Assessing the Net Overall Distributive Effect of a Congestion Charge

Discussion Paper

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Roundtable

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International Transport Forum

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The International Transport Forum

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Introduction

It is widely accepted that congestion is a serious problem, causing economic and social stress. In recent years there has been much interest in seeking solutions by more and better infrastructure of roads and/or their alternatives, clever management of demand, regulation, transport and land-use planning, better understanding of the economic, social and psychological reasons for choices, publicity, 'nudges', and marketing. Among these instruments is the use of economic prices set at a level where the users of transport systems broadly pay for the resources their choices require: among these resources, the use of time by other travellers is an important case. Each driver using the road system in congested conditions causes delays to all other road users, and the idea of congestion charging is that if these delays are paid for, the system overall will operate in a more efficient way.

This is a simple economic principle, but implementing it requires charging for something which has for generations been considered, in a sense, 'free', and therefore some people will pay more than they did before for their travel. Others, when the reduction in congestion is taken into account, will pay less. However unfair the present situation might be considered to be, new patterns of unfairness are politically sensitive, and therefore it is sensible to have a good understanding of who gains and who loses: it is not adequate simply to say that the economy 'as a whole' benefits, without also analysing who gets that benefit.

This paper is structured in five sections as follows: Firstly, we outline how economists have classically treated this issue, with special attention to understanding why it has often been hardly considered at all.

Secondly, we outline some reasons why the approach above breaks down in current circumstances, putting greater pressure not only on distributional effects, but on a wider definition of those effects to include the distribution of benefits as well as the distribution of payments.

Thirdly we reflect on some practical experience of how the discussion on congestion charging has broadened the definitions beyond the payment of a congestion charge, to include issues of taxation, complementary policies in the context of transport strategic thinking, and the effects of congestion charging on the incidence of health and environmental benefits.

Fourthly, we describe some empirical analyses exploring distributional effects by simulation, and by analysis of the geographical patterns of car ownership and use.

Finally, we draw together the methodological considerations of assessing the *'Net Overall Distributional Effect'* of a charging intervention.

The founding economic principles of road pricing and distributional impacts

The classical case

Until recently, the economic case for road pricing has focussed mainly on congestion (hence 'congestion charging'), and has always depended on strong assumptions about its distributional effects, but that has not always been recognised. In one of the seminal papers in the field, Walters (1961) wrote briefly:

> *"Problems of the distribution of income – who would and who would not be harmed by the policy advocated – will not be considered here. The general ramifications of such a policy are reasonably clear, but the detailed analysis would be cumbersome and boring."*

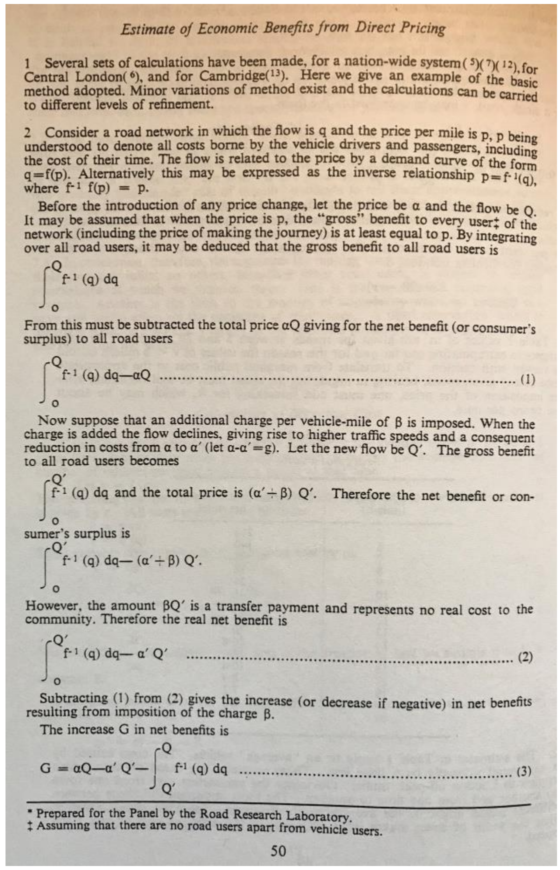
This approach, albeit not always stated in such a provocative manner, underpinned much of the technical and policy studies of the 1960s through to around the mid-1980s. However, it is important to note that this was not due to a lack of interest, but was on the basis of a theoretical rationale which sought to justify ignoring distributional consequences by demonstrating that the economic advantages applied independently of the effects on distribution. This conclusion derived from the development of welfare economics in the 1930s and subsequently, where a 'Pareto Optimum' was defined in terms of the possibility that efficiency improvements would enable losers to be compensated by gainers, whether or not that compensation was actually made.

This is seen in the Smeed Report of 1964, the first explicit formal technical and policy study by a Government[1] (Ministry of Transport, 1964). A series of technical appendices demonstrated, though using a calculus presentation which was not widely accessible in policy discussion, that the direct effects of a congestion charge would be to *reduce* the consumer surplus (economic welfare) enjoyed by two important groups of road users – both those who continued to make their journeys, with less congestion but at a higher money cost larger in magnitude than the congestion benefits, and those whose journeys were deterred by the extra cost. Critical to the existence and calculation of benefit was the proposition (Figure 1) that the loss in utility to these groups would be more than offset by the increase in utility contained in the revenue collected from the charge, after allowing for the administrative or technical costs of the system. The entire discussion on this point is contained in one page of the Appendix, where the crucial single sentence is:

> *"However, the amount…is a transfer payment and represents no real cost to the community"*

In other words, the amount of welfare surplus lost by the initial payers of the charge is exactly compensated by the amount gained by those who receive the revenue, whoever they may be, leaving the reduction in congestion as the net efficiency benefit. This principle has underpinned all subsequent appraisals of the economic benefit of congestion charging, from the simplest theoretical case to the much more complex considerations of different types of road users and wider categories of benefit beyond congestion. The relevant page of the Smeed Report is shown in Figure 1.

Figure 1. **Smeed's estimate of the economic benefits from direct road pricing**



Estimate of Economic Benefits from Direct Pricing

1 Several sets of calculations have been made, for a nation-wide system(5)(7)(12), for Central London(6), and for Cambridge(13). Here we give an example of the basic method adopted. Minor variations of method exist and the calculations can be carried to different levels of refinement.

2 Consider a road network in which the flow is q and the price per mile is p, p being understood to denote all costs borne by the vehicle drivers and passengers, including the cost of their time. The flow is related to the price by a demand curve of the form $q=f(p)$. Alternatively this may be expressed as the inverse relationship $p=f^{-1}(q)$, where $f^{-1}\,f(p) = p$.

Before the introduction of any price change, let the price be α and the flow be Q. It may be assumed that when the price is p, the "gross" benefit to every user‡ of the network (including the price of making the journey) is at least equal to p. By integrating over all road users, it may be deduced that the gross benefit to all road users is

$$\int_0^Q f^{-1}(q)\,dq$$

From this must be subtracted the total price αQ giving for the net benefit (or consumer's surplus) to all road users

$$\int_0^Q f^{-1}(q)\,dq - \alpha Q \quad \text{.......} \quad (1)$$

Now suppose that an additional charge per vehicle-mile of β is imposed. When the charge is added the flow declines, giving rise to higher traffic speeds and a consequent reduction in costs from α to α' (let $\alpha-\alpha'=g$). Let the new flow be Q'. The gross benefit to all road users becomes

$\int_0^{Q'} f^{-1}(q)\,dq$ and the total price is $(\alpha' \div \beta)\,Q'$. Therefore the net benefit or consumer's surplus is

$$\int_0^{Q'} f^{-1}(q)\,dq - (\alpha' \div \beta)\,Q'.$$

However, the amount $\beta Q'$ is a transfer payment and represents no real cost to the community. Therefore the real net benefit is

$$\int_0^{Q'} f^{-1}(q)\,dq - \alpha' Q' \quad \text{.......} \quad (2)$$

Subtracting (1) from (2) gives the increase (or decrease if negative) in net benefits resulting from imposition of the charge β.

The increase G in net benefits is

$$G = \alpha Q - \alpha' Q' - \int_{Q'}^{Q} f^{-1}(q)\,dq \quad \text{.......} \quad (3)$$

* Prepared for the Panel by the Road Research Laboratory.

‡ Assuming that there are no road users apart from vehicle users.

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Source: Extract from the "Smeed Report", Ministry of Transport, 1964, p50.

The main text of the report therefore gave no great attention to the question of what should be done with the revenue, since by axiom it made no difference to the economic benefit. There were a few sentences exploring the possibility of using it in part for the provision of parking spaces, with a moderately favourable treatment, but it was probably to clarify the 'transfer payment' proposition, rather than a policy recommendation in itself, that the report:

> *"assumed that the introduction of road prices would be accompanied by a corresponding reduction in road taxes."*

The basic contention was that calculation of the real economic benefits of congestion charging can be carried out independently of any consideration of distributional effects or wider policy context. Therefore distributional effects were a subordinate question, and if discussed at all, were mainly in the context of the amount of the charge which would be paid by different groups of motorists, mostly classified by income group.

Why the classical case stopped working

This emphasis was, however, challenged by the experience of policy discussions centred specifically on congestion charging as they got closer to practical application, as this in turn affected how the theory was described – see, for example, Nash (2001), Calthrop and Proost (2003) and Ubbels and Verhoef (2007). This was because:

Arguments of 'integrated transport policy' and a more strategic view of the interaction between public and private transport, especially in urban contexts where congestion was most severe, triggered studies of the relative benefits of, for example, investment in new light rail systems, priority systems favouring buses, cycling and walking, and land use planning. These often had greater benefits than construction of new road capacity which provided only temporary relief to congestion (see Goodwin (2010)).

The range of problems from excessive traffic, and the use of transport charging to tackle them, went beyond the traditional concerns with congestion and traffic accidents, to include emissions of harmful pollutants, emissions of carbon dioxide contributing to climate change, effects on health of transport-related activity, and interactions with social and community life. This put more attention on the importance of behavioural change including greater reliance on active modes, walking and cycling, with measures which would reinforce the use of road pricing by more favourable conditions for alternative transport choices and provide additional, and different, benefits.

It became obvious in many political discussions and debates that public acceptability of new systems of charging for road use was very dependent on what other policies would be implemented – at the same time, and as part of the same package of measures – to improve the alternatives. Although public opinion can be volatile and will vary in different contexts and places and times, one particular strand was that new road charges would only be acceptable if accompanied by better public transport, especially rail. Since congestion charging could produce a cash surplus, and such investments depended on new funding sources, it was a logical step to suggest that revenue received from road user charges could be used to improve the alternatives, thus giving a carrot as well as a stick and making behavioural change advantageous rather than forced. See, for example, Jones (1995), Musselwhite and Lyons (2009), Goodwin and Lyons (2010).

A general approach to assessing the distributional consequences of road pricing

The result of the above discussions was that the policy context within which it was realistic to think that new charging systems could be implemented, radically changed. The original single policy assumption, made partly to simplify the argument, of 'tax neutrality' defined as a compensating reduction in road taxes, became a policy alternative to be chosen or rejected, not an axiom. An alternative was to deliberately use the revenue collected for other specific purposes: such purposes are varied, but broad groups of objectives can be distinguished. The important point is that each of these has different distributional consequences which will offset, reinforce, or cut across the distributional pattern of who is paying the charge. Therefore we are led to the idea of a *net* distributional effect, for each individual, family or segment of the population, consisting of what they pay out offset by what they receive, in money and material benefit. Once it is decided that use of the revenue is *part of* the charging policy, it only makes sense to see distributional effects as the combined effects of both.

Therefore we first consider, in very broad brush qualitative terms, what sort of pattern of distributional costs and benefits we might see for each of the four main groups of charging strategy.

Return of charging revenue to road users in the form of reductions in other road taxes.

We note that if this is done (a) there will be no additional revenue available for other transport or social improvements, and (b) there is not a direct match between the amount paid by individual road users on existing road taxes and the amount they would pay in congestion charges, so the approach would necessarily involve a shift in the distribution of income between some groups of road users and others, even if road users as a whole (or the owners of tax-paying vehicles) were deemed to be collectively compensated for the charge. There will still be the benefits directly following from the charge, but they will not accrue to the same motorists in proportion to the charge paid.

Therefore it is likely that the main payers would be those who travel in the most congested conditions, and continue doing so. There would be a reduction in congestion on the most congested streets, which would accrue as an incidental side-effect in part to bus users or any services that might be exempt from paying. The residents in those areas would benefit from a reduction in emissions, and this would include children living there, whose own car use would be small. Car ownership in such areas is lower than average, so residents would benefit from some reduction in travel by motorists living outside the area. There might be some shift in net benefit to those car-owning residents in rural areas who did not commute to towns. All the effects would be rather small as there would be no additional investment in alternative travel.

Spending the revenue on increased road capacity

This would provide some benefit to some of the road users paying the charge. In earlier days there would have been plans for large scale urban road building – ring roads etc. – which might more closely have benefitted the main payers in terms of their car travel. Nowadays, there is little appetite for such policies because additional traffic induced by the new construction would tend to reduce the period of benefit considerably. There could be additional emissions in the urban areas themselves, and a reduction of the services offered by public transport, so the main losers would be residents in those areas (both car users and non-car users, but more so for the latter, especially children living close to the expanded roads). Those who gain the most would be the car-owning residents of non-urban areas who drive largely in congested areas in towns, or more likely on trunk roads and motorways outside towns, which are the roads which would most likely be expanded. The resulting reduced congestion would also reduce the revenue from charges.

Spending the revenue on public transport, walking and cycling

This policy would see motorists on congested urban roads and congested trunk roads paying more. Those who live in the towns would see benefits in the form of reduced pollution, and those who continue to drive would see some benefit in the form of reduced congestion. However, this would (by the Smeed report mathematics) be of less value than the charge they were paying on average, though with a net benefit to those with high values of time and low values of money, being wealthy and busy. The main beneficiaries in this case would be (a) those who changed their travel behaviour to the now improved alternative modes, benefitting from better health and more pleasant surroundings; (b) those who did not previously drive and now have better environmental conditions and improvements to their own travel. Drivers who continue to drive, and pay the charge, might receive a bigger congestion benefit than the road-building case, since there would be a greater number of their fellow drivers transferring to other modes.

Putting the revenue in to general taxation

In this case the main beneficiaries could be different groups entirely, who have a reduction in some other class of taxation, eg on income, or increases in public expenditure e.g. on health services or education. The principle involved is a simple one – increase tax on activities which cause damage and reduce taxes on activities which cause good – independently of what sector they are in. If it is possible to identify the spending, a distributional analysis can be carried out, but otherwise it probably comes closer to the 'neutral' assumption of compensation. In terms of perception, it is not a given that drivers who pay the charge would be happier if the money were returned to other drivers than to their children at school or employees where they work, or themselves when sick.

Interim conclusion

We argue that there are two important consequences of these considerations.

First, any attempt to explore the distributional consequences of a road pricing intervention solely in terms of the incidence of payments cannot produce a useful picture of who gains and who loses. The distributional effects must be analysed in terms of the net impacts of both the new charges and of the new patterns of the benefits arising from plans about use of the revenue (including any related changes in regulation, control and operations).

Second, there is a crucial methodological difficulty in that the salient dimensions which affect variations in the incidence of payment will, in general, not be identical to the salient dimensions which affect the incidence of transport and other benefits and losses. Thus for example distributional analysis often features distinctions by income group, but the amount of payment made will vary according to the pattern of journeys made by car users especially, while the incidence of changes in air pollution, say, will be affected by the geographical location of residents living near a road which will include people of different incomes and car use patterns. Statistically, the type of disaggregation of the population by those who gain benefits and those who suffer losses demands a complex pattern of joint distributions by economic, social, travel and geographical variables which stands in danger of being intractable to carry out and complex to understand.

The role of distributional issues in practical discussions on congestion charging in the UK

Important political lessons were developed in the preparations for what became the 1998 UK Transport White Paper (DETR, 1998) and the Transport and Greater London Acts (1999). The basis for a new road pricing for urban transport was a major part of preparatory discussions among departments and with outside advisors, intended to lay the basis for the authorities in large urban areas to be *able* (but not *required*) to charge motorists in proportion to use, mostly either by new charges for movement or for workplace parking.

Specific aspects of the wider question of distribution – relevant to the idea of the Net Overall Distributional Effects (NODE) – was the question of what to do about taxation, and what to do with the revenue. These were crucial to the decision, but were actually not discussed mostly using the *language* of equity, but the language of political powers, public opinion, and transport strategy. The political decision was to be led by the local authority (held responsible to its own electors), and a crucial – indispensable – reward for doing so was that they would retain control over the revenue, with a form of hypothecation not reserved for roads, but for all transport modes in accordance with their own preferred transport strategy. It was judged that a hypothecation purely for roads would be rejected by most if not all authorities, and an equivalent reduction in other taxes was not a live issue. It was judged that a more balanced inclusion of public transport and the new priorities for walking and cycling would command more public support. This was supported by a wide range of (generally convincing) public opinion research, and in any case sat sensibly within a planning approach based on the interaction between all important methods of transport.

A wide range of transport stakeholders (including motoring organisations and, cautiously, freight movers) bought into this idea, as well as town planners, environmentalists, and those most informed about the economic successes of reducing traffic in European town centres by other means. The two key sources of resistance were the evident and understandable caution from the UK Government's advisors about the risk of having a row with motorists, and an official reluctance in the Treasury to give way on their objection to the principle of hypothecation. This was resolved at high level politically, but at official level by what became a significant agreement on words: the new system was to be described as a *charge, or price, for services, explicitly not a tax*. In this way, Government financers could accept the fact of hypothecation, while retaining opposition to the principle, a tidy solution for all.

In the Government's Ten Year Plan for Transport (2000) provision was made for 20 of the largest cities to sign up for road user charging in some way by 2010. Apart from London (which was certainly important), and a few minor initiatives later, it did not happen. Most local authorities either came to the view that the amount of money available from small scale town centre schemes was not enough to justify the political hassle or would be rejected by voters, or their objectives could more easily be achieved by various other more classical funds and revenue sources that they could apply for. The particular element of the Ten Year Plan to 2010 which depended on hypothecated road user charging simply did not happen and as a live document of transport strategy, the Plan was no longer discussed after about 2004.

In London, however, the strategy was successful more or less as planned. It was labelled a congestion charge (not road pricing), it applied only to the central area, it provided rather less money than forecast (but a greater impact on traffic volume), and the revenue was a helpful addition to the cost of improving other modes, which was indeed done. It is interesting that these different strands have come together very strongly in the current plans to implement an emissions-based extension (the 'T-Charge', for toxicity) to the congestion charge in Central London, an example of the increasing importance of wider considerations than congestion alone. Discussion in the London newspaper, the Evening Standard (2017) has placed as much focus on the distributional effects as on air quality. The paper's editorial stated that:

> *"Like the original C-charge, it is regressive – falling hardest on the poorer car owners. But it is those on the lowest incomes who suffer the greatest health problems"*

and the Mayor of London also emphasised that:

> *"it is the poorest and most disadvantaged who are being disproportionately affected",*

while at the same time supporting a compensation scheme for those motorists (mostly not the poorest) who bought diesel cars 'in good faith, based on government advice'[3].

Thus we argue that the evolution of experience, especially in London, illustrates the themes discussed above – an active consideration of the implications for where the money would be spent, in the context of a more integrated and coherent transport strategy, and a broader consideration of effects other than congestion. Distributional issues have been at the heart of the decisions, though formal distributional appraisal has been very sketchy indeed.

Therefore it does seem to follow that the development of more formal appraisal tools would be useful, which we now address.

Micro-simulation as a method of exploring the effects

The use of micro-simulation techniques offers a way to explore these consequences. In these, a population of simulated individuals is generated which corresponds with the overall statistical properties of the real population of a city, region or country. Estimation techniques typically involve cloning or matching households in surveys (which often have the spatial information removed) with small-area census data. From this, any subgroup of interest can be considered at fine spatial resolutions in terms of the charging and its related effects on travel and other potential benefit and losses. Such a method gives a direct (approximate) way of counting up the overall numbers of gainers and losers (generally based on individuals or households) in each sector of the population or area of a city or country. Each sector or area has a complex set of characteristics and varies in terms of the average and variation of the advantages, disadvantages and vulnerability to road pricing.

Previous work at the Leeds University Institute for Transport Studies (ITS) used a synthetic population to establish the impacts on at-risk groups of congestion charging in the city (Bonsall and Kelly, 2005). Using a case study for Leeds, UK, the authors generate a synthetic population from probabilities of traveller characteristics derived chiefly from the UK Census. This was then linked to a traffic assignment package to identify the spatial patterning and characteristics of those impacted by different charging regimes and policies. They defined 'at risk' groups as those on low incomes, carers, mobility impaired, elderly and social minorities with no realistic alternatives to the car for particular journeys for a variety of reasons including health restrictions. The simulation highlighted the sensitivity of these groups to the location and extent of the charge, but also whether exemptions can be targeted efficiently at them.

In the next sub-section we describe two very recent studies which use novel data sets and spatial analysis that would complement the microsimulation approach specifically in ways that would assist in the evaluation of distributional impacts.

Enhancing microsimulation with novel data and area classifications

Birkin and Clarke (2012, p515) note:

> *"When [microsimulation] model estimates are benchmarked against real-world data, the models are typically well behaved and very robust, but they can struggle to capture the diversity of spatial variations shown by observed data."*

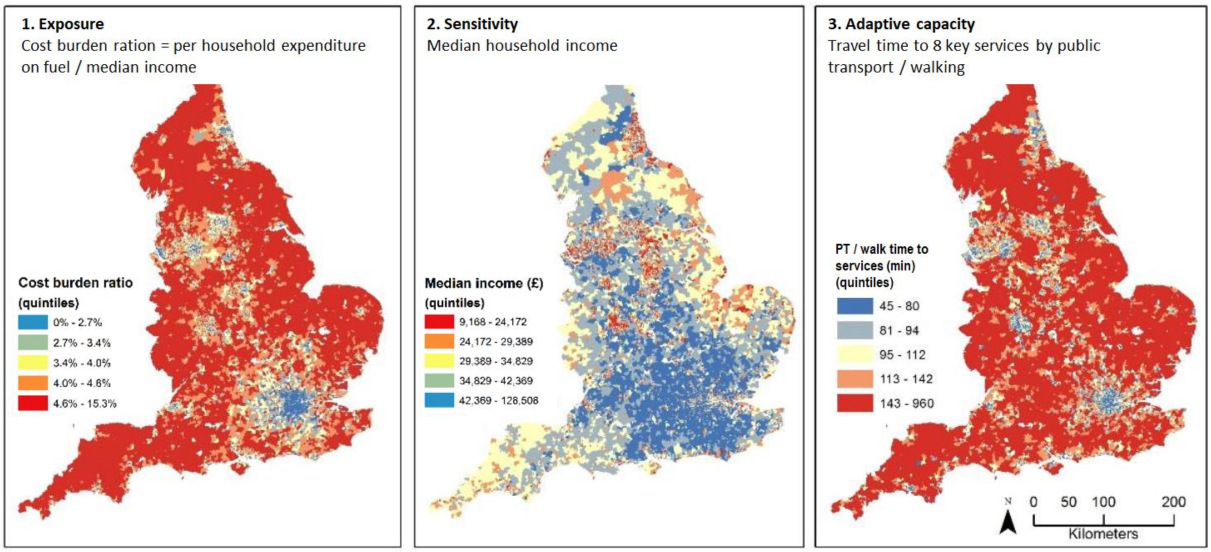
The authors suggest that one reason for this is the often considerable variation of household types in the surveys being reweighted and that, in any case, similar household types may show different behaviours or have different attributes depending on geographical factors not contained in surveys.

By starting with the *full* population of cars and vans in the UK, Mattioli et al. (2017) developed an area classification of vulnerability (in this case to motor fuel price increases) which allows investigation of how different dimensions of vulnerability correlate spatially as potentially useful input into a microsimulation study. The data was obtained from a novel anonymised vehicle inspection record dataset (MOT data, see Cairns et al., 2016) which provides vehicle characteristics, annual mileage and vehicle keeper location for all registered cars. From this, estimates of per household fuel consumption and expenditure for all journey purposes by car/van could be estimated at a spatially disaggregated level (Lower-layer Super Output Area[4]). By combining these estimates with income data (median household income[5]) and data to assess the ability of households to shift to other modes (using the UK Department for Transport's 'Accessibility Statistics' on travel time to key services by public transport and walking[6]), three dimensions of vulnerability were calculated: (i) exposure (the cost burden of motor fuel) (ii) sensitivity (income) and (iii) adaptive capacity (accessibility with modes alternative to the car). These were combined into a spatial metric of social vulnerability to fuel prices for England. The most vulnerable areas were defined as those with a high cost burden of motor fuels, low income and high levels of car dependence.

The results show diverse spatial patterns and processes of vulnerability both at the national level and within city-regions, and the complex interplay between the constituent dimensions of the index. Figure 2 shows the spatial patterns of the three components of the index, with five different colours corresponding to quintiles in the distribution (in each case from lowest (blue) to highest (red) vulnerability). Figures 3 shows the distribution of vulnerability for separate city regions.

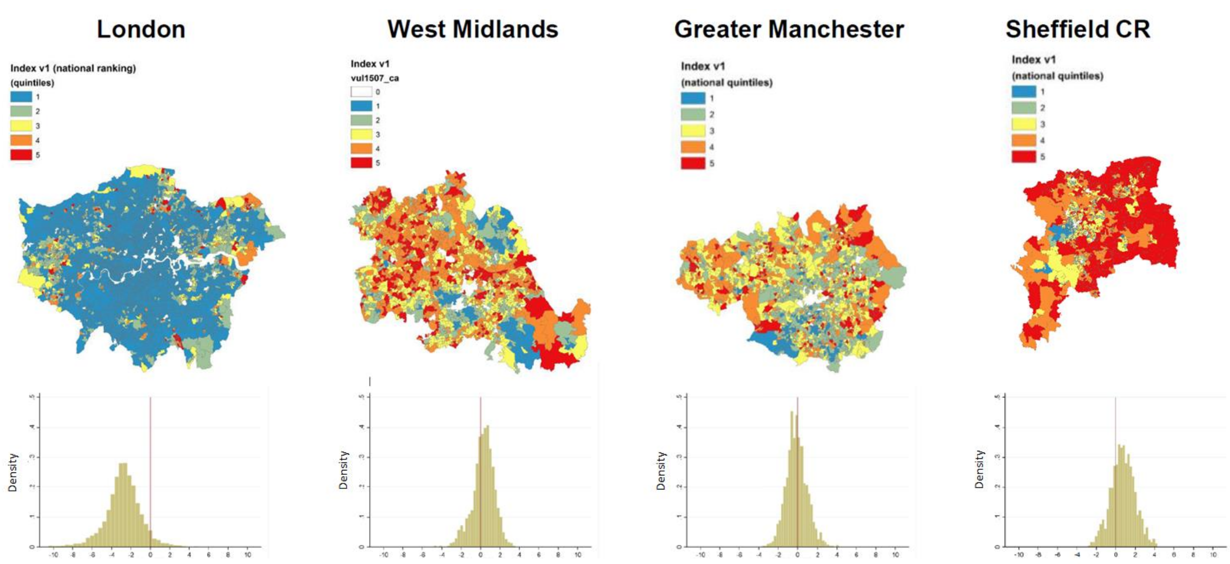
The first map in Figure 2 shows the cost burden ratio. On average, this is around 3.7% - meaning that per household expenditure on fuel typically corresponds to around 3.7% of the median income in the area. This is lower in most urban areas, although is much more pronounced in London than in city regions in the North of England. The second map shows income. Here colours other than red tend to dominate, even though the same colour-scheme based on quintiles is used. This is because lower income areas are concentrated in dense, inner-urban areas, which are smaller in land area on the map. Note that this is not true for London or the peri-urban areas in between cities in the North, which are mostly in the higher income classes, along with most of the South-East. Outer rural areas (e.g. Cornwall, the east coast) tend to be middle income. The third map shows accessibility - that is time taken to travel to essential services by public transport or walking. This is very high in rural areas and is lower in and around major cities and along some (rail) corridors. The values can then be mapped as a composite index. The map (not shown here) is dominated by areas in the highest quintile of vulnerability as these tend to have a larger land area because of a lower population density and thus inferior accessibility. On the other hand, many suburban and peri-urban areas around London have low levels of vulnerability, despite high car dependence and relatively high expenditure on fuel, because of very high (average) income. This buffer zone around cities is less prominent in the North of England, where the areas between cities tend to be high vulnerability, despite relatively high income, possibly due to very high levels of expenditure and very poor accessibility. Inner cities, even in the North, tend to be low vulnerability but show very high vulnerability in the interstitial spaces between the major urban areas.

Figure 2. **Mapping the three components of the vulnerability index**



Source:Mattioli et al. (2017), p7.

Figure 3. **Mapping the composite vulnerability index for four city regions in England**



Note: the ranking is based on a national, not regional, benchmark.

Source: Mattioli et al. (2017).

This fine spatial scale sheds light on Bonsall and Kelly's conclusions about the sensitivity of the at-risk groups to the geographical boundaries of any road user charge. In Figure 3, it can be seen that whilst London is skewed towards a generally low level of vulnerability, it has pockets of high vulnerability. If this information were to be coupled with a house affordability factor, the pattern of vulnerability would be very different with a high likelihood of much more red on this map. Other city regions show immense diversity such as the general mosaic pattern in Birmingham or the north/south split in Greater Manchester. This, comprehensively of the underlying vehicle fleet and mileage data means that it can be used to assess vulnerability with respect to the vehicle efficiency and to shed light on issues such as the equity implications of restructuring a whole gamut of charges related to vehicle emissions, road tax, fuel tax as well as the structure of the road user charge, as was indeed the proposition in the recent Wolfson Prize winning entry (Raccuja, 2017).

Even without the vulnerability index being used as a relevant constraint in a population synthesis, it could contribute to assessing the social impacts of road user charging if coupled with origin-destination data and cross tabulated with the costs to residents in different zones. Availability of the fleet composition at small geographical scales combined with the ability to calculate annual mileages, allows the emissions generated by all cars registered in an area to be estimated. In turn, this can be related to journey patterns and mapped against data on actual pollution concentrations or exposure levels. This allows analysis of the relationship between the polluters (i.e. locations where those vehicles responsible for the highest emissions are registered) and the polluted (those living in the pollution hotspots).

Chatterton et al. (2015) found that those living in the most polluted areas are the least responsible for the production of those pollutants. This is largely because those living in the most polluted areas tend to drive older, smaller petrol cars which are less polluting than larger, newer diesel cars in higher income areas. And, crucially, they drive fewer miles. Something similar is being carried out with the same vehicle registration/testing data in order to assess implications of a new cordon-type charge around a Clean Air Zone relating to the highest NOx polluting vehicles in Edinburgh (Morton et. al, 2018). In the Edinburgh City Region, information on total vehicle mileage was augmented with information about where cars are used. This was based on locally modelled Origin-Destination matrices to reveal where the vehicles that travel through the pollution hotspots in the city tend to come from. Each local in the region was graded according to the proportion of cars in that area that comply with Euro 4 Petrol and Euro 6 Diesel standards[7] and according to the proportion of traffic it supplies to the city centre in the morning peak. This analysis illustrated that traffic in the pollution hotspots is comprised of a combination of city and regional flows and that the majority of vehicles originate from areas with high rates of non-compliance.

Overall, this work clearly shows that targeting the cars that reside in the polluted central areas would not target the majority of cars responsible for those emissions. The Chatterton et al. and Morton et al. studies also clearly highlight the vital importance of having a detailed understanding of the vehicle fleet as well as total mileage and journey patterns - as it is this which ultimately corresponds to emission levels. The analysis also highlights how any social impact analysis is very sensitive to assumptions about how an emissions related charge would be structured. For instance, as discussed above, in November 2017 London) introduced a new T-charge which bases its criteria for high/low polluting vehicles on the date of first registration, which it is assumed crudely relates to a Euro-standard[8]. Not only is this method in danger of misclassifying a car due to common mismatches in registration dates and Euro-standards, there are very large discrepancies between the test-cycle allocated emissions factors and real world emissions (Fontaras et al., 2017). Overall, given Chatterton et al.'s conclusions cited above, such a charge is in danger of penalising the very people who are also suffering the most from the poor air quality, yet who are not causing the bulk of it. The exact impact would be sensitive to journey patterns and the structure of any charge including exemptions for those living 'locally'. The net impact would depend on the degree to which the air they breathe is eventually improved by the charge. If the charge is structured with the polluter/polluted relationship in mind, it could be that the groups currently most vulnerable to the poor air quality may actually receive an enhanced benefit if the charge is based on a sophisticated method of classifying vehicles that also accounts for new data on real-world emissions (e.g. Tietge et al., 2017), as well as benefitting from air pollution improvements. The next stage of this research is to combine the vulnerability index with the evaluation of the Clean Air Zone charge work to include capacity for drivers to adapt in terms of using alternative modes. However, adaptation can also take the form of changing the vehicles used. Work has shown that high income areas are much more likely to have the lower fuel efficient cars and in this sense, have more "steps of adaptation" that they could adopt.

Discussion

The purpose of this paper has been to explore the methodological challenges that flow from intervention design considerations that account for the *'Net Overall Distributional Effect'* (NODE) which will not only vary by income group, but also by age, gender, car ownership and use, and geographical area of residence, work and activity. Specifically, we have profiled data and methods that measure small-area spatial variability in travel behaviour, opportunities and household characteristics and could be used to define, measure and operationalise dimensions of social vulnerability to some form of road user or congestion charge. In doing so, we have identified a set of concerns to be addressed in the assessment and evaluation of the distributional consequences of a road pricing intervention.

Distributional impacts must be analysed in terms of the net impacts

Any attempt to explore the distributional consequences solely in terms of the incidence of payments cannot produce a useful picture of who gains and who loses. The distributional impacts must be analysed in terms of the net impacts both of the new charges and of the new patterns of the benefits arising from plans about use of the revenue (including any related changes in regulation, control and operations).

This approach is in sympathy with that proposed by Tovar-Reanos and Sommerfeld (2017) but not identical to it. They propose a consumer surplus method to calculate the distributional effects of various ways of implanting fuel tax changes, including compensation, with a focus on distinguishing 'progressive' and 'regressive' effects related essentially to income: They conclude that:

> *"…an additional tax on conventional fuel is regressive. However, returning the additional tax revenue via lump-sum transfers can alleviate this effect. Second, when the additional revenue is also used to finance subsidies for electrical and compressed natural gas (CNG) vehicles, households that own such vehicles experience welfare gains. However, this policy also increases income inequality and decreases social welfare".*

There would seem to be no reason why this method should not be extended to the more complex issues of distribution when location, access and the range of choices available may be as important dimensions as income, though (as noted above) the question of a lump sum compensation in practice does not lend itself to correcting unfairness at the level of small groups or individuals, which in turn affects judgements about whether equality has increased or reduced. But overall this approach reflects a similar judgement that distributional effects cannot be determined from the first round of price changes alone.

Net impacts will change over time depending on behavioural response

Bonsall and Kelly (2005) identify the need to extend their work to investigate behavioural responses to allow consideration of the second order impacts of charges and linked policies. However, they note the technical challenge and express concern that this could be counterproductive in terms of introducing uncertainty. They suggest this effort would be considerably aided by adding characteristics to any modelling.

Adaptive response is not in itself an indicator of a gain or a loss

Impact is related to adaptive capacity; but adaptive response is not in itself an indicator of a gain or a loss. Just because people currently use cars a lot, cannot be taken as measure of car dependence (defined as the need to travel by car) in and of itself. In other words, it cannot be assumed that impacts of a charge on car users will be directly in proportion to how much the car was used preceding the charge. This is because car users have differential opportunities to escape, reduce and adapt to that charge. Therefore, a NODE assessment requires some measure of adaptive capacity as well as understanding of dynamic behavioural responses – both of which are big methodological challenges in themselves. For one thing, accessibility indicators do not measure lived accessibility well, tending to rely on crude assessments of the quantity rather than the quality of services (Curl et al., 2017) and focus on modal shift, ignoring the many other adaptations that could take place (timing, destination, car type etc). Most importantly, measures of behavioural response need to be disaggregated and longitudinal not only because different behavioural adaptations take different lengths of time to embed, but also because the target groups will themselves change as previous groups adjust (Sloman et al., 2010). Perhaps most challenging of all in terms of evaluation is the question that Bonsall and Kelly (2005, p417) pose:

> *"The prediction of response would however bring an additional issue to the fore, namely do travellers who change their behaviour in response to policy gain or lose more or less than those who, because they regard the alternatives to be less desirable, choose to retain their existing pattern of behaviour?"*

Distributional analysis requires understanding the joint effect of different factors

The salient dimensions which affect variations in the incidence of payment will in general not be identical to the salient dimensions that affect the incidence of transport and other benefits and losses. Thus, for example, distributional analysis often features distinctions by income group. Yet, whilst the amount of payment made will vary according to the pattern of journeys made by car users especially, the incidence of changes in air pollution, say, will affect the geographical location of residents living near a road which will include people of different incomes and car use patterns.

The vulnerability analysis summarised above by Mattioli et al. (2017) offered some insight into how the different dimensions of vulnerability interact with each other. Other work on Australian cities has shown a 'regressive' urban structural effect, whereby low income and high cardependence are strongly co-located in the urban periphery (Dodson and Sipe, 2007). Similar work on city-regions in New Zealand (Rendall et al., 2014) and continental Europe (Büttner et al., 2013) has highlighted different patterns (Mattioli & Colleoni, 2016). Similarly, previous research on Australian cities has suggested that areas with high vulnerability are also characterised by lower rates of diffusion of diesel and other alternative energy vehicles, and thus worse average fuel economy of the vehicle fleet. This further affects their overall level of wellbeing (Li et al., 2017). However, work by Chatterton et al. (2015) summarised in the previous section to this paper showed that, in the UK, those living in the most polluted actually tend to own relatively less polluting cars (because they are smaller and not diesel), even though they are not the newest cars. This in turn poses a design challenge for the design of a graduated charge that may try to address not only congestion but both fuel economy (CO_2) and local air pollution. In addition, income is not itself necessarily a good indicator of 'exposure' to any charge as this and housing costs or job insecurity may impact vulnerability to increased motoring costs.

Conclusions

Congestion charging is not a single well defined intervention. It involves a wide range of different projects that differ in terms of the financial instruments used and the principle of their application. Congestion charging also requires defining the primary and secondary objectives of the scheme especially in terms of the benefits sought (economic, social, environmental, political, engineering, pragmatic, legal and indeed distributional), the time horizon of assessment, and unintended consequences. Therefore there is no generic well-defined distributional impact, but a series of different distributional impacts specific to the policy and design decisions taken.

Distributional consequences will be primarily impacted by:

Whether a scheme is designed to be revenue neutral in terms of public accounts or designed to internalise external costs (which will, in some important contexts with high levels of congestion and environmental damage, generally not be revenue neutral but initially generate a surplus).

Decisions about the use of that revenue. Whether revenue neutral or not in overall terms, all charging schemes generate revenue held initially by the charging authority or agency. For practical reasons, the formation of a political consensus strong enough to achieve implementation will require promises and plans about the spending. Options may include (a) return to general tax revenue, (b) spending on road construction aimed at the classes of vehicles and users more or less in proportion to their payments (c) spending on alternative means of transport, e.g. rail, other public transport, walking and cycling to facilitate reductions in congestion and pollution and provide alternatives to the now more expensive road vehicle use (d) use of revenues collected in richer areas to improve the travel opportunities in poorer areas and e) return of the revenue collected to taxpayers in the form of reductions in specific taxes or generally across the board. In the case of a scheme run by a private company for the benefit of its shareholders, the distributional consequences will be a product of its calculations of a profit-maximising design, which may be modified by public regulation.

Deciding which impacts are most important and what benefits are being sought. This is not just about congestion but requires some form of hierarchy or possible weighting of a set of costs and benefits resulting from specific vehicles at specific times, or cumulatively and dynamically over time, in specific areas to specific people or sets of people.

The sensitivity of the charge and revenue allocation to changes over time. Dynamic effects of redistributing the revenue will take time to build up, with intended and unintended longer term consequences. In addition, individuals do not stay in the same classification used for the initial analysis, and therefore people who may be initial beneficiaries may be losers in the longer term, and vice versa.

All these considerations are underpinned by an important feature of the classical economic case for road pricing, which shows theoretically that in general a large part of the potential benefit of marginal social cost pricing is captured in the revenue collected, and is only made concrete when that revenue is spent. As well as affecting the distributional consequences, proposed decisions on the pattern of spending will affect the political and attitudinal responses of individuals and organised interests – partly as a result of their own separate expectations of distributional impacts (‘how will this affect me?’) which may not correspond with the formal judgments of the official assessment.

Notes

1 The report was commissioned by one UK Government but swiftly dismissed by following Government at the time of its publication – the Prime Minster responded by vowing 'never again' to commission such a study. In fact successive Governments have many times commissioned such studies.

2 It can be seen that if the amount of charge paid were exactly to be returned to each individual paying it – were such a thing practically possible – nobody would be paying out any more or less than previously, and it is difficult to see what behavioural consequences there could be in the longer run. There would be little or no effect on congestion or anything else. Any compensation scheme relies on some individuals getting back more than they paid, and some less. It is not at all obvious that a class like 'motorists' for collective compensation is fairer than a class like –say – 'urban residents'.

3 The paper's editor is George Osborne, a former member of the Conservative Government and Chancellor of the Exchequer, i.e. the Minister of Finance. The Mayor, Sadiq Khan, is the candidate of the Labour opposition in Government, defeating Boris Johnson, the former Mayor, who is (at the time of writing) a member of the Government. Support for expansion of diesel cars was initiated by the former Labour Government, now widely thought to have been a mistake, and the current reversal is based on the EU test-regime results related to age of vehicle, which, as discussed below, does not convey an accurate picture of the relationship between vehicle age and emissions.

4 As defined for the 2011 Census.1 In England and Wales, there are 34,753 of these areas. They have been designed to be relatively similar in population size, containing 1,000–3,000 people, or 400–1,200 households, and to represent people with relatively similar characteristics. In Scotland, the equivalent unit is the Data Zone, of which there are 6,976, with a population of 500–1,000 residents.

5 Median annual household income in 2011, from Experian Ltd.

6 https://www.gov.uk/government/collections/journey-time-statistics

7 However, as explained in the paper, this parameter is estimated from the date of first registration and fuel type which is a proxy for Euro standard and the accuracy of this method of approximation is being assessed.

8 https://tfl.gov.uk/modes/driving/emissions-surcharge/emission-standards-and-the-t-charge-zone?intcmp=49129

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Assessing the Net Overall Distributive Effect of a Congestion Charge

This paper offers new insights into the definition, measurement and operationalisation of different dimensions of social vulnerability to road user charges, using unique data sets available in the UK. Assessing distributional effects of road pricing or congestion charging schemes requires evaluating distributional patterns: who receives the benefits of reduced congestion and who receives the revenues collected? How these impacts change over time also needs consideration.

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