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PRELIMINARY RESULTS OF THE LONDON CONGESTION CHARGING SCHEME

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On February 17, 2003, the London Congestion Charging Scheme came into effect. Preliminary results show a significant response to the £5 (U.S. $8) charge. Congestion over the first year decreased by 30%. Overall traffic levels within the charging zone fell by 16%. Speeds for car travel increased by more than 20%, and bus travel became more reliable. Elasticities of demand for trips by car with respect to generalized costs are estimated to be between –1.32 and –2.10. The average marginal congestion cost within the central zone is estimated at £1.65/vehicle-km (approximately U.S. $2.58/vehicle-km). The net economic benefits of the Scheme for the first year were £50 million (U.S. $78 million) and the net revenues, £68 million (U.S. $106 million). Net revenues are mainly being used to improve public transport.

Keywords: *traffic congestion; London congestion charging; demand elasticities; congestion costs; road pricing*

Garrett Hardin's (1968) *Tragedy of the Commons* depicts a classic example of the harmful effects of unabated negative externalities. In Hardin's story, the villagers of a small English town have equal and free access to a commons wherein they can place their animals. When making the decision to add a cow to the commons, a villager takes into account the animal's own ability to graze and roam, but not its effect on others. This is the classic description of the so-called free-rider problem commonly associated with public goods.

The modern version of Hardin's story could easily depict drivers as, perhaps unflatteringly, the cows and roads in place of the commons. When a potential driver makes the decision to use private transport by comparing his or her marginal private costs and benefits, that driver typically excludes from the analysis any external costs that his or her action of driving may impose on others. Arthur Pigou, a Cambridge economist, first identified this problem of "divergences between marginal social and private net products" in his book *The Economics of Welfare* (Pigou, 1920). To remedy this problem, Pigou proposed a tax or levy on drivers to ensure that their perceived private costs were consistent with the true social costs of driving.

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The city of London has taken Pigou's idea from theory to practice. Since February 17, 2003, motorists within the central London area must pay a £5 charge (approximately U.S. $8) for the right to drive or park within the zone. The charge differs from a true Pigouvian tax in that it is not equal to the marginal congestion cost (MCC). A charge equal to the MCC would vary with time and location. Although technically the charge differs temporally, given that a license costs £5 between 7:00 AM and 6:30 PM from Monday to Friday versus £0 at all other times, true marginal cost pricing (or Pigouvian taxation) would require more finely tuned spatial and temporal differences. Nevertheless, the London Congestion Charging Scheme is a dramatic step towards internalizing the externalities associated with driving.

This article analyzes some of the preliminary effects, as recently published by Transport for London (TfL, 2003a, 2003b, 2004). It presents the basic theory of optimal road pricing, describes the London Scheme and its preliminary results, which are then used to compute elasticities with respect to changes in generalized cost, as well as area marginal congestion costs. It then briefly touches on the costs and benefits of the Scheme, the use of revenues, and the potential equity impacts. The prevailing elasticities, as shown by motorists' responses to the Scheme, are higher than expected. This is probably because of the public transport system in London, which provides an alternative to the car. The calculated area MCC suggests that the £5 charge is a reasonable approximation to marginal cost pricing.

The Economics of Congestion Charging

Suboptimal levels of congestion are a result of drivers failing to take into account the effect that their vehicle will have on others. This "neglected externality" means that drivers will often use private vehicles when the net marginal social benefit of doing so is actually negative.

The optimal method to internalize externalities is marginal cost pricing, whose basics Pigou (1920) first proposed. In a seminal paper, Walters (1961) more fully developed the specific application of marginal cost pricing to a congested highway. His model is based on engineering-related speed-flow relationships on links to derive the optimal congestion charge. The formal derivations shown below follow Newbery (1990) and Nash (1997).

Assume a generalized travel cost/km function that consists of money costs (fuel, maintenance, etc.) and time costs:

$$g = m + \frac{b}{s(q)} \tag{1}$$

where g = generalized cost (pence/PCU-km), m = money cost (pence/PCU-km), b = value of time (pence/PCU-hour), s = speed as a function of total flow (km/hour), and q = flow (PCU/hour).

PCU stands for passenger car unit, a measure of the relative disruption that different vehicle types impose on the network. A car, for example, has a PCU rating of 1, whereas a light goods vehicle has a PCU rating of 1.5, and so on. In the U.S. passenger car equivalents (PCE) are used instead. The meaning, however, is the same.

Total costs (in pence/km-hour) are:

$$C = gq = mq + \frac{bq}{s(q)} \tag{2}$$

and marginal costs are:

$$\frac{\partial C}{\partial q} = m + \frac{b}{s(q)} - \frac{bq}{[(q)]^2} s'(q) \tag{3}$$

or more simply:

$$\frac{\partial C}{\partial q} = g + \frac{b}{s(q)} e_{sq} \tag{4}$$

where e_{sq} is the elasticity of speed with respect to flow.

This last expression clearly identifies the marginal social costs as a function of marginal private costs, g, plus an external cost term, the congestion externality. By way of a Pigouvian tax, an individual's decision can be reconciled with the socially optimal choice. The tax in this case would be equal to $\frac{b}{s(q)} e_{sq}$ per PCU-km.

Because marginal cost pricing is not very practical, transport economists have lately devoted their efforts to the study of second-best alternatives.

Although the above concept of first-best road pricing remains central to transport theory, its application to a congested urban design poses a few problems. Introducing marginal cost pricing in the transport sector does not guarantee an efficient outcome when there are externalities in other (related) sectors in the economy, which are not priced according to marginal cost. In addition, marginal cost pricing has proved difficult to implement in dense networks. In today's technologically advanced world, the calculation of instant marginal cost pricing may not be very difficult to envisage. Its cost-effectiveness, however, would be dubious; and most important, its transparency would be at least arguable, as drivers would not know what congestion charge they would be required to pay before starting their journey. Marginal cost pricing would require highly differentiated pricing systems in time and space and would be expensive to provide and confusing to users (Nash & Sansom, 2001).

Because marginal cost pricing is not very practical, transport economists have lately devoted their efforts to the study of second-best alternatives (May, Liu, Shepherd, & Sumalee, 2002; Shepherd & Sumalee, 2004; Verhoef, 2002; Zhang & Yang, 2004). Policy makers have opted for simpler, less expensive, more practical, and transparent options such as cordon tolls and area-licensing schemes. Examples are the original Singaporean scheme, the Norwegian toll rings, and the new London area-license scheme.

The London Congestion Charging Scheme

The London Scheme traces its origin back to the Smeed report (Ministry of Transport, 1964), which studied the technical feasibility of road pricing in the United Kingdom. Numerous studies have been produced since then, including the influential report by the TfL-commissioned London Congestion Charging Research Programme (LCCRP) in 1995 (MVA Consultancy, 1995). The LCCRP final report suggests as its medium case a £4 electronic cordon toll (using intravehicle units) to enter a central London area, which is essentially identical to the ultimately chosen charging zone. The Road Charging Options for London (ROCOL) report published in 2000 followed the LCCRP. The ROCOL report (ROCOL Working Group, 2000) presents the technical details as well as predicted impacts of a variety of congestion-reducing strategies that encompass area-licensing schemes, and cordon tolls (central only, multizone, paper, and electronic) as well as workplace parking levies.

The discussion became closer to reality in May 2000, when Ken Livingstone was elected mayor of London based on a manifesto promising the introduction of congestion charging. The Greater London Authority (GLA) Act 1999 (Acts of Parliament, 1999) gave this new mayor the power, for the first time, to impose congestion charges.[1]

The final decision, made by the mayor, was to go with an area-licensing scheme using a £5 charge applied to central London only. The method was chosen because of its relative ease of implementation as compared to full-scale road pricing. Automatic number plate recognition (ANPR) technology was selected as a feasible intermediate between an inexpensive but inefficient paper-based system and a sophisticated, yet complex and expensive electronic road pricing scheme (ROCOL Working Group, 2000).

One of the key features of the run-up to the Scheme was the extensive consultation process, which took place over 18 months. The process included meetings with key stakeholders, the distribution of thousands of information leaflets on the proposed Scheme to all the 33 London

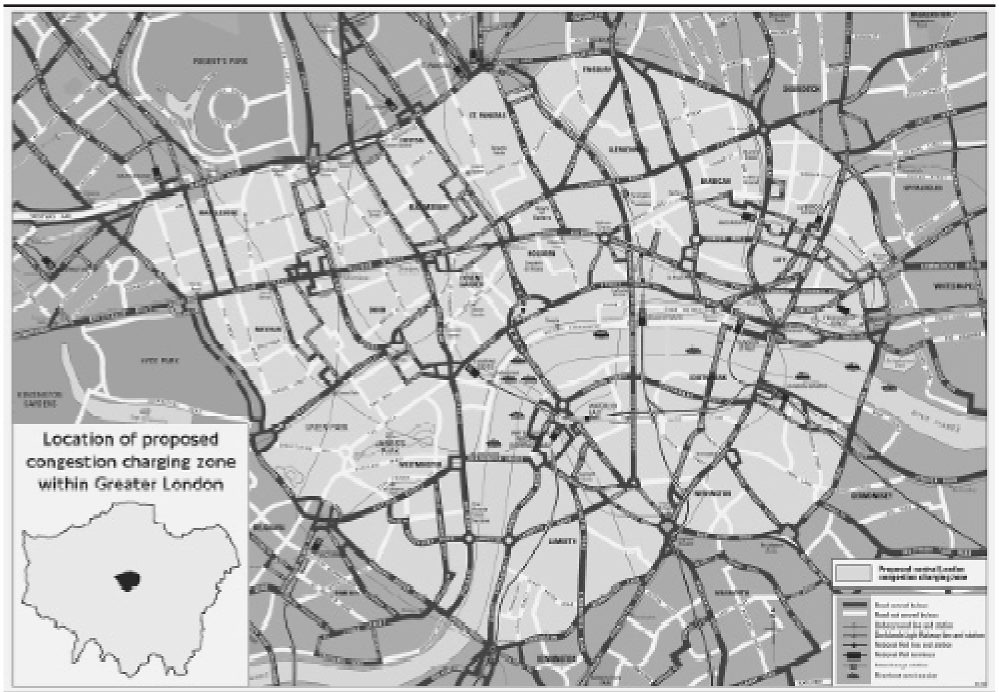

Figure 1: Map of the Charging Zone
SOURCE: www.london.gov.uk/approot/mayor/congest/pdf/zone_map.pdf
NOTE: Map reproduced with permission from Transport for London.

boroughs, and placement of newspaper and radio advertisements with details of the Scheme and information on how the public could participate in the consultation process. This consultation exercise increased the public acceptability of the Scheme.

HOW THE SCHEME OPERATES

Figure 1 shows the limit of the area where the charges apply, the Inner Ring Road, which runs along Euston Road, Pentonville Road, City Road, Old Street, Commercial Street, Tower Bridge Road, New Kent Road, Kennington Lane, Vauxhall Bridge Road, Park Lane, Edgware Road, and Marylebone Road. No charge is made for driving on the Inner Ring Road itself.

We can see from the figure that the charging area is relatively small. It only covers 21 km^2 (8 miles^2), representing 1.3% of the total 1,579 km^2 (617 miles^2) of Greater London.

There are 174 entry-and-exit boundary points around the zone. Traffic signs make clear the exact location of the charging zone. A red symbol accompanies the signs on each lane of traffic at the entry points to the charging zone. The Scheme charges all cars driving into or within the zone, plus those parked in nonprivate spaces within the zone, regardless of movement. Essentially, one can consider the charge a "day pass" for use of central London's roads. The ROCOL report (2000) used a further scenario encompassing all of inner London and a differentiated-price scheme using both zones. Ultimately, it was thought that implementating the Scheme in the somewhat more manageable smaller size of central London would be more suitable as a first step, with the possibility of later expansion.

The Scheme charges all cars driving into or within the zone, plus those parked in nonprivate spaces within the zone, regardless of movement.

The applicable hours of the Scheme are 7:00 AM to 6:30 PM, Monday to Friday, excluding bank and public holidays. This is a slight departure from the ROCOL recommendation of 7:00 AM to 7:00 PM. The decision to change the evening end-time was primarily a result of lobbying by the entertainment community who argued that having the charge apply until 7:00 PM would damage the West End and discourage theatre-goers from coming downtown.

Table 1: Exemptions and Discounts

Discount/Status	*Category*
Fully exempt	Motorcycles, mopeds, and bicycles Emergency vehicles Public service vehicles with nine or more seats licensed as buses Vehicles used by (and for) disabled persons that are exempt from VED Licensed London taxis and minicabs
100% discount with free registration	Certain military vehicles Local government service vehicles (e.g., refuse trucks, street maintenance) Vehicles with nine or more seats not licensed as buses (e.g., community minibuses)
100% discount with a one-off £10 registration	Vehicles driven by (or for) individuals or institutions that are Blue Badge holders[a]
100% discount with £10 registration	Alternative fuel vehicles—requires emission savings 40% above Euro IV standards Roadside assistance vehicles (e.g., motoring organizations such as the Automobile Association)
90% discount with £10 registration	Vehicles registered to residents of the central zone

SOURCE: Transport for London, Congestion Charging Web site: www.cclondon.com/exemptions.shtml
NOTE: VED: Vehicle excise duty.
a. Blue Badges, which existed before the scheme was implemented, are special parking permits issued to people with disabilities to allow them to park near shops, stations, and other facilities. The badge belongs to the person who is disabled who qualifies for it (who may or may not be a car driver) and can be used in any vehicle he or she is traveling in.

Table 2: Methods of Payment

	Percentage (%)
Retail outlets	36
Telephone	19
Post	< 1
Internet	26
SMS text messaging	19

SOURCE: Transport for London (2004, p. 30).
NOTE: SMS = short message service.

The ROCOL consultants analyzed scenarios of £2.50, £5, and £10 charges. They used stated preference results from surveys as well as spatially detailed representations of road-traffic movements to estimate changes in travel conditions due to the introduction of area licensing. They predicted reductions in car trips and vehicle-km driven in Central London of 20% to 23% (ROCOL Working Group, 2000, pp. 69-70). These predictions are not out of line with what has actually happened. TfL (2004) reports reductions in vehicle-km driven within the charging zone during charging hours of 15% for vehicles with four or more wheels between 2002 and 2003. For potentially chargeable vehicles (cars, vans, and lorries) the reduction of vehicle-km driven has been 25%. When only cars are considered, vehicle-km driven have been reduced by 34%.

Because of the unsophisticated nature of an area-licensing scheme, the system lacks the ability to adequately charge differentiated prices temporally and spatially. Ultimately, the mayor settled upon the £5 charge, deciding that it provided adequate incentive to achieve significant congestion reduction but with less public backlash likely to be associated with a £10 charge. The heavy goods vehicle (HGV) charge, originally set at £15 (3 times the car charge), was reduced to be the same as that for cars.

The Scheme allows for a variety of 90% to 100% discounts, as well as exemptions. A summary is shown in Table 1.

Payments can be made by a variety of methods. These are shown in Table 2, along with their share of use during the first year.

The charge has to be paid in advance or on the day until 10:00 PM with late payment available between 10:00 PM and 12:00 AM but with the charge rising to £10 (U.S. $16). Drivers can pay the charge daily, weekly, monthly, or yearly. It is at the drivers' initiative to pay the charge.

Enforcement is undertaken with video cameras. There is a network of 203 camera sites, with these located at every entrance and exit to the congestion-charging zone as well as inside the charging zone. The cameras provide high-quality video signals to ANPR software, which reads and records each number plate with a 90% accuracy rate. At midnight, images of all of the vehicles that have been in the congestion-charging zone are checked against the vehicle registration numbers of vehicles for which congestion charges have been paid that day. The computer keeps the registration numbers of vehicles for which these charges have not been paid. A manual check of each recorded image is then made, and a penalty charge notice of £80 (U.S. $126) is then issued to the registered keeper of the vehicle. As with parking penalties, this amount is reduced to £40 (U.S. $63) for prompt payment within 14 days. Failure to pay the penalty charge within 28 days results in the penalty being increased to £120 (U.S. $190).

Preliminary Results of the London Scheme

In this section, we summarize the traffic impacts of the Scheme over the first year.

EFFECTS ON TRAFFIC

According to TfL (2003a, 2003b, 2004), the average travel speed in the charging zone in the first few months after the Scheme was implemented, was 17 km/hour (10.6 miles/hour), and this continued over the first year. This number compares with the average speed precharging, which was 14 km/hour (8.7 miles/hour), as listed in the TfL first annual report (2003c, p. 52). There has therefore been a 21% increase in average travel speeds in the charging area.

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TfL defines congestion as "the difference between the average network travel rate and the uncongested (free-flow) network travel rate in minutes per veh-km" (TfL, 2003a, p. 46). The uncongested network travel rate of 1.9 minutes/km (approximately 32 km/hour) from TfL (2003a, p. 52), and pre- and postcharging average travel rates of 4.2 and 3.5 minutes/km respectively, show that congestion has decreased from 2.3 to 1.6 minutes/km. Note that the optimal amount of congestion is not zero congestion. Zero congestion would suggest an underuse of road space. On the other hand, TfL admits that there is an optimal level of congestion, which is achieved at the optimal level of traffic. However, it considers the optimal level of congestion difficult to define and that is the reason why it defines congestion using free-flow time as the base (TfL, 2003a). Bearing this caveat in mind, we can conclude that congestion has been reduced by 30.5%. This calculated value is roughly equal to the listed value in the *Update of Scheme Impacts and Operations* (TfL, 2004, point 1.8, p. 4) of 30%. Furthermore, it is in line, albeit at the upper end, with expectations of congestion reduction of between 20% and 30%.

Traffic levels are a measure of the volume or number of vehicles entering or driving within central London. Compared to precharging conditions, the count of all cars entering the central zone has decreased by 31%. Increases in incoming motorcycles (by 19%), taxis (by 19%), and buses (by 16%) have partially offset the reduction in the number of cars. Traffic levels (all vehicles) inside the central zone have decreased by 15%, again roughly in line (but at the upper end) with TfL's expectations of 10% to 15%.

Finally, travel times also show significant improvements. Travel times to central London from outer London, inner London, and central London have all decreased. A basket of 5,000 journeys from all areas of greater London showed a reduction in travel times of 13% (TfL, 2003a, point 2.4, p. 5).

A summary of the above results is shown in Table 3.

Table 3: Preliminary Effects on Traffic

	Precharging	*Postcharging*	*Change (%)*
Average speed	14 km/h	17 km/h	+21
Congestion	2.3 min/km	1.6 min/km	–30.5
Traffic levels[a]			
Incoming (cars only)	193,912	133,016	–31
Incoming (noncars)	178,149	193,485	+9
Inside central zone	na	na	–16
Travel times to central zone			
From outer London	59 min	52 min	–12
From inner London	37 min	33 min	–11
From central London	38 min	35 min	–8
Basket of 5,000 journeys	47 min	41 min	–13

Source: Transport for London (2003a, b).
NOTE: na = nonapplicable.
Precharging: spring 2002; Postcharging: spring 2003.
a. Data supplied by Transport for London on request.

Table 4: Average Workday Travel Times Into London (Morning Peak)

Route	*Orientation*	*Feb. to Sept. 2002 (min)*	*Feb. to Sept. 2003 (min)*	*Change (%)*
A1 Mill Hill to Islington	N-NW	46	49	7
A41 Mill Hill, Five Ways to Regent’s Park	NW	36	38	6
A40/M Denham to Marylebone	W	62	61	-3
A4 Langley, Slough to Talgarth Road	W	57	57	1
A30 Stanwell to Osterley	W-SW	15	16	6
A316 Sunbury Cross to Ravenscourt Park	W-SW	40	41	2
A3 Cobham to Clapham	SW	50	62	25
A23 Hooley to Brixton	S	59	64	8
A20 Swanley to Eltham	SE	20	23	14
A2/A102 Dartford to Blackwall Tunnel	E-SE	39	44	14
A12 Harold Wood to Blackwall Tunnel	E-NE	66	72	9
A10 Waltham Cross to Stoke Newington	N	44	51	15

SOURCE: Trafficmaster PLC (data supplied on request).

Because traffic traveling on the Inner Ring Road does not pay the congestion charge, TfL expected that through traffic, with origin and destination outside the charging zone, would instead divert and use the Inner Ring Road . This indeed happened and raised the total vehicle-km on the Inner Ring Road by 4% when compared with 2002 (TfL, 2004). However, improved traffic management arrangements were put in place on the Inner Ring Road before the Scheme started, and this prevented an increase in congestion. For example, between 1 and 2 seconds were taken off green-light time on radial roads, which were anticipated would have less traffic, and added to green-light time on the Inner Ring Road. This made a sufficient difference to keep the Ring Road operating satisfactorily with marginally lower levels of congestion, compared to precharging conditions.

Trafficmaster PLC, a private company that provides real-time traffic information on major routes, began a study on February 17, 2003, to assess the commuting impacts of the Scheme outside the zone. Although after 6 months of monitoring, average travel times recorded by Trafficmaster had increased on most routes, there were no constant patterns. Table 4 shows the average travel times (in minutes) and travel time changes for the first 7 months after the Scheme started. We can see from the table that most routes had longer travel times. Table 5 compares some examples of how travel time on some routes increased and decreased in comparison to the same month the year before and shows no constant pattern of variation.

Table 5: Examples of Nonconstant Patterns in Percentage Changes in Travel Times

Route	*April 2002 (min.)*	*April 2003 (min.)*	*Change (%)*	*May 2002 (min.)*	*May 2003 (min.)*	*Change (%)*
A1 Mill Hill to Islington	50.1	51.7	3	55.4	53.9	–3
A41 Mill Hill, Five Ways to Regent’s Park	35.8	38.4	7	42	46.4	10
A40/M Denham to Marylebone	65.4	68.9	5	62.6	58.7	–6
A4 Langley, Slough to Talgarth Road	58.6	56.1	–4	64.4	59.7	–7
A30 Stanwell to Osterley	16.5	17.5	6	14.8	17.7	20
A316 Sunbury Cross to Ravenscourt Park	42.9	39.7	–7	44.3	48.4	9
A3 Cobham to Clapham	58.4	59.3	2	51.2	66	29
A23 Hooley to Brixton	66	66.7	1	64.8	71.6	10
A20 Swanley to Eltham	23	23.2	1	21.7	26	20
A2/A102 Dartford to Blackwall Tunnel	46.7	46.7	0	40.7	45.8	13
A12 Harold Wood to Blackwall Tunnel	72.5	70.7	–2	71.7	69.4	–3
A10 Waltham Cross to Stoke Newington	55.8	58.1	4	53.4	57	7

SOURCE: Trafficmaster PLC (data supplied on request).
NOTE: Both months are within school term.

The apparent contradiction between Tables 3 and 4 can be explained by the fact that Table 4 measures travel times all the way up to and including the charging zone, where travel times have decreased and therefore push the average down. Table 4, on the other hand, does not include any road inside the charging zone.

EFFECTS ON PUBLIC TRANSPORT

TfL predicted that approximately 20,000 individuals would switch from car travel to public transport during the morning peak period as a result of the Scheme. Of this number, 5,000 were expected to use the Underground system; 14,000, the buses; and the remainder, rail system without transfers to bus or Underground. It was also expected that the morning peak hour (8:00 AM to 9:00 AM) increase would be of an additional 7,000 bus users (TfL, 2002b).

Although bus ridership increased in line with expectations, Underground travel did not. Underground usage across London and especially in central London decreased. The decrease in passenger levels on the London Underground is probably linked to the slowdown of the economy and the decrease in tourism in London, which, in turn, may be linked to the war in Iraq (TfL, 2003b). In addition, the Central Line was temporarily closed for almost 3 months following a derailment at Chancery Lane station in January.

Although bus ridership increased in line with expectations, Underground travel did not.

Average bus speeds in the morning peak did not change too much, and it is difficult to establish a pattern of variation. Although speeds on some route sections increased, speeds on others decreased (TfL, 2003b). On the other hand, additional time waited by passengers over and above the route schedule decreased by 25% across Greater London and by more than 33% in the routes serving the charging zone and the Inner Ring Road (TfL, 2003b, point 3.75). To accommodate the increase in bus ridership, TfL increased the number of buses in the central zone by 19% over the year previous to the introduction of the Scheme. Other improvements included the addition of new routes, the switch of 10 major routes from single-deck to double-deck buses, and the addition of 18-metre ‘bendy’ buses on heavily traveled routes.

The provision of good public transport is a key part of implementing a fair pricing scheme. Without or with inferior public transport alternatives, a road pricing scheme is just a regressive tax on the middle and poor classes.[2] With good public transport, road pricing is, to some degree, a luxury tax—without it, it is just a regressive tax. TfL’s increase in the bus service before and after the Scheme started is an example of changes that need to be part of the process to promote fair social outcomes.

EFFECTS ON OTHER TRANSPORT

TfL (2003b, point 3.64) estimates that 15% to 25% of the reduction in car use per charging day is the result of car users switching to other modes of transport—such as car share, motorcycles, and bicycles—or making adaptations such as altering travel plans to avoid the charging hours or charging zone, and walking. Table 6 shows that the total counts of bicycles and motorcycles going into the charging zone increased by 31% and 19%, respectively. The increases, higher than TfL's expectations (2003b, point 3.38), are not surprising, given the fact that neither of those vehicle categories pays the charge. Surprisingly enough, the number of powered two-wheelers (motorcycles and mopeds) and bicycles involved in accidents following the introduction of the Scheme fell by 15% and 17%, respectively, when compared to the same period in 2002 (TfL, 2003b, point 3.97). These results probably reflect the long-term trend of declining accidents in London rather than any feature linked to the Scheme.

Incoming taxis also increased by 19%, more than TfL expected (2003b, point 3.38). In addition, the count of working vehicles, such as LGVs and HGVs, decreased.

Although when PCU ratings are taken into account the percentage changes change, the final results do not change too much, mainly as a consequence of traffic composition. Table 6 shows changes in vehicle counts and in PCU counts. It can, therefore, be concluded that the increase in the use of buses, taxis, motorcycles, and bicycles does not jeopardize the reduction in overall traffic, which has been larger than expected. Grounds to extend the charge to include other vehicle categories, as done in Singapore, seem absent.

Empirical Analysis

This section includes a calculation of the elasticity of demand for car trips with respect to the generalized cost of travel, as well as a calculation of the marginal cost of congestion within the central London zone. The results are then compared with estimates from the literature.

PRICE ELASTICITY OF DEMAND

An elasticity measures the percentage change in one variable with respect to a percentage change in another. Herein it measures the responsiveness of demand for trips due to a change in travel costs. The generalized costs of travel include money costs and time costs, as defined in Equation 1.

To proceed with the calculations, it is necessary to determine the average generalized cost of travel into central London. The U.K. Automobile Association provides detailed estimates of motoring costs (money costs) for cars, split out by fixed and variable costs (Automobile Association, 2003). The values depend on annual mileage (for fuel, maintenance) and cost of vehicle (financing, insurance, depreciation).

We had to make several assumptions in selecting the appropriate measure of motoring costs. Firstly, we chose the Automobile Association's above-average cost of car category to reflect the fact that the average Londoner has a higher income than the national average (National Statistics, 2003). The cost of a car affects the fixed costs of insurance and financing. To attain per km costs, we used the average annual distance driven by a Londoner of 8,800 km (5,466 miles) (TfL, 2001, p. 2). The corresponding motoring costs for an average Londoner are thus roughly 47.5 pence/km (U.S. \$1.2/mile), of which 12.25 pence (U.S. \$0.20 cents) are variable costs. The motoring costs are presented in Table 7.

To calculate time costs, it is necessary to determine a value of travel time savings (VTTS). The *Transport Economics Note* (Department of the Environment, Transport, and the Regions,

Table 6: Vehicle Counts Pre- and Postcharging

	Pedal Cycles	*Motorcycles*	*Cars*	*Taxis*	*Bus & Coach*	*LGVs*	*HGVs & Other*	*4+ Wheels*	*Total*	*Total Noncars*	*Pedal and Motorcycles*
Spring 2002 incoming	13,836	25,840	193,912	55,971	13,393	53,780	15,329	332,386	372,062	178,149	39,676
Spring 2002 outgoing	11,346	22,940	192,840	57,036	13,079	59,487	16,256	338,697	372,982	180,143	34,285
Spring 2002 total	25,181	48,780	386,752	113,007	26,472	113,267	31,585	671,083	745,044	358,292	73,961
Spring 2003 incoming	18,131	30,779	133,016	66,836	15,518	48,745	13,476	277,591	326,501	193,485	48,910
Spring 2003 outgoing	12,535	25,426	125,151	64,917	15,735	50,660	14,402	270,865	308,826	183,675	37,961
Spring 2003 total	30,666	56,205	258,168	131,753	31,253	99,405	27,878	548,456	635,328	377,160	86,871
Changes (%)											
Incoming vehicles	31	19	–31	19	16	–9	–12	–16	–12	9	23
Outgoing vehicles	10	11	–35	14	20	–15	–11	–20	–17	2	11
Total vehicles	22	15	–33	17	18	–12	–12	–18	–15	5	17
PCU ratings	0.2	0.5	1	1	2.5	1.5	2.5				
Changes (%)											
Incoming PCUs								–14	–13	3	21
Outgoing PCUs							–17	–16	–1	11	
Total PCUs							–16	–15	1	16	

SOURCE: Transport for London, data provided on request.
NOTE: PCU = passenger car units, LGVs = light goods vehicles, HGVs = heavy goods vehicles.

Table 7: Motoring Costs

	Standing Costs (£ Annual)
Road tax	160
Insurance	448
Cost of capital	412
Depreciation	2080
Standing costs total (pence/km)	35.2
Running costs (pence/km)	
Fuel	7.18
Service: tires, parts, and labor	3.95
Parking	1.13
Running costs total (pence/km)	12.25
Total costs (pence/km)	47.48

SOURCE: U.K. Automobile Association at www.theaa.com/allaboutcars/advice/advice_rcosts_home.html

Table 8: Estimates of the Value of Car Travel Time Savings at End of 1997 Values

Income Band	*Commuting (p/min)*	*Other (p/min)*
Below £17,500	3.6	4.6
£17,500 to £35,000	5.9	5.9
Above £35,000	8.6	7.1

SOURCE: Mackie et al. (2003).
NOTE: p/min.: pence/minute.

2001) provides base figures and guidelines on how to estimate working and nonworking VTTS. Another source for VTTS in the United Kingdom is a report to the Department for Transport by Mackie et al. (2003). This comprehensive report reexamines a substantial stated preference data set used in an earlier investigation commissioned by the same department in 1994. In addition, the results are cross-referenced with those obtained from meta-analysis. Table 8 details some of their recommended estimates.

Although we computed the elasticity of demand following the *Transport Economics Note* (Department of the Environment, Transport, and the Regions, 2001) in the first instance, we also used another set of values following the recommendations in Mackie et al. (2003). The main difference between the two documents is that Mackie et al. (2003) recognize that although commuting trips are nonworking they tend to have a slightly higher VTTS than shopping or leisure trips.[3]

To produce working and nonworking VTTS following the *Transport Economics Note* (Department of the Environment, Transport, and the Regions, 2001), we updated the values to 2003 prices. We also increased the working value of time by 34%, to reflect the difference in the average earnings in London, as indicated in the New Earnings Survey 2003 (National Statistics, 2003). We considered two categories of trips: working, as trips made in the course of work, excluding commuting, and nonworking. We estimated the working VTTS at 42.2 pence/minute and the nonworking VTTS at 4.9 pence/min. TfL provided us with provisional data indicating that 10% of car trips in London are business trips. The weighted VTTS we used was therefore 8.6 pence/minute. Using the average car occupancy rate of 1.35 (TfL, 2002c, p. 19), this amounts to 11.7 pence/PCU-minute. Other numbers needed to calculate the elasticities are shown in Table 9.

Using all this information, we computed the percentage change in generalized costs. We estimated elasticities of demand for trips by car with respect to changes in generalized costs including all vehicle costs as well as generalized costs including time costs and car running costs but excluding fixed costs. For a change in travel demand, the appropriate statistic is the 31% reduc-

Table 9: Details of an Average Trip by Car in London

Distance traveled per day[a]	23.4 km
Time traveled per day (precharging)	94 min
Time savings per day (postcharging)	12 min
Vehicle costs	47.5 pence/km
Running costs	12.3 pence/km
Value of time per car	11.7 pence/min
Average occupancy	1.35

a. Transport for London (2002a) concludes that the average car trip in London is 11.7 km (Table 7.1, p. 25) and two trips per day are assumed in the current study.

Table 10: Elasticities of Demand for Car Trips With Respect to Costs

	All GC	*GC Excluding Fixed Costs*
Occupancy rate	1.35	1.35
Average car trip (km)	11.7	11.7
Number of trips per day	2	2
VTTS per person (pence/min)	8.6	8.6
Time per trip (min)	47	47
Time savings per trip (min)	6	6
Vehicle operating costs (pence/km)	47.5	12.3
GC per day (£)	22.07	13.82
Toll (£)	5.00	5.00
Time benefits (£)	1.40	1.40
Reliability benefits[a] (£)	.35	.35
Change in GC (£)	–3.25	–3.25
Change in GC (%)	–14.7	–23.5
Change in Demand (%)	31	31
Elasticity	–2.1	–1.3

SOURCE: Own calculations with numbers from Tables 7 and 9.
NOTE: Dodgson, Young, and van der Veer (2002) argue that reliability benefits are worth approximately 25% of time benefits.
a. VTTS = value of travel time savings.

tion in car travel entering the central zone. This statistic best represents the demand response of those who are not exempt from the charge, such as residents. Unfortunately it is not possible to determine whether the reduction in demand for car trips is entirely the result of the charge or the result of a combination of factors in addition to the charge, such as the economic slowdown.

Table 10 presents the results. The most relevant value in the short run is –1.32, as that excludes fixed costs from the calculations.

For the calculations following Mackie et al. (2003), we considered three categories of trips: working, commuting, and other. Of all trips made by car in London, 10% are for business purposes, 26% for commuting, and 64% for other purposes such as leisure, shopping, etc.[4] We derived the value of working time from the gross weekly earning in London indicated in the New Earnings Survey 2003 (National Statistics, 2003). We took the VTTS for commuting and other purposes for different income levels from Mackie et al. (2003), updated them to 2003 values, and calibrated them to the average salary in London. In this way, we estimated the average VTTS at 32.9 pence/minute, 7.7 pence/minute, and 6.4 pence/minute for working, commuting, and other-purpose car trips, respectively. The weighted VTTS we used was therefore 9.4 pence/min, equivalent to 12.7 pence/min, assuming a car occupancy rate of 1.35. Thus, we obtained elasticities of –2.5 and –1.6, very similar to –2.1 and –1.3 of Table 10.

Literature regarding elasticity of demand with respect to congestion charges is relatively rare. In Singapore, however, where charges are revised regularly, there has been considerable scope for evaluating effects of price changes. Dodgson et al. (2002) summarize various studies for Singapore suggesting point elasticities in the order of –.12 to –.35 with respect to congestion charges.

More commonly calculated are elasticities of demand with respect to fuel prices. Goodwin (1992) calculated short-run and long-run elasticities of –.16 and –.32, respectively. These numbers are still considered standard values for the responsiveness of car travel demand with respect to changes in fuel prices (Graham & Glaister, 2002).

As a general rule, the sensitivity of demand to generalized cost changes will broadly be equal to the fuel price elasticity divided by the fuel share of generalized cost (Dodgson et al., 2002, p. 28). For example, if fuel costs change by 10%, but the share of fuel costs in terms of total costs is only one fourth, then generalized costs have changed by only 2.5%. In heavily congested London, where time costs have a much larger share of total costs, the share of fuel costs can be estimated at roughly 8% to 16%, with the higher range going to the running-costs-only scenarios. Therefore, Goodwin's value of –.16 for short-run fuel price elasticity corresponds to a generalized cost elasticity of between –1.3 and –2.1, exactly the values computed in Table 10.

These high elasticities in London are probably linked to the wide availability of public transport. In a region with poor public transport alternatives, we would expect to observe a lower elasticity of demand for travel by car.

MARGINAL CONGESTION COST

As explained earlier, the MCC is equal to the value of time divided by speed, then multiplied by the elasticity of speed with respect to flow.

$$MCC = \frac{b}{s(q)} e_{sq} \tag{5}$$

This expression typically computes the MCC of vehicles on a given link. Here the same expression computes an "area MCC," when traffic is assumed to be homogeneous within the small, congested central zone with disregard for link-versus-intersection differences.

The calculations within the central zone can thus be carried out assuming that speed within the zone has risen from 14 km/hour to 17 km/hour (21% increase) and total traffic levels, measured in PCUs and including all vehicle types, have decreased by 15%, as indicated in Table 6.

The average VTTS within the central zone was estimated at 29.6 pence/PCU-minute at 2003 prices. This value computes the precharging shares of traffic as implied by Table 6, their associated PCU values and occupancy rates, and trip purposes as provided by TfL on request. Following the practice set for the London Congestion Charging Research Programme (MVA Consultancy, 1995) and for the ROCOL study (ROCOL Working Group, 2000) a single value of time was used for all modes in the case of working time, and a single value of time was used for all person types in the case of nonworking time.

Ordinarily, flow measures in terms of vehicles per hour on a link; however, in the context of an urban setting, this link-based measurement is less applicable. Therefore, the use of traffic volumes serves as a better proxy for flow in urban areas. Using this data, the implied area marginal cost of congestion is:

$$MCC = \frac{29.6 \times 60}{14} \times \frac{0.21}{0.15} = 186.5 \text{ pence/PCU-km.}$$

When converted to vehicle-km from PCU-km using an average PCU/vehicle rate of 1.13, the calculated MCC is 165 pence/vehicle-km at 2003 prices. This calculated MCC value is higher than the value computed by Sansom, Nash, Mackie, Shires, and Watkiss (2001), who by estimating speed-flow relationships for a variety of road settings, calculated a MCC of 86 pence/vehicle-km updated to 2003 prices in a major urban center such as London. The values we estimated here, however, rest on the latest data and empirical evidence and are therefore more reliable.

Table 11: Preliminary Estimates of the Annual Costs and Benefits of the London Scheme (£ million at 2003 prices)

Annual costs	
Transport for London administrative and other costs	5
Scheme operation	90
Additional bus costs	20
Charge payer compliance costs	15
Total	130
Annual benefits	
Time savings to car and taxi occupants, business use	75
Time savings to car and taxi occupants, private use	40
Time savings to commercial vehicle occupants	20
Time savings to bus passengers	20
Reliability benefits to car, taxi, and commercial vehicle occupants	10
Reliability benefits to bus passengers	10
Vehicle fuel and operating savings	10
Accident savings	15
Disbenefit to car occupants transferring to public transport, and so on	–20
Total	180

SOURCE: Transport for London (2003b, Table 3).

The estimated area MCC of £1.65 illustrates that for the £5 congestion charge to reflect on average the congestion externality, an average vehicle would need to travel a distance of about 3 km/day inside the charging zone, which is a reasonable expectation given that the zone has a diameter of roughly 5 km.

Costs and Benefits

The capital costs of the Scheme were approximately £200 million at 2003 prices, most of which the central government provided.[5] The annual operational costs and benefits are presented in Table 11, as detailed in the *Six Months On* report (TfL, 2003b). The table suggests a net benefit of around £50 million for the first year of operation.

The table suggests a net benefit of around £50 million for the first year of operation.

A 5-year monitoring program has been set up, beginning 1 year before the start of charging and ending 4 years after. It consists of more than 100 surveys and studies designed to measure and understand the impacts of the Scheme. Although 1 year into the Scheme may still be early to draw any conclusions, it is clear that the Scheme will have economic, social, and environmental impacts. The monitoring program is already assessing all these different aspects, and Transport for London will produce annual reports describing and explaining them.

Westminster City Council conducted a survey to find out how businesses felt about the congestion charge. Of all the respondents, 68% have their businesses inside the charging zone, 44% are retailers, and 27% are bars and/or restaurants (Westminster City Council, 2003). Almost 69% of the respondents feel the Scheme has had a negative impact on their business, 8% feel it has had a positive impact, and 23% feel it has had no impact. Almost 28% of the respondents are considering relocating outside of the zone as a result of the charge.

During October and November 2003, TfL surveyed more than 700 businesses in and around the charging zone. Concerns about the negative impact of the Scheme mainly came from the retail and leisure sectors, which reported a 2% reduction in sales for the first half of 2003 (TfL, 2004). According to these sectors, the reasons for the decline in sales were economic and tourism factors, though congestion charging constituted about one fifth of the reported causes (TfL, 2004).

TfL (2004) presents some preliminary evidence of the relationship between the reduction in sales, tourism, and Underground patronage. The main conclusion is that retail sales and tourism numbers are strongly correlated and show a negative trend during the first months of 2003. Underground patronage during 2003 was 7% to 10% lower in the charging zone and 4% to 7% lower across the entire network when compared with 2002. When Underground travel is added on to the analysis, the significant reductions in Underground travel during spring 2003 (reflecting not only lower tourism levels but also the Central line closure) coincide with the period of negative retail growth (TfL, 2004, p. 25). Although the exact impact cannot be quantified, a link between the decline in Underground travel and in sales in the charging zone is clear. The Scheme encouraged the switch from the car to the Underground. A reduction in Underground travel cannot be linked to the Scheme in any way.

A central area where the centers of government, law, business, finance, retail activity, and entertainment concentrate creates positive externalities. With businesses considering relocation in the long run, the benefits of the Scheme would be affected by losses in social welfare, mainly a result of the loss of these positive externalities. It is early to determine what the trend will be, and some more monitoring is needed before any conclusions can be drawn.

Use of Revenues

The mayor's transport strategy (Greater London Authority [GLA], 2001), as well as congestion reduction, also includes objectives such as investing in the Underground, improving bus services, and integrating National Rail with other transport systems. The GLA Act 1999 (Acts of Parliament, 1999) ensures that revenues from charging schemes will be earmarked for the mayor's transport strategy projects for at least 10 years from their implementation date.

Transport investment in London has been inadequate since the mid 1980s and, therefore, unable to accommodate economic and demographic growth, resulting in high levels of congestion together with overcrowded and unreliable public transport (GLA, 2001, p. 23). The plan to revert the situation entails delivering the necessary additional public transport capacity and reliability in conjunction with demand management policies, such as congestion charging.

The Scheme raised £68 million in 2003/04 and is expected to raise £80 to £100 million in future years for investment in transport.[6] Transport improvements in London in 2003/04 totaled £82.8 million at 2003 prices (GLA, 2004, p. 51). The difference was covered with resources that became available from other sources such as increased revenues from public transport.[7] TfL constantly monitors changes in revenues from the Scheme, as well as other incomes and expenditure. It constantly adjusts the budget appropriately and makes reallocations where necessary.

The *Mayor's Annual Report* (GLA, 2004, p. 51) gives details of the transport improvements carried out in the period 2003/04. Of the £82.8 million, £62.8 million were allocated to bus network improvements (higher frequencies, additional routes, enhanced route supervision, and conversion to higher capacity routes); £10.5 million to road safety (research, engineering works, and education campaigns); £2 million to safer routes to schools, £6 million to walking and cycling (strategic and local engineering schemes on all London's roads as well as information campaigns); and £1.5 million to freight (measures to make the distribution of goods more sustainable).

A very important factor in the success of the Scheme is the revenues going back into the transport sector. Londoners can see where the money is going. The integrated nature of TfL seems to be a positive example of the kind of coordination that may produce good social outcomes from a pricing scheme.

Equity Impacts

A regressive tax, by definition, takes a larger percentage of the income of low-income people than of high-income people. Strictly speaking, a congestion charge is not a tax but is perceived as a tax by the motoring public. According to the *System of National Accounts 1993* (Commission of the European Communities et al., 1993) taxes are "compulsory, unrequited payments" for which "the government provides nothing in return to the individual unit making the payment, although governments may use the funds raised in taxes to provide goods or services to other units" (Point 8.43).

Although congestion charges are not taxes, they are still regressive in the sense that they do not vary with income (i.e., the charge paid by drivers is the same regardless of their income). A daily toll of £5 to drive into central London, for example, represents a larger percentage of the income of low-income people than of the income of high-income people.

In that sense the Scheme may be having perverse impacts on lower income groups. Although the answer to this problem would be a switch to public transport, the necessary conditions of reliability, safety, and frequency may have been met during the times of operation of the Scheme but not during other times, and this may pose a problem. For example, when low-income workers drive into the charging area at early hours in the morning (2:00 AM for some butchers) the charge does not apply, yet they have to pay the charge when they finish work later in the morning and want to leave the zone to drive home. Public transport during the night is perceived as infrequent, unsafe, or unreliable. These low-income workers have to choose between the inconvenience of traveling by bus or paying the charge when they finish work. The 5-year monitoring program will assess any impacts on equity when more evidence becomes available.

The data on traffic counts presented in Table 6 combined with the occupancy rates given in the *London Travel Report 2002* (TfL, 2002b, Table 5.1, p.19) and in the *Transport Economics Note* (Department of the Environment, Transport, and the Regions, 2001, Table 2/3 imply that 52% of all people traveling to or from the charging zone used buses before the Scheme was introduced. Taxi, pedal, and motorcycle use raises the total share of people that did not use a chargeable mode of transport before the Scheme to 63.9%. These are winners, in the sense that they are enjoying lower congestion without paying a penny, and suffer no disutility from changing mode. From a very conservative point of view, the remaining 36.1% would be losers. However, those with very high values of time also have a net benefit after paying the congestion charge. In addition, Table 1 gives a number of exemptions and discounts. The share of people travelling by car was reduced from 27% to 18%; thus 9% of the original car users have transferred to some other mode or made alternative arrangements. The second part of Table 11 shows a disbenefit of £20 million for this group.

Conclusions

The preliminary results suggest that the London Scheme has so far succeeded in achieving the stated congestion reduction targets. Traffic decreased by more than expected, which means that elasticities might have been underestimated prior to the implementation of the Scheme. Goodwin (2003) suggests that elasticities were revised down by a sort of so-called ratchet effect from one study to the next. Their authors probably wanted to be conservative and would choose the lowest estimate. The fact that public transport in London was substantially improved before the Scheme started points to the rationale for these high elasticities of demand.

The preliminary results suggest that the London Scheme has so far succeeded in achieving the stated congestion reduction targets.

The calculated area MCC suggests that the £5 charge is a reasonable approximation to marginal cost pricing.

The largest potential hurdle, the political one, is perhaps where the largest success has been made. Although economists have suggested for over 80 years that drivers should face the true social cost of their actions, it is inevitably a politically unpopular decision to implement any form of charge on the act of driving. However, despite this there has been surprisingly little public backlash. The system is simple, feasible, and transparent, a key factor that accounts for its success. Furthermore, the hypothecation of revenues, guaranteed by the Greater London Authority Act 1999 (Acts of Parliament, 1999), and a lengthy consultation process before the Scheme was introduced provided a feeling of trust to the public in knowing where their money would be spent. Surveys carried out by Market & Opinion Research International, an independently owned research company in the U.K., show that although only 50% of London residents support the Scheme, 73% think it has been effective at reducing congestion (Market & Opinion Research International, 2003).

Public consultation on a revision to the mayor's transport strategy began on February 16, 2004 and lasted for 10 weeks. The revision would allow an extension of the charging zone to include parts of the City of Westminster, the Royal Borough of Kensington and Chelsea (GLA, 2004, p. 52). This reform would double the size of the charging area, imply higher revenues, and thereby allow more investment in public transport.

In London, where traffic had returned to speeds of 100 years ago (TfL, 2002a) the costs of congestion were recognized as being too high and the public acknowledged that supply-side measures do not work in themselves. The introduction of congestion charging to one of the major cities of the world is perhaps a sign that the world is ready to shift road pricing from its theoretical hideaway to a practical center stage.

Notes

1. The following year the Transport Act 2000 (Acts of Parliament, 2000) was passed, allowing for joint schemes, including ones involving London authorities, as long as the order has been submitted to and confirmed by the Greater London Authority. This power to make joint local-London charging schemes does not limit any of the powers to introduce road-user charging in greater London given by the Greater London Authority Act 1999.
2. A brief discussion on the potential equity impacts of the Scheme is presented beginning on page 178.
3. This is probably because of the potential penalty for arriving late.
4. These figures were provided by TfL on request and are part of the London Area Transport Survey 2001, Household Survey, Interim weighted data. They will be included in the London Travel Report 2003 when it is published.
5. Information provided by TfL via e-mail.
6. Even though net revenues were £69 million (U.S. $108 million), net economic benefits were £50 million (U.S. $78 million).
7. Information provided by GLA via e-mail, on request.

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