Web appendix for Road Pricing: Lessons from London

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WEB APPENDIX FOR ROAD PRICING: LESSONS FROM LONDON

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Part I: Generalised cost elasticity of demand for trips in the original Congestion Zone

This part describes step by step how we computed the elasticities for the London Congestion Charging Scheme so that the process can be replicated by anyone wishing to do so.

The formula used to compute the generalised cost elasticity of demand for trips is

$$\eta =)q/)GC \,.\, GC/q$$

where *q* is number of trips by the relevant mode, and *GC* is Generalised Cost of a trip by the relevant mode: car, taxi or Light Good Vehicle (LGV).

GC per km = VOC per km + VOT per km + congestion charge per km – reliability benefits

Alternatively the GC can be computed in pence per trip (by multiplying the cost per km by the average number of km travelled in a trip) or per day (by multiplying the GC per km by the number of km travelled in a day). In any case, the percentage change of the GC is the same.

VOT = Value of time
VOC = Vehicle operating cost
The reliability benefits are a percentage of the time benefits due to higher speeds.

VOT is usually given in pounds per hour. Using speed this can be expressed in pounds per km.

Both VOT and VOC were taken from TAG Unit 3.5.6, part of Webtag, a free Internet publication by the UK Department for Transport (DfT), which provides recommendations on the values of time and vehicle operating costs for use in economic appraisals of transport projects in Great Britain. From now onwards, where we refer to a ‘Point’, we are referring to a specific ‘Point’ in TAG Unit 3.5.6 on the Value of Time and Operating Costs.

In this annex we explain the different steps involved in computing the elasticities, as there are a number of considerations to be taken into account for anyone wishing to replicate the results.

The problem with these calculations however is that they pose many instances where assumptions need to be made. As a result, the estimates can vary substantially.

Values of time used for our calculations

Table 1: Values of working time per person
£ per hour, 2002 prices and values

Vehicle occupant	Resource cost
Car driver	21.86
Car passenger	15.66
LGV (driver or passenger)	8.42
Taxi driver	8.08
Taxi passenger	36.97

Source: Table 1, TAG Unit 3.5.6 (Department for Transport, 2004a)

Time spent travelling during the working day is a cost to the employer's business. [Point 1.2.3]. Working time values apply only to journeys made in the course of work. This excludes commuting journeys. The perceived value of working time is the value as perceived by the employer or in other words, the resource cost. The resource cost is calculated as the gross wage rate plus non-wage labour costs such as national insurance, pensions and other costs which vary with workers hours. [Point 1.2.4]

Non-working trips also impose a time cost, born by the person making the trip. This non-working value of time varies according to the trip makers' income, trip purpose (and urgency), and the conditions of travel. Following the recommendations of Mackie *et al* (2003) the DfT considers that the numbers presented in Table 2 are good representatives of the average values of non-working time in the UK.

Table 2: Values of non-working time per person
£ per hour, 2002 prices and values

Purpose	Perceived cost
Commuting	5.04
Other	4.46

Source: Table 2, TAG Unit 3.5.6 (Department for Transport, 2004a)
Note$_1$: Non-working values of time are the same for all modes (Department for Transport, 2004a)
Note$_2$: Average car occupancy rate: 1.35 (Transport for London, 2004a, *London Travel Report 2004*, Table 1.5.2, p.8, www.tfl.gov.uk/tfl/reports_library_stats.shtml)

In order to compute an average value of time per vehicle type we need information on taxi passenger occupancy. Since this information does not exist we will assume there is one passenger per taxi. Some taxis will have no passengers some of the time, and some will have more than one passenger. There are not even estimates on this so we shall make an assumption *ad hoc*: one passenger per taxi all the time.

We assume LGV only make working trips (although some may indeed make some trips with commuting and other purposes). We assume the national average weekday occupancy of LGV making working trips of 1.20 (Table 5, TAG Unit 3.5.6).

Table 3 below presents the value per vehicle on different trip purposes.

Table 3: Values per vehicle type and trip purpose
£ per hour, 2002 prices and values

Vehicle type	Working	Commuting	Other
Car	21.86+15.66*0.35= 27.3	5.05*1.35=6.8	4.46*1.35=6.0
	8.08+36.97=45.05	8.08*1+5.04*1=13.1	8.08*1+4.46*1=12.5
LGV	8.42*1.20=10.1	Not applicable	Not applicable

Source: Own calculations on the basis of Tables 1 and 2 plus the assumptions made above.

Since we are computing the elasticity of demand for the year 2003, and for the case of London, we need to make some adjustments to the numbers above. First of all we can update them to 2003 prices and values.

The value of non-working time is assumed to increase with income, with an elasticity of 0.8 [Point 1.2.21]. This is also based on the findings by Mackie *et al* (2003).

The value of working time on the other hand, is assumed to grow in line with income per capita, with an elasticity of 1.

We do not need data on GDP per capita because Table 3 of TAG Unit 3.5.6 provides the forecast growth in the working and non-working values of time, taking into account the growth of real GDP per capita and income elasticity of the working and non-working values of time. These are reproduced below.

Table 4: Forecast growth in the working and non-working values of time

Year	Work VOT Growth (% pa)	Non-work VOT Growth (% pa)
2002-2003	1.98	1.58

Source: Table 3, TAG Unit 3.5.6 (Department for Transport, 2004a)

We can now update the numbers of Table 3 to 2003 values (although the numbers will still be in 2002 prices).

Table 5: Values per vehicle type and trip purpose
£ per hour, 2003 values and 2002 prices

Vehicle type	Working	Commuting	Other
Car	27.3*1.0198=27.84	6.8*1.0158=6.91	6.0*1.0158=6.09
Taxi	45.05*1.0198=45.94	13.1*1.0158=13.31	12.5*1.0158=12.7
LGV	10.1*1.0198=10.3	Not applicable	Not applicable

Source: Own calculations based on Tables 3 and 4

In order to update this to 2003 prices we use the HM Treasury GDP deflator series available at http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

The factor is 3.39, so we multiply all the numbers on Table 5 by 1.0339.

Table 6: Values per vehicle type and trip purpose
£ per hour, 2003 values and prices

Vehicle type	Working	Commuting	Other
Car	28.8	7.1	6.3
Taxi	47.5	13.8	13.1
LGV	10.6	Not applicable	Not applicable

Source: Table 5 and HM Treasury GDP deflator series available at http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

The values presented until now correspond to national averages. Since we are interested in the case of London, where salaries are on average higher than in the rest of the country, and therefore the average value of time is also higher, we need to adjust accordingly.

Until 2003, the Office for National Statistics (ONS) used the average earning as their headline statistic. In 2004 the median replaced the mean. The median is now preferred because it is influenced less by extreme values and also because of the skewed distribution of earnings data (ONS, 2004, p.8).

Following the Office for National Statistics, we have decided to use the median rather than the average to adjust the value of time.

The median of earnings in London (for full time employees on adult rates whose pay for the survey pay-period was not affected by absence) has been between 28 and 29 per cent higher than the national median for the years 2003, 2004 and 2005 (ONS, 2003, 2004, 2005). For our calculations we shall assume the difference is 29 per cent.[1]

The working values of time can be increased by 29 per cent, as the elasticity is 1. The values of non-working values of time on the other hand, have to be increased by 23.2 per cent only, as the elasticity of the value of non-working time with respect to income is 0.8.[2]

[1] It was 29 per cent in April 2003, 28 per cent in April 2004, and 29 per cent in April 2005.
[2] This is computed as 0.8*0.29.

Table 7: Values per vehicle type and trip purpose adjusted to London median earnings. £ per hour, 2003 values and prices

Vehicle type	Working	Commuting	Other
Car	37.15	8.75	7.76
Taxi	61.28	17.00	16.14
LGV	13.67	Not applicable	Not applicable

Source: Own calculations based on Table 6 and assumptions explained above.

We now need an average value of time per vehicle type, taking into account the trip purpose split.

Since we assume that 100 per cent of trips made by LGVs are for working purposes, we only need to know the split of trip purpose by car and by taxi. Unfortunately this information is not published in the London Travel Report. However, Henry Burroughs from Transport for London (0207 126 4608) provided us with Interim weighted data from the London Area Transport Survey 2001. These values however correspond to an average weekday (24 hours: 0400-0359) in 2001, rather than charging times during 2003. The numbers are presented in Table 8 below.

Table 8: Trip purposes by cars and taxis

Purpose	Car (%)	Taxi (%)
Working	10	15
Commuting	26	21
Other	64	64

Source: Interim weighted data from the London Area Transport Survey 2001 provided by Henry Burroughs from Transport for London (0207 126 4608)

We can now combine the numbers of the tables above to obtain the numbers in Table 9.

Table 9: Average values of time per vehicle type
£ per hour, 2003 prices and values

Car	Taxi	LGV
37.15*0.10+8.75*0.26+7.76*0.64=10.96	61.28*0.15+17*0.21+16.14*0.64=23.09	13.67*1=13.67

Source: own calculations

Table 10: Average values of time per vehicle type
pence per hour, 2003 prices and values

Car	Taxi	LGV
1096	2309	1367

The speed pre and post charging inside the Charging Zone is reported to be 14 and 17 km per hour respectively (Transport for London, 2003a,b; 2004b,c; 2005).

However, the average speed in Greater London is higher. Most trips that start or finish inside the Charging Zone have an origin or destination outside the Charging Zone.

This presents us a new challenge. So far we have assumed one passenger per taxi, although we have no data to back that up, and we have assumed that all LGV make working trips only, which is not exactly the case. We have also assumed national occupancy for LGVs, as the numbers for London do not exist. The shares of different trip purposes are not published anywhere as such either and the numbers provided to us are weekday averages of all trips in London, corresponding to 24 hours, not just to charging hours.

Now we need to decide what speeds to assume. There are some contradictions in the data we have found. For example, according to the *Three Months On* report (Transport for London, 2003a, Fig. 5, p.5), across a basket of 5,000 car journeys, covering all parts of Greater London, the average time taken to/from the charging zone went down from 47 minutes to 41 minutes. Bearing in mind that the average car trip length is 11.6 km (Transport for London, 2003c, Table 3.6, http://www.tfl.gov.uk/tfl/pdfdocs/ltr/london-travel-report-2003.pdf) the average speed would need to be roughly 14.8 km per hour pre-charging, and 16.97 km per hour post-charging.

This cannot be right. Average speed has always been and still is higher the further the vehicle is from the charging zone. Put differently, average speeds in the charging zone pre-charging were considered very low, unlike average speeds in say, Outer London. In that sense, the average speeds computed in the paragraph above, seem to be too low.

Transport for London (2003c, Table 3.2, p.17) provides average speeds. In this table, average speeds in Greater London, including the charging zone, plus Inner and Outer London, are much higher than 14.8 km per hour or 16.97 km per hour. The average for 2000-2003, for the morning peak, which is the time period when average speeds are lowest, is 24.14 km per hour. This contradicts the findings above because with that speed, an average journey of 11.6 km would take 28.8 minutes, and not 41 or 47, as stated in the *Three Months On* report (Transport for London, 2003a, Fig. 5, p.5).

The question is what speeds should we assume?

The speed pre and post charging inside the Charging Zone is assumed to be 14 and 17 km per hour respectively because these are the values repeatedly cited in all the Transport for London reports (Transport for London, 2003a,b; 2004b,c; 2005).

Average speed in the rest of London is assumed to be 26.65 km per hour. This assumption is based on Table 11, presented below.

Transport for London (2003c, Table 3.2, p.17) provides average speeds in miles per hour. These can be converted to km per hour. The average computed is presented in the table below.

Table 11: Average traffic speeds in Greater London
km per hour, period 2000-2003

Period	Number of hours	Percentage of time
Morning peak period (7am to 10am) 24.14	3 hours	26
Daytime off-peak period (10am to 4pm) 28.48	6 hours	52
Evening peak period (4pm to 6:30pm) 25.27	2.5 hours	22
Weighted average for all 11.5 hours 26.65		

Note: Table includes all areas inside the M25, corresponding to central, inner and outer London
Source: Transport for London (2003c, Table 3.2, p.17)

We therefore assume that the speed in Greater London pre and post-charging is 26.65 km per hour.[3]

We now need the average trip length and the average distance travelled inside the Charging Zone by each vehicle type so that we can use the relevant speeds for each section of the trip: that outside the charging zone, and that inside the charging zone.

[3] Strictly speaking we need the average speed in the whole of Greater London excluding the Charging Zone. Unfortunately this piece of information is not readily available, and the average speed inside the Charging Zone is included in the average. However, given the small size of the zone, as well as the small share of the zone in the geographical share of an average trip, this small bias can be ignored.

Table 12: Average distance driven per trip by cars, taxis and LGVs

	Cars[a]	Taxis[a]	LGVs[b]
Average trip length	11.6 km	8.4 km	12 km
Average daily km driven	23.2 km	Not applicable	24 km

[a] Source: Transport for London (2003c, Table 3.6, available at http://www.tfl.gov.uk/tfl/pdfdocs/ltr/london-travel-report-2003.pdf
[b] Source: London Sustainable Distribution Partnership (2005), available at http://www.tfl.gov.uk/tfl/downloads/pdf/Freight-Plan-sc-app-bc.pdf, p.12
Note: The number of km actually travelled daily can be reasonably assumed to be the average trip length multiplied by 2. The reason for this is that a vehicle that travels to a place will typically return.

Using the vehicle-km from TfL (2005, Table 15, p.29) and the total traffic counts in the congestion zone provided to us by TfL (and presented below) we can compute the average number of kilometres travelled by the different vehicle types inside the congestion charging zone on a typical weekday.

Table 13: Number of vehicles using the charging zone during charging hours

	2002	2003	2004
Cars	386,752	255,256	251,427
Taxis	113,007	127,133	126,497
LGVs	113,267	98,542	97,557

Data provided by TfL on request (last two years computed using the % changes published in the *Third Annual Report* (TfL, 2005).

Table 14: Vehicle-km (millions) driven within the Charging Zone during charging hours

	2002	2003	2004
Cars	0.77	0.51	0.47
Taxis	0.26	0.31	0.29
LGVs	0.29	0.27	0.26

Source: TfL (2005, Table 15, p.29) available at
http://www.tfl.gov.uk/tfl/cclondon/pdfs/ThirdAnnualReportFinal.pdf

Table 15: Average km driven inside the Charging Zone during charging hours

	2002	2003	2004
Cars	1.99	2.00	1.87
Taxis	2.30	2.44	2.29
Vans	2.56	2.74	2.67

Source: Tables 13 and 14
Note: We assume that half of the average km driven inside the Charging Zone during charging hours correspond to the out trip, and half to the return trip.[4]

It is reasonable to assume for example, that a car making an average trip 11.6 km long, will drive 10.6 km at 26.65 km per hour and 1 km[5] at 17 km per hour in 2003. A similar pattern will be repeated for the return trip. The same applies to the other vehicle types.

With the speeds, the average values of time per hour can be converted into values of time per km, and thus given an estimate of the average time cost of a trip, expressed in pence per km. Table 16 presents these values.

[4] This may not always be the case however. For example, a car may enter the Charging Zone at 5am before charging begins, and leave the zone during charging hours. The speeds in the Charging Zone during non-charging hours may be different. However, there is no data available and this is a necessary simplifying assumption.

[5] This is computed as 1.99 km divided by 2 (in and out trip).

Table 16: Average time costs per vehicle type
pence per km, 2003 prices and values

	Car	Taxi	LGV
Pre-charging	44.33	97.36	56.24
Post-charging	43.14	93.37	54.40

Note: the time cost of a trip in pence per km is computed as follows:

$$\frac{\frac{Do}{Vo} * VOT\ (\text{in £/h}) + \frac{Di}{Vi} * VOT\ (\text{in £/h})}{(Do + Di)} * 100$$

where:

Do: average distance driven outside the charging zone
Di: average distance driven inside the charging zone
Vo: average speed outside the charging zone
Vi: average speed inside the charging zone
VOT: value of time

It should be noted that although the average speed inside the charging zone is higher, the time costs of an average LGV trip and of a taxi trip are higher if the new distances (as reported in Table 15) are included in the calculations. The reason for this is that taxis and LGVs increased the average distance travelled inside the charging zone after the introduction of the charge, and this more than compensated the reduced time spent travelling due to the increased speed. Since we would like to know the sensitivity of response to the increase in speed, we use the 2002 average kilometres travelled inside the charging zone by vehicle type.

Vehicle operating costs (VOC) used for our calculations

Fuel VOC

Following the *Transport Analysis Guidance (Webtag)* published by the Department for Transport in December 2004, the fuel consumption was estimated using a function of the form:

$$L = a + b\ V + c\ V^2$$

where

L = consumption in litres per km
V = average link speed in km per hour (although we use this as average speed in km per hour)
a, b and c are parameters defined for each vehicle category

Table 17: Fuel VOC Formulae Parameter Values (litres per km 2002)

Vehicle category	Parameter		
	a	b	c
Petrol car (private cars)	0.1617	-0.0029	0.00002001
Diesel car (ie taxis)	0.1347	-0.0022	0.00001553
LGV	0.2148	-0.0038	0.00002934

Source: Table 10, TAG Unit 3.5.6 (Department for Transport, 2004a)

In order to uprate the values from 2002 to 2003, the following increase in fuel efficiency was used:

Table 18: Increase in fuel efficiency

Vehicle category	Fuel efficiency improvement 2003-2010 (% per year)
Petrol car	-2.93
Diesel car	-2.72
LGV	-1.35

Source: Table 13, TAG Unit 3.5.6 (Department for Transport, 2004a)

Following the *Transport Analysis Guidance (Webtag)* published by the Department for Transport in December 2004, the fuel costs were computed using the following table:

Table 19: Fuel costs, fuel duty and VAT rates (year 2003, 2002 prices)

	Resource cost (pence per litre)	Duty (pence per litre)	VAT (%)
Petrol	18.2	46.1	17.5
Diesel	19.7	46.1	17.5

Source: Table 11, TAG Unit 3.5.6 (Department for Transport, 2004a)
Note: VAT is applied on the pre-tax price plus the duty. Taxis and LGVs are assumed to run on diesel and to get a VAT rebate, as they are working vehicles

We update these numbers to 2003 prices using the values from Table 14 in TAG Unit 3.5.6, some of which we reproduce below:

Table 20: Growth in the Cost of Fuel

Range of years	Petrol (% pa)	Diesel (% pa)
2002-2003 (actual)	10.2	7.15

Source: Table 14, TAG Unit 3.5.6 (Department for Transport, 2004a)

Following TAG Unit 3.5.6 we assume that fuel duty remains constant.

Table 21: Fuel costs, fuel duty and VAT rates (2003 values and prices)

	Resource cost (pence per litre)	Duty (pence per litre)	VAT (%)
Petrol	20.02	46.1	17.5
Diesel	21.11	46.1	17.5

Source: Own calculations using tables 19 and 20

We can now compute the total fuel costs for each vehicle type.

Table 22: Total fuel VOC costs in pence per km
2003 values and prices

	Cars	Taxis	LGVs
Pre-charging	7.61	5.94	9.14
Post-charging	7.56	5.90	9.08

Source: Own calculations using tables 17 and 21
Note: Taxis and LGVs get a VAT rebate so this was subtracted from the fuel costs.

Non-fuel VOC

The components of the non-fuel vehicle operating costs include oil, tyres, maintenance, depreciation and vehicle capital saving (only for vehicles in working time).

Following the *Transport Analysis Guidance (Webtag)* published by the Department for Transport in December 2004, the non-fuel elements of VOC were combined in a formula of the following form:

$C = a_1 + b_1/V$

where

C = cost in pence per kilometre travelled

V = average link speed in kilometres per hour (although we use average speed per hour)

a_1 is a parameter for distance related costs defined for each vehicle category, and b_1 is a parameter for vehicle capital saving defined for each vehicle category. (This parameter is only relevant to working vehicles).

These parameters are presented in Table 23 below.

Table 23: Non-fuel VOC Formulae Parameter Values
pence per km, 2002 prices

Vehicle category	Perceived cost parameters	
	a_1	b_1
Car work	4.069	111.391
Car non-work	3.810	-
LGV	5.910	38.603

Source: Table 15, TAG Unit 3.5.6 (Department for Transport, 2004a)
Note: The perceived cost of non-fuel VOC of working vehicles (ie car work and LGV) is the cost perceived by businesses and is therefore equal to the resource cost. The perceived cost of non-work cars on the other hand is the cost perceived by the consumer and is therefore equal to the market price, which includes all indirect taxation (such as VAT) [Point 1.1.6].

Non-fuel VOCs are assumed to remain constant in real terms over the forecast period. This assumption is made because the main elements which make up non-fuel VOCs are subject to less volatility than fuel VOCs (TAG Unit 3.5.6, Pint 1.3.17, Department for Transport 2004a)

Using the numbers presented in Table 23 and updating the non-fuel VOC using the HM Treasury GDP deflator series available at

http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

where the factor is 3.39 we get the values presented in Table 24.

Table 24: Total non-fuel VOC costs in pence per km
2003 values and prices

	Cars	Taxis	LGVs
Pre-charging	4.43	4.71	7.46
Post-charging	4.42	4.68	7.41

Source: Own calculations and HM Treasury GDP deflator series available at http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

Note: Using the percentage splits of Table 8, only 10 per cent of cars are considered working cars, and therefore the values obtained using the parameters from Table 23 are weighed accordingly.

With all the information above the GC for cars, taxis and LGV was computed before and after the charge. Dodgson *et al* (2002) argue that reliability benefits are worth approximately 25 per cent of time benefits, and this was the value assumed for the increase in reliability.

The GC of each vehicle type was the time cost per km plus the fuel and non-fuel VOC per km minus 25 per cent of the value of the time saved.

Taxis of course are exempt of the charge, so the congestion charge per km was only computed and added into the calculation of GC for cars and LGVs.

In order to estimate the congestion charge per km, we divided the £5 charge by the average distance travelled by cars and LGVs multiplied by 2, as any vehicle going in, would need to come out, and the £5 is a charge per day. We did not use the average km travelled inside the charging zone but the average km travelled in a given trip because we were computing the GC per km, not per km inside the Charging Zone.

The GC pre and post charging is presented in the table below.

Table 25: Pre and post charging GC in pence per km
2003 values and prices

	Cars	Taxis	LGVs
Pre-charging	56.37	108.01	72.84
Post-charging	76.38	102.95	90.74

Source: Own calculations
Note: Reliability benefits were computed as 25 per cent of the value of the time savings, using the following formula:

Reliability benefits, expressed in £ per hour:

$$\text{Reliability benefits} = \frac{0.25 * [\, Di/Vi_{pre} - Di/Vi_{post}\,] * Di * VOT \text{ (in £/hr)}}{(Do + Di)}$$

where pre and post stand for pre and post charging.

The GC of cars and LGVs increased after charging was introduced because the charge of £5 was not compensated by the time savings, even when including the reliability benefits of 25 per cent. The GC of taxis on the other hand decreased because taxis do not pay the charge, and the average speed inside the charging zone increased.

The percentage change in the number of trips made is presented in the table below. We assume that each vehicle count equals one trip.

Table 26: Vehicle counts pre and post charging

	Cars	Taxis	LGVs
Spring 2002 total	386,752	113,007	113,267
Spring 2003 total	255,256	127,133	98,542
Changes (%)			
Total	-34%	+13%	-13%

Source: Transport for London, data provided on request

The formula used to compute the generalised cost elasticity of demand for trips was:

η =)q/)GC * GC/q

where

q = trips by the relevant mode

Table 27 below shows the final numbers input in the elasticity formula.

Table 27: Input values to compute elasticities

	Cars	Taxis	LGVs
)q	-131,496	14,126	-14,725
)GC	20.0	-5.0	17.9
GC	56.4	108.0	72.8
q	386,752	113,007	113,267

Source: All the tables above

Table 28: Generalised cost elasticites of demand for trips

	Cars	Taxis	LGVs
η	-0.958	-2.672	-0.529

Source: Table 27 values

For all three elasticities computed in Table 28 it should be borne in mind that:

a) They are point elasticities, using the quantities and costs pre-charging as the base point.
b) They all correspond to the change in GC when the £5 charge was first introduced. The changes correspond to the period 2002 vs 2003.
c) They are also subject to the assumptions made above, most of them based on data or guidelines from the Department for Transport. However, if the assumptions changed, the elasticities would change as well. For example, if

the value of time for cars were twice as high, the elasticity for cars would change to 1.85, almost twice the one computed in Table 28. Therefore elasticities are sensitive to the assumptions made and they only apply if the assumptions apply.

A number of important observations also need to be made:

Cars
The GC elasticity of demand for trips by car is -0.958. This elasticity is fairly high because London has a reasonably good public transport system and many car users switched to the bus. Some also switched to taxis, but we discuss this below.

Taxis
The GC elasticity of demand for trips by taxi is very high: -2.672. This can be explained by the substitution effect between cars and taxis. The cross price elasticity of demand for trips by taxi with respect to the GC of trips by car is approximately 0.35.[6] Unfortunately, when calculating this cross price elasticity, the GC of trips by taxi cannot be held constant, as it also changes because the average speed in the charging zone is higher.

If we use this estimated cross price elasticity of 0.35, we may assume that when the GC of trips by car increases by 35 per cent (as it was the case in London for the years 2002 to 2003), the demand for trips by taxi will increase 12.25 per cent. The demand for trips by taxi increased 12.50 per cent. What this is telling us is that most of the increase in demand for trips by taxi can be explained by the increase in the GC of trips by car, rather than by the 5 per cent decrease in the GC of trips by taxi. The own price elasticity of demand for trips by taxi in Table 28 is capturing the substitution effect resulting from the increase in the GC of trips by car.

LGVs
Being commercial vehicles they have less flexibility to change route or time of travel, and not having close substitutes, the own price elasticity is lower.

Congestion charge elasticity

Dodgson *et al* (2002, p.28) argue that the sensitivity of demand to generalised cost changes will broadly be equal to the fuel price elasticity divided by the fuel share of generalised cost. Using the same reasoning, we could say that the congestion charge elasticity will roughly be equal to the generalised cost elasticity multiplied by the congestion charge share of generalised cost. This share is presented in Table 29 below for each vehicle type and the congestion charge elasticity is estimated accordingly, using the elasticities computed in Table 28.

[6] This is computed as the percentage change in trips by taxi divided by the percentage change in the GC of trips by car, using the numbers of Table 27.

Table 29: Estimated congestion charge elasticites of demand for trips

	Cars	LGVs
Share	0.28	0.23
Elasticity	-0.27	-0.12

Source: Own calculations

These elasticities rest on the same assumptions as the GC elasticities, and they are an approximation, as they are computed as an elasticity multiplied by a share of one of the components of the GC.

Since taxis do not pay the congestion charge the exercise cannot be carried out for them.

Differences with the elasticities computed in Santos and Shaffer (2004)

There are three main differences in the assumptions, which inevitably result in different elasticity estimates for cars. Ours is -0.958 whilst theirs is -1.3.

The first difference is that Santos and Shaffer (2004) include parking and exclude insurance and depreciation in VOC whereas we exclude parking and insurance and include depreciation (although depreciation is included for working cars only). We follow the guidelines published by the DfT (2004) exactly, and they do not. They use values published in the Automobile Association website, whereas we use the formulae and coefficients from DfT (2004). This is not a very important difference, as the final VOC in pence per km in their study is 12.3 (pre and post charging as they do not differentiate) and ours are 12.04 and 11.98 pre and post charging respectively.

The second difference is that they assume a value of time of 11.7 pence per minute (per car) whereas we assume a value of 18.27 pence per minute (also per car). They base their assumption on previous VOT numbers given in the Transport Economics Note (Department of the Environment, Transport and the Regions, 2001), together with London earnings. Their value of time is lower mainly because their working and non-working values of time are lower. With our value of time being higher than theirs one would expect the elasticity to be higher, not lower as is. The effect that the higher value of time assumption would have had on the estimated elasticity is more than compensated by the difference in the time savings assumed.

The third and most important difference then, which is the reason for their elasticity to be higher, is that they assume six minutes saving per car trip, and twelve minutes per day. Although they base this assumption on the *Three Months On* report (Transport for London, 2003a, Fig. 5, p.5), we believe that those are overestimates of the time savings due to congestion charging. As explained above, they would imply very low speeds, which contradict the speeds published in Transport for London (2003c, Table 3.2, p.17), which seem by all means more reasonable. With a very high time saving, their car elasticity is necessarily higher.

This technical annex describes the assumptions made in the process of computing the point elasticities for the Congestion Charging Scheme in London in 2002 - 2003. It should be emphasised that these estimates depend on the assumptions made. If the assumptions change, the elasticities change as well.

Part II: Area marginal congestion cost estimates in the original Congestion Zone

The Marginal Congestion Cost (MCC) per passenger car unit (PCU)[7] can be computed with the following formula, standard in the road pricing literature:

$$MCC = e_{sq} . b / s(q)$$

where b is value of time in pence per PCU per hour, s is speed in km per hour, dependent on traffic volume[8] in the area, q, in PCUs per hour, and e_{sq} is the elasticity of speed with respect to traffic volume.

The information we need is then:

(a) value of time in pence per PCU per hour
(b) speed in the charging zone, which we have (14 and 17 km for pre and post charging respectively)
(c) number of PCUs (which approximates traffic volume)

Like in the case of elasticities, a number of assumptions need to be made. We describe the steps and assumptions involved in the MCC estimates.

(a) Value of time in pence per PCU per hour

In order to compute the value of time in pence per PCU per hour we need to compute the average value of time per vehicle type per hour first.

The average values of time per vehicle type in pence per hour for cars, taxis and LGVs were presented in Table 10 in Part 1 of this Technical Annex.

We now need to compute the average values of time for the remaining vehicle types.

[7] PCU is a measure of the relative disruption that different vehicle types impose on the network. A car has a PCU rating of 1, a Light Goods Vehicle (LGV) has a PCU rating of 1.5, a Heavy Goods Vehicle (HGV) has a PCU rating of 2.5 or 3, a bus has a PCU rating of 2.5, a motorcycle has a PCU rating of 0.5, and a bicycle has a PCU rating of 0.2. In the US passenger car equivalents (PCE) are used instead. The meaning however is the same.

[8] Since it is an area rather than a link what we are considering we need to talk about traffic volume rather than traffic flow.

Table 1: Values of working time per person
£ per hour, 2002 prices and values

Vehicle occupant	Resource cost
Bus driver	8.42
Bus passenger	16.72
OGV (driver or passenger)	8.42
Cyclist	14.06
Motorcyclist	19.78

Source: Table 1, TAG Unit 3.5.6 (Department for Transport, 2004a)
Note: OGV: Other Goods Vehicles (ie, lorries)

The values of non-working time per person are the same for all vehicle modes and here we use the same values presented in Table 2 in Part 1 of this Technical Annex.

We assume that all the trips made by OGV are made during working times.

Table 2: Values per vehicle type and trip purpose
£ per hour, 2002 prices and values

Vehicle type	Working	Commuting	Other
Bus driver	8.42	Not applicable	Not applicable
Bus passengers	16.72*23=384.8	5.05*23=116.15	4.46*23=102.58
OGV	8.42	Not applicable	Not applicable
Cycle	14.06	5.05	4.46
Motorcycle	19.78	5.05	4.46

Source: Own calculations
Note$_1$: The occupancy of OGVs is assumed to be 1, following Table 6 of TAG Unit 3.5.6 (Department for Transport, 2004a)
Note$_2$: The passenger occupancy per bus in the charging zone during charging hours is assumed to be 23, following Transport for London (2005, Fig. 27, p.45). *Congestion Charging Central London - Impacts Monitoring: Third Annual Report*, April. http://www.tfl.gov.uk/tfl/cclondon/pdfs/ThirdAnnualReportFinal.pdf

Now we update the numbers from Table 2 to 2003 prices and values. From Part I of this Technical Annex we know that the value of non-working time is assumed to increase with income, with an elasticity of 0.8, whereas the value of working time is assumed to grow in line with income per capita, with an elasticity of 1.

Using the growth in the working and non-working values of time (Table 4 of Part I of this Technical Annex) and the HM Treasury GDP deflator series available at

http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

the updated numbers are as follows.

Table 3: Values per vehicle type and trip purpose
£ per hour, 2003 prices and values

Vehicle type	Working	Commuting	Other
Bus driver	8.9	Not applicable	Not applicable
Bus passengers	405.7	122.0	107.7
OGV	8.9	Not applicable	Not applicable
Cycle	14.8	5.3	4.7
Motorcycle	20.9	5.3	4.7

Source : Table 2, HM Treasury GDP deflator, and Table 4 of Part I of this Technical Annex

The values presented until now correspond to national averages. Since we are interested in the case of London, where salaries are on average higher than in the rest of the country, and therefore the average value of time is also higher, we need to adjust accordingly. We do so in exactly the same way we did it in Part I of the Technical Annex: we increase the working values of time by 29 per cent, and the non-working values of time on the other hand by 23.2 per cent.

Table 4: Values per vehicle type and trip purpose adjusted to London median earnings. £ per hour, 2003 values and prices

Vehicle type	Working	Commuting	Other
Bus driver	11.5	Not applicable	Not applicable
Bus passengers	523.37	150.3	132.7
OGV	11.5	Not applicable	Not applicable
Cycle	19.1	6.5	5.8
Motorcycle	27.0	6.5	5.8

Source: Table 3 and London mark-ups

We now need an average value of time per vehicle type, taking into account the trip purpose split. Unfortunately there is not much information on that.

However, Henry Burroughs from Transport for London (0207 126 4608) provided us with Interim weighted data from the London Area Transport Survey 2001 for motorcycles. The trip purpose split for bicycles is published in the London Transport Report 2004 (Transport for London, 2004). The values for bicycles and motorcycles correspond to an average weekday (24 hours: 04:00-03:59) in 2001, and not to charging hours only.

OGV are assumed to make only working trips.

For buses there is no data for London at all. We therefore used national data from Table 8 of TAG Unit 3.5.6 (Department for Transport, 2004a). This corresponds to national values in an average weekday (24 hours: 07:00-06:59).

Table 5: Trip purposes by buses, OGVs, bicycles and motorcycles

Purpose	Bus	OGV	Bicycles	Motorcycles
Working	1.5	100	9	13
Commuting	27.0	0	39	56
Other	71.5	0	52	31

Source: TAG Unit 3.5.6, Table 8; Chart 4.4.2 London Travel Report 2004 (Transport for London, 2004a), and Interim weighted data from the London Area Transport Survey 2001 provided by Henry Burroughs from Transport for London (0207 126 4608)

We can now combine the numbers from tables 4 and 5 to obtain the numbers in Table 6.

Table 6: Average values of time per vehicle type
£ per hour, 2003 prices and values

Vehicle type	Value of time
Bus driver	11.5
Bus passengers (assumed to be 23)	142.2
OGV	11.5
Cycle	7.27
Motorcycle	8.9

Source: own calculations

Table 7: Average values of time per vehicle type pence per hour, 2003 prices and values

Vehicle type		Value of time
Bus driver	1150	
Bus passengers (assumed to be 23)	14220	
Bus total		15370
OGV		1150
Cycle		727
Motorcycle		890

Source: Table 6

With the values from Table 7 above and the values from Table 9 in Part I we can compute the value of time per PCU. In order to do so we multiply the VOT per vehicle type by the standard PCU rating for each vehicle type. Table 8 below presents the results.

Table 8: Average values of time summary pence per hour, 2003 prices and values

Vehicle type	Value of time
Car	1096
Taxi	2309
LGV	1367
Bus	15370
OGV	1150
Cycle	727
Motorcycle	890

Source: Table 7 (Part II) and Table 9 (Part I) of this Technical Annex

Table 9: Vehicle counts pre and post charging (and relevant PCU values)

	Vehicles		PCUs		Share of PCUs	
	2002	2003	2002	2003	2002	2003
Car	386,752	255,256	386,752	255,256	0.46	0.36
Taxi	113,007	127,133	113,007	127,133	0.13	0.18
LGV	113,267	98,542	169,901	147,813	0.20	0.21
Bus	26,472	32,296	66,180	80,740	0.08	0.11
OGV	31,585	27,953	78,963	69,883	0.09	0.10
Cycle	25,181	28,329	5,036	5,666	0.01	0.01
Motorcycle	48,780	52,926	24,390	26,463	0.03	0.04
Total	**745,044**	**622,435**	**844,229**	**712,954**	**1**	**1**

Source: Transport for London, data provided on request

The PCU ratings assumed are the ones standard in the UK, and are as follows:

Table 10: PCU ratings

Vehicle type	PCU rating
Car	1.0
Taxi	1.0
LGV	1.5
Bus	2.5
OGV	2.5
Cycle	0.2
Motorcycle	0.5

If we multiply the value of time of each vehicle type by the vehicle counts of that vehicle type, and we add all the value of time * vehicle counts for all vehicle types, and then divide by the total number of PCUs, we get the value of time per PCU, as follows.

Table 11: VOT per PCU
£ per PCU per hour, 2003 prices

2002	15.93
2003	18.29

Source: Own calculations explained above

In 2002 the average value of time in the charging zone was £15.93 per PCU. In 2003 the average VOT per PCU had increased to £18.29 in real terms. The reason for this is the change in traffic composition due to the congestion charging scheme.

Going back to the information we need in order to compute MCC as detailed at the beginning of Part II of this Technical Annex, we seem to have everything now:

(a) value of time in pence per PCU per hour: Table 11 above
(b) speed in the charging zone: 14 and 17 km for pre and post charging respectively
(c) number of PCUs (which approximates traffic volume): Table 9 above

The elasticity of speed with respect to traffic volume is the percentage change in speed over the percentage change in traffic volume, computed as a point elasticity with 2002 as the base year.

change in speed: 21.5 per cent (change from 14 to 17 km per hour)
change in traffic volume: 15.5 per cent (change from 844,229 to 712,954 PCUs, as indicated in Table 9 above)

Elasticity of speed with respect to traffic volume: 1.38

We can now compute MCC.

MCC pre-charging = 1.38 *15.93 / 14 = 1.57 = 157 pence per PCU.km

MCC post-charging = 1.38 *18.29/ 17 = 1.48 = 148 pence per PCU.km

Part III: Description of the model we use for the expansion

In this part of the Technical Annex we describe the model we use. The model is available on request from the corresponding author, Georgina Santos (Georgina.Santos@tsu.ox.ac.uk).

We model the expanded congestion charging area as a rectangular grid, which is a close geometric approximation to the actual shape of the area. We make the following assumptions:

1. Cost Minimisation
All drivers are assumed to choose their routes to minimise generalised cost, defined as the sum of the time costs, the vehicle operating costs, and the congestion charge. This assumption ensures speeds, and hence the cost of travel, are equalised on all routes.[9]

2. Uniformity
The distribution of traffic arriving at the edge of each zone is assumed to be discrete uniform across all nodes. Moreover the distribution of destinations within the zone is assumed to be discrete uniform. This assumption facilitates calculation of average distances.

3. No switchback
Drivers are assumed to make a maximum of one turn within or around the zone. This is a common assumption in traffic models and substantially simplifies the model.

4. $Speed_{RR} > Speed_{ZONE}$
The speed on the ring road is assumed to be greater than that inside the zone.

5. Two trips per day
Every driver is assumed to make one outbound and one inbound trip.

With these assumptions in place the first stage in building the final model was to create an ex-ante model of the situation prior to the westwards extension of charging. The data used to construct this model was provided by TfL and is a series of synthetic matrices of all trips made to any area in London. From these matrices, average inbound, outbound and internal traffic for both the original Central Zone (CZ) and expanded zone in Kensington and Chelsea (KC) were calculated. In addition, a further cordon matrix provided by TfL for KC was used to obtain through traffic for KC. Through traffic for the CZ is easily obtained by summing up all vehicles that pay the charge, but do not have an origin or destination within the CZ.

The ex-ante model was then calibrated to obtain speeds, using the (linear) speed-flow relationship as provided in the Department for Transport's National Transport Model (DfT, 2004a). Flows were calculated separately for horizontal and vertical routes.

[9] Unused routes may have equal or greater cost.

The behaviour of drivers after the implementation of a £8 charge for entry into KC is ascertained piecemeal, and then a solution is iterated towards. There will be two types of effects on drivers from implementing such a charge. Firstly drivers may alter routes to divert around the zone, by means of the ring road or the free route that divides the original and new charging zones; this effect is called the *switching effect.* Secondly there will be trip suppression where some users are priced off the roads, or conversely trip generation for some groups, where costs fall as a result of the expansion; this effect is called the *suppression effect* (or *creation effect* where appropriate).

Switching Effects

The extent to which through traffic behaviour changes as a result of a charge being imposed to enter Kensington and Chelsea is calculated by segmenting traffic into six groups: Car Work, Car Non-Work, LGV Work, LGV Non-Work, Taxi Work, Taxi Non-Work.[10] National values of time (VOT), fuel operating costs, and non-fuel operating cost parameters are available for each of these groups from the Department for Transport's Webtag TAG Unit 3.5.6. They were all uprated using exactly the same methodology explained in Parts I and II of this Technical Annex. The final values are presented in Part IV.

Using the parameters described above, speed contingent generalised costs were calculated for routes through and around the zone for each group. Users arriving at nodes for which the distance round implied lower generalised costs were assumed to route around.

For vertical routes, 25 per cent of drivers belonging to each of the groups described above (car work, car non-work, etc) route around. The reason that all groups behave the same is that time costs contribute to most of the generalised costs (GC) when there is no charge. In other words, if all other GC parameters were held constant apart from the VOT, the cost minimising actions for all groups must simply be the quickest route regardless of VOT. This equivalence does not hold ex-post since groups face a charge to take a quicker route and value placed on the time saving becomes crucial.

For horizontal routes, 100 per cent of drivers belonging to each of the groups described above choose to go through the extended charging zone. No horizontal traffic will route round prior to the charge being implemented (except corner traffic). In fact, after the charge, horizontal traffic that has already paid the charge in the CZ will never switch to going around the zone once the charging zone has been extended. Vehicles routing through the new part of the charging zone (KC) from East to West, having already routed through the CZ and paid the charge, will continue to do so after the extension. They will get a further benefit in the form of lower travel time in KC. Similarly, traffic routing West to East through both KC and CZ are already paying the

[10] A Taxi is classified as work only if the passenger is 'working'.

charge for CZ, and will continue to do so after the extension, with the additional benefit of higher speeds in KC.

It may seem strange that vertical traffic routes round but horizontal traffic does not. Intuitively this happens because the punishment in terms of extra distance to horizontal traffic routing round is larger than that for vertical traffic, because the vertical 'height' of the zone (5 km) is greater than the horizontal 'width' of the zone (3.2 km).

Suppression and Creation Effects

Suppression and Creation effects are simpler to model than switching effects, since routes do not change - only the number of trips changes. GC elasticities are detailed in Part I of this Technical Annex.

In order to compute suppression effects, the percentage change in GC for each vehicle group is calculated, and this is then multiplied by the elasticity to obtain the corresponding percentage change in demand for trips.

Since non-residents pay a charge of £8 per day (£4 per trip) compared to 80p per day (40p per trip) for residents, these two groups frequently experience opposite outcomes.[11] Those travelling inbound/outbound from North to South and those travelling inbound from or outbound to the West (not through CZ) will experience suppression for all non-resident sub-groups paying the charge (car and LGV drivers), but creation for taxi drivers who do not pay the charge. Residents actually experience a small fall in GC and as a result increase the number of trips made.[12] Those travelling from or to CZ already must pay the charge by virtue of entering the CZ, experience a large trip creation effect. This effect is much discussed in the media, since it makes travel into the CZ cheap for Kensington and Chelsea residents.

A priori one might expect that internal traffic to the zone, with origin and destination inside the zone, would be suppressed. But as it turns out the users of these 'residential' vehicles experience travel time savings in excess of the 40p charge and are thus subject to creation rather than suppression. Finally, the North-South traffic experiences suppression due to higher costs of routing through and switching costs of routing around. In contrast, horizontal East-West traffic, which already pays the charge, gains from the falls in travel time and is thus subject to trip creation.

[11] The term 'Resident' refers to any agent living in the new expanded zone (KC and CZ).
[12] LGV work category is assumed to pay the full charge since the vehicles are likely to be owned by companies.

Part IV: Value of time and vehicle operating costs input in the model

The values of time and vehicle operating costs input in the model were all at 2007 values and 2004 prices. The procedure used was exactly the same one described in Part I of this Technical Annex. However, we used 2007 values and 2004 prices.

The final values of time used are presented in Table 1.

Table 1: Average values of time summary
pence per hour, 2007 values and 2004 prices

Vehicle type	Value of time
Car working	4,254
Car non-working	905
Taxi working	7,010
Taxi non-working	677
LGV working	1,572
LGV non-working	943
Bus passenger*	697
Bus driver	1,310

Source: TAG Unit 3.5.6 (Department for Transport, 2004a), HM Treasury GDP deflator series available at http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

*There does not seem to be any data for the split of trip purpose for bus passengers in London. We therefore had no choice but to use national averages from Table 8, TAG Unit 3.5.6 (Department for Transport, 2004a). These are: work: 1.5 per cent, commuting: 27 per cent, other: 71.5 per cent.

The updates of the fuel and non-fuel vehicle operating costs were done on the original parameters of TAG Unit 3.5.6, rather than to the results. The reason for this was that we needed to input the parameters in the model in order to compute generalised costs, and having the already updated parameters made things easier.

The final parameters input in the model are presented in Table 2.

Table 2: Fuel and non-fuel VOC parameters
pence per litre, 2007 values and 2004 prices

Component		Car W	Car NW	LGV W	LGV NW	TAXI W	TAXI NW
Fuel operating costs	***a***	10.56044	10.56044	13.24350	15.56111	7.744055	7.744055
	b	-0.1894	-0.1894	-0.234289	-0.2752897	-0.12648	-0.12648
	c	0.001307	0.001307	0.0018	0.0021255	0.000893	0.000893
Non-fuel operating costs (Perceived)	a_1	4.324313	4.049062	6.280828	7.5943816	4.324313	4.049062
	b_1	118.3803	0	41.025177	0	118.3803	0

Source: TAG Unit 3.5.6 (Department for Transport, 2004a), HM Treasury GDP deflator series available at http://www.hm-treasury.gov.uk/economic_data_and_tools/gdp_deflators/data_gdp_annex.cfm

Part V: Environmental benefits

a) Emission formulae input in the model

The following formula for emissions of carbon dioxide, carbon monoxide, nitrogen oxides and particulate matter per km is employed (Highways Agency *et al*, 2003) [13].

$$E = \left(a + bv + cv^2 + dv^e + f \ln v + gv^3 + \frac{h}{v} + \frac{i}{v^2} + \frac{j}{v^3} \right).x$$

This formula is an approximation to the true relationship between speed (v), and emissions (E) per km. The parameters specific to each pollutant are given in the table below by vehicle type. Cars are assumed to run on petrol and taxis are assumed to run on diesel.

b) Emission parameters

Table 1: Carbon dioxide

	a	b	c	d	e	f	g	h	i	j	x
Car petrol	36.25	0	0	0	0	0	0.0000138	655	12.2	0	2.563
Car diesel	43.74	0	0	0	0	0	0.0000273	428	0	0	2.563
LGV diesel	77.43	0	0	0	0	0	0.000156	483	1264	2215	2.563

Source: The Highway Agency *et al* (2003), Volume 11, Section 3, Part I, Annex 2.

Table 2: Carbon monoxide

	a	b	c	d	e	f	g	h	i	j	x
Car petrol	0.51	0	0	0	0	0	0	8.01	0	0	0.6
Car diesel	0.632	-0.0135	0.000075	0	0	0	0	2.38	0	0	0.6
LGV diesel	-1.49	0.0181	0	0	0	0	0	52.5	-140	0	0.6

Source: The Highway Agency *et al* (2003), Volume 11, Section 3, Part I, Annex 2.

[13] Volume 11, Section 3, Part I, Annex 2.

Table 3: Nitrogen oxides

	a	b	c	d	e	f	g	h	i	j	x
Car petrol	0.302	0	0	0	0	0	1.99E-07	0	0	0	0.32
Car diesel	0.844	-0.00884	0	0	0	0	7.08E-07	0	0	0	0.5
LGV diesel	1.31	0	-0.00025	0	0	0	2.32E-06	0	0	0	0.37

Source: The Highway Agency *et al* (2003), Volume 11, Section 3, Part I, Annex 2.

Table 4: Particulate matter

	a	b	c	d	e	f	g	h	i	j	x
Car petrol	0.0024	-0.000046	0	0	0	0	5.59E-09	0	0	0	1
Car diesel	0.0722	0	-0.000018	0	0	0	1.51E-07	0	0	0	0.35
LGV diesel	0.127	0	-0.000038	0	0	0	4.15E-07	0	0	0	0.49

Source: The Highway Agency *et al* (2003), Volume 11, Section 3, Part I, Annex 2.

c) Environmental benefit estimates

The parameters detailed above were used to compute emissions of carbon dioxide, particulate matter, nitrogen oxides and carbon monoxide per km before and after the implementation of charging. This emission value was then multiplied by the total kilometres travelled inside the zone. The increased emissions from drivers switching to go around the zone was then added to this figure.

The monetisation of the reduced emissions intrinsically carries some degree of uncertainty. Clarkson and Deyes (2002) review the literature and conclude that £70/tC at 2000 values and prices is the value that enjoys the greatest support in the literature. This is also the value suggested by DfT (2004c). Clarkson and Deyes (2002) also suggest increasing it by £1/tC per year in real terms, which yields £77/tC in 2007 values and 2000 prices. The high and low estimate values of the health costs of carbon monoxide, nitrogen oxides and particulate matter were taken directly from McCubbin and Delucchi (1999). All values were converted to pounds and inflated to 2004 prices using HM Treasury's GDP Deflator Series. Estimates for the values of nitrogen oxides and particulate matter from DfT (2004c) were also used.

Table 5 provides a summary of the social costs of the different pollutants. The range of values reflects the considerable uncertainty attached to them. These values were applied to the emission reductions and benefits computed, as presented in the main body of the paper.

Table 5: Social cost of the different pollutants
(£ per tonne, 2007 values and 2004 prices)

	(a) From Department for Transport	(b) From McCubbin and Delucchi (1999)	
		Low estimate	High estimate
Carbon dioxide	86	-	-
Particulate matter	429,566	8,013	75,736
Nitrogen oxides	1,187	1,325	19,433
Carbon monoxide	-	11	84

Note: Carbon dioxide tonnes have been converted to tonnes of carbon.
Source: (a): DfT (2004c), (b): McCubbin and Delucchi (1999)

Part VI : Sensitivity analysis

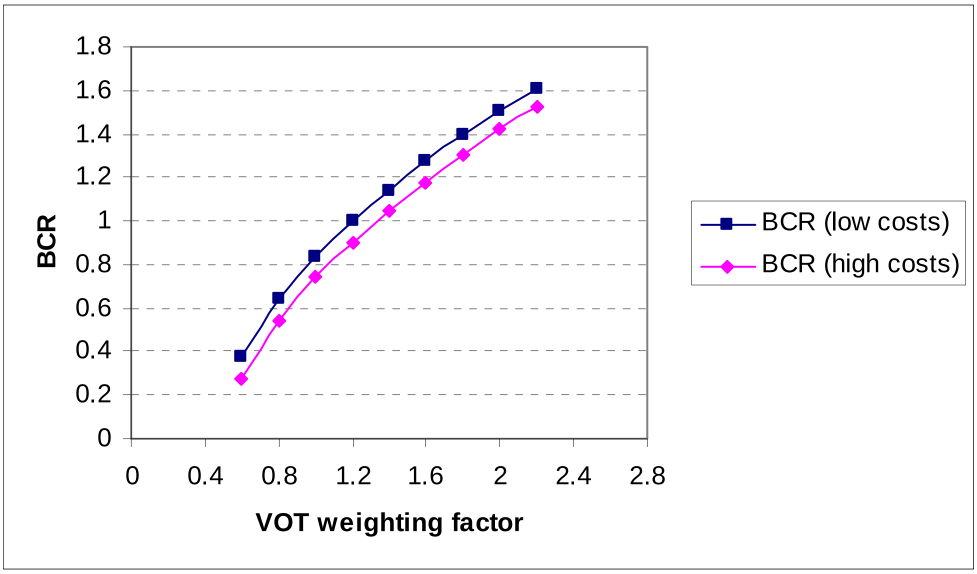
We conducted a sensitivity analysis of the benefit cost ratio with respect to value of time, elasticities and charge level assumed. We ignore accident and environmental benefits in all our sensitivity analyses.

a) Value of time

Working and non-working values of time are different. This was taken into account and also an adjustment for London was made, as explained in Part I of this Technical Annex. The sensibility analysis was carried out with a weighting factor that multiplied the working and non-working value of time respectively. As expected, the higher the VOT, the higher the BCR.

Table 1: VOT weighting factors and BCRs

VOT weighting factor	BCR (high costs)	BCR (low costs)
0.6	0.38	0.28
0.8	0.64	0.54
1	0.84	0.74
1.2	1.00	0.90
1.4	1.14	1.05
1.6	1.28	1.18
1.8	1.40	1.30
2	1.51	1.42
2.2	1.61	1.52



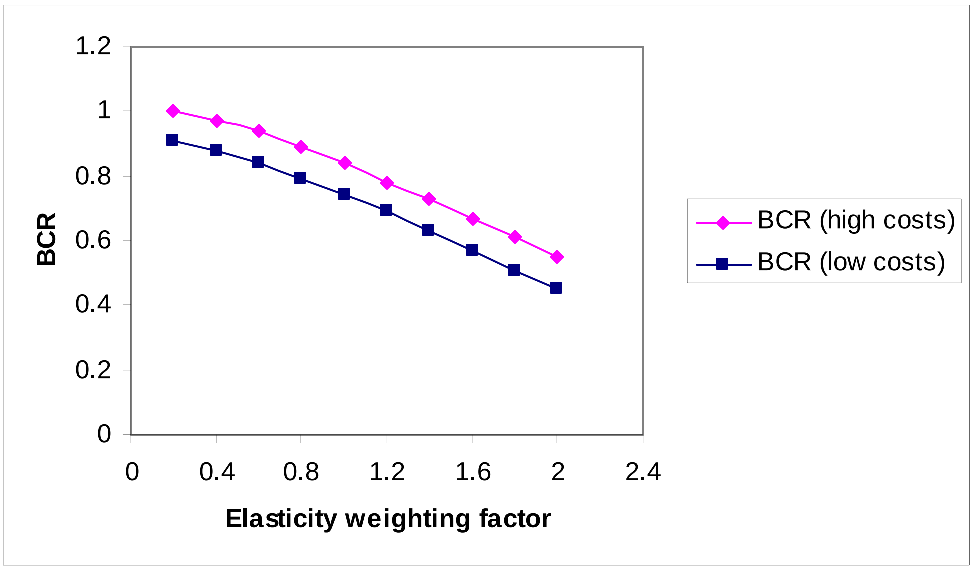
In order for the BCR to be at least unity, the VOT would need to be 20 per cent higher than that assumed in the paper.

b) Elasticities

Table 28 gives the point elasticities estimated for the original charging zone. Since we do not have any estimates of the elasticities for the Western Extension we used the point elasticities computed for a different area, and for a different charge. However, we carried out the sensitivity analysis presented below. Since all three vehicle types have different elasticity values, the sensitivity analysis was done using a weighting factor, which multiplied the elasticity for each vehicle type.

Table 2: Elasticity weighting factors and BCRs

Elasticity weighting factor	BCR (high costs)	BCR (low costs)
0.2	1	0.91
0.4	0.97	0.88
0.6	0.94	0.84
0.8	0.89	0.79
1	0.84	0.74
1.2	0.78	0.69
1.4	0.73	0.63
1.6	0.67	0.57
1.8	0.61	0.51
2	0.55	0.45



Although the BCR decreases with the elasticity, it is not too sensitive to it in the sense that big errors in the elasticity assumed are needed before the BCR decreases substantially.

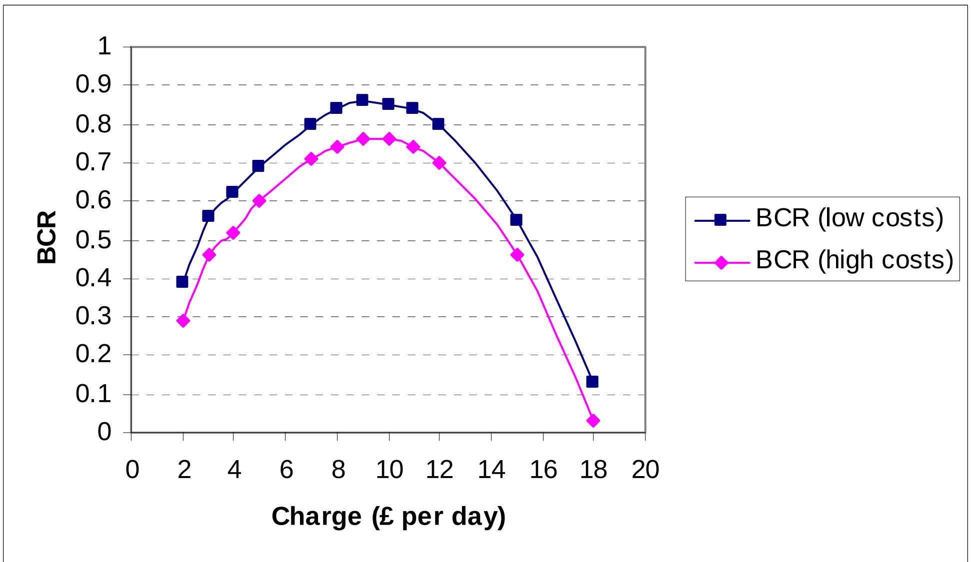
As explained in the main body of the paper, benefits would increase with the elasticity if the only possible response from drivers was to cancel their trips (suppression effect). This is not the only response, and drivers may decide to use an alternative route instead of not making the trip at all. When the switching effect is large, speeds on these routes go down and so do time savings and as a consequence, overall benefits.

c) Charge

We tried a different number of charges and interestingly we found that the £8 charge does not seem to be far away from the charge that would maximise the BCR. This is not any reassurance as what this analysis tells us is that under the current assumptions, the BCR will be below unity, whatever the charge.

Table 3: Charges and BCRs

Charge (£ per day)	BCR (high costs)	BCR (low costs)
2	0.39	0.29
3	0.56	0.46
4	0.62	0.52
5	0.69	0.60
7	0.80	0.71
8	0.84	0.74
9	0.86	0.76
10	0.85	0.76
11	0.84	0.74
12	0.80	0.70
15	0.55	0.46
18	0.13	0.03



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