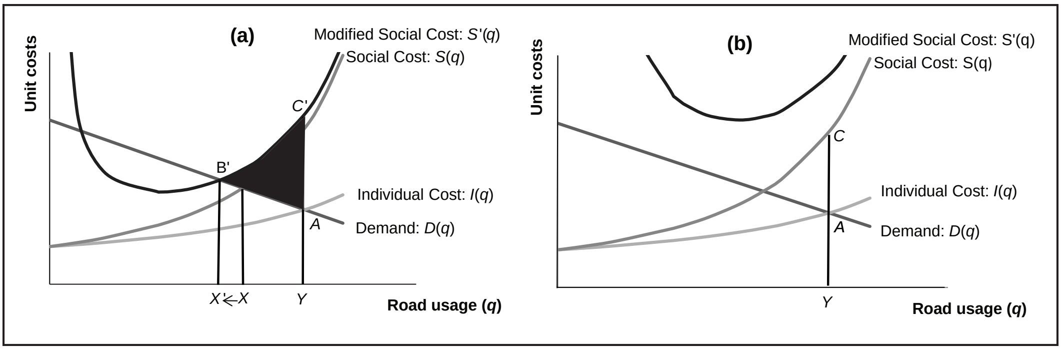
The optimal level of congestion charge (*BE*) is the congestion externality (the difference between the social and private costs) at the social optimal equilibrium, not the original equilibrium. In fact, charging the congestion externality at the original equilibrium is suboptimal and higher than the social optimal charge. Finally, a thorough cost/benefit analysis of a congestion pricing scheme should compare the benefits of a congestion charge (*BCA* or a lower amount of social welfare gain from a charge) to its transaction costs or the collection costs of the charging scheme (McDonald et al. 1999; Prud’homme and Bocarejo 2005).

AN EXTENSION OF THE MODEL

An important part is missing in the social cost calculation of the simple model: the opportunity cost of having roads in place or the rent that can be gained by leasing the lands occupied by roads.

The social cost associated with rent depends on road usage. So the higher the road usage, the lower the social cost of the rents. In fact, the associated social cost is equal to the total fixed rent that can be gained from leasing the lands divided by the quantity of road usage. One could add this cost to the common social cost curve. Figure 2 shows the results of adding the rents to the common social cost. Instead of an increasing curve, the modified social cost curve will have a U shape. For the modified social cost, the social optimum will be X' instead of X, and a higher congestion cost of $B'C'A$ will result if the modified social and demand curves intersect (Figure 2-a). In the cases of very high levels of rents, the modified social cost may no longer intersect with the demand curve (Figure 2-b). For this case, because of over-supply, some low-demand roads or some lanes of the roads should be closed so that the social benefits of driving (associated with travel demand) match social costs. It should be noted that the alternative decision to adding the rent costs to the analysis is leasing the land for purposes other than driving and decrease capacity. In this case, the individual cost curve (supply curve) would be different. However, the assumption of this study is that charging for the rent is preferred.

Figure 2: Modifying the Social Cost by Adding the Rents (a) With an Intersection (b) No Intersection



The addition of the rents and/or decreasing capacity are long-run decisions by nature. In the standard analysis of road pricing (Small and Verhoef 2007), short-run calculations are based on short-run marginal social costs for which capacity, and consequently rent, should be held constant. The rents enter long-run marginal social cost along with congestion, where every factor (capacity, rent, and congestion) can vary.

In fact, the analysis in this study is focused on a long process where the higher value of road space is realized by land owners or tax payers. The public funding, used long ago to build roads, may now have much more value than before, especially for a city like London with its very high present value for land. When the land owned by the citizens of the relevant jurisdiction has drastically increased in value (going from short-run to long-run), the citizens as the rightful owners might decide to use the land for purposes other than roads or charge the rents from users. The goal of this study is the appropriate inclusion of the rents in the long-run optimal road usage analysis.

In summary, adding the rents to the unit social cost leads to lower optimal road usage, a higher optimal charge, and a higher social cost. And in some cases, this addition may imply closing roads because the costs of providing roads are higher than the benefits of driving (based on the area under a demand function above the equilibrium price). The new social cost includes the unit opportunity cost associated with the rent (not paid by users) as well as private costs (time, fuel costs including taxes, insurance, etc.) and congestion costs, both of which have been typically considered in the previous optimal road usage studies.

BACKGROUND ON THE LONDON CONGESTION PRICING

The application of the London congestion pricing scheme[2] results from a long history of studies over the congestion costs of driving, and an interesting political process. In 1995, the London Congestion Charging Research Program (MVA Consultancy 1995) proposed a £4.00 toll on vehicles entering the central London area. The proposal led to another report in 2000: Review of Charging Options for London (ROCOL 2000). The latter report focused on the central London area and recommended two alternatives for charging: an area licensing scheme based on video camera enforcement and a workplace parking levy. With the election of Ken Livingstone as the Mayor of London in 2000 and after an 18-month period of extensive public consultation (as the main factor for the public acceptance of the scheme), an area licensing congestion pricing scheme was chosen for central London (Leape 2006).

As a result of the decision, since 2003, a daily charge has been imposed for driving or parking a vehicle on roads within central London. A constant charge of £5 (later increased to £8 and then to £10) must be paid for driving or parking within the congestion charging zone between 7:00 am and 6:30 pm on weekdays, with some exemptions for motorcycles, licensed taxis, and some alternative fuel vehicles (Litman 2006). Also, a 90% discount to residents and a 12.5% discount to fleets, and various discounts for monthly and annual payments are offered (de Palma and Lindsey 2011). Users can pay the charges at selected retail outlets or payment machines located in the area, by Internet and cellular telephone messaging, any time during the day of usage. Automatic number plate recognition is used to ensure the charges are applied, assigning penalties for the offenders.

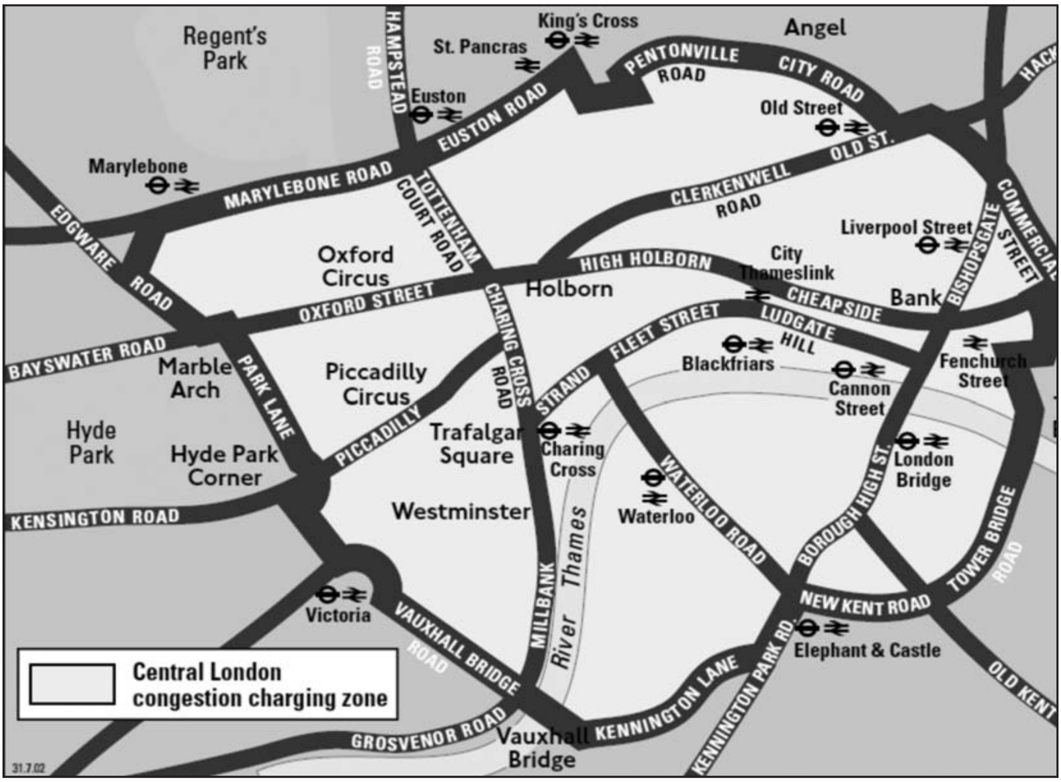
The congestion charge zone covers an area of about 22 km^2 (8 square miles) in downtown London (more than 1% of the total area of Greater London). The zone includes the financial centre, Parliament and the principal government offices, and the major tourist and entertainment centers (Leape 2006). Although the area is small compared with Greater London, it includes the main areas for the worst congestion. Figure 3 illustrates the London congestion zone.

Transport for London (TFL Sixth annual report 2008) cites four contributions of the pricing scheme as follows: 1) to reduce congestion; 2) to improve the bus system; 3) to reduce travel time for car users; and 4) to increase the efficiency of goods and services' distribution.

The early estimations showed that the charging scheme reduces vehicle miles traveled in the zone by around 15% and increase average speeds by around 20% (Banister 2003). Litman (2006) reported a higher increase of traffic speed (30% higher than prior to charging). Also, he reported that after imposing charges, peak period congestion delays declined about 30%, bus congestion delays declined 50%, bus ridership increased 14%, subway ridership increased about 1%, and taxi travel costs declined significantly (by 20%–40 %) due to reduced delays.

The effects on externalities other than congestion are also significant. By introducing congestion charging in London, total NO_x emissions and PM10 emissions have been reduced by about 12% in the charging zone. In addition to the travel pattern impacts, the charging scheme has important effects on the generalized cost of various users of the London transportation system, which is not limited to car users (Santos and Bhakar 2006).

Figure 3: A Map of the London Congestion Zone with Extended Areas



Source: Transport for London, 2004.

Transport for London (TFL Fifth annual report 2007) has estimated a gross benefit of £200 million and a total cost of £88 million, resulting in a net annual benefit of £112 million. Opposite to what was found by Transport for London, and in a controversial study, Prud'homme and Bocarejo (2005) estimated a negative net benefit for the London congestion pricing scheme (-€393 thousand per day or -£75 million per year). There are various factors that led to the different results from the two studies. In the benchmark model section, some of the critiques of the Prud'homme and Bocarejo (2005) study will be discussed.

MODEL FRAMEWORK

Benchmark Model

Prud'homme and Bocarejo (2005) have studied the conventional model of optimal road usage for the London congestion zone. They estimated the unit individual cost, the demand, and the unit social cost functions. Their estimated unit individual cost ($I(q)$) and unit social cost ($S(q)$), both in terms of euros per vehicle-km, are functions of road usage q, in terms of thousand vehicle-km per day, as follows:[3]

$$(1)\quad I(q) = 0.15 + \frac{20.9}{(31.6 - 0.0124.q)}$$

$$(2)\quad S(q) = I(q) + I'(q).q = 0.15 + \frac{20.9}{(31.6 - 0.0124.q)} + \frac{0.26.q}{(31.6 - 0.0124.q)^2}$$

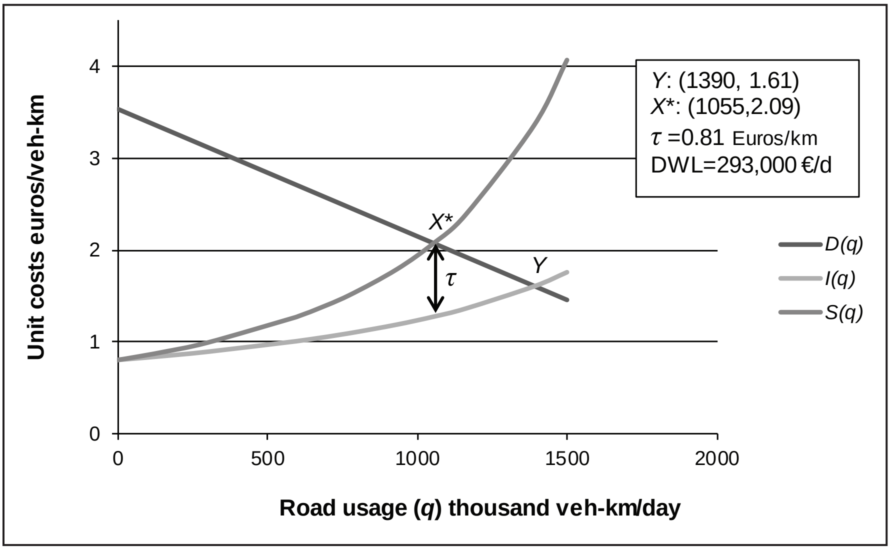
The estimated individual cost function consists of two parts; a fixed part representing amortization and fuel cost (0.15 euros/veh-km), and a variable part representing the value of time spent driving one km for each vehicle (20.9/(31.6-0.0124.q)). To estimate the second part, they used 20.9 euros/veh-hour for the value of time, and estimated travel time function (speed function) using the free flow speed, and a point based on average speed and road usage in 2002. There are several important questionable assumptions made: 1) the value of time of 20.9, which has been reported low by some studies (Raux 2005; Mackie 2005); 2) the linear speed (travel time) function, which is estimated by using only two points; and 3) fixed fuel costs and some other costs, which should be affected by road usage.

To determine the demand equation ($D(q)$), they used two points on the curve based on the data before (2002) and after imposition of the charges (2003). Their estimated demand function is as follows:

(3) $D(q) = 3.54 - 0.00139.q$

Figure 4 shows their estimated demand, individual cost, and social cost. The original equilibrium (without imposing any charge), where $D(q)$ and $I(q)$ intersect, is at 1,390 thousand vehicle-km per day, with the unit individual cost of 1.61 euros per vehicle-km. The social optimal point, where $S(q)$ and $D(q)$ intersect, is at 1,055 thousand vehicle-km per day, with an optimal congestion charge of 0.81 euros per vehicle-km (equivalent to a charge of £7.2 per day [Prud'homme and Bocarejo 2005]) required to move from the original equilibrium to the social optimal point. Based on the estimation, the charges initially imposed on the congestion zone (£5) capture 90% of the potential benefit of a charge.

Figure 4: The Optimal Road Usage and Congestion Charge from the Prud'homme and Bocarejo Study



Using this framework, Prud'homme and Bocarejo (2005) showed that the economic costs associated with the London charging system are larger than the economic gains. The main assumed benefit of the charging system is the reduction in congestion costs while the costs are calculated using the operating and investment costs of the system. Their conclusion was that the London congestion charge, although politically and technically successful, seems to be an economic failure.

However, other studies (Raux 2005 and 2006; Mackie 2005) argued that with different parameters (higher value of time, more environmental benefits, more detailed public transportation system), the results could dramatically change. Taking these factors into account, the Prud'homme and Bocarejo model is used in this study as the benchmark model.[4]

Modified Model

The calculations show that around 10% of the total area of the existing London congestion zone consists of road proper (an area of 2.16 km^2), excluding sidewalk space, which allows continued access to the area. The annual rent of the lands in the area is assumed to be 300 euros/m^2 (£21.6/ft^2). This figure is calculated by converting the present value of different properties to the annual rent, considering the area of each property, and averaging the rents over different properties. Note that the assumed annual rent is relatively low. But, as can be observed in Figure 5, the cost associated with this rent is high relative to the demand curve, and assuming higher levels of rent will result in no intersection of demand and supply curves.

The annual rent of 300 euros/m^2 results in a total rent of 648 million euros per year or 2,541 thousand euros per working day.[5] But one could reasonably argue that not all roads should be considered in the calculation. Some roads are critical, for example, offering lifeline routes for emergencies; eliminating these roads may interfere with vital activities in the area. Although a counter argument is that people can travel using public transit or even by walking, especially in a city like London with a ubiquitous and largely efficient public transportation system, it is still reasonable that some roads would be necessary. In addition to the private costs, the social costs of closing the critical roads could be much more than other roads. However, calculating these costs is beyond the scope of this study.

Using a proxy, this study considers a new concept called "substitutable roads." In order to disregard the social costs of closing critical roads, the assumption is that only the roads which can be substituted by other roads are considered. It is difficult to estimate the percentage of roads that are practically substitutable. Therefore, different values for this parameter are assumed and applied to the model.

The modified model incorporates the percentage of substitutable roads as a new parameter. Another argument in favor of including a proportion of, not all, the rents in the analysis is that the current fuel taxes cover part of the rents. In addition, the figures for fuel taxes paid are small relative to the rents in central London, given the value of land. So considering a proportion of the rents seems reasonable.

Note that the unit individual cost remains the same as before because the rent is not paid by the users. However, the rent costs are present, and should the rent costs be paid, it would be shared by all users. So the total rent cost should be divided by the road usage (q), and multiplied by the percentage of substitutable roads. The new unit social cost function is as follows:

$$(4)\quad S(q) = I(q) + I'(q).q + \text{rent cost} = 0.15 + \frac{20.9}{(31.6 - 0.0124.q)} + \frac{0.26.q}{(31.6 - 0.0124.q)^2} + \frac{2541 * P_{SR}}{q}$$

where P_{SR} is the percentage of substitutable roads.

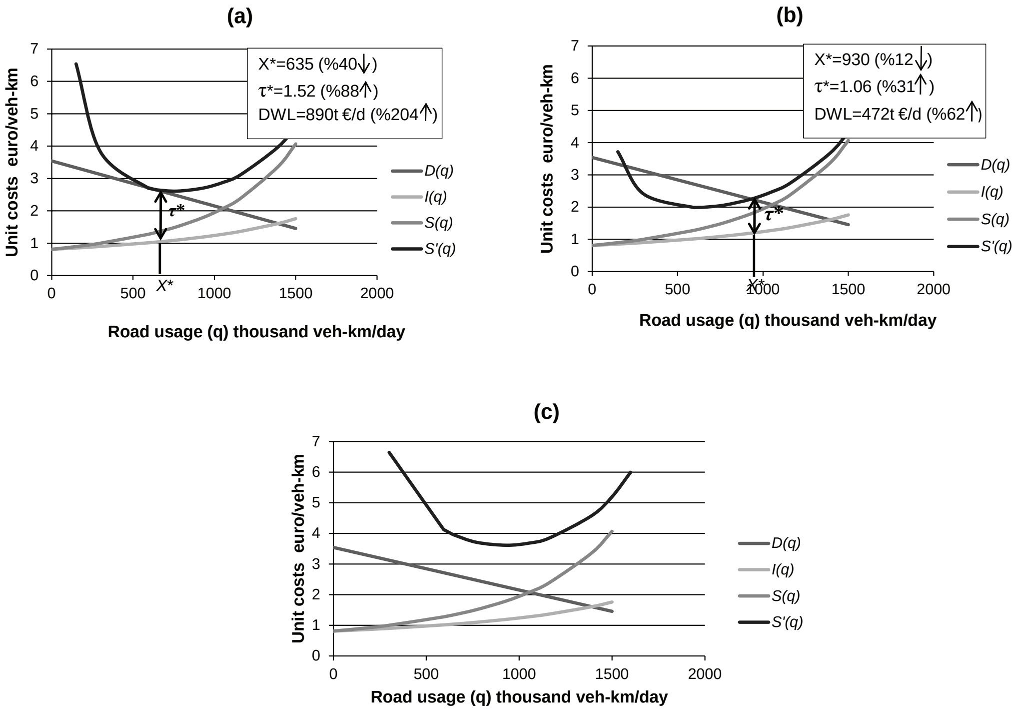
An important consideration is that the relationship between land rents and road supply is reciprocal; the land rents also depend on accessibility and, consequently, road usage. In fact, the last term in equation (4) should include another term for road usage (q) in its numerator, reflecting accessibility. This reciprocal relationship should be considered in the optimal road usage analysis. Reducing road supply can reduce land values (rents) because of less accessibility (Clonts 1970; Paulsen 2013), which in turn reduces the optimal charge and increases the optimal road usage. On the other hand, reducing road supply can increase land values by pedestrianization and traffic calming, which further increases the optimal charge and reduce the optimal road usage. However, the relationship can be very complex to determine. Therefore, this more detailed complex analysis has not been considered in this study.

RESULTS

Assume first that the annual rent is 300 euros/m^2, (£21.6/ft^2) and 33% of the roads (or road areas) are substitutes, or $P_{SR} = 0.33$ (Figure 5-a). This level is equivalent to the rent of 100 euros/m^2 for the whole road area. Before going over the results, it should be noted that the assumed values for P_{SR} are based on round equivalent rents per squared meters; for example, 33% is equivalent to 100 euros/m^2 for all the roadway area. However, the selected values are used to run a sensitivity analysis, represent the limits of the parameter for the analysis, and lack a theoretical background.

For this level of P_{SR}, the modified social cost translates into a 40% decrease in the optimal road usage (see background section), and an 88% increase in the optimal charge, compared with the raw model (developed by Prud'homme and Bocarejo 2005). Now, the formerly applied charge (£5/day) only captures 69% of the social costs (DWL) vs. 90% from the raw model, and the existing charge (£10/day) captures about 97% of the social costs (DWL) even though the optimal charge (£13.5/day) is significantly more than the existing charge.

Figure 5: Optimal Congestion Using the Modified Social Cost for Rent of (a) 100 euros/m^2-33% Substitute (b) 50 euros/m^2-16% Substitute (c) 200 euros/m^2- 67% Substitute



An important observation is that the rent cost, the difference between $S'(q)$ and $S(q)$, comprises a substantial part of the total social cost and is even higher than the congestion cost, the difference between $S(q)$ and $I(q)$ for this case, at the optimal road usage point. This fact can further support the hypothesis that the rent cost should be involved in the calculation of social optimal road usage because of its significant impacts. Another important reason for involving the rent cost is that the rent cost is definitely more than the fuel tax paid by each driver (in Figure 5-a, $I(q)$ is lower than $S'(q)$- $S(q)$; fuel tax is only part of the $I(q)$). This evidence shows that drivers are not fully paying for the rent cost through taxes. Even a large proportion of fuel taxes are used for purposes other than renting or buying the land for driving such as maintenance, and alternative modes.

Assuming only 16% of the roads are substitutable (equivalent to 50 euros/m^2 for all area), a significant impact can still be seen: a 12% decrease in the optimal road usage and a 30% increase in the optimal charge, compared with the original model. The initially existing charge captures 80% of the potential benefits of a charge, and the existing charge (£10/day) is higher than the optimal level of charges (Figure 5-b).With the assumption that 35% or more of the roads are substitutes (equivalent to 105 euros/m^2 for all the road area), the modified social cost curve no longer intersects with the demand curve (Figure 5-c). With this assumption, low demand roads in the zone should be closed and for which land rents could be made available for other purposes.

Table1 reports a number of significant observations for various scenarios. First, the optimal road usage decreases dramatically as a result of the added land rents (down from 1,055 to as much as 635 thousand veh-km) while the change in the individual cost at the optimal point is relatively smaller (from 1.28 to 1.03 euros/veh-km). In fact, the decrease in the optimal road usage has only a small effect on the congestion costs, but significantly affects the social costs associated with the rents. This means that for the optimal level of road usage, most of the social costs are from the rent costs rather than congestion costs; the rent costs can be more significant than congestion costs in an expensive city like London, especially if road usage is being set at its optimal level, not at its actual level.

Table 1: Results of Various Scenarios

	Non-modified Social cost	Modified 16% substitute (50 €/m^2)	Modified 33% substitute (100 €/m^2)
Optimal road usage (1000 veh km)	1055	930	635
Individual cost at optimal (€/veh-km)	1.28	1.19	1.03
Social cost at optimal (€/veh-km)	2.09	2.25	2.65
Pre-charge social cost (€/veh-km)	3.38	3.67	3.98
Optimal Charge (€/veh-km)	0.81	1.06	1.52
Optimal benefits (1000 €/day)	296	474	895
Collection costs (1000 €/day)	689	689	689
Net benefits (1000 €/day)	-393	-215	206

Note: Pre-charge road usage and individual cost are 1390 and 1.16, respectively.

Second, modifying the social cost curve increases the optimal charges, as expected. The optimal charge increases from 0.81 to 1.52 euros/veh-km (equivalent to £7.2/day to £13.5/day). So, the inclusion of the rents in the analysis results in higher optimal charges. Prud'homme and Bocarejo model's optimal charges are lower than what was found by TFL (2008). So the existing charge (£10/day) should be further increased if the rent is taken into account.

Third, the increase in optimal charge is substantial, but the increase in optimal benefits from charging (DWL) is even more (from 296 to 895 thousand €/day or from 57 to 172 million £/year).[6] One of the main findings of the Prud'homme and Bocarejo (2005) study was that the net benefits of any charges to alleviate congestion are negative, which means that, even for the optimal benefits, the economic costs of collecting charges is higher than the benefits. But if the land rents are added to the social cost, this finding can be reversed.

Table1 shows that for a high share of substitutable roads (33% or 100 euros/m^2 for the whole area), the net benefits become positive. So, instead of being an economic failure, as found by Prud'homme and Bocarejo (2005), the London congestion charge system would be considered an economic success, especially if higher charges are imposed. This outcome demonstrates the importance of taking the rents into account. The net benefits can range from -393 to +206 thousand €/day (-75 to 39 million £/year) based on the levels of P_{SR}. Also, this shows the importance of the share of substitutable roads in the analysis. One important note in Table 1 is that toll collection costs are assumed to be fixed while these costs could be affected by the number of trips (Rouhani et al. 2014*a*). Since the main London scheme's toll collection costs are sunk capital costs, we ignore the change in toll collection costs.

CONCLUSION

The opportunity cost of having roads in place is the rents that may be acquired by leasing the road space itself. Society may gain more from leasing the lands for other purposes than from using it for roads, assuming that the charges for rents will be returned to the users or will be used for public finance. For geographic regions where land is valuable, these ignored social costs may have significant consequences on the externalities associated with driving.

Based on the results of the London congestion zone case study, modifying the social cost by adding the rent of the lands dedicated to roads can have significant impacts on the analysis of optimal road usage. To summarize the results, the addition of the rent can increase the total social costs by as much as 204%, decrease the optimal road usage by as much as 40%, and increase the optimal charge by as much as 88%. And with the assumption of high values for rent or a high share of substitutable roads, the results suggest that some roads could be closed.

Also, the inclusion of the rents can substantially increase the benefits from charging. The net benefits from charges in the London congestion zone can change from -393 (found by Prud'homme and Bocarejo (2005)) to +206 thousand euros per day (-75 to 39 million £/year) using a relatively moderate value for the rents. The impact on the cost/benefit analysis demonstrates the importance of taking the rents into account. For high rent values, the rent costs can be even more significant than congestion costs, especially in an expensive city like London.

The applied model in this study suffers from several limitations. The share of substitutable roads could be extremely important in the optimal road usage analysis. This study employs only a sensitivity analysis for the related parameter, and the selected values lack a theoretical background. Some interesting further research would be developing a method to estimate this parameter.

The other limitation is that the details about who will get the benefits of selling or leasing the roads are missing in the analysis. A public fund, the residents of the relevant jurisdiction, or the federal government could potentially receive the benefits. The choice of the potential beneficiary could have important ramifications for social welfare analysis (Levinson 2005; Geddes and Nentchev 2012; Rouhani et al. 2014*b*).

Finally, the applied model in this study cannot estimate the costs (and benefits) to the property owners and is unable to capture the benefits (and costs) of the congestion pricing scheme beyond the congestion charge zone. Another interesting future study would estimate the effects of the changes in road capacity and road supply, which can affect the access to different land use functions, on the value of the neighboring land, using a method like Hedonic pricing (Earnhart 2006). The rental value of roads is a function of road supply; the value of land and consequently the rents could fall once the roads are removed. In fact, the relationship between road supply and land rent is reciprocal, and this fact should also be considered in the analysis.

Acknowledgements

The authors express their special gratitude to anonymous reviewers and the editor of the journal for reviewing the paper, sharing thoughts, and insightful comments on the paper.

Endnotes

1. In some European countries, new roads can be completely financed through high fuel taxes paid. So, one can argue that roads are completely financed because fuel taxes are high enough. However, very few new roads are built in old cities with already developed urban environments. As a result, the fuel taxes are not used for developing these cities' road networks.

2. The London's congestion charging scheme is different from conceptual congestion charging systems in its structure. The London scheme is a zonal scheme that is unable to price the social costs of congestion efficiently. In fact, the scheme can incentivize more traveling once the charge is paid (opposite to what a congestion pricing system should follow). In spite of the difference, the scheme is called the London congestion pricing.

3. Considering $I(q)$ as the generalized cost of a trip, the total cost is $TC=I(q).q$, the marginal social cost of a trip is $MSC=\mathrm{d}TC/\mathrm{d}q=I(q)+I'(q).q$, and the external social cost is $MSC-I(q)=I'(q).q$. Therefore, the Pigouvian tax is $\tau = I'(q).q$.

4. The Prud'homme and Bocarejo model (our model) is a partial equilibrium model. A general equilibrium model is valuable for a comprehensive analysis of the benefits and costs of congestion pricing schemes, which should include changes outside the limited scope of the partial equilibrium model (such as employment, land values, activities). The changes in these parameters are not considered in this analysis.

5. To calculate the total annual rent, the annual rate (300 euros/m^2) is multiplied by the area of the congestion zone (2.16 km^2). The result will be 648 million euros per year. And dividing the result by 255 working days, the total rent per working day will become 2,541 thousand euros (648 million/255).

6. To estimate the optimal benefits, we used the (approximately) triangle $B'C'A$, as shown in Figure 2. For example, P_{SR} = 0.16, $C'A$ = 3.67 (pre-charge social cost) – 1.61 (pre-charge individual cost) = 2.06; and $X'Y$ = 1,390 (pre-charge road usage) – 930 (optimal road usage) = 460. So, the optimal benefits equal 0.5* $C'A$* $X'Y$ = 473.8.

References

Banister, David. “Critical Pragmatism and Congestion Charging in London.” *International Social Science Journal* 55, (2003): 249–264.

Cheshire, Paul C. and Christian A.L. Hilber. “Office Space Supply Restrictions in Britain: The Political Economy of Market Revenge.” *Economic Journal* 118, (2008): F185–F221.

Clonts, Howard A. “Influence of Urbanization on Land Values at the Urban Periphery.” *Land Economics* 46, (1970): 489-497.

Cornes, Richard. *The Theory of Externalities, Public Goods and Club Goods*. Cambridge University Press, New York, 1986.

de Palma, André and Robin Lindsey. “Traffic Congestion Pricing Methodologies and Technologies.” *Transportation Research Part C* 19, (2011): 1377–1399.

Earnhart, Dietrich. “Using Contingent-Pricing Analysis to Value Open Space and Its Duration at Residential Locations.” *Land Economics* 82, (2006):17-35.

Eliasson, Jonas and Lars-Göran Mattsson. “Equity Effects of Congestion Pricing: Quantitative Methodology and A Case Study for Stockholm.” *Transportation Research Part A* 40, (2006): 602–620.

Eliasson, Jonas. “Lessons from the Stockholm Congestion Charging Trial.” *Transport Policy* 15, (2008): 395–404.

Eliasson, Jonas. “A Cost–Benefit Analysis of the Stockholm Congestion Charging System.” *Transportation Research Part A* 43, (2009): 468–480.

Geddes, Richard and Dimitar Nentchev. “Private Investment and Road Pricing: The Investment Public-Private Partnership.” *PERC Research Paper* 12-16, 2012.

Hamilton, Carl J. “Revisiting the Cost of the Stockholm Congestion Charging System.” *Transport Policy* 18, (2011): 836–847.

Leape, Jonathan. “The London Congestion Charge.” *The Journal of Economic Perspectives* 20, (2006): 157–176.

Levinson, David. “The Political Economy of Private Roads.” Gabriel Roth, ed. *Street Smart: Competition, Entrepreneurship, and the Future of Roads.* Transaction Publishers (2006): 79-96.

Litman, Todd. *London Congestion Pricing Implications for Other Cities.* Victoria Transport Policy Institute, 2006.

Mackie, Peter. “The London Congestion Charge: A Tentative Economic Appraisal: A Comment on the Paper by Prud’homme and Bocajero.” *Transport Policy* 12, (2005): 288–290.

McDonald, John F., Edmond L. d’Ouville, and Nan Liu Louie Nan Liu. (ed.). *Economics of Urban Highway Congestion and Pricing*. Boston: Springer Vol. 9, Kluwer, (1999).

MVA Consultancy. “The London Congestion Charging Research Programme: Final Report.” London, HMSO, ISBN: 0115517553, 1995.

Nash, Chris, Batool Menaz, and Bryan Matthews. “Inter-urban Road Goods Vehicle Pricing in Europe.” Richardson, H. and C. Bae (eds.), *Road Congestion Pricing in Europe: Implications for the United States*. Northampton, MA: Edward Elgar, Cheltenham, UK (2008): 233–251.

Olszewski, Piotr and Litian Xie. “Modelling the Effects of Road Pricing on Traffic in Singapore.” *Transportation Research Part A* 39 (7), (2005): 755–772.

Paulsen, Kurt. “The Effects of Growth Management on the Spatial Extent of Urban Development, Revisited.” *Land Economics* 89, (2013): 193–210.

Pigou, Arthur Cecil. (ed.). *The Economics of Welfare*. Macmillan and Co., London, 1920.

Prud’homme, Rémy and Juan Pablo Bocarejo. “The London Congestion Charge: A Tentative Economic Appraisal.” *Transport Policy* 12, (2005): 279–287.

Raux, Charles. “Comments on ‘The London Congestion Charge: A Tentative Economic Appraisal.’ (Prud’homme and Bocajero, 2005).” *Transport Policy* 12, (2005): 368–371.

Raux, Charles. “Comments on ‘The London Congestion Charge: A Tentative Economic Appraisal.’ (Prud’homme and Bocajero, 2005).” 2006 report, Available on-line at http://ideas.repec.org/p/hal/journl/halshs-00067920.html, accessed March 2011.

ROCOL [Review of Charging Options for London] Working Group. “Road Charging Options for London: A Technical Assessment.” London, HMSO, 2000.

Roth, Gabriel Joseph. *Paying for Roads: The Economics of Traffic Congestion.* Penguin Books Ltd., Harmondsworth, 1967.

Rouhani, Omid M. “Road Privatization and Sustainability.” *MIT Journal of Planning* 9, (2009): 82–105.

Rouhani, Omid M. and Debbie Niemeier. “Urban Network Privatization.” *Transportation Research Record: Journal of the Transportation Research Board* 2221, (2011): 46–56.

Rouhani, Omid M. *Frameworks for Public-Private Partnerships.* PhD dissertation, University of California, Davis, 2013.

Rouhani, Omid M., H. Oliver Gao, and Arash Beheshtian. “Social and Private Costs of Driving.” Presentation at the 2013 Annual Conference of the International Transportation Economics Association, Northwestern University, Evanston, Illinois, 2013*a*.

Rouhani, Omid M., Debbie Niemeier, Christopher R. Knittel, and Kaveh Madani. “Integrated Modeling Framework for Leasing Urban Roads: A Case Study of Fresno, California.” *Transportation Research Part B* 48, (2013*b*): 17–30.

Rouhani, Omid M., H. Oliver Gao, Richard Geddes, and Hossein Zarei. “Policy Lessons for Regulating Public-Private Partnership Tolling Schemes in Urban Environments.” Poster presentation in *the 2014 Transportation Research Board*, Washington, D.C., USA, 2014*a*.

Rouhani, Omid M., H. Oliver Gao, Richard Geddes, Germa Bel, and Hossein Zarei. “Social Welfare Analysis for Alternative Investment Public-Private Partnership Approaches.” Lecture presentation in *the 2014 Transportation Research Board*, Washington, D.C., USA, 2014*b*.

Safirova, Elena, Kenneth Gillingham, Ian Parry, Peter Nelson, Winston Harrington, and David Mason. "Welfare and Distributional Effects of Road Pricing Schemes for Metropolitan Washington, DC." *Research in Transportation Economics* 9, (2004): 179–206.

Santos, Georgina and Jasvinder Bhakar. "The Impact of the London Congestion Charging Scheme on the Generalised Cost of Car Commuters to the City of London from a Value of Travel Time Savings Perspective." *Transport Policy* 13 (1), (2006): 22–33.

Schweitzer, Lisa and Brian D. Taylor. "Just Pricing: The Distributional Effects of Congestion Pricing and Sales Taxes." *Transportation* 35, (2008): 797–812.

Shoup, Donald C. *The High Cost of Free Parking.* Planners Press revised 2011, Chicago, 2005.

Shoup, Donald C. "The Ideal Source of Local Public Revenue." *Regional Science and Urban Economics* 34, (2004): 753–784.

Small, Kenneth A. and Erik T. Verhoef. *The Economics of Urban Transportation.* Routledge, London, 2007.

Transport for London. "Central London Congestion Charging: Impacts Monitoring." *Fifth Annual Report*, 2007, July 2007, Available on-line at

http://www.tfl.gov.uk/assets/downloads/fifth-annual-impacts-monitoring-report-2007-07-07.pdf , accessed September 2011.

Transport for London. "Central London Congestion Charging - Impacts Monitoring." *Second Annual Report*, 2004, April 2004, Available on-line at http://www.tfl.gov.uk/cdn/static/cms/documents/impacts-monitoring-report-2.pdf, accessed April 2014.

Transport for London. "Central London Congestion Charging - Impacts Monitoring." *Sixth Annual Report*, 2008, July 2008, Available on-line at http://www.tfl.gov.uk/assets/downloads/sixth-annual-impacts-monitoring-report-2008-07.pdf, accessed September 2011.

Transport for London (TFL) website. Available on-line at www.tfl.gov.uk/ accessed June 2012.

Verhoef, Erik T. and Herbert Mohring. "Self-Financing Roads." *International Journal of Sustainable Transportation* 3, (2009): 293–311.

Vickrey, William S. "Pricing in Urban and Suburban Transport." *American Economic Review* 52, (1963): 452-465.

Walters, Alan A. "The Theory and Measurement of Private and Social Cost of Highway Congestion." *Econometrica* 29, (1961): 676–699.

Xie, Litian and Piotr Olszewski. "Modelling the Effects of Road Pricing on Traffic Using ERP Traffic Data." *Transportation Research Part A* 45, (2011): 512-522.

Yang, Hai and Hai-Jun Huang. "Principle of Marginal-Cost Pricing: How Does It Work in a General Road Network?" *Transportation Research Part A* 32, (1998): 45-54.

Youn, Hyejin, Michael T. Gastner, and Hawoong Jeong. "Price of Anarchy in Transportation Networks: Efficiency and Optimality Control." *Physical Review Letters* 101 (12), (2008) 128701. Available on-line at http://link.aps.org/doi/10.1103/PhysRevLett.101.128701, accessed September 2011.

Omid M. Rouhani *is a postdoctoral research associate at Cornell University, where he works on policy options to improve New York City's transportation system. Omid's research focuses on the application of systems analysis, economics, optimization, simulation, and modeling methods to transportation problems at different scales. His academic articles have appeared in* the Journal of Transportation Research Part B, Environmental Modeling and Software, Energies, the European Journal of Operational Research, Transportation Research Record, *and many other journals.*

Christopher Knittel *is the William Barton Rogers Professor of Energy Economics in the Sloan School of Management and the director of the Center for Energy and Environmental Policy Research at the Massachusetts Institute of Technology. He joined the faculty at MIT in 2011, having taught previously at UC Davis and Boston University. His research focuses on environmental economics, industrial organization, and applied econometrics. He is a research associate at the National Bureau of Economic Research in the Productivity, Industrial Organization, and Energy and Environmental Economics groups. Professor Knittel is an associate editor of* The Journal of Industrial Economics, Journal of Transportation Economics and Policy, and Journal of Energy Markets. *His research has appeared in* The American Economic Review, The American Economic Journal, The Review of Economics and Statistics, The Journal of Industrial Economics, The Energy Journal *and other academic journals.*

Deb Niemeier *is a professor in the Department of Civil and Environmental Engineering at the University of California, Davis. Her research interests focus on sustainability, climate change, the complex interactions between policy, energy use and land use, and productivity and innovation in public agencies.*