THE IMPACT OF THE LONDON CONGESTION CHARGING SCHEME ON MOTORISTS FROM A VALUE OF TIME PERSPECTIVE

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Abstract

This paper shows that the impacts of the London Congestion Charging Scheme (LCCS) should not be analysed from the standard approach to Value of Travel Time Savings (VTTS). This will invariably lead to the mistaken conclusion that drivers who value their travel time savings below the £5 congestion charge will be regarded as losers from the Scheme. The use of a simple expression of generalised costs leads to different conclusions. First, a motorist who continues to drive but values the time savings of the LCCS less than £5 can still gain from the Scheme, if the generalised cost post-charging is lower than the generalised cost pre-charging. Second, a motorist who switches to the bus can still gain from the Scheme. Since the bus travel time post-charging will typically be lower than the bus travel time pre-charging, it is possible that the generalised cost of a trip by car pre-charging will be higher than the generalised cost of a trip by bus post-charging, even after taking into consideration the inconvenience of switching.

Keywords: London Congestion Charging; Value of time; Value of travel time savings; Road pricing
Topic Area: H10 Urban Transport Policy

1. Introduction

Travel time savings undoubtedly constitute one of the main benefits that motorists can obtain as a result of any congestion charging scheme. How any given pre-charging motorist values these time savings is clearly an important determinant of the overall impact of the scheme on him or her. Having said this, this paper highlights that a more complete assessment of the impact of a congestion charging scheme on pre-charging motorists requires a broader use of values of travel time savings.

Essentially, if values of travel time savings are used to evaluate time savings, they should also be used to evaluate the cost of the time actually spent travelling. In the context of the London Congestion Charging Scheme, the standard approach to determining the effect of charging on a given individual that continues to drive in the zone, is to evaluate the car travel time savings received and compare them to the £5 toll. Similarly for an individual that switches to bus travel, the bus travel time savings would be evaluated and compared to the inconvenience of switching. These comparisons are not incorrect but they are not enough to determine whether the individual gains or loses as a result of the Scheme. Where possible, though, implications of the London Congestion Charging Scheme using this standard approach

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are derived, although only on the basis of aggregate data on commuters to the City of London, an area entirely within the charging zone.

A revised, more complete, approach to using values of travel time savings in such an assessment is presented in this paper, and it is shown that the standard approach puts a negative slant on the predicted fate of both those that continue to drive and those that switch to bus travel. The practical relevance is examined, as far as possible, again in the context of the commuters to the City of London.

2. Theoretical and empirical background to the value of travel time savings

The theory underlying the value of a travel time saving is different depending on whether the individual receives it during or outside his or her working hours. However, in this paper, the emphasis will be on how individuals themselves value travel time savings. Strictly speaking, this value should be termed the individual, behavioural, or subjective value of travel time savings. However, for ease of exposition, the term value of travel time savings (VTTS) will be used, in all that follows, to specifically mean the value an individual puts on travel time savings received out of working hours.

There have been several distinct advances in the literature, which have led to the current microeconomic interpretation of the VTTS. It is useful to summarise these to add intuition to how it is actually defined today.

Becker (1965) was one of the first to allude to a 'value of time' (VOT). In developing his theory of time allocation, he extended standard consumer theory by replacing goods with basic commodities, which were a combination of market goods with a consumption (and preparation) time requirement (e.g. the eating of a meal). Since time was required for the consumption of basic commodities, constraints to utility maximisation needed to additionally reflect the scarcity of time. Crucially, Becker did not include a separate time constraint, but instead incorporated time into the standard budget constraint by assuming that working hours are flexible, so time is convertible into money by working more. Time, therefore, contributed to the consumption of basic commodities directly and indirectly, through its reallocation to work, which increased income and thereby the quantity of goods affordable. In equilibrium, time would fulfil its two roles equally well, so the VOT out of work equalled the value put on time spent in work. Since the latter was assumed to equal the wage rate, the VOT out of work was defined as the wage rate.

Johnson (1966) and Oort (1969) improved this definition by noting that the value an individual assigns to work time is probably not just the wage rate, since time spent in work, could well, itself, have a direct effect on utility[1]. The VOT was therefore better defined as the wage rate plus the marginal value of time spent in work.

Evans (1972) re-examined this work by Oort and Johnson. Additionally, however, he highlighted the importance of distinguishing between the value to an individual of (a) an increase in total time available and (b) a reduction in the time required in a particular activity. He explained that (b) is similar to (a), as it involves more time available for an individual (to reallocate as desired), but differs, in that it also involves the value put on spending less time in some activity. Assuming this additional item is not zero, (a) and (b) necessarily differ. Evans

[1] Work time therefore featured as an argument in the utility functions of their models, meaning that the time and budget constraint could not be combined as in Becker's approach, since work hours were no longer a pivotal variable (Jara-Díaz, 1998).

argued that Oort and Johnson mistakenly interpreted them as equal. This insight is important since the VTTS is identical to (b), with the relevant activity being travel.

The question then arose as to how one can model the value of saving time to be activity specific as Evans' distinction naturally implies. The answer comes in a paper by DeSerpa (1971)[2]. The important development is the addition of 'minimum time constraints', which reflected the fact that many activities involve a minimum time allocation, which, in several cases, will be above that which an individual would optimally choose. Additionally, times spent in all activities (including travel) were included as arguments of the utility function.

MVA *et al* (1987) present a model, influenced by DeSerpa's insights, which incorporates all of these elements. Thus, utility was a direct function of all goods and the times allocated to different activities. The first order conditions to this constrained optimisation problem reveal that:

$$\varphi_j/\lambda = \mu/\lambda - (\delta U/\delta t_j)/\lambda \qquad (1)$$

where t_j is time spent in activity *j* and the Lagrange multipliers λ, μ, and φ_j give the marginal value of income, the total time endowment, and decreasing time in *j*th activity[3] respectively.

Equation (1) shows that an individual's valuation[4] of a marginal reduction in travel time, φ_j/λ (taking *j* to represent travelling), is equal to the marginal value attained through effectively having more time, μ/λ, *plus* the marginal value of spending *less* time travelling, $-(\delta U/\delta t_j)/\lambda$. It is precisely φ_j/λ that is now the commonly accepted definition of a given individual's VTTS[5]. Thus, φ_j/λ, for a given individual, reveals what he or she is willing to pay for a marginal reduction in travel time.

The presence of $(\delta U/\delta t_j)/\lambda$ in Equation (1) is intuitive - the lower the marginal utility of travel time the more one is willing to pay to reduce it. Inclusion of μ/λ assumes that saved time is only reallocated to an activity, say *i*, in which the individual is not already spending more time than he or she would optimally choose, so $\varphi_i = 0$ (such an activity, in DeSerpa's terminology, was called a pure leisure activity). Hence the marginal value associated with the reallocation of saved time, $(\delta U/\delta t_i)/\lambda$, is simply μ/λ, as can be seen from Equation (1), since replacing the *j* with *i* means that $\mu/\lambda = (\delta U/\delta t_i)/\lambda$.

Given this definition, however, if one applies a single VTTS to evaluate the monetary equivalent of a given travel time saving, one implicitly assumes that marginal units of saved travel time are equally valued. In other words, the relevant individual's willingness to pay for a thirty minute travel time saving is equal to his or her willingness to pay for three separate (for example, on different days) ten minute travel time savings. Effectively, such use of a VTTS assumes that travel time savings are valued linearly. There is some evidence that confirms this. Small (1992) for example, reviews empirical studies on how small and how large time savings are valued, and concludes that such differences are negligible (p. 37, 38). Mackie *at al* (2003) also state that 'a constant value per minute is more defensible than any alternative', including lower than average or zero values for small time changes (Section 3, point 27).

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[2] Evans (1972) does not seem aware of DeSerpa's work.

[3] Multipliers in a Lagrangean give the change in the objective function evaluated at the optimum, due to a marginal relaxation of the relevant constraint.

[4] Value is defined in monetary terms. Hence, it involves dividing the relevant marginal utility by λ.

[5] Somewhat confusingly it remains a convention in transport literature to use the term VOT when what is meant technically is the VTTS.

2.1. Sources of variation

The intuitive notion that higher income individuals have a higher VTTS is made obvious by the expression φ_j/λ, in Equation (1). So long as the marginal utility of income (λ) is decreasing in income, individuals with higher incomes will have a higher VTTS, *ceteris paribus.* Aside from variations in λ, every other factor affecting φ_j/λ does so through its impact on $\delta U/\delta t_j$ and/or μ. Interpreting *j* as a specific type of travel shows that the VTTS of an individual may not only be dependent on travel mode, but also on the conditions of travel in the relevant mode. For example, the marginal utility of travel time in a crowded and non-crowded bus, for a given individual, may obviously differ, justifying the need for two different values of travel time savings.

$\delta U/\delta t_j$ may also vary for reasons unrelated to the nature of travel. In particular, the purpose of the trip in question could have an effect on $\delta U/\delta t_j$. Thus, one may be relatively unaffected by increasing travel time in a leisure journey, but may be significantly negatively impacted by increasing time in journeys where a specific arrival time is important, such as the journey to work. The VTTS, of any given individual, is also therefore likely to vary according to journey purpose.

The marginal utility of the total time available, μ, is independent of the characteristics of the travel being considered. Specific factors that would systematically affect μ are, however, not immediately obvious. In any case, as noted above, the presence of μ/λ in Equation (1) assumes that individuals are able to transfer saved travel time to a pure leisure activity. MVA *at al* (1987) however point out the problem of constrained transferability of time. Basically, the assumption that saved time can be transferred to a pure leisure activity is not very realistic.

The main sources of systematic variation in a given individual's VTTS, identified by this re-examination of theory, are therefore those that induce changes to $\delta U/\delta t_j$, which we have showed notably include trip purpose and the specific nature of travel.

2.2. Estimating the value of travel time savings

Where different modes involve different monetary and time costs for any given trip, mode choice data clearly contains useful information that can help one to estimate values of travel time savings. Beesley (1965) suggests a way to use this information. Specifically, he considers individuals choosing between two modes of travel, say A and B, and assumes that time and monetary costs are the only two modal attributes of interest to individuals. Each individuals' mode choice is plotted in Figure 1, which is now known as the 'Beesley graph' (Hensher, 2001).

Every dot depicts a particular mode choice scenario, with Δc and Δt indicating the attributes of B relative to A. For example, a point in the south-east quadrant represents an instance where an individual chose between A and B where B was more time expensive ($\Delta t > 0$) but less expensive in monetary terms ($\Delta c < 0$). Bold and hollow dots imply that A and B was chosen respectively.

A line through the origin is drawn, as above, so that, as far as possible, instances where mode A and B are chosen are north-east and south-west of the line respectively. This 'line of best fit' can be thought of as representing those combinations of Δc and Δt that make the average individual indifferent between mode A and mode B, as combinations either side of this line result, in the majority of cases at least, in a particular mode being selected. Consequently, the magnitude of the line's slope gives the 'average VTTS', or in other words, the change in monetary cost, which when combined with a marginal reduction in travel time, keeps the average individual just as well off.

Discrete choice modelling, using disaggregate mode choice data, has been used to progress from Beesley's basic approach[6]. The microeconomic basis for such an approach is that an individual's mode choice is governed by an effort to maximise modal utility, otherwise known as his or her conditional indirect utility function. It has been shown that the ratio of the coefficients on time and cost, which are estimated as part of the modal utility in such models, reflects precisely the VTTS as defined above, that is φ_j/λ in Equation (1) (Jara-Díaz and Guevara, 2003). Values of travel time savings for individuals with different incomes or travel purposes, for example, can be deduced using this procedure by segmenting the sample of individuals used in the estimation.

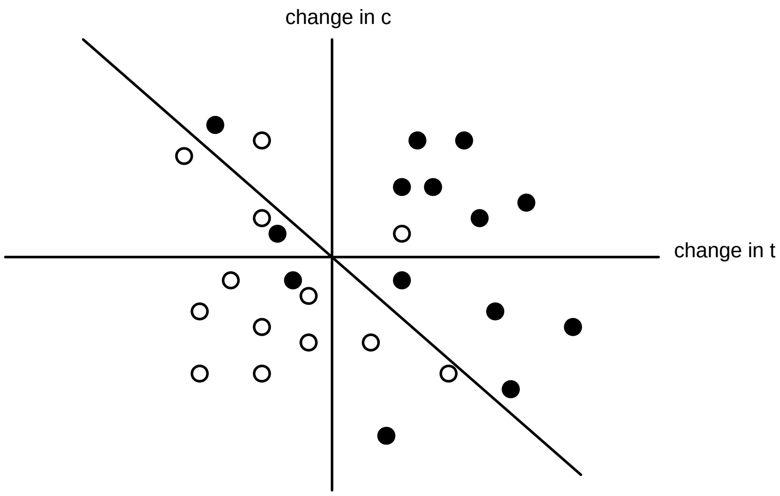

Figure 1: Beesley graph

In estimating values of travel time savings that are more specific (for example, for a particular mode), however, it is common to move away from (real-life) revealed preference data of mode choice, due to data limitations. In line with this, studies on the VTTS have tended to use stated preference data, which is much more readily obtainable.

2.3. Empirical findings for the UK

A recent and comprehensive source for values of travel time savings in the UK is a report to the Department for Transport by Mackie *et al* (2003). This report re-examines a substantial stated preference data set used in an earlier investigation commissioned by the same department in 1994. Additionally, the results are cross-referenced with those obtained from meta-analysis[7]. Table 1 details some of their recommended estimates.

Variation in the level of congestion essentially equates to a change in the specific nature of car travel (especially when considering drivers). This is a potentially prominent source of variation in a given individual's VTTS. The report by MVA *et al* (1987) gives an estimate of

[6] For details of discrete choice modelling, see Ben-Akiva and Lerman (1985).
[7] Statistical analysis which involves integrating results of many independent studies on the same issue.

the relationship between congestion and value of time. In the presence of congestion, the latter could be increased by up to 40% and in very congested conditions the increase could be higher (MVA *et al,* 1987, p. 176). Additionally, Wardman (2001), after conducting a substantial meta-analysis[8], concludes that time spent in congested traffic is valued 50% higher (p. 125).

Table 1: Estimates of the value of car travel time savings[9] at end of 1997 values

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

Source: Mackie *et al* (2003)
Note: p/min: pence per minute

3. The London Congestion Charging Scheme

The London Congestion Charging Scheme (LCCS) is essentially an area licensing scheme, which covers an area of approximately 21 km^2, representing 1.3% of the total 1,579 km^2 of Greater London. The limit is defined by the Inner Ring Road. All vehicles entering, leaving, driving or parking on a public road inside the congestion charging zone (CCZ) between 7 AM and 6.30 PM Monday to Friday, excluding public holidays are charged £5. No charge is made for driving on the Inner Ring Road itself.

The Scheme allows for a variety of exemptions and discounts. Exemptions include motorcycles and mopeds, emergency vehicles, buses and coaches with 9 or more seats, vehicles used by (and for) disabled persons, licensed London taxis and mini-cabs, certain military vehicles, and local government service vehicles (e.g. refuse trucks, street maintenance). Vehicles that can be registered to receive a 100% discount include alternative fuel vehicles (requires emission savings 40% above Euro IV standards) and roadside assistance vehicles. Residents can also register up to one car to receive a 90% discount.

The charge has to be paid in advance or on the day until 10 PM with late payment available between 10 PM and midnight but with the charge rising to £10. The charge can be paid daily, weekly, monthly or yearly. The fine for non-payment is £80, reduced to £40 for prompt payment within 14 days. Failure to pay the penalty charge within 28 days results in the penalty being increased to £120.

A summary of the impacts of the LCCS are provided in the reports published by Transport for London (TfL) in June and October 2003 and in February 2004 (TfL, 2003a, 2003b, 2004). The three main facts that are specific to the present study are:

- Congestion, as defined by TfL[10], has undoubtedly fallen within the CCZ since the introduction of the Scheme.

[8] 143 UK studies produced between 1980 and 1996 were included.
[9] Mackie *et al* (2003) also suggest that these figures should be updated using the GDP/head level in the relevant period compared to 1997, and an elasticity of 0.8. This was the procedure used in the empirical analysis in Sections 3.3 and 3.4.

- Predicted increased congestion in the area surrounding the CCZ has not materialised. LCCS' impact on congestion has thus been limited to the CCZ.
- Bus and car average speeds inside the CCZ have increased from 10.9 km/h to 11.6 km/h and 14.3 km/h to 16.7 km/h respectively[11].

3.1. Assessing the impact of congestion charging on motorists

The standard congestion externality diagram reveals that introducing a congestion charge, equal to the marginal congestion cost at the efficient level of traffic flow, leads to the avoidance of a 'dead-weight loss', which in turn represents the net benefit to society as a whole. Rietveld and Verhoef (1998) also make clear, however, that congestion pricing, according to traditional (first best) theory and assuming homogeneous individuals, makes all previous road users worse off, prior to revenue redistribution[12].

To the extent that theoretical results of traditional first best congestion pricing theory provide a benchmark for the effects of real (second-best) congestion pricing schemes, the problem of road users being left worse-off highlights the importance of revenue allocation. Having said this, it is important to recognise that the LCCS is certainly not a perfect example of a congestion pricing scheme that traditional theory considers.[13]

The purpose of this section is to illustrate the sensitivity of the conclusions reached over this important issue with respect to how values of travel time savings are applied. In our terminology, the 'standard approach' refers to that conceptually adopted in several studies[14] where, at an individual level, the VTTS is used in discussions of who wins and who loses, only to evaluate time savings generated by the congestion pricing scheme. The appropriate value is then simply compared to the toll paid, if one continues to drive, or the (vaguely defined) 'inconvenience of changing mode', if one switches to a mode that has become quicker (Gómez-Ibáñez, 1992, p. 348) or cheaper in monetary terms. In either case, only if the valuation of the time saving exceeds the item it is being compared to, is the pre-charging motorist considered a winner.

As highlighted in Section 2.1, it is important to remember that values of travel time savings vary across several dimensions. Thus, values used in the analysis of the LCCS ought to be adjusted properly to reflect income levels, trip purpose, and, in the case of car travel, congested versus uncongested conditions, since these are the obvious sources of variation, in this context, for which we have empirical support.

In addition to the above, it is important to recognise that the VTTS is relevant not only to saved travel time but also to time that is actually spent travelling, and so embodies more information than the standard approach takes into account.

The implicit assumption made when using a single VTTS to give the monetary equivalent of a travel time saving is that such time savings are valued linearly. An individual's VTTS

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[10] TfL defines the level of congestion, in min/km, as the actual travel rate *minus* the free-flow travel (assumed equal to the travel rate at night).

[11] Car speeds were obtained from TfL (2003b). Bus data was provided on request from TfL and reflects average bus speeds for route sections inside the CCZ for sample periods before and after charging.

[12] By allowing for income heterogeneity across motorists, and the corresponding variation in their values of travel time savings, it has also been shown that this stark theoretical result changes *slightly*, in that *some* motorists (those with the highest values of travel time savings) may gain prior to revenue redistribution (Hau, 1992).

[13] For example, the congestion charge does not vary according to the level of congestion and the charge is the same regardless of vehicle type.

[14] Such as Gómez-Ibáñez (1992), Richardson and Bae (1998), Teubel (2000).

reveals what he or she is willing to pay for a marginal reduction in travel time. Clearly, this value is precisely equal to how costly that marginal unit of travel time was to this individual. For this reason, values of travel time savings can be used to both 'monetarise' time savings, and derive the monetary equivalent of the time costs associated with travel itself.

The cost of a trip inside the CCZ before and after the LCCS will be different, not just because of the £5 toll, or the shorter travel time, but also because of the different VTTS. The value of travel time and time saved changes with levels of congestion and mode used.

In what follows, we seek to examine the importance of the variations in VTTS in the context of commuters to the CCZ, who previously travelled by car. The standard approach will be used first, to establish, as far as possible, the likely impact of the LCCS on these motorists. A 'revised approach', which represents a more complete utilization of the information in values of travel time savings, will then be used to analyze the same issue.

3.2. Data

Our data consists of estimates from the Labour Force Survey[15], provided by the Office of National Statistics, relevant to the periods Autumn 2002 and Autumn 2003, that detail the mode of travel to work and average incomes of commuters to the City of London that are resident in Greater London.

Although the average income in the City of London is higher than the average income anywhere else in the CCZ, the data are still valid and useful for the purpose of this paper, which is to compare two different approaches to assessing the impacts of the LCCS from a value of time perspective.

The CCZ does not lie precisely within any well-established geographical areas. The City of London lies entirely in the CCZ. Despite its size (approximately 2.6 km^2), in employment terms, the City of London is substantial, as 19.64% of all jobs located within the six main boroughs which comprise the CCZ[16], are located within it[17].

Data from several Greater London boroughs is excluded, however, where the details are prohibitively incomplete. Additionally, boroughs which have sections, geographically speaking, that lie in the CCZ are excluded since many of the City of London commuters resident in them may also be resident in the CCZ and therefore eligible to a 90% discount from the standard charge. The specific boroughs considered in this empirical analysis are therefore Haringey, Hackney, Tower Hamlets, Kensington & Chelsea, Wandsworth, Brent, Merton, Bromley, Barking & Dagenham, Redbridge, Havering, and Bexley.

This data is supplemented with data on car speeds as published in the different TfL reports (TfL, 2003a, 2003b, 2004) and bus speeds as provided by TfL on request. The fact that this does not chronologically correspond precisely with Autumn 2002 and 2003 is not a problem since the effects of the LCCS have been broadly stable since its introduction.

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[15] The sample size of this UK-wide survey is now about 60,000 households each quarter. However, estimates provided here are likely to be obtained from relatively small samples, meaning that results drawn from this data must be interpreted cautiously due to the potential problem of sampling error.

[16] These are the City of London, Camden, Lambeth, Islington, Southwark, and Westminster.

[17] The source of this information are the Economic Borough Profiles (2003), of the London Development Agency, which were provided by GLA Economics.

3.3. The standard approach to applying values of travel time savings

The data shows that car commuting to the City of London by residents in the boroughs considered, fell by around 11.6% between Autumn 2002 and Autumn 2003[18], which means that approximately 88.4% of these commuters pay the congestion charge.

In order to apply the standard approach, we need an estimate of how these commuters value the travel time savings generated by the LCCS. The average time saving is calculated on the basis of the change in average car speeds in the CCZ, which have increased from 14.3 km/h to 16.7 km/h. We also assume that the average commuting trip to the City of London involves 5 km of travel in the charging zone[19].

In light of the discussion earlier, Mackie *et al* (2003) values of travel time savings estimates for car journeys with a commuting purpose are adjusted here to reflect that driving conditions in the CCZ prior to charging were very congested[20].

Figure 2 depicts how the valuation of the estimated car travel time saving (which is doubled to reflect a return journey) compares to the charge paid for commuters with different weekly incomes.[21]

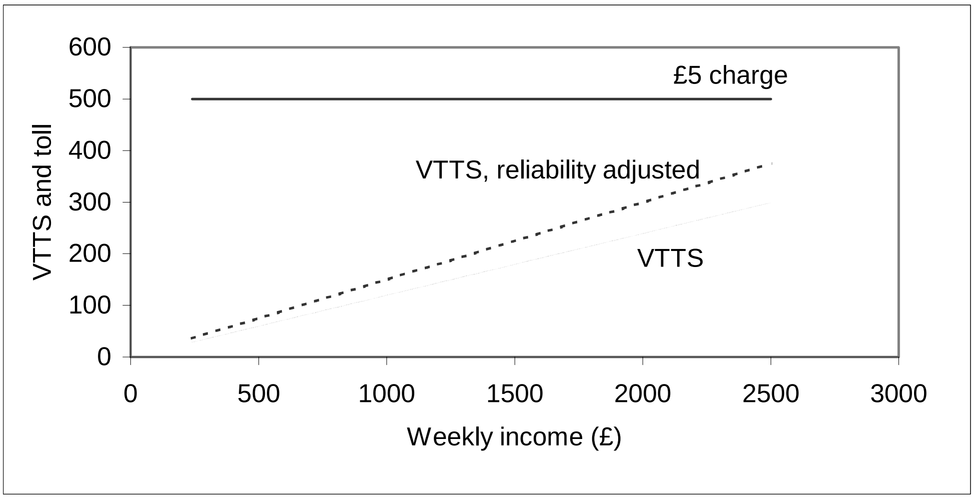

Figure 2: Standard approach, assuming travel distance = 5 km

The average weekly income of those working in the City of London is £812, and this increases to £926 when we consider only those commuters who in Autumn 2003 travelled by car. Given these incomes it is evident, from the diagram above, that essentially no commuter will value the time savings more than the £5 charge.

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[18] Differences in total number of commuting trips (by all modes) made in the two periods are accounted for by re-weighting the Autumn 2002 figures to make the two years commensurate.

[19] The CCZ has a diameter of approximately 5 km, yet roads are not perfect straight lines and the CCZ involves several 'one-way systems', which lengthen average trip distances.

[20] It is assumed that the VTTS in car travel is 50% greater in congested conditions. Mackie *et al* (2003) estimates are assumed to represent uncongested car travel. The estimates have also been updated using GDP/capita data for the UK (2001) and applying the suggested elasticity of 0.8, following the recommendations of Mackie *et al* (2003).

[21] A simple interpolation procedure was applied to Mackie *et al* (2003) VTTS estimates to obtain sufficiently detailed income differentiated values of travel time savings.

Proponents of the LCCS may, in light of this, argue that commuters also benefit from journey time reliability improvements. Dodgson *et al* (2002) argue that reliability benefits amount to, on average, one quarter of time saving benefits. Taking this on board, the basic result of the standard approach remains unchanged, as shown in Figure 2. In all likelihood, effectively no pre-charging car commuters would be classified as winners using the standard approach. It is important to note that there are obviously many simplifications being made in this analysis. For example, the possibility that an individual gains additional time savings from other trips made in the same day is ignored. Additionally, the issue of car-pooling is not considered at all. It is simply assumed that all car commuters to the City of London drive alone. These significant simplifications are justified here, since the objective of this section is to highlight the effect that different approaches to applying values of travel time savings can have on these conclusions.

Of the estimated 11.6% that have switched, we only consider those that have switched to the bus. This simplification is supported by noting that the majority of those that switch from driving are likely to have switched to the bus. Pre and post charging vehicle counts, combined with average vehicle occupancy figures, indicates that out of the trip making which has generated the observed increases in the number of bicycles, motorcycles, taxis, and buses and coaches in the CCZ, 84% can be associated with increased bus and coach patronage[22]. Additionally, other modes of travel for commuting to the CCZ, such as London Underground and National Rail services, have seen no noticeable increases in patronage following congestion charging[23]. Alongside this, as shown later, much of the switching away from cars appears to have occurred amongst commuters to the City of London resident in Inner London boroughs, where switching to the bus is more plausible, compared to from Outer London boroughs, for obvious reasons.

Gómez-Ibáñez (1992) labels the outcome for individuals that switch to bus travel as uncertain, in the sense that it seems difficult to determine whether they win or lose from a congestion charging scheme. The source of this problem is undoubtedly the expression 'inconvenience of changing mode', which has no obvious value. There are studies that have, however, implied that such individuals are net losers, on grounds, usually, that congestion pricing coerces modal switch[24]. The simple conclusion reached with the standard approach is therefore that nearly all pre-charging car commuters to the City of London are worse off as a consequence of the LCCS.

3.4. The revised approach to applying values of travel time savings

A basic concept used in transport analysis is that of generalised cost (GC). The expression below defines the generalised cost of a given individual making a particular trip. A trip is

[22] Vehicle occupancy ratings, used in this calculation, were taken from the London Travel Report (2002) and Transport Economics Note (TEN). Gross vehicle counts from Spring 2002 and Spring 2003 (supplied by Transport for London) are provided in the appendix.

[23] Underground usage across London and specially in Fare Zone 1 decreased. The reason for this decrease is obviously not related to the LCCS in any way. If anything the congestion charge might have caused a marginal increase in demand. The reasons for the decrease in passenger levels on the London Underground are probably linked to the slowdown of the economy and the decrease in tourism in London, which in turn may be linked to the war in Iraq (TfL, 2003b). In addition to that, the Central Line was temporarily closed for almost three months following a derailment at Chancery Lane station in January. No significant changes in demand for trips by rail have resulted from the Scheme, and this is in line with TfL's expectations (TfL, 2003b).

[24] Such as Santos and Rojey (2004, p. 5) and Litman (1999).

assumed to have a monetary cost (e.g. vehicle operating cost or bus fare) and a time cost, which can be expressed in monetary units, given a value of time. In the present study the VTTS is explicitly used to convert the time costs of a trip into their monetary equivalent[25], under the assumption that time savings are valued linearly.

$$GC_i^j = m_i + b_i^j t_i^j \qquad i = C,B \text{ (indicating car or bus respectively)}$$
$$j = 1,2 \text{ (indicating before and after charging respectively)}$$

where m_i is the (constant) monetary cost of i, b_i^j is the VTTS specific to mode i during period j and t_i^j is in-vehicle time of mode i during period j. Walking and waiting time costs associated with car and bus travel are assumed to be constant and embodied in m_i.[26]

We now make two propositions and assess them for practical relevance to the LCCS.

Proposition 1
A motorists who continues to drive (and pay the £5 congestion charge) but values the time savings of the LCCS less than £5 can still gain from the Scheme. The idea behind this proposition is depicted graphically in Figure 3.

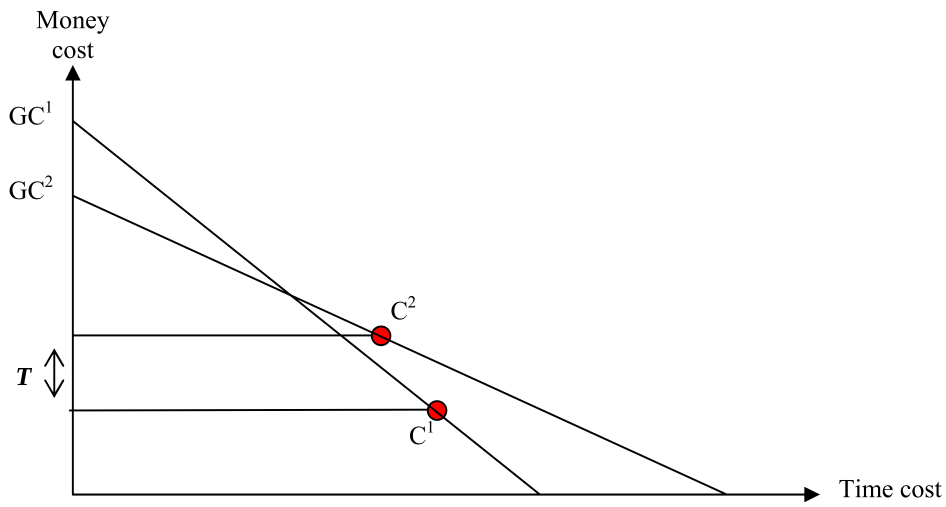

Figure 3: An example of GC before and after charging

The characteristics of the car mode, for a particular trip, before and after congestion pricing, in terms of monetary cost and in-vehicle time cost, are given by its location in

[25] Hensher (1997) supports the use of the behavioural VTTS in generalised cost functions.
[26] This assumption is obviously plausible for car travel and bus walking time. As for bus waiting times, data obtained from TfL on 'excess waiting time' (the difference between the observed average bus waiting time and the actual waiting time if all buses ran exactly to schedule) indicates that changes in actual bus waiting times are only in the order of one minute or less, assuming that 'scheduled bus waiting times' (data for which is unavailable) are unchanged.

(money, time) space, C^1 and C^2, respectively. The north-westerly movement of C^1 to C^2, reflects the impact of congestion pricing. The magnitude of the slope of the lines passing through C^1 and C^2 reflect the VTTS of this individual for using a car before and after congestion pricing. The lines are thus isocost lines since a movement along either of them reflects how the individual is willing to trade-off car travel time for money. The VTTS is shown to fall across C^1 and C^2 as it is assumed that the VTTS for driving is higher in congested versus uncongested conditions, thus the isocost line passing through C^1 is steeper than that passing through C^2. The individual's valuation of the time saving is depicted as below the congestion charge *T*, since C^2 is north-east of the initial isocost line. The GCs associated with C^1 and C^2 are given by the intersection of the relevant isocost line with the money-axis, since, at this point the entire time costs of the trip are converted into their monetary equivalent. Thus, although *T* is greater than the valuation of the time saving, it is evident that the GC of driving for this particular trip has fallen. Of course, the crucial assumption here is that, for a given time saving generated by the congestion pricing scheme, the VTTS in car travel falls sufficiently due to there being less congestion.

Having said this, the LCCS has only, as expected, reduced congestion inside the CCZ. Therefore, the VTTS of a given individual travelling by car can only be expected to fall for that portion of the trip that is made inside the CCZ, not its entirety, as pivoting the car isocost line in Figure 3 assumes.

In terms of the LCCS, then, the proposition is more accurately illustrated as below:

$$GC_C^1 = m_C + b_C^* t + b_C^1 t_C^1$$

$$GC_C^2 = m_C + b_C^* t + b_C^2 t_C^2 + T$$

$$GC_C^1 - GC_C^2 = b_C^1 t_C^1 - b_C^2 t_C^2 - T =$$

$$b_C^1 \left(t_C^1 - t_C^2\right) + t_C^2 \left(b_C^1 - b_C^2\right) - T$$

where b_C^* is the VTTS for the portion of the car journey outside the CCZ, b_C^j is the VTTS for the portion of the car journey inside the CCZ during period *j* (before or after charging), *t* is the time spent travelling from origin to the CCZ perimeter, t_C^j is the time spent travelling inside the CCZ during period *j* (before or after charging), and *T* is the £5 congestion charge. b_C^* and *t* are assumed to be constant and the VTTS for the portion of the car journey inside the CCZ before charging is assumed to be greater than the one after charging, to reflect the impact of the congestion charging scheme ($b_C^1 > b_C^2$).[27] Even when the time savings are valued below the congestion charge *T*, it is still possible for $GC_C^1 - GC_C^2 > 0$, implying a reduction in the GC of the same trip, so long as b_C^1 is sufficiently above b_C^2.

In the last expression $b_C^1 \left(t_C^1 - t_C^2\right)$ represents the valuation of the time saving and $t_C^2 \left(b_C^1 - b_C^2\right)$ represents the reduction in cost of time still spent travelling.

[27] As explained in Section 2.3 the VTTS is higher with higher congestion.

The standard approach misses the crucial issue that even when an individual values the time savings received below the toll paid, by continuing to drive he or she additionally benefits from being able to do so in more desirable conditions as implied by the reduction in the VTTS, and can thus still benefit overall.

The question is whether this proposition has any practical relevance for the LCCS. Figure 4 reflects how commuters with different incomes would value the time savings generated by the Scheme compared to the £5 charge (just like Figure 3) together with GC_C^1 and GC_C^2 as defined above, but excluding the elements which have been assumed constant for simplicity.[28] A 50% premium is added to the VTTS for driving in congested conditions, in line with the findings presented in Section 2.3.

Figure 4 shows that Proposition 1 has real practical relevance for car commuters to the City of London with weekly incomes in excess of approximately £1400/week. Although this is not outside the conceivable range of incomes for the sample of City of London commuters, it implies that the proposition only 'converts' relatively few of the losers predicted by the standard approach into winners, and would certainly not 'convert' the average pre-charging commuter to the City of London. However, it does represent a significant improvement to the negative conclusions of the standard approach.

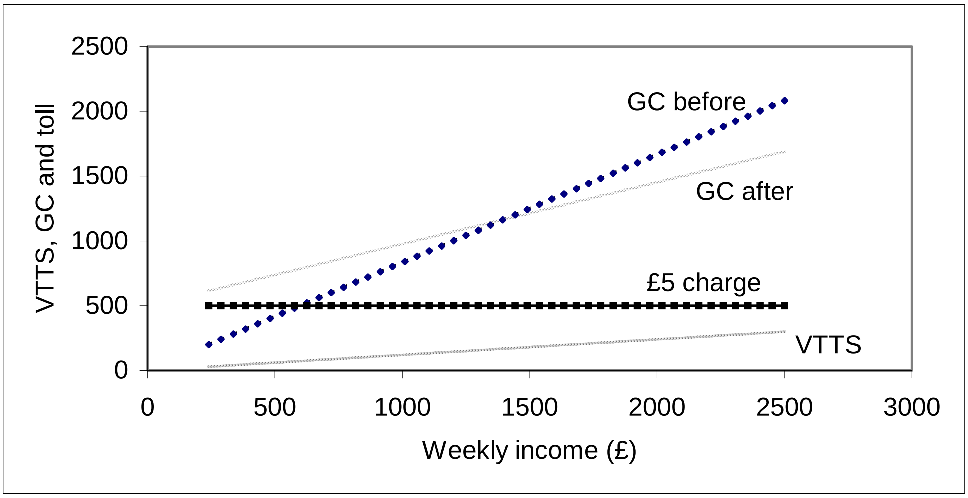

Figure 4: Revised approach, assuming travel distance = 5 km

If the travel distance inside the CCZ were assumed to be 2.5 km, which would perhaps be more realistic for the current CCZ, the intersection of the GC curves would only occur at an income level of approximately £2,800/week. If that were the case, virtually all drivers would be categorised as losers, even in the revised approach.

An interesting issue, however, is brought to light if we increase the assumed distance that is travelled in the CCZ (currently set at 5 km). Figure 5 shows the same curves assuming that the travel distance inside the CCZ is 9 km. Of course this is very unrealistic with the current CCZ. However, if this zone were to be increased, then the example would become very relevant.

[28] Ignoring the other elements of GC is justified assuming they are constant since, in this case, the income levels at which $GC_C^1 - GC_C^2 > 0$, will be identical to those for which $b_C^1 t_C^1 > b_C^2 t_C^2 + T$.

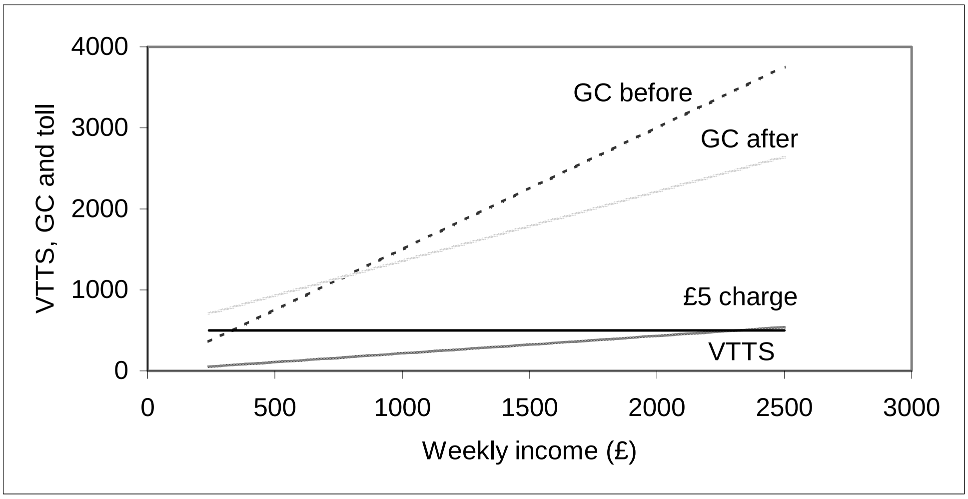

Figure 5: Revised approach, assuming travel distance = 9 km

As the distance increases, the income range over which the proposition is relevant becomes increasingly realistic. With an assumed distance of 9 km, the average car commuter to the City of London (with a weekly income of £926) is 'converted' by Proposition 1 from a loser to a winner.

When the distance travelled increases, the time savings increase as well (because those continuing to drive post-charging enjoy reduced congestion for a greater proportion of their travel time) and the shortcomings of the standard approach become more relevant.

If the proposal to extend the CCZ to Kensington & Chelsea and Westminster[29] were materialised, Proposition 1 would become very relevant. The longer the distances driven in less congested conditions, the greater the number of winners from the Scheme there would be.

Having said all the above, there are three important assumptions that are being made in this analysis, and that deserve some attention. Firstly, the change in average speed for travel in the new parts of the CCZ is assumed to be the same as it has been for the existing CCZ. Secondly, it is assumed that the pre-charging level of congestion in these additional areas is similar to what it was in the existing CCZ prior to charging. Thirdly, the reduction in congestion in the new areas is assumed to be of a similar degree to that which occurred in the existing CCZ, so that the corresponding VTTS of car travel, for a given individual, falls by a similar proportion.

If those assumptions are correct, the above implies that, if the CCZ is extended, many more of the identified 88.4% of commuters to the City of London will be winners, even though they do not still value the time savings in excess of the toll. Effectively, then, increasing the size of the zone seems a useful way to convert many of those who are otherwise losers into winners, and thus constitutes a useful compensating device in itself. The reason for this is not only that time savings are more substantial with a larger zone but that the time now being spent driving is less costly due to congestion being lower for a greater proportion of any car trip.

A potentially puzzling feature of the data is that a significant number of commuters especially from outer London boroughs appear to have switched to the car as a result of the

[29] See 'A proposal to extend the central London congestion charging scheme to cover most of Kensington & Chelsea and Westminster' (www.tfl.gov.uk/tfl/cc-ex/proposal-index.shtml).

LCCS. Figure 6 shows the percentage change in car commuting from different boroughs to the City of London.

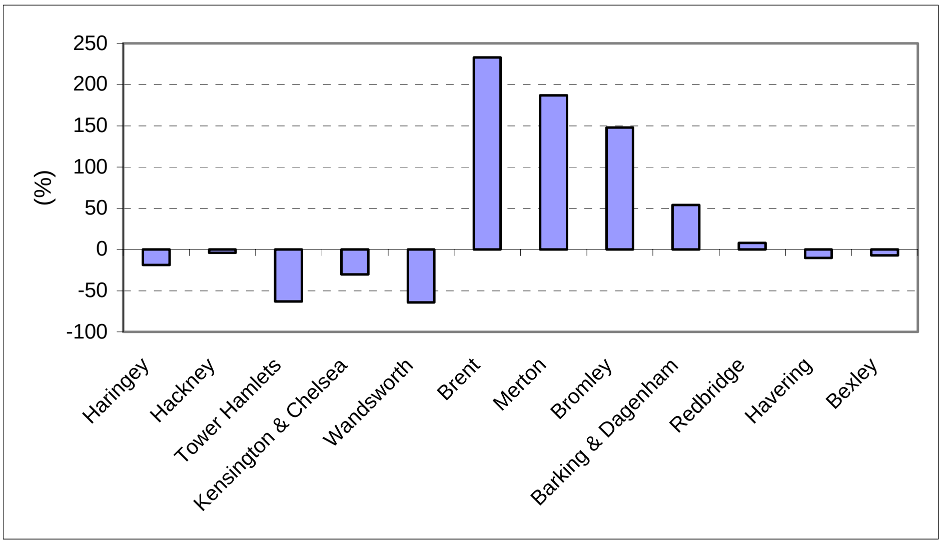

Figure 6: Percentage change in car commuting from different boroughs to the City of London

From the standard approach it is difficult to explain why commuters who previously travelled by bus would switch to the car after the introduction of the LCCS. The insight developed above, however, can help to explain this phenomenon. Thus, even if the car travel time savings are not valued more than £5, the LCCS could make the GC of car commuting fall sufficiently to motivate a switch to driving for those other-mode users whose VTTS in car travel is very elastic with respect to the level of congestion. Additionally, the precise pattern illustrated above can be conveniently explained with reference to Calfee and Winston (1998). Their empirical study, which focused specifically on estimating the VTTS of car commuters in congested conditions, found that the VTTS 'was surprisingly insensitive to travel conditions' (p. 85). The explanation given for this was that commuters most averse to congestion adjust their residential and workplace choices, inter alia, to minimise the congestion they face. This reasoning can be adapted to the LCCS. Thus, non-car commuters who own a car but are particularly averse to congestion are more likely to reside in outer London, so as to avoid the relatively more congested roads of central London in the other car journeys they undertake. As a result, the VTTS in car travel of these individuals is likely to be most responsive to a change in driving conditions and thus it is these individuals who are most likely to switch to using a car following the LCCS.

Let us now concentrate on the second proposition.

Proposition 2
A motorist who switches to the bus can still gain from the Scheme.

If we assume that mode choice of commuters is governed by an effort to minimise generalised costs[30], then for all those that originally travelled by car $GC_C^1 - GC_B^1 < 0$. The change in GC as a result of switching to the bus, for any given commuter is

$$GC_C^1 - GC_B^2 = \left(m_C + b_C^* t + b_C^1 t_C^1\right) - \left(m_B + b_B t_B^2\right)$$

where t_B^2 is the total bus journey time in period 2, after charging has been put into place.

This representation is useful in that it more formally conceptualises the standard approach of comparing the 'inconvenience of switching mode' to the valuation of the time saving which bus trips offer post-charging. Essentially 'the inconvenience of switching' can be intuitively defined as the degree to which $GC_C^1 < GC_B^1$ originally. Thus, the difference between GC_C^1 and GC_B^2 is given by

$$GC_C^1 - GC_B^2 =$$
$$= GC_C^1 - GC_B^1 \quad + \quad b_B(t_B^1 - t_B^2) =$$
$$= \text{'inconvenience of switching'} \quad + \quad \text{'valuation of bus time saving'}$$
$$= \left(m_C + b_C^* t + b_C^1 t_C^1\right) - \left(m_B + b_B t_B^1\right) \quad + \quad b_B(t_B^1 - t_B^2)$$

Since we know that $t_B^1 > t_B^2$, it is clearly theoretically possible that some of the commuters to the City of London will be better off (in terms of now being able to make the trip at a lower generalised cost) as a result of the LCCS, even though they incur the 'inconvenience of switching'.

Assessing the precise practical relevance of this for the LCCS would require a substantial amount of data. Thus, we would need to have values for m_C, m_B, t, etc. Unfortunately such data is not available. Having said this, we know that $(t_B^1 - t_B^2)$ is small in the case of the LCCS[31]. It seems likely, therefore, that most of the commuters who switched to the bus will not, even in the revised approach, become categorised as better off, in the sense that $GC_C^1 < GC_B^2$.

It is, however, interesting to see what the effect would be if $(t_B^1 - t_B^2)$ was larger, which is the likely implication of having a larger charging zone. Re-arranging the above expression once more, sheds light on this:

$$GC_C^1 - GC_B^2 =$$
$$GC_C^1 - GC_B^2 = \left(m_C - m_B\right) + \left(b_C^* t + b_C^1 t_C^1 - b_B t_B^1\right) \quad + \quad b_B(t_B^1 - t_B^2)$$

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[30] This seems reasonable for at least some commuters, since due to the regularity of a commuting trip (i.e. undertaken every weekday), benefits associated with it are likely to be consistently small across modes because of diminishing marginal utility. Thus, mode choice is more likely to be governed by an effort to minimise the generalised cost of each trip.

[31] Assuming that the average commuting trip (by car and bus) to the City of London consists of 5km of travel in the CCZ, average speed data for cars and buses reveals average daily (two-way) time savings of 6.0 minutes and 3.3 minutes, respectively.

The first term $(m_C - m_B)$ is, by assumption, constant. Thus, out of those commuters who have switched to the bus and have lost out, commuters for whom b_B is relatively large will, on average, have incurred relatively large increases in generalised costs. However, it is precisely these individuals that will benefit most from $(t_B^1 - t_B^2)$ becoming larger as a result of the extension, again because they have a relatively high b_B.

Extending the zone appears to be a useful device for compensating motorists that have lost out, since, in the case of those switching from car to bus, it will, on average, likely benefit those most severely affected proportionately more.

4. Conclusions

This paper shows that the impacts of the LCCS should not be analysed from the standard approach to VTTS. This will inevitably lead to the mistaken conclusion that all those drivers who value their travel time savings below the £5 congestion charge will be regarded as losers from the Scheme.

The use of a simple expression of generalised costs per trip was shown to be a useful way to more comprehensively utilise the informational content in values of travel time savings. This revised approach leads to a different outcome in terms of impact assessment from a VTTS perspective. First, a motorist who continues to drive but values the time savings of the LCCS less than £5 can still gain from the Scheme, if the generalised cost post-charging is lower than the generalised cost pre-charging, and this is likely when the VTTS post-charging are sufficiently below the VTTS pre-charging. Second, a motorist who switches to the bus can still gain from the Scheme. Since the bus travel time post-charging will typically be lower than the bus travel time pre-charging, it is possible that the generalised cost of a trip by car pre-charging will be higher than the generalised cost of a trip by bus post-charging, even after taking into consideration the inconvenience of switching.

These findings have practical relevance in the case of the LCCS. At least some commuters to the City of London win from the Scheme although their valuation of received time savings is below £5. This however becomes less relevant the lower the distance travelled inside the CCZ. Variation in a given individual's VTTS in car travel due to the level of congestion was shown to be of paramount importance for Proposition 1, yet the precise degree of sensitivity of values of travel time savings to the level of congestion was not speculated upon. Instead a simple assumption, motivated by findings from other studies, that values of car travel time savings are 50% greater in congested conditions compared to in uncongested conditions was applied throughout. Assessing the practical relevance of Proposition 2, however, required significantly more data than was available.

The revised approach was additionally useful in illustrating the impact of having a larger CCZ. It appears that an enlargement of the zone would benefit those pre-charging car commuters that have switched to bus travel, who incur a relatively substantial increase in generalised cost. Assuming that the pre- and post charging traffic conditions in the additional areas of an extended zone are similar to those in the current CCZ, it is also possible that those charge-paying motorists who at present incur a greater generalised cost post-charging, may actually see their generalised cost decrease. Thus, from losers they would be turned into winners, by having a larger zone (and driving longer distances and saving more time inside the CCZ). For these reasons, extending the zone could well constitute an effective means to compensate many of those motorists who have been left worse off by the LCCS, in terms of now having a higher GC for the same trips post-charging.

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Appendix

Total daily counts of incoming and outgoing vehicles

Mode	% Change	Spring 2002	Spring 2003	Change
Cars	-33	386,752	258,168	-128,584
Taxis	+17	113,007	131,753	18,746
Bus & Coaches	+18	26,472	31,253	4,781
LGVs	-12	113,267	99,405	-13,862
HGVs & Other	-12	31,585	27,878	-3,707
4+ Wheels	**-18**	**671,083**	**548,456**	**-122,627**
Pedal Cycles	+22	25,181	30,666	5,485
Motor Cycles	+15	48,780	56,205	7,425
All cycles	**+17**	**73,961**	**86,871**	**12,910**
Total	**-15**	**745,044**	**635,327**	**-109,717**

Source: Transport for London, data provided by request.
Note: shading indicates that the mode is exempt from the toll.