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THE DISTRIBUTIONAL IMPACT OF VARIOUS ROAD CHARGING SCHEMES FOR LONDON

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ABSTRACT

FOWKES, AS, MILNE, DM, NASH, CA, MAY, AD (1993). The distributional impact of various road charging schemes for London. *ITS Working Paper 400*, Institute for Transport Studies, University of Leeds.

This Working Paper presents results obtained using the MVA START model for London, with the primary intention of investigating the distributional impact of road pricing in various forms and at various levels. In order to look at distributional effects the START model had to be 'disaggregated' by income groups - three each for non-car owning and car-owning households. Initially, this allowed us to see the distributional impact of the LPAC Preferred Strategy, mainly involving public transport and traffic management policies. Beyond this we tested three structures (or 'regimes') of road pricing, varying from a complex three cordon plus screenlines structure, to a single Central London cordon. Somewhat surprisingly, the latter was found to be regressive in its application. The structure with the highest benefits, as well as being relatively progressive, was the complex structure of three cordons plus screenlines, with an optimum charge level of 50 pence per cordon crossing, each way but with the outer two cordons being peak only.

KEY-WORDS: Road pricing; distributional impact; public transport; traffic management policies; cordons

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1. INTRODUCTION

This Working Paper presents the results obtained by the ESRC project "Assessing the benefits and incidence of road pricing in London" (May and Nash, 1990). The principal aims of this project were to examine both the size of the overall benefits from alternative road pricing schemes for London and the degree to which different groups in society gain or lose from its introduction. Previous studies led us to believe that there would be substantial overall benefits from road pricing, but that there was little evidence on the degree to which different groups would gain or lose. Obviously in general, one would expect road users to disbenefit from the increased charge, which would persuade some people to change their travel behaviour and thus reduce congestion. Because this disbenefit would be partly offset by the gains they made from faster journeys, the overall disbenefit to road users should be less than the revenue gained by government and available for redistribution. However, some groups of road users might actually gain from road pricing even without redistribution of part of the revenue to them. These include bus operators and users, freight operators, and high income car users, who were happy to pay the charge for the faster journey times they could now achieve.

To examine these issues, we needed use of a computer model which was able to reflect the large number of ways in which road users might respond to charges, including changing the number of journeys they make, time of travel, route, destination and the means of travel they use. The most suitable model available to us appeared to be the START model developed by the consultants MVA (Bates et al, 1991), and we worked with them to apply this model to London with funding partly from the London Planning Advisory Committee (LPAC, 1992). We also obtained a programme, EVAL, which measured the scale of the benefits and costs to each group identified within the model. However, to look at the effects on different income groups, we had to modify the model to break down the two categories of car-owning and non car-owning households each into high, middle and low income households. This was achieved using data from the 1985/6 National Travel Survey. We also made a thorough review of the evidence on the value different income groups place on their time savings and of the sensitivity of their travel decisions to the cost of travel (Fowkes et al, 1993). These stages of the work took longer than anticipated and reduced the number of options we were able to examine. Nevertheless, we achieved some interesting results.

After some experimentation, it was decided to use the prediction year 2001 as the basis for comparisons since this was consistent with earlier work for LPAC. We have chosen resource values of time for evaluation purposes and there is room for disagreement as to which values should be used. Unless otherwise stated, we have for evaluation purposes used the same resource values of time for all household types.

Section 2 reports tests with the aggregate model; section 3 discusses disaggregation of the model by income group. We then look in turn at the base situation with the disaggregate model, the optimal level of pricing for each of three different road pricing regimes and the implied changes of traffic in these regimes. Some sensitivity testing is undertaken before we draw our conclusions.

2. TESTS WITH THE AGGREGATE MODEL

The London START model, as installed at Leeds ITS, contained a division between car owning and non-car owning households, although both groups were given an identical value of time. Our initial experiments with the START model looked at traffic data for Central London with the LPAC Preferred Strategy for 2001, with road pricing implemented at differing charging levels.

In addition to road pricing, the Preferred Strategy included substantial public transport investment, fares reductions and the use of road space for traffic calming. The road pricing strategy tested was a somewhat complex one involving three cordons around Central London and a set of screenlines within the central area (LPAC, 1990).

The results are presented here as Table 2.1. Car mode share declines by a substantial proportion, with a transfer to bus and not rail. The percentage reductions in flow are greater off-peak. Speeds improve both in the peaks and inter-peak, with the slowest speeds still being in the inter-peak.

Table 2.1: The effect of road pricing on travel and traffic. Aggregate START model (X). LPAC Preferred Strategy.

CODE	X0	X25	X50	X100
CROSSING CHARGE	0	25p	50p	100p
(a) Mode share for trips to Central London all day				
Car	11.9	10.6	9.3	7.2
Bus	5.5	7.3	8.1	9.2
Rail	40.1	39.1	38.8	38.7
Slow	42.5	43.1	43.8	44.9
(b) Flow in Central Area (pcu - km x 10^6)				
AM Peak (3 hours)	1.36	1.09	0.97	0.84
Off Peak (6 hours)	2.47	2.23	2.10	1.96
PM Peak (3 hours)	1.33	1.08	0.95	0.78
(c) Speed in Central Area (km/hr)				
AM Peak	23.1	26.7	28.2	30.0
Off Peak	21.8	23.7	24.6	25.7
PM Peak	22.5	25.9	27.8	30.1

Table 2.2 shows the benefits from the LPAC Preferred Strategy, with and without road pricing. All benefits are shown relative to LPAC's Strategy 1, which represents continuation of current policies. As elsewhere in this report they refer to the single year 2001. The X0 column shows the results for the LPAC Preferred Strategy without road pricing (LPAC Strategy 2). There are costs for government, but large gains for households, freight and operators. The remaining columns show the benefits with various levels of road pricing, using the LPAC road pricing structure. Three different levels of (each way) crossing charge are tested (25p, 50p and 100p per crossing in either direction). From the point of view of total benefits, the best of these charge levels is 50p, and rough interpolation suggests an overall optimum charge of about 45p.

A clearer impression of the effect of different charge levels will generally be gained by expressing the benefits with respect not to the LPAC Strategy 1 (as in Table 2.2) but to the LPAC Preferred Strategy. This is done in Table 2.3, largely to set the pattern for later results tables. Naturally, our conclusions regarding optimal charge levels are the same as above. It is notable that there are substantial benefits for local government (the assumed recipient of revenues) and disbenefits for households.

Table 2.2: Benefits compared to LPAC Strategy 1 of the LPAC Preferred Strategy with and without road pricing, with the aggregate START model (denoted X). Figures in £m for 2001.

Code	X0	X25	X50	X100
Crossing Charge	0	25p	50p	100p
Households	147.4	41.7	-29.8	-131.4
Freight	23.5	20.8	38.8	54.4
Operators	47.6	79.9	93.0	115.0
Local Government	-18.7	84.9	137.2	169.3
UK Government	-0.3	-9.5	-14.2	-19.8
TOTAL	199.5	217.8	224.9	187.5

Table 2.3: Effects of adding road pricing to the LPAC Preferred Strategy, with the aggregate START model (denoted X). Figures in £m for 2001.

Code	X25	X50	X100
Crossing Charge	25p	50p	100p
Households	-105.7	-177.2	-278.8
Freight	-2.7	15.3	30.9
Operators	32.3	45.4	67.4
Local Government	103.6	155.9	188.0
UK Government	-9.2	-13.9	-19.5
TOTAL	18.3	25.4	-12.0

It will be seen that public transport, and in most cases freight operators, gain from road pricing, as does local government. Households and central government lose, the latter from lost tax receipts. In the form of the model we used, public transport operators' profits are not ploughed back into improved services or lower fares.

3. DISAGGREGATING THE MODEL BY INCOME

3.1 PURPOSE

In this section we will essentially be doing two things. Firstly a six way split of the households of London will be made, being two car ownership levels by three income levels. Secondly we shall associate with these a value of time for each START journey purpose. In the aggregate model as used at Leeds ITS, and reported in Section 2 above, only a single value of time was used, to retain consistency with earlier tests (LPAC, 1992) although there was the possibility of inputting separate values for car owners and non-car owners by each of the seven journey purposes described in Section 3.3. Section 4 will report on the effect this disaggregation has had, using disaggregated values of time whose derivation is described below.

3.2 DATA SOURCES

Values of time, principally derived from the DOT Value of Time Study (MVA, ITS, TSU, 1987) were set out by journey purpose in Working Paper 345 (Fowkes, Sherwood, and Nash, 1993). That Working Paper was originally written on the assumption that the START model would use 11 categories of trip, as had its predecessors for Edinburgh and Bristol. Belatedly we discovered that this was not the case, and this caused us difficulties as will be described below. WP 345 was later amended.

The source of our income distribution data was the DOT 1985-86 National Travel Survey (NTS), kindly provided to us by the ESRC Data Archive. This gave us the proportions of journeys falling into each income band, by journey purpose. Had we not required a breakdown by journey purpose, then we could have used the numbers of households to get our distribution. As we wanted to consider journey purpose we were forced to use trip weighted distributions of households. This, however, is exactly what we want for the next stage of our work, i.e. using in the disaggregate model values of time whose average equals that used in the aggregate model.

3.3 CHOICE OF CATEGORIES

Difficulties with the START model have constrained our ambitions in this work. Taking first the categorisation of JOURNEY PURPOSE, this is incompatible with that used in the Value of Time study. The latter study found for cars, values of time highest for Employers' Business, and lowest for Commuting with "Other" coming in between. We will refer to this "Other" as "Leisure". START uses the following journey purposes:

Home Based Work (HBW)
Home Based Education (HBE)
Home Based Other (HBO)
Non Home Based (NHB)

where the first three are broken down by to/from home. These seven journey purpose categories are used here.

It follows from the distribution of VOTs by purpose that if the proportion of Employers' Business trips in HBW is relatively small, we will get an average value of time not too different from that for Leisure. We therefore decided to use for all START journey purposes the relationship between value of time and Income derived for Leisure in WP 345. As income distributions will vary by journey purpose, so VOTs will also vary by journey purpose. Indeed, since as will be seen we have a good estimate of average incomes within each income band and these too vary by journey purpose, it transpires that VOTs vary by purpose a little even within a given income band. Effectively, however, we have lost any effect of a given traveller's value of time varying due to the type of journey he is making, and this should not be lost sight of.

Turning to the income categories, START currently subdivides all its matrices and manipulations into two household Car Ownership Categories (NONE and SOME). It was felt simpler to expand this dimension rather than try to add an extra dimension to START. The latter would have required extra loops to be set up, whereas the former only requires the upper loop limit to be redefined once. We chose to retain the non car-owning/car-owning division and to split each into three (different) income bands. We chose these after seeing the distributions for NTS journeys by London households. For non car-owning households (C0) the bands chosen were £0-5K, £5-10K and £10+K. For car owning households (C1) the bands chosen were £0-10K, £10-20K, and £20+K. The bands are measured in 1985 pounds, and this convention is maintained throughout. Some income growth will have occurred after this date but that is ignored.

In summary we have seven journey purpose categories, broken down by six car ownership/income categories. As START already has the division by car ownership, it remains for us to provide the proportion of journeys for each journey purpose at that car ownership level by the relevant three income bands. This is done in the next subsection. We then require the average income in each of our 42 categories. Measured in 1985 pounds these are then converted to 1985 values of time and finally to reciprocal 1989 values of time as required for START. This is done in subsection 3.5.

3.4 INCOME DISTRIBUTIONS

The initial level for us to work at with the NTS data was the household level, although even this took much effort due to the enormous size of the NTS data set relative to modern day computing systems workspaces, particularly given the scratchspace requirements of Statistical Packages. We used SPSS since a set of SPSS control cards were provided by the ESRC Data Archive, who we must thank for providing the data tape commendably quickly. However, most of the control lines needed a full stop adding and we found it desirable to make other subtle changes.

A particular problem was that, although the survey data is stored in hierarchical form, the data on vehicles is separated out into a separate file. We have no hopes of being able to recombine this with the other survey data. We presume the reason for the separation is that one or more cars might be associated with more than one traveller and so the position in the hierarchy would be unclear and require detrimental assumptions to be imposed. One consequence of not having the vehicle records in a form cross-classifiable with households is that we cannot classify households by car subsidy levels as we had desired. In any event it would have been extremely difficult to have tried to classify individual trips by car subsidy level, which is what we really would have liked.

Having lost the reason to work at the household level we determined to try to work at the journey level. This was not straightforward, and in the meantime some work had been done at the household level. Nevertheless, when it became possible to work at the journey level this work was redone (and is presented below). The logic of working at the journey level is that road pricing will affect individual trips (for a particular purpose, by a person from a car owning household or not, and with a given household income). If a certain section of the population never make car trips in London (say those for non car owning households with income below £5K) then they will not be represented in the traffic. Similarly, if richer households make more car trips than average, then we should take account of this when considering what the reaction of current traffic will be to the imposition of road pricing. Perhaps we should have gone further and only taken car journeys, but this would have severely depleted our data on non-car owning households and anyway seemed wrong as any journey could potentially have been made by car.

Fortunately, it proved possible (if difficult and messy) to match the START journey purpose categories with the combinations of replies to four NTS questions (with two different codings!). We selected households only in Inner or Outer London, although their journeys need not be located there and other households will have made journeys in London. Table 3.1 shows the results in percentage form within car ownership levels. Income bands and Journey Purposes are as discussed in subsection 3.3, with the suffix "/F" denoting FROM HOME and "/T" denoting TO HOME. The figures look plausible. Naturally, journeys involving work tend to be made from richer households then average. Journeys by car owning households are from greatly richer households than those by non-car owning households. Non-home-based journeys seem to have a fairly average household income distribution, possibly an indication that they should not be taken as a proxy for Employer's Business trips. In fact, the NTS definition of non-home-based journeys was very wide since any deviation from route to a main destination was deemed to be a destination in itself, whereafter the continuation journey was automatically non-home-based. For example, a visit, other than fleeting, to shops on the way home from work would be a NHB followed by a HBO/T and not just a HBW/T. Note that no attempt has been made to weight trips by distance.

Table 3.1: Percentage of journeys by London households of a given car ownership level by income for seven journey purposes

	JOURNEY PURPOSE						
	HBW/F	HBW/T	HBE/F	HBE/T	HBO/F	HBO/T	NHB
CO	(1198)	(1104)	(463)	(434)	(2796)	(2892)	(1361)
- £5K	8.3	8.4	37.2	35.9	50.2	49.1	33.2
£5-10K	31.6	33.0	27.2	28.8	24.1	23.6	25.1
£10k +	60.1	58.6	35.6	35.3	25.7	27.3	41.7
C1	(5710)	(5309)	(1674)	(1534)	(10006)	(10525)	(6857)
- £10K	12.8	13.0	16.0	15.3	20.6	20.4	15.2
£10-20K	47.0	47.4	52.0	52.2	43.5	43.3	43.2
£20K+	40.2	39.6	32.0	32.5	35.9	36.3	41.6

Source: NTS, 1985-86. Income bands in 1985/86 prices.
Note: Figures in brackets are sample sizes, the grand total being 51843 journeys.

3.5 RECIPROCAL VALUES OF TIME

The parameter input to START requires reciprocal Values of Time in 1989 prices. The method of deriving these has already been stated, and this section gives the detail and the results. It should be noted that considerable accuracy has been held where possible. although the final results are only given in much rounded form. NTS recorded exact incomes where available, but these are tabulated on our tape in £1000 p.a. bands up to £15000 pa, then £2500 p.a. bands till £25000 p.a. As always, these are in 1985/6 prices and we took only London households. Again we worked at the journey level, and so can present results by the seven journey purposes.

From a consideration of raw tabulations, three way divisions by income were determined for non-car owning and car owning households separately, as has already been stated. Average incomes in 1985/6 prices within these income bands are given in Table 3.2 by journey purpose. These look reasonably plausible. The £15878 for CO, £10K +, HBO/T looks too high, but has been checked. A possible explanation is that rich non-car owning household travellers are more than averagely likely to travel to work from home, then on to an "other" destination and then return to home from there. This seems sufficiently plausible not to recheck, particularly as supporting evidence comes from HBW/F > HBW/T for this group. It should also be noted that, even with sensible choice of income bands, the sample sizes are not everywhere sufficiently large to totally overcome sampling variation, and so small variations may not be important.

Table 3.2: Average incomes in 1985/6 prices in 1985/6 income bands for non-car owning and car owning households journeys by seven journey purposes

	JOURNEY PURPOSE						
	HBW/F	HBW/T	HBE/F	HBE/T	HBO/F	HBO/T	NHB
C0							
- £5K	3239	3155	3605	3622	3002	2929	3009
£5-10K	7926	7915	8143	8172	7590	7619	8070
£10K +	16161	15809	13895	14025	14018	15878	16759
C1							
- £10K	7883	7862	7235	7467	6710	6704	7322
£10-20K	14969	14978	14578	14499	15006	15021	15159
£20K +	26549	26488	26901	27171	26437	26360	26963

Source: NTS 1985-86. All in 1985/6 prices.

At this point we needed to convert the incomes in Table 3.2 into Values of Time, using the relationships set out in WP 345. There was a strong temptation to use the car values of time for the car-owning households and some public transport values of time for the non-car owning households. However, road pricing will mainly affect car journey travel, so it is the proper conversion for these effects that we seek. Furthermore, the use of low base Values of Time for non-car owning households seemed undesirable on a priori grounds.

A further complication is that the DOT Value of Time study reports Values of Time for the car as a whole, including all occupants. The Department on receiving these results, however, decided to use the values for car drivers, and multiply them up to take account of occupants. Hence we have another reason for not using the obviously per person values for public transport modes together with these car values. We decided to use the car VOT v Income relation from Table 1 in WP 345 for journey purpose Leisure for all the incomes in Table 2. The reason for not adjusting according to the WP 345 journey purposes was discussed earlier. We had determined an adjustment to the price levels used by START (presumed to be 1989) and this was applied at the same time reciprocals were taken. The results now suitable for input to START are given in Table 3.3, rounded to two decimal places.

Table 3.3: Reciprocal values of time in 1989 prices for 1985/6 household income bands by journey purpose and non car-owning and car-owning household journeys (in minutes/penny).

	JOURNEY PURPOSE						
	HBW/F	HBW/T	HBE/F	HBE/T	HBO/F	HBO/T	NHB
C0							
- £5K	0.27	0.27	0.26	0.26	0.27	0.27	0.27
£5-10K	0.23	0.23	0.23	0.23	0.23	0.23	0.23
£10K +	0.20	0.20	0.22	0.21	0.21	0.20	0.20
C1							
- £10K	0.23	0.23	0.23	0.23	0.24	0.24	0.23
£10-20K	0.21	0.21	0.21	0.21	0.21	0.21	0.21
£20K +	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Source: Table 2 above, plus Table 1 of WP 345 using a 1.25 factor to convert from NTS prices to START prices.
Note: The current value in START is 0.205. The average of the above figures is close to this at 0.20, the large number of journeys in the C1/£20K + group pulling the average down.

In order to compare benefits to individual household types from the START model runs we need to know how many households fall into each household type. NTS gives us this information for 1985/6, and this is reported in Table 3.4 both by number of households and by number of journeys they make. The START model data is for 2001, though, so some adjustment is necessary. In LPAC (1990), LTS planning data for 2001 is quoted, giving a breakdown between car owning and non-car owning households. MVA (1992) state the assumed growth rate of motorised trips up to 2001. By careful editing of this information, revised projected household distributions for both household numbers and trips have been calculated and are presented in Table 3.4. Also shown is the projected distribution of persons, assuming household size to remain constant within household types. In this table, and subsequently, the codes, C01, C02, C03, C11, C12 and C13 have been used for the six household types.

Table 3.4: Definition of household types and their distributions, in terms of numbers and of journeys, in 1985/6 and 2001

Household Type Code	Car?	Income Band	1985/6 % of house-holds	1985/6 % of trips	2001 % of households	2001 % of trips	2001 % of persons
C01	NO	-£5k	22	7	18	6	10
C02	NO	£5-10k	8	5	7	4	6
C03	NO	£10k	9	7	7	6	6
C11	YES	-£10k	16	14	18	15	16
C12	YES	£10-20k	27	36	30	38	35
C13	YES	£20k+	18	30	20	31	27

4. THE BASE SITUATION WITH THE DISAGGREGATE MODEL

In this study we have taken as our base situation the LPAC preferred strategy without road pricing. This is derived from a run of the START model, forecasting for the year 2001. The assumptions included for this preferred strategy have been set out in section 2, but the distributional effects have not before been presented.

Table 4.1 shows that of the £210M p.a. of benefits resulting from the preferred strategy, some £148M relate to households, i.e. are benefits to individual passenger travellers. The distribution of benefits can be seen to broadly mirror the distribution of trip making by household types, with a slight tendency for the richer households to come off best. Here, as elsewhere unless otherwise stated, a single evaluation value of time has been used. If we were to assume instead that values of time increase as incomes increase, then in situations such as the present case where we can assume that all income groups are receiving some time benefits, the effect will be to further favour richer households. A fully detailed investigation of such effects would require differential values of time by mode as well as income to be used, but this was beyond the scope of the software we were using, even if suitable input values of time could have been determined.

Compared to the distribution of the actual number of households by type (in 2001), rather than their trip making, the preferred strategy can be seen to clearly benefit the richer car-owning households disproportionately. The 18% of poor non-car owning households get only 5% of the benefits. Even rich non-car owners do no better than benefit in proportion to their numbers. Poor car-owning households benefit less than proportionally, even more than was the case when using the trip-weighted distribution of households. As was mentioned earlier, if a value of time related to household income had been used, these effects would have been magnified further.

Columns X and Z in Table 4.2 compare the results of Table 4.1 with column X0 of Table 2.2. We see reasonable agreement. There is close agreement on the total of benefits to householders from the LPAC Preferred Strategy, and this is principally the area we are interested in. The freight benefit is reduced. The benefit to operators is nearly identical to what it was. Local government, however, has much smaller disbenefit. Overall the effect is to raise the total benefit from £199.5M p.a. to £210.0M p.a. We are unable to explain these small discrepancies.

As an experiment we tried running the disaggregate model with a single value of time, i.e. the modifications to allow income disaggregation within START were made, but the same (reciprocal) value of time was used for all household types and journey purposes. The results are shown in column Y. The disaggregate model used with varying values of time was a closer match for the aggregate model than was the disaggregate model with all of the values of time set to that of the aggregate model.

Table 4.1: Distribution of benefits for the LPAC Preferred Strategy compared to LPAC Strategy 1, with the disaggregate START model

	Percentage of households in 2001	Percentage of trips in 2001	Benefit (£M in 2001)	Percentage of household benefits
Household Type				
C01	18	6	7.5	5
C02	7	4	8.1	6
C03	7	6	12.8	9
C11	18	15	18.5	12
C12	30	38	54.4	37
C13	20	31	47.0	32
Households	100	100	148.1	
Freight			18.6	
Operators			47.5	
Local Government			-3.5	
UK Government			-0.7	
TOTAL			210.0	

Table 4.2: Comparison of benefits (£M in 2001) from the LPAC Preferred Strategy using (a) the aggregate model (X); (b) the disaggregate model with a single value of time (Y); (c) the disaggregate model with values of time varying by household type and journey purpose (Z)

	X	Y	Z
Household Types			
C01		7.6	7.5
C02		8.1	8.1
C03		12.8	12.8
C11		18.5	18.5
C12		54.6	54.4
C13		46.7	47.0
Households	147.4	148.3	148.1
Freight	23.5	18.5	18.6
Operators	47.6	46.7	47.5
Local Government	-18.7	-0.9	-3.5
UK Government	-0.3	-0.8	-0.7
TOTAL	199.5	211.7	210.0

However, it will be noted that all three sets of results are telling the same broad story. As the Y results are clearly closer to the Z results than to the X results, it is probably safe to say that the major part of the difference between the X and Z results is due to the process of disaggregating START by income type, rather than due to the method of disaggregating the values of time used.

5. THE IMPACT OF ROAD PRICING FOR THE LPAC FORM OF ROAD PRICING (STRUCTURE A)

In the present study three structural forms for road pricing in London were tested. The first, the one used in the LPAC study, had charges for crossing (either way) three cordons, and a set of screenlines in Central London. The second structure tested will be charges just for crossing the three cordons. The third and final structure tested will be for crossing the central cordon only (ie the innermost cordon). The central cordon is located just inside the Inner Ring Road. The two other cordons are both in what is termed "Inner London". The outermost of these cordons is just inside the North and South Circular roads. Measured from Charing Cross, the three cordons are roughly 3km, 5km and 8km out. A map is contained in the TASTE III report (LPAC, 1990). The 5km and 8km cordons are 'peak only' while the central cordon and screenlines operate both peak and off-peak. All charges are in both directions.

We shall denote the LPAC structure by the letter A and so the LPAC test becomes "A50", i.e. 50p per crossing on the LPAC structure. Charging on just the three cordons, i.e. without the screenlines, is denoted by the letter B. Charging on just the central cordon will be denoted by the letter C. Throughout the tests for Structures A and B, the charges were equal on all cordons.

The remainder of this section will report on sensitivity tests on the charging level using Structure A. We shall assume we are optimising the overall net benefit. The main expected effects of road pricing are listed in Table 5.1, with benefits denoted by (+) and disbenefits (-). Some of these will cancel exactly, while others will be offsetting.

Table 5.1: Main expected effects of road pricing

1.	Payments of charges by drivers	(-)
2.	Receipts of charges by local government	(+)
3.	Time savings by continuing drivers	(+)
4.	Time savings for buses	(+)
5.	Increased waiting times if buses/trains become overcrowded	(-)
6.	Fares paid by ex-drivers	(-)
7.	Fares received from new travellers	(+)
8.	Car operating cost savings by ex-drivers	(+)
9.	Fuel tax losses by UK government	(-)
10.	Operating cost savings for buses due to less congestion	(+)
11.	Operating cost increase for public transport due to extra traffic	(-)
12.	Savings in parking charges by ex-drivers	(+)
13.	Losses in parking charge receipts by local government	(-)

Note: time changes for transferring drivers could be (+) or (-).

Table 5.2 gives comparative summary results for various charge levels. The overall best for Structure A is A50, i.e. the 50p per crossing tested by LPAC. Rough interpolation suggest that the optimal charge would be around 45p.

This result is similar to that for the aggregate model (Table 2.3) although close inspection indicates some differences in the distribution of benefits, particularly for test A100.

Table 5.2: Benefits from adding road pricing to the LPAC Preferred Strategy, using the LPAC charging structure (denoted A). Figures in £M for 2001.

Code	A25	A50	A100
Crossing Charge	25p	50p	100p
Household Types			
C01	-6.7	-10.7	-15.0
C02	-4.2	-7.5	-12.4
C03	-4.7	-9.2	-17.0
C11	-17.7	-28.5	-42.7
C12	-43.8	-72.6	-112.1
C13	-24.1	-43.1	-73.3
Households	-101.3	-171.5	-272.5
Freight	2.4	19.9	31.7
Operators	31.8	44.7	65.6
Local Government	101.8	150.7	200.2
UK Government	-4.1	-5.4	-5.7
TOTAL	30.7	38.4	19.0

The pattern of effects of charging successively higher charges can be easily seen. Households, even non-car owning households, disbenefit increasingly as the charge is raised. Conversely, the charging authority, assumed here for convenience to be the local authority, benefits increasingly, but at a declining rate. The "gap" is more than made up by (increasing) benefits to freight traffic and public transport operators. The latter take more fares revenue as motorists are priced off of the road. The disbenefits to motorists of pricing them off the road are accounted for in the household benefit figures. The UK government is here not assumed to be receiving any of the revenue, and so disbenefits very slightly as charges are increased due to reductions in receipts from taxation on motoring.

Table 5.3 investigates the distributional implications. The broad pattern is to follow the trip weighted distribution of households, i.e. household types disbenefit roughly in proportion to how many trips they make. Beyond this we can see that non-car owning households disbenefit slightly less than proportionately to their trip making. Compared to the numbers of households they disbenefit much less than proportionately. The main losers are clearly the middle-income car owning households (C12). Poor car owning households disbenefit slightly more than proportionately, while rich car owning households (C13) disbenefit less than proportionately to their trip making, but more than proportionately to their numbers.

The distributional impact does not vary greatly as the charge is varied, and the above can be taken to apply for the optimal charge of 45/50p. It appears that as the charge level is increased there is a slight tendency for the distribution of benefits to more closely resemble the distribution of household trip making.

Table 5.3: Distributional implications of the results of Table 5.2

Household Type	% of Households	% of Persons	% of Trips	% of Net Disbenefits		
				A25	A50	A100
C01	18	10	6	7	6	6
C02	7	6	4	4	4	5
C03	7	6	6	5	5	6
C11	18	16	15	17	17	16
C12	30	35	38	43	42	41
C13	20	27	31	24	25	27

NB. As elsewhere (unless otherwise stated), a common value of time has been assumed for all household types.

6. THE IMPACT OF ROAD PRICING FOR THE THREE CORDON STRUCTURE (STRUCTURE B)

In this section we report results of setting various charge levels on the three cordons together, but without the screenline charges in Central London. Again the results for the LPAC Preferred Strategy without road pricing are used as a base and results presented as differences from this position. Table 6.1 gives the results for six levels of charges; these apply to all three cordons, each way.

One surprising feature of these runs is that the B25 and B50 runs show a disbenefit to freight. This had not occurred for A25 or A50 (see Table 5.2) and is hard to explain. We presume that freight experienced a mix of benefits and disbenefits as charges are imposed and that the net effect for A25 and A50 was positive, whereas for B25 and B50 the net effect was negative due to loss of benefits in Central London from traffic reduction attributable to the screenline charges. As a rough guide to the magnitude of the revenue from these screenline charges, we can compare Local Government benefits in Table 5.2 with those in Table 6.2. For A25 the benefits are twice those for B25 (£101.8M p.a. as against £50.4M p.a.) and the position is similar for the 50p and 100p charges. Clearly the dropping of the screenline charges is not a trivial matter, and so the reported effect on freight is plausible.

Another way of looking at the general relationship between Table 5.2 and Table 6.1 is that each penny of crossing charge in Table 5.2 has roughly the same impact as 2p of crossing charge in Table 6.1. For example, whereas 45/50p was optimal in Table 5.2, it appears that 100p (or a little over that) is optimal for Table 6.1. Interpolation using statistical techniques suggests 102.5p as the "exact" optimum, but we are not working to that level of accuracy and so we will call this 100p. Above this charge level the receipts level off and the disbenefits to households are no longer exceeded by the combined increased benefits to freight and public transport operators.

Table 6.1: Benefits from adding road pricing to the LPAC Preferred Strategy, using the 3-cordon charging structure (denoted B). Figures for 2001 in £M p.a.

Code	B25	B50	B100	B150	B200
Crossing Charge	25p	50p	100p	150p	200p
Household Types					
C01	-3.6	-5.0	-7.6	-9.7	-11.3
C02	-2.0	-2.5	-4.1	-5.7	-6.9
C03	-2.0	-2.2	-4.1	-6.4	-8.1
C11	-10.0	-14.4	-21.4	-25.8	-28.1
C12	-23.6	-34.3	-52.2	-64.1	-70.0
C13	-12.2	-16.8	-27.8	-37.4	-43.2
Households	-53.3	-75.2	-117.1	-149.1	-167.6
Freight	-24.7	-7.6	6.9	15.6	20.2
Operators	23.4	31.3	43.2	53.8	60.4
Local Government	50.4	79.4	100.4	109.7	103.0
UK Government	-1.4	-3.2	-4.0	-4.3	-4.4
TOTAL	-5.5	24.8	29.3	25.6	11.7

Table 6.2: Distributional implications of the results of Table 6.1

Household Type	% of Households	% of Persons	% of Trips	% of Net Disbenefits				
				B25	B50	B100	B150	B200
C01	18	10	6	7	7	7	7	7
C02	7	6	4	4	3	4	4	4
C03	7	6	6	4	3	4	4	5
C11	18	16	15	19	19	18	17	16
C12	30	35	38	44	46	45	43	42
C13	20	27	31	23	22	24	25	26

NB. As elsewhere (unless otherwise stated), a common value of time has been assumed for all household types.

Table 6.2 reports the distributional effects of the various charge levels with this structure. Poor non-car owners disbenefit in proportion to their trip making. Other non-car owners disbenefit less than in proportion to their trip making. In all cases non-car owning households disbenefit less than in proportion to their numbers. Poor and middle income car owners disbenefit more than in proportion either to their numbers or their trip making, faring slightly worse than they did with Structure A charging (Table 5.3). Rich car owning households disbenefit less than in proportion to their trip making, but more than in proportion to their numbers as for Structure A. Once again there is little change in the distribution of disbenefits as the charge level is increased. Comparing the two charging structures, A and B, at their optimal charge (A50 and B100) there is little difference in the incidence of disbenefits; the main difference being the relatively worse position of middle income car owners under B100.

7. THE IMPACT OF ROAD PRICING FOR THE CENTRAL CORDON STRUCTURE (STRUCTURE C)

We now turn to the third pricing structure tested, denoted C, namely the single cordon around Central London. Benefit results are presented in Table 7.1. Clearly a given crossing charge will now raise much reduced revenue since the number of charged cordons has been reduced by a factor of three. Hence, if we compare the Local Government benefit of a 100p crossing charge, Table 7.1 shows £38M p.a. while Table 6.1 shows £100M p.a. It follows that we shall be interested in much higher charge levels than for structures A or B. By starting testing at a 100p crossing charge we observe none of the disbenefits to freight noted in Table 6.1.

The optimal charge appeared to be in the range 400p to 600p, so an additional run was made at 500p, which turned out the best of those run. Statistical interpolation suggests 462p as the "exact" optimum. Interestingly this is four and a half times the optimal charge for Structure B, rather than three as might have been expected. The revenue from these high charges, though, is much smaller than that for the lower charges of Structure B. There the B100 revenue was about £100M p.a., whereas the C400 revenue is less than £30M p.a., and falling as the crossing charge is increased.

For the first time in these tables, we see the disbenefit to households falling as the charge is raised. However, the local authority simultaneously loses a vast amount of charge and parking revenue. For the optimum Structure A charge (A50) the disbenefit to households was £171.5M p.a. For the optimum Structure B charge (B100) the disbenefit to households was £117.1M p.a. For the optimal Structure C charge in the range C400 to C500, we find the disbenefit to households much lower, at £73M to £64M p.a. Conversely, the associated benefits to public transport operators and Local Government are also lower, although freight does very well. The overall highest net benefit of all runs is for A50, which has a net benefit of £38M p.a. The limited size of revenues generated for Local Government substantially reduces the benefits of Structure C. Again, A50 is the best in this respect, with £150M p.a. generated for Local Government. Structure A is also the most robust against "overcharging", i.e. setting the charge too high. Setting charges at twice the optimum level for Structure A reduces total net benefit by 50% (A100), but for Structure B this rises to 60% (B200 v B100) and for Structure C over 100% of the total net benefits are lost.

Turning to the distributional effects of Structure C, we find that Table 7.2 shows a much less satisfactory picture than Tables 5.3 or 6.2. At our optimal range (C400 to C500) poor non car owners disbenefit in more than twice the proportion to their trip making, although still not quite in proportion to their numbers. Middle and high income non-car owners disbenefit more than in proportion to their numbers or their trip making. Poor car owners disbenefit roughly in proportion to their numbers, but slightly more than proportionately to their trip making. Middle income car owners disbenefit in proportion to their numbers, but much less than in proportion to their trip making. Rich car owners are the big gainers, disbenefiting much less than in proportion to their trip making and even less than in proportion to their numbers. Furthermore, these inequities are no longer stable against level of charge, but become increasingly regressive as charges are raised.

Table 7.1: Benefits from adding road pricing to the LPAC Preferred Strategy, using only the central (ie "innermost") cordon (denoted C). Figures are net benefits in £M for 2001.

Code	C100	C200	C400	C500	C600	C800
Crossing Charge	100p	200p	400p	500p	600p	800p
Household Types						
C01	-6.1	-9.4	-12.1	-12.1	-12.0	-11.4
C02	-3.3	-5.8	-7.7	-7.2	-6.5	-4.7
C03	-3.8	-7.1	-10.4	-9.5	-8.4	-5.1
C11	-9.3	-11.7	-11.9	-11.4	-11.4	-10.3
C12	-20.6	-24.8	-19.9	-16.4	-14.8	-9.6
C13	-12.1	-15.4	-11.2	-7.7	-6.2	-2.8
Households	-55.2	-74.2	-73.1	-64.2	-59.2	-43.8
Freight	1.9	18.1	37.6	40.9	41.8	52.4
Operators	22.3	27.1	34.5	36.5	40.0	43.2
Local Govt.	38.0	38.5	26.0	12.9	-2.1	-46.8
UK Govt.	-3.5	-4.3	-5.5	-5.8	-5.9	-7.2
TOTAL	3.6	5.1	19.6	20.4	14.5	-2.1

Table 7.2: Distributional impacts analysis of the results of Table 7.1

Household Type	% of Households	% of Persons	% of Trips	% of Net Disbenefits					
				C100	C200	C400	C500	C600	C800
C01	18	10	6	11	13	17	19	20	26
C02	7	6	4	6	8	11	11	11	11
C03	7	6	6	7	10	14	15	14	12
C11	18	16	15	17	16	16	18	19	24
C12	30	35	38	37	34	27	26	25	22
C13	20	27	31	22	21	15	12	11	6

NB. As elsewhere (unless otherwise stated), a common value of time has been assumed for all household types.

8. COMPARISON OF CHARGING STRUCTURES

Table 8.1 compares the best runs under each structure, i.e. approximately optimal charge levels. Car owners clearly do worst under the A structure, while the C structure is worst for non-car owners. For some reason freight does not do well under the B structure; it does best under the C structure. Public transport operators do best under the A structure, but there is not much difference. Local Government does best under the A structure. When comparing the effects of the three charging structures, we should remember that the differences are not merely spatial, but temporal. The outer two cordons in both structures A and B apply off-peak only, whereas the whole of Structure C's charging operates all day.

Table 8.1: Comparison of the net benefits of optimal charge runs for the three charging structures. Figures in £M for 2001.

CODE	A50	B100	C400	C500
Household Types				
C01	-10.7	-7.6	-12.1	-12.1
C02	-7.5	-4.1	-7.7	-7.2
C03	-9.2	-4.1	-10.4	-9.5
C04	-28.5	-21.4	-11.9	-11.4
C05	-72.6	-52.2	-19.9	-16.4
C06	-43.1	-27.8	-11.2	-7.7
Households	-171.5	-117.1	-73.1	-64.2
Freight	19.9	6.9	37.6	40.9
Operators	44.7	43.2	34.5	36.5
Local Government	150.7	100.4	26.0	12.9
UK Government	-5.4	-4.0	-5.5	-5.8
TOTAL	38.4	29.3	19.6	20.4

Distributional effects will in practice be mitigated or exacerbated by whatever is done with the charge revenues raised. Table 8.2 investigates the effect, for the runs given in Table 8.1, of distributing government (local and national) net revenues in proportion to household numbers. We are not suggesting that such a scenario is at all likely. In the recent past surplus government revenues have been dissipated in income tax reductions, favouring the rich.

The most striking feature of Table 8.2 is that non-car owners are shown as net beneficiaries of structures A and B with their optimal charges (A50 and B100). Conversely, middle and upper income car owners are worst off under those structures. All households disbenefit for Structure C, the benefits mostly going to freight. This again suggests that the C structure should not be considered favourably. From Table 8.2 the choice between A50 and B100 becomes clearer. We had previously seen A50's advantage in overall net benefit. We now see that A50 has no negative aspects relative to B100. Poor non-car owners are protected, and poor car owners have relatively little net disbenefit. Middle and upper income car owners lose out, but the large disbenefit figures shown are spread out over a large proportion of households (45% in these two groups).

Table 8.2: Comparison of the net benefits of optimal charges for the three charging structures, with national and local government net benefits redistributed to households in proportion to their numbers. Figures in £M for 2001.

CODE	A50	B100	C400	C500
Household Types				
C01	15.5	9.8	-8.4	-10.8
C02	2.7	2.6	-6.2	-6.7
C03	1.0	2.6	-8.9	-9.0
C11	-2.3	-4.0	-8.2	-10.1
C12	-29.0	-23.3	-13.7	-14.3
C13	-14.0	-8.5	-7.1	-6.3
Households	-26.2	-20.8	-52.5	-57.1
Freight	19.9	6.9	37.6	40.9
Operators	44.7	43.2	34.5	36.5
TOTAL	38.4	29.3	19.6	20.4

Table 8.3: Comparison of the net benefits of optimal charge runs for the three charging structures, with national and local government net benefits redistributed to households in proportion to their tripmaking. Figures in £M for 2001.

CODE	A50	B100	C400	C500
Household type				
C01	-2.0	-1.8	-10.9	-11.7
C02	-1.7	-0.2	-6.9	-6.9
C03	-0.5	1.7	-9.2	-9.1
C11	-6.7	-6.9	-8.8	-10.3
C12	-17.4	-15.6	-12.1	-13.2
C13	1.9	2.1	-4.8	-5.5
Households	-26.2	-20.8	-52.5	-57.1
Freight	19.9	6.9	37.6	40.9
Operators	44.7	43.2	34.5	36.5
TOTAL	38.4	29.3	19.6	20.4

Many transport commentators have supposed that revenues would be used to improve public transport, thereby benefiting the poor and/or non-car owners. This however would require further strategy tests with the model. A simpler way of testing such an approach is to distribute the net receipts to government in proportion to tripmaking. Table 8.3 repeats the exercise, but with net benefits of central and local government distributed amongst householders in proportion to their tripmaking. This clearly shows Structure C to be much more regressive than Structure A, although rich car owners actually fare better under A50 than either C400 or C500. Rich non-car owners do best under Structure B. In all cases middle income car owners face disbenefits but for Structure A these are more than proportional to their tripmaking while for Structure C they are less than proportional.

The results shown in Tables 8.2 and 8.3 are only meant to be illustrative of what might be the overall distributional effects. If the revenue were used to help poorer households, with subsidised good quality public transport, then they might even become net beneficiaries overall. No account is taken here, of course, of the potential adverse effect of road pricing on city centre facilities, which, if it caused migration of these beyond the M25, would impose great disbenefits on non-car owners. However, the structure which might be expected to be most generally affected by such effects, (namely C, the Central cordon only) does not emerge from the limited testing performed in this paper at all well.

9. CHANGES IN ROAD TRAFFIC

In this section we will investigate the implied elasticities of car trips with respect to changes in the charge. Working Paper 345 (Fowkes, Sherwood and Nash (1993)) has given the evidence on elasticities that we have found from investigating the literature. We now wish to find the implied elasticities built into our START model of London, and investigate how they vary in response to various input changes. In particular, if we were to find the implied elasticity at our starting position to be implausible, then we could adjust the parameters of the model to rectify this. In the event this was unnecessary as the implied elasticities at the starting position were small, but not implausibly small given the findings of our literature review and other relevant considerations.

In some cases we were able to measure elasticities at particular points by performing two runs very close together, e.g. a charge of 50p and a charge of 50.5p. However, this is very expensive in computing time and even in physical computer "space" requirements. We were already using a very expensive microcomputer (not funded by this project) and the file sizes were such that downloading to other computer storage systems was deeply unattractive. Consequently, the number of runs of START that could be kept for in-depth analysis was limited, and preference had to be given for trying meaningfully different charge values rather than 1% variations. However, some of the latter were performed and these are reported next. Thereafter, elasticity values are derived as "arc elasticities" based on sizeable changes in charges.

The workings of the START model did not permit disaggregation of the traffic statistics by our car ownership/income classification. Hence all our elasticities are for car trips by all households. It was possible to disaggregate trips (but not trip kilometres) by the four START journey purposes:-

HBW: Home Based Work
HBE: Home Based Education
HBO: Home Based Other
NHB: Non-Home Based

Unfortunately, the traffic statistics available from the EVAL program as supplied related to the whole road system, including trips to/from external zones, i.e. well beyond London. This is one reason for expecting relatively low elasticity values from the model.

A further reason for expecting low elasticity values is that the values we shall derive are not "pure" elasticities in the usual sense. By this we mean that "all else" has not been held constant. As we change the charge level, the model's many adjustment mechanisms work to counter the direct effect of the charge. For example, as the charge level is raised there will be a direct effect as some traffic is priced off the roads. This direct effect is what we would wish to have in order to calculate a pure elasticity. However, the model immediately adjusts to the new situation by noting that congestion has fallen, and hence road speeds have risen. This is allowed to have an effect on traffic levels by attracting additional road traffic to partly take the place of those priced off. These additional users will be ones who judge the extra monetary cost to them (if any) to be outweighed by the true saving. For example, if a cordon charge scheme is used, some traffic passing through the cordon will be priced off. There is then more road space for traffic operating within that cordon, and so facing no charge. The model's reported traffic statistics, used here to calculate elasticities, are the composite of all direct and indirect effects of the charge. Since there are likely to be significant offsetting effects, we should expect the measured elasticities to be significantly lower than the corresponding true "pure" elasticities. However, for policy makers, similarly unable to hold all else constant, the elasticities presented here are likely to be most relevant.

Tables 9.1 and 9.2 give some elasticity results for Structure A applied to the LPAC preferred strategy. Table 9.1 presents point elasticity estimates, first for the pure charge, and secondly for total car costs, where other (ie non-charge) costs are taken to be equivalent to the charge costs at the £1 level. This latter assumption is purely arbitrary since we have no data on the proportions paying charges, the amount they pay, or the time average level of non-motoring costs. The small survey by HFA, ITS, ACCENT (1993) found the average car journey cost to be £2.05 for an average journey of 24 miles (out and back). The higher "other" car costs are, the lower the proportion that the charge will form of total cost and so the higher will be the estimate of elasticity resulting from any given fall in car trips. Furthermore, for structures A and B the charging at the outer cordons is peak only. In any event, under all structures, there is no suggestion that all trips will face charges.

Table 9.1 shows that the pure charge elasticities are very small. A 1% change in charge causes about a 0.03% change in trips. Non-home based trips are the most elastic and "Home Based Other" trips least elastic, although there are some "blips" in the data. The charge elasticities do not appear to vary much with the charge level, which is surprising.

The cost elasticities were derived by scaling up the charge elasticities to take account of the assumption that a 1% change in charge is a much smaller percentage change in cost. The results in Table 9.1 show that a typical value of cost elasticity is -0.06, i.e. a 1% change in cost will bring about a 0.06% change in trips. The relativities with respect to journey purpose are, by definition the same as for the charge elasticities. It also follows from the lack of relation between the charge elasticities and the charge levels, that the cost elasticities must fall with charge level. This is a rather undesirable result. The actual sizes of the cost elasticities are not out of line with values from the literature or as found by HFA, ITS, ACCENT (1993), but the patterns and relationships of the various values are not pleasing.

Turning to Table 9.2 we move from point elasticities to arc elasticities, here defined as

$$EL\ (TRIPS;\ COST) = \frac{(Trips\ 1 - Trips\ 2)\ (Cost\ 1 + Cost\ 2)}{(Trips\ 1 + Trips\ 2)\ (Cost\ 1 - Cost\ 2)}$$

Also shown is the base data on trips at the various charge levels, and the same data expressed as percentages of the trips at zero charge. It can be seen that even the £1 charge level has little effect on trip levels, for no journey purpose causing more than a 5% suppression of trip numbers. Home Based Education is least affected by the charges, and this is confirmed by the cost elasticity figures given, again on the assumption that "other" costs are the equivalent on average to the £1 charge costs. This result is contrary to that of HFA, ITS, ACCENT (1993) who found education at the top end of the elasticity range. However, peculiarities in their sample could explain this away, since it was only at very high charge levels that this was pronounced. Moreover, many HBE trips are of short distance, and less likely to cross charging cordons.

Table 9.1: Point elasticities for various charge levels on the LPAC Preferred Strategy, with the LPAC Structure (denoted A)

DEMAND = CAR TRIPS

Journey Purpose	Pure Charge Elasticities			Cost Elasticities Assuming "Other" Costs = £1 Charge Level		
	A25	A50	A100	A25	A50	A100
HBW	-0.039	-0.016	-0.034	-0.197	-0.048	-0.068
HBE	-0.030	-0.003	-0.029	-0.149	-0.009	-0.058
HBO	-0.020	-0.020	-0.025	-0.101	-0.060	-0.050
NHB	-0.037	-0.032	-0.040	-0.185	-0.096	-0.080
ALL	-0.032	-0.020	-0.032	-0.158	-0.060	-0.064

Table 9.2: Arc elasticities for various charge level combinations on the LPAC Preferred Strategy, with the LPAC Structure (Denoted A)

Code	0	A25	A50	A100
Crossing Charge	0	25p	50p	100p
(i) Base Data - Daily Car Trips by Purpose at each Charge Level				
HBW	3639552	3581564	3542398	3485692
HBE	657953	655918	653053	646025
HBO	3284961	3232307	3198345	3151323
NHB	1996198	1962305	1937495	1900350
ALL	9578665	9432094	9331292	9183389
(ii) Base Data Converted to Percentage of "Zero Charge" Trips				
HBW	100	98.407	97.331	95.773
HBE	100	99.691	99.255	98.187
HBO	100	98.397	97.363	95.932
NHB	100	98.302	97.059	95.198
ALL	100	98.470	97.417	95.873
(iii) Arc Cost Elasticities for moving from Zero Charge to Stated Charge, assuming that "Other" Costs at Zero Charge are equivalent to the 100p Charge				
HBW		-0.072	-0.068	-0.065
HBE		-0.014	-0.019	-0.027
HBO		-0.073	-0.067	-0.062
NHB		-0.077	-0.075	-0.074
ALL		-0.069	-0.065	-0.063

The average level of the cost elasticities is once again around -0.06, with most journey purposes showing values around -0.07, the average being brought down by the low elasticities for education, discussed above. Of the rest, Non-Home Based trips have the highest elasticities, but there is not much difference between them. Three sets of arc elasticities have been found, by comparing each charge level in turn with the non-charge situation. We could have compared pairs of charge levels, and did in fact do a few of these, but this course was not felt worth pursuing.

HFA, ITS, ACCENT (1993) had found arc cost elasticities to rise as higher charges were imposed, but Table 9.2 shows no evidence of this. The former study had found particularly high arc elasticities, sometimes approaching unity but these were for very large charge levels. Section 5 of this paper found the optimal charge level for this charge structure to be about 50p, so there seems little to be gained in considering charges outside the range presented in Table 8.2.

Table 9.3 repeats the exercise but for Structure B (ie just the three cordons). Daily car trips are shown for 25p, 50p, 100p, 150p and 200p charges in part (i) of the table, and these are comparable with the "0" column of Table 9.2, where the zero charge trip numbers are shown. Taking percentages for the former of the latter gives part (ii) of the table. Even a 200p charge never causes more than a 4% reduction for any journey purpose. Most interestingly, we see that the model predicts that education trips (HBE) will be greater with a 25p or 50p charge than without a charge. This can be put down to the complex second order effects described earlier, which we generally feel are greatly reducing our measured elasticities relative to the true pure elasticities. With percentages greater than 100% it is, of course, impossible to get an elasticity estimate at all. For the other entries the corresponding elasticity values are reported in part (iii) of the table, where it has been assumed that the non-charge motoring costs are equivalent to the 200p charge, on average. In Table 9.2 we had used a 100p charge, but that charging structure included screenline charges and we gave reasons in Section 6 for believing that every penny of charge in Structure A was equivalent to 2p of charge in Structure B.

Looking at Table 9.3 (iii) in more detail, we again see very low elasticities for education. The only way for us to explain this is to say that the predicted traffic levels for 2001 in London are sufficiently high for congestion effects to hold a lot of education related trips off of the road, going instead by foot, cycle or public transport. With road pricing, congestion is reduced and relatively few education trips are affected by charges due to their generally short distance nature (i.e. tending not to cross cordons). The improved road conditions therefore cause education trips to switch mode to car, leading to the sort of result we have obtained. These figures certainly do not represent a pure price elasticity.

Leaving aside education, most of the other elasticities are not much different from the -0.06 previously found. They do tend to be lower than those shown in Table 9.2 for Structure A, though. At the optimal charge (B100), one might say that a typical elasticity was -0.05. The derived elasticities tend to fall as the charge level increases.

Table 9.4 repeats the same exercise, but for the central cordon only structure (C). Again predicted car trips for each charge level, by journey purpose, are shown in part (i). Interestingly, work trips initially decline as charge rises (as expected) but at about a 400p charge they start to rise again. This is consistent with the belief that work journeys to Central London tend to be by public transport, with car being a minor mode. Hence we might expect a central cordon not to intercept relatively many car work trips. As other, possibly "through" traffic is removed from people's localities by the effect of the central charge, then new car work trips can take advantage of the eased congestion conditions. As has been commented earlier, the elasticity values calculated will be composite ones and not pure price elasticities.

Table 9.3: Arc elasticities for various charge level combinations on the LPAC Preferred Strategy, with the 3 cordon charging structure (denoted B)

Code	B25	B50	B100	B150	B200
Crossing Charge	25p	50p	100p	150p	200p
(i) Base Data - Daily Car Trips by Purpose at each Charge Level					
HBW	3612345	3591451	3560699	3540136	3525077
HBE	658264	658299	657235	655399	653229
HBO	3260907	3247630	3225364	3208437	3195554
NHB	1980990	1969956	1951642	1938851	1928538
ALL	9512506	9467337	9394938	9342824	9302399
(ii) Base Data Converted to Percentage of "Zero Charge" Trips					
HBW	99.252	98.678	97.833	97.268	96.855
HBE	100.047	100.053	99.891	99.612	99.282
HBO	99.268	98.864	98.186	97.670	97.278
NHB	99.238	98.685	97.768	97.127	96.611
ALL	99.309	98.838	98.082	97.538	97.116
(iii) Arc Cost Elasticities for moving from Zero Charge to Stated Charge, assuming that "Other" Costs at Zero Charge are Equivalent to the 200p Charge at the 3 Cordons					
HBW	-0.064	-0.060	-0.055	-0.051	-0.048
HBE	-	-	-0.003	-0.007	-0.011
HBO	-0.063	-0.051	-0.046	-0.043	-0.041
NHB	-0.065	-0.060	-0.056	-0.053	-0.052
ALL	-0.059	-0.053	-0.048	-0.046	-0.044

Part (ii) of Table 9.4 reports the percentage of zero charge trips that continue at each charge level. Part (iii) reports the implied elasticities. Again these tend not to be too far removed from -0.06. The work elasticities (HBW) become very small, for reasons just discussed, as the charge level increases. Education elasticities are low, but not as low as for the other charging structures (Table 8.2 and 8.3). The assumption made for non-charge motoring costs in Table 8.4 (iii) is that they are equivalent to an 800p charge. This is consistent with our earlier finding that 1p of charge on Structure B was equivalent to 4p on Structure C. If too high it would explain some of the high elasticity values obtained for the lower charge values in Table 8.4 (iii). For the optimal range of charges, as found earlier, namely C400 to C500, if we exclude work and education for the reasons previously discussed, a typical elasticity of -0.06 once again emerges.

Before closing this section we repeat once more that what we have referred to as elasticities are by no means price elasticities in the usual sense. Firstly, demand has been allowed to recover from a price increase by second round effects due to road congestion changes. Secondly our demand variable, car trips, relates to all such trips modelled, many of which will not face any charge (for a variety of reasons).

Table 9.4: Arc elasticities for various charge level combinations on the LPAC Preferred Strategy, with just the central cordon (denoted C)

Code	C100	C200	C400	C500	C600	C800
Crossing Charge	100p	200p	400p	500p	600p	800p
(i) Base data - daily car trips by purpose at each charge level						
HBW	3614053	3605149	3599478	3601985	3605539	3610831
HBE	656022	654243	650653	649457	648370	646344
HBO	3244672	3223285	3200081	3195318	3192467	3190935
NHB	1976086	1964339	1949725	1942841	1942841	1938452
ALL	9490833	9447018	9399939	9392366	9389219	9386564
(ii) Base data converted to percentage of "zero charge" trips						
HBW	99.299	99.055	98.899	98.968	99.065	99.211
HBE	99.707	99.436	98.890	98.709	98.544	98.236
HBO	98.774	98.122	97.416	97.271	97.184	97.138
NHB	98.992	98.404	97.672	97.465	97.327	97.107
ALL	99.083	98.626	98.134	98.055	98.022	97.994
(iii) Arc cost elasticities for moving from zero charge to stated charge, assuming that "other" costs at zero charge are equivalent to the 800p charge at the cordon						
HBW	-0.060	-0.043	-0.028	-0.022	-0.017	-0.012
HBE	-0.025	-0.025	-0.028	-0.027	-0.027	-0.027
HBO	-0.105	-0.085	-0.065	-0.058	-0.052	-0.044
NHB	-0.086	-0.072	-0.059	-0.054	-0.050	-0.044
ALL	-0.078	-0.062	-0.047	-0.041	-0.037	-0.030

10. SENSITIVITY TESTING FOR THE EFFECT OF CHANGE IN THE MODEL PARAMETERS

It is our understanding that the parameters of the London START model were carefully determined to be those most consistent with the available evidence, and we have no specific reason to doubt these values. However, all estimates are subject to some uncertainty, and so we wished to obtain a feel for how robust our results would be to changes in these parameters. Furthermore, part of the project objective was to investigate the elasticity of traffic to road pricing, and one obvious way of affecting the model's elasticities is to change the model's parameters.

However, START is a very large and complicated model and its parameters must clearly be viewed as a whole, i.e. the value of any particular parameter will have been chosen to be consistent with the remaining parameters. Having regard to the time and modelling expertise available to us, it was clear that only relatively simple changes to the model's parameters could be contemplated. In particular, the model contains a complex hierarchical nesting and we decided that we could meet our objectives without interfering with it. This left the obvious course of action of changing all the model's logsum parameters (here referred to as "lambdas") by a common factor (here denoted λ). These parameters weight the utility values used to predict choices.

Our first experiment was to radically shake the model by a large change to these parameters, and so doubled them. Perhaps not unsurprisingly the model would not run with these parameter values. This negative result was helpful to us in confirming that it was probably only sensible to look at quite small changes to the parameters. Accordingly, we next decided to factor up all the logsum parameters by 10%. This time the model did run and the results are summarised in Tables 10.1 to 10.3.

Table 10.1 shows the distribution of benefits from the base model (the LPAC Preferred Strategy, without charges) as reported in Table 4.1. This is denoted U. Alongside are the new results denoted λ, obtained by multiplying the logsum parameter by 1.1. It can be seen that the distribution of benefits over household types is hardly affected, the changed parameters only having indirect effects. The benefit to freight is also little affected. However, there is a big shift in benefits away from transport operators to households. Given the present unsettled state of the London bus market, we would in any event not have wished to put much reliance on the model's split of benefits between bus users and bus operators for the year 2001. The overall benefit is slightly higher.

Table 10.2 reports tests designed to find the optimum charge. The LPAC regime (Structure A) was assumed and so the relevant table for comparisons is Table 5.2. All the entries in Table 10.2 are taken relative to those (for λ) in Table 10.1 and so already start with slightly higher benefits than the equivalent figure in Table 5.2. Despite this, the increased benefits relative to the uncharged situation are themselves higher in Table 10.2 than they are in Table 5.2. Once again, it is household benefits which have increased.

We were unable to perform a run with a 25p charge due to model non-convergence and so used a 30p charge instead. The optimal charge is slightly below 50p, which is the result obtained from Table 5.2 too. As there, rough interpolation suggests an optimum around 45p. Based on this limited evidence our feeling is that our results regarding optimal charges are unlikely to be adversely affected by any imprecision in the estimates of the logsum parameters used in the model.

Table 10.3 investigates the distribution effects when using the revised logsum parameters, and should be compared with Table 5.3. Again, the pattern of distributional benefits is remarkably similar between the two tables. Again, we conclude that the analysis of distributional effects presented in this paper is unlikely to be overly sensitive to any imprecision in the estimates of the logsum parameters used.

Table 10.1: Comparative benefits, using the LPAC Preferred Strategy without charges, of the model with its usual parameters (denoted U) and with these parameters raised by 10% (denoted λ)

	Benefit (£M in 2001) U	Percentage of Household Benefits U	Benefit (£M in 2001) λ	Percentage of Household Benefits λ
Household Types				
C01	7.5	5	8.4	5
C02	8.1	6	9.1	5
C03	12.8	9	14.5	8
C11	18.5	12	21.8	12
C12	54.4	37	64.5	37
C13	47.0	32	55.2	31
Households	148.1		177.1	
Freight	18.6		22.4	
Operators } Local Government } UK Government }	43.3		14.1	
TOTAL	210.0		213.6	

Table 10.2: Effect of placing various charges onto the LPAC Preferred Strategy, having raised the model parameter (the lambdas) by 10%. Figures in £M for 2001.

Code	λA30	λA50	λA100
Crossing Charge	30p	50p	100p
Household Types			
C01	-7.1	-9.9	-13.3
C02	-4.3	-6.6	-10.8
C03	-4.8	-8.0	-14.6
C11	-18.6	-26.3	-38.7
C12	-45.9	-66.6	-100.6
C13	-25.2	-39.1	-65.4
Households	-105.9	-156.5	-243.4
Freight	10.0	21.3	34.0
Operators } Local Government } UK Government }	144.4	186.5	249.7
TOTAL	48.4	51.3	40.3

Table 10.3: Distributional impacts of the results of Table 10.2

Household Type	% of Households	% of Trips	% of Net Disbenefits		
			λA30	λA50	λA100
C01	18	6	7	6	6
C02	7	4	4	4	4
C03	7	6	4	5	6
C11	18	15	18	17	16
C12	30	38	43	43	41
C13	20	31	24	25	27

NB. As elsewhere (unless otherwise stated) a common value of time has been assumed for all household types.

Table 10.4: Arc elasticities for various charge level combinations on the LPAC Preferred Strategy, with the LPAC Charging Structure (denoted A) with the model parameters (the lambdas) raised by 10%

CODE	0	A30	A50	A100
Crossing charge	0	30p	50p	100p
(i) Base data- Daily Car Trips by Purpose at each Charge Level				
HBW	3649998	3578449	3546110	3488211
HBE	657000	654419	651913	644502
HBO	3278701	3215797	3188204	3141397
NHB	1995130	1954474	1934191	1896699
ALL	9580831	9403200	9320420	9170809
(ii) Base data converted to Percentage of "Zero Charge" Trips				
HBW	100	98.040	97.154	95.567
HBE	100	99.616	99.226	98.098
HBO	100	98.081	97.240	95.812
NHB	100	97.962	96.946	95.066
ALL	100	98.146	97.282	95.720
(iii) Arc Cost Elasticities for moving from Zero Charge to Stated Charge, assuming that "Other" Costs at Zero Charge are equivalent to the 100p Charge.				
HBW		-0.089	-0.072	-0.068
HBE		-0.017	-0.019	-0.029
HBO		-0.087	-0.070	-0.064
NHB		-0.093	-0.078	-0.076
ALL		-0.084	-0.069	-0.066

Table 10.4 calculates arc elasticities with the logsum parameters multiplied by 1.1. Table 10.4 should be compared with Table 9.2, being careful to note that the A25 run could not be rerun for changed lambdas and so we present A30 instead. The elasticities in Table 10.4 are definitely higher but showing much the same pattern as Table 9.2. Education once again has very low elasticity. For the other journey purposes, except for the 30p charge which shows rather higher values; the typical elasticity value is -0.07. We might suppose that further raising the logsum parameters would further raise the elasticities, but to only a small extent before the model failed. Conversely, reducing the logsum parameters might be expected to reduce the implied elasticities somewhat. Relating the results here back to those earlier in this section, suggests that small changes in cost elasticities across the board would not have much effect on the determination of the optimum charge or the distributions of benefits, although it would affect the overall benefit. The caveat at the end of Section 9 on the interpretation of these 'elasticities' applies here also.

We could not see how to change the parameters of the model differentially for subgroups of travellers, and so were unable to investigate the effect of assuming different elasticities for different groups. In any event the literature search reported in WP 345 gave little guidance as to how this could be done. However, there will be an implicit effect on elasticities via the journey purpose/household type split of values of time we have used.

11. INVESTIGATING THE EFFECT OF EVALUATING TIME SAVINGS USING VALUES OF TIME APPLICABLE TO EACH HOUSEHOLD TYPE

In this section we investigate the effect of using variable values of time for evaluation. Up until now we have always used a common evaluation value of time for all household types. In fact, three values of time are used - one for work, one for non-work, and one for freight, but they do not vary by household type. We have used values of time that vary by household type for modelling the traffic effect of the charges. However, for evaluation we have followed the usual practice of using a common appraisal value (or equity value) of time. Since we had the individual relativities of the behavioural modelling values of time available by household type, we decided to investigate what would happen if these values were used for appraisal.

Firstly, we must introduce a note of caution. It must be realised that the overall value of time is, implicitly at least, a trip weighted average. Hence for given values of time by household type, any change in the distribution of trips by household type will throw out the average. Since changing the distribution of trips by household type is exactly what we are evaluating it is clear that there will be interpretational problems, and that there will be a case for constraining certain values to be equal to values found earlier. When, as with road pricing and with the LPAC Preferred Strategy, we are giving people time savings, it is hardly surprising if benefits rise as the evaluation value of time is raised. If by allowing trips to be switched from low value of time groups we raise the average value of time used for evaluation then we will see increased benefits. Depending on our purposes, we may or may not wish to do this.

Table 11.1 repeats the analysis of the LPAC Preferred Strategy using multiple values of time, both for modelling and evaluation. Overall benefits are seen to rise from £210M p.a. to £226M p.a., reflecting the higher average value of time assumed. Non-car owners disbenefit relatively, although rich non-car owners do benefit slightly in absolute terms. Poor car-owners disbenefit absolutely and relatively. Rich car owners benefit significantly both absolutely and relatively.

Table 11.1: The effect of using variable evaluation values of time for the LPAC Preferred Strategy. Figures are benefits in £M for 2001.

	SINGLE EVALUATION VOT	MULTIPLE EVALUATION VOT
Household Types		
C01	7.5 (5%)	5.7 (3%)
C02	8.1 (5%)	7.2 (4%)
C03	12.8 (9%)	13.1 (8%)
C11	18.5 (12%)	16.6 (10%)
C12	54.4 (37%)	55.7 (34%)
C13	47.0 (32%)	66.1 (40%)
Households	148.1	164.4
Freight	18.6	18.6
Others	43.3	43.0
TOTAL	210.0	226.0

NB. The bracketed figures show the percentage of household benefits by household type.

Table 11.2: Effects of placing various charges onto the LPAC Preferred Strategy using the LPAC structure (denoted A) with separate evaluation values of time for each household type. Figures are benefits in £M for 2001.

Code	MA25	MA50	MA100
Crossing charge	25p	50p	100p
Household type			
C01	-4.7	-7.4	-10.3
C02	-3.6	-6.3	-10.6
C03	-4.9	-9.5	-17.5
C11	-15.5	-24.8	-37.3
C12	-45.1	-74.8	-115.5
C13	-36.8	-65.5	-110.9
Households	-110.5	-188.4	-302.1
Freight	2.4	19.9	31.4
Others	128.1	186.8	255.8
TOTAL	19.9	18.3	-15.0

Table 11.2 shows the revised effects of charges on the LPAC structure, compared to the benefits from the LPAC Preferred Strategy. Comparing Table 11.2 with Table 5.2 we find poor non-car owners experiencing a reduction of up to a third in disbenefit, medium income non-car owners and low income car owners experiencing reductions of around a fifth in disbenefit, high income non-car owners and medium income car owners scarcely affected, and high income car owners

experiencing around a 50% increase in disbenefit. The optimum charge appears to have fallen to around 30-35p. While the household disbenefit at any level of charge has increased by about 10%, the disbenefit at the (lower) optimum charge is little different. These changes are consistent with the changes in evaluation values of time, and suggest that, on this basis, road pricing may be slightly more progressive than indicated in Sections 5-7.

The optimal charge appears to have fallen to the 30-35p range, but this has the implicit assumption that we accept the increase in trip weighted evaluation values of time from the value used in Table 5.2. This latter effect, however, does not appear to be large, total household disbenefits only rising by about 10%.

12. CONCLUSIONS

This paper has discussed the results of disaggregating the START model by income group and applying it to testing the magnitude and incidence of benefits from road pricing in London.

We examined three different approaches to pricing; charges for crossing each of three cordons at varying distances from Central London with a further charge for crossing screenlines within Central London, a similar structure without the screenlines, and a single charge for entering Central London. Whilst the outer cordon charges applied in the peak only the Central London cordon and screenlines applied all day. For each of these we found the overall best charge, which was about 50p in each directions per cordon or screenline crossed for the first option, £1p per cordon for the second and £5 for entering or leaving Central London in the third. Overall, the first of these options appeared the most effective, the second one was less beneficial and the third by far the poorest in its results.

We then looked at who gained and who lost. Obviously the public sector gained from the revenue, as did public transport and (in most cases) freight operators from an overall operating cost saving. Generally all groups of households lost. In most alternatives, the costs were roughly proportional to the number of trips made, and therefore were concentrated on better off and car owning households, who made more trips than other groups. However, the all day charge for entering Central London impacted far more heavily on poorer non car owning households than did the other two options. We also examined the effect of ploughing back the revenue the government gained from road pricing into the transport sector in such a way as to benefit households roughly in proportion to the number of trips they make. For the best road pricing option, this largely offset the effects of road pricing, although middle income car owners still had significant overall disbenefits. For the all day charge for entering Central London, other groups, including poorer non car owners, still had significant disbenefits. The results indicate that a government which wished to introduce road pricing but was concerned to ensure that no group incurred major disbenefits as a result would need to pay careful attention not just to how the revenue from it was used but also to the structure of pricing used.

While these results have important implications for the design of road pricing systems, it should be noted that they raise a series of questions, on the changes in trip making patterns, the effects of all day charging, and the impact of other road pricing structures, which still need to be addressed. The delay in acquisition of the model and its evaluation package have limited our ability, as yet, to explore these further issues.

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