An evaluation of national road user charging in England

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Abstract

This paper explores the effects of road user charging throughout England. It develops a model to test charging scenarios including revenue raising and revenue neutral charging options, and economically efficient pricing. For each scenario we estimate effects on traffic volumes, user charges and fares, subsidies, environmental costs, benefits to consumers, government revenue, and overall net benefits. We show that appropriate charging structures coupled with compensating reductions in existing motoring taxes can make a real difference to traffic growth, congestion and environmental damage, and can relieve pressure to build new roads.

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Keywords: Pricing; Traffic; Congestion; Environmental costs

1. Introduction

Rapid traffic growth is placing a heavy burden on the capacity of Britain’s road infrastructure. Current UK government estimates indicate that if present policies are maintained there could be 22% more traffic by 2010 (DETR, 2000; DfT, 2003). Consequently congestion looks set to get
worse on certain sections of the network. A recent Transport Select Committee report notes that even if there were the political will to develop sufficient capacity to meet the forecast demands for travel by road, bus and rail, the cost implications would be unaffordable in terms of the current public spending environment. In this paper we investigate whether, in the words of that Committee, “the only effective way of achieving a sustained cut in congestion appears to be to introduce some road user charging on our busiest roads during peak periods charging road users according to the use they make of the roads” (Transport Select Committee, 2003).

This is a study of what road user charges across the whole of England might have to offer if they reflected marginal social costs in full. Our method provides a basis for a comparison of the current structure of transport taxes and charges with that implied by the analysis of several policy scenarios. The paper recognises three fundamental linkages:

(i) varying prices will change volumes which, in turn, will vary important dimensions of quality such as speed;
(ii) varying relative prices will affect the mode of travel;
(iii) varying prices, taxes and subsidies will change the burden on government finances and may change the funding available for new infrastructure from both public sources and from privately funded investment.

Thus, differing charges will create changes in patterns of demand, and consequential changes in the case for investment in infrastructure. The research presented in this paper provides a basis for a discussion of the merits of present investment intentions and the investment requirements under a reformed pricing regime.

The paper is structured as follows. Section 2 describes our demand model and the numerical algorithm used. Data sources are outlined in Section 3. Section 4 discusses the implementation of the model, including a description of the charging scenarios that we consider, and emphasises some of the limitations of our analysis. Results are presented in Section 5. The final section presents a summary and conclusions.

2. The model

The starting point for our analysis is the hypothesis that transport prices have been set on the basis of historical precedent or political expediency; they do not reflect the actual costs that transport users impose. Given a free hand to adjust taxes and prices the economically efficient traffic flow is given by the point where the benefit of an extra vehicle kilometre is in balance with the marginal social costs. Our aim is to estimate this point, and thus to identify the unit charge that would create the appropriate shift from today’s equilibrium. However, we also use our model to evaluate a range of charging options that deviate from this idealised situation.

The generalised cost \( g_i \) to a user of a specific mode \( i \), in a particular place at a particular time of day is a measure of the total of all the costs faced per passenger kilometre:

\[
g_i = p_i + \tau_{ie} \left( \frac{1}{s_i} \right) + t_i + \sum_c U_{ic}, \tag{1}
\]
where $p_i$ is the price of the mode or money cost, $\tau_{iv}$ is the value of in vehicle time, $s_i$ is speed, $t$ is taxation, and $U_{ic}$ is any other relevant user cost. The modes we consider include private vehicles on any one of six different journey purposes, commercial vehicles, bus and rail.

For each mode $i$ we assume that the demand in the observed base, $x_i^0$, represents the equilibrium at the prevailing set of all generalised costs, $g_j^0$. The position of some new equilibrium of generalised costs and demands relative to the base equilibrium, and thus the magnitudes of the charges and the traffic volume reduction required to reach this new point, is dependent on the shape of the demand relationships. Furthermore, the demand for any one mode will depend upon the new generalised costs for all the others through the propensities to switch mode. There is little conclusive evidence about the shape of these demand relationships. Candidates include the linear and the constant elasticity forms. A particularly useful intermediate form is the semi-logarithmic in which the demand for mode $i$, expressed in passenger trips per unit of time, is given by

$$x_i = x_i^0 \exp \left\{ \sum_j \lambda_{ij} (g_j - g_j^0) \right\}, \quad (2)$$

where $x_i$ is the demand for mode $i$ following some change in generalised cost. The $\lambda_{ij}$ are constant parameters that relate changes in demand for any one mode $i$ to changes in generalised costs (including prices and taxes) for all modes.

An advantage of the semi-logarithmic demand form is that it has the intuitively reasonable property that the implied own price elasticity is directly proportional to the respective price: as a price rises the mode becomes progressively less competitive, so the relative loss of market accelerates as the price continues to rise. From (2) we can derive a simple relationship between the $\lambda$’s and the respective price elasticities:

$$\frac{\partial \log x_i}{\partial \log p_j} = \lambda_{ij} p_j. \quad (3)$$

Price elasticities are crucial to our model because we use them to derive the $\lambda_{ij}$ parameters. Starting from national own and cross price elasticity values we derive a set of ‘local’ elasticity values for every case in the model recognising that the magnitude of own and cross-price elasticities will be determined to a large extent by relative mode shares, which vary by locality and time of day. Assuming symmetry of the compensated cross partial derivatives of demand and assuming that prices are constant across space and that consumers behave everywhere in the same way, we derive the following expressions for local own and cross price elasticities for mode $i$:

$$\eta_{ii}^L = \eta_{ii}^N \cdot \left( \frac{x_i^N / x_i^N}{x_i^L / x_i^L} \right), \quad (4)$$

$$\eta_{ij}^L = \eta_{ij}^N \cdot \left( \frac{x_i^N / x_j^N}{x_i^L / x_j^L} \right) \quad \text{and} \quad \eta_{ji}^L = \eta_{ij}^L \cdot \frac{p_i}{p_j} \cdot \frac{x_j^L}{x_j^L}, \quad (5)$$

where $\eta$ denotes an elasticity, $x$ is the demand for all modes, and the superscript $N$ refers to a national value and $L$ to a local value. A full derivation of these formulae is given in Graham and Glaister (2004b).
In our model the $\lambda_{ij}$'s are constant when moving from the base to the new equilibrium but the elasticities are recalculated at each iteration in terms of current money costs and market shares.

As noted, we have preserved the symmetry of the compensated cross-price effects that would be necessary for path independence of integration in calculating consumer surplus precisely. However, for computational tractability our consumer surplus calculations use the first order approximation of the “rule of one half”. This may have introduced a small bias in our estimates of consumer benefit but we believe this does not change the broad orders of magnitude of our estimates.

For each mode we use this demand form, the generalised costs and appropriate elasticities and apply a numerical algorithm to search for new price and tax levels according to some predefined scenario. The steps for computing the movement from today’s situation to the new equilibrium are

(i) Establish an equilibrium for the base situation, in which speeds, traffic flows, demands, and generalised costs are mutually consistent.
(ii) Establish suitable national average own-price and cross-price elasticities.
(iii) Modify these elasticities to local conditions using local market shares.
(iv) Convert from the modified elasticities to the respective $k$'s.
(v) Change a policy variable, such as a road user charge, a rail fare or a tax on fuel.
(vi) Calculate a new, mutually consistent set of speeds, generalised costs and demands.

This last stage involves an iterative algorithm because of the inherent interdependencies. In scenarios where charges are to be set to reflect incremental congestion costs the last two steps will be iterated many times. Having found the set of taxes and charges corresponding to the new equilibrium, this yields estimates of the revised volumes of travel and hence the changes to tax revenues and public transport costs, revenues and subsidies. An estimate is produced of the overall net effect on the government finances, and we use our results to provide an economic evaluation that details effects on environmental costs, passenger benefits (including freight), changes in subsidies, and net overall benefits.

3. Data sources

In order to establish the base equilibrium, data are required on travel demands, values of time, vehicle operating costs, traffic speeds, external costs, and travel demand elasticities.

3.1. Travel demand data

Detailed road traffic flow data were provided by the UK Department for Transport (DfT). These annual data relate to England for the year 2000 and are used by the DfT as part of their national road traffic forecasting exercise. We used these data to create a “base” set of figures to represent the situation in 2000, although we express financial quantities in 2003 prices. The annual traffic flow data comprise 8960 “cases”. Each case corresponds to
1. a type of road (motorway, trunk, principal, B-road, C-road, Unclassified), in
2. a particular area type (central London, inner London, outer London, inner conurbation, outer conurbation, urban-population exceeding 250000, urban-population exceeding 100000, urban-population exceeding 25000, urban-population exceeding 10000, rural), in
4. at some time of the day (divided into 19 periods covering peak and off peak weekdays and weekends), and in
5. a ‘busy’ or ‘non-busy’ direction.

Within each of the 8960 cases five vehicle types are defined: cars, light goods vehicles (LGVs), rigid heavy goods vehicles, articulated heavy goods vehicles, and buses (public service vehicles). The data on cars are further classified according to six journey purposes: home based work (HBW), home based employers business (HBEB), home based essential other (education and private business) (HBEO), home based discretionary other (social and holiday) (HBDO), non-home based work/employers business (NHBWEB), and non-home based discretionary other (NHBO). Vehicle occupancies and passenger car unit equivalences for each vehicle type are taken from data given in the Department’s Transport Economics Note (DETR, 2001). The specific values used are given in Table 1.

Demand data for public transport were derived from published sources, principally Transport Statistics for Great Britain (DTLR, 2001a) and Regional Transport Statistics (DTLR, 2001b). The public transport data are not nearly as detailed as our statistics for road traffic and for this reason our representation of bus and rail travel is less satisfactory than that for car and lorry traffic. In particular, we have had to make some simplifying assumptions about public transport costs and capacity and how these respond to changes in patronage. These assumptions in turn may influence results regarding the financial viability of public modes and consequently the levels of subsidy required.

Distances travelled by person by mode by region, together with population by region were used to estimate bus and rail passenger kilometres by region. Regional data on bus kilometres and rev-

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**Table 1**

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Vehicle Occupancies</th>
<th>PCU Equivalences</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>1.6</td>
<td>1</td>
</tr>
<tr>
<td>HBEB</td>
<td>1.22</td>
<td>1</td>
</tr>
<tr>
<td>HBEO</td>
<td>1.22</td>
<td>1</td>
</tr>
<tr>
<td>HBDO</td>
<td>1.22</td>
<td>1</td>
</tr>
<tr>
<td>NHBWEB</td>
<td>1.6</td>
<td>1</td>
</tr>
<tr>
<td>NHBO</td>
<td>1.6</td>
<td>1</td>
</tr>
<tr>
<td>LGV</td>
<td>1.25</td>
<td>1</td>
</tr>
<tr>
<td>Rigid</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Artic</td>
<td>1</td>
<td>2.9</td>
</tr>
</tbody>
</table>

enues were used to estimate average bus fares paid. While bus fares varied by region, rail fares did not because we could not secure satisfactory rail receipts data by region. A national average was used for rail.

We pro-rated bus travel within the region to each of the cases in proportion to the amount of travel by car. Since we already had an estimate for the number of bus kilometres by case this implied an average load per bus by case. These loads were assumed constant: so a change in bus patronage was assumed to be matched by a proportionate change in bus vehicle kilometres and that would lead to a corresponding change in bus operating costs. This is plainly unrealistic at the level of the individual bus route but constant returns to scale may be a reasonable approximation at the level of market aggregation at which we are dealing.

For rail we were unable to determine how costs might vary with rail traffic. We therefore assumed that train services and hence train costs would be unchanged throughout, changes in patronage being accommodated by changes in average train loadings. In cases where rail demand falls this may be realistic. In cases where it rises then it is unrealistic because the railway is already at or near full capacity in many cases, for instance, in the London commuter market.

3.2. Values of time

Values of time in 1998 prices and values were taken from the DfT's Transport Economics Note (DETR, 2001) and adjusted to allow for inflation and real income growth between 1998 and 2003 (see DETR, 2001, Table 2/7). Table 2 lists the specific values used.

3.3. Vehicle operating costs

The DfT's Transport Economics Note also provides vehicle operating cost formulae. Fuel efficiency gains between 1998 and 2003 were applied (see DETR, 2001, Table 3/4). Fuel was assumed priced at £0.80 per litre for cars and commercial vehicles and at £0.34 per litre for public service vehicles, after rebate of fuel duty.

Table 2
Values of time per vehicle (pence per kilometre, 2000 prices)

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Value (pence per kilometre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HBW</td>
<td>8.95</td>
</tr>
<tr>
<td>HBE</td>
<td>25.32</td>
</tr>
<tr>
<td>HBE</td>
<td>8.95</td>
</tr>
<tr>
<td>HBDO</td>
<td>8.95</td>
</tr>
<tr>
<td>NHWEB</td>
<td>25.32</td>
</tr>
<tr>
<td>NHBO</td>
<td>8.95</td>
</tr>
<tr>
<td>LGV</td>
<td>10.62</td>
</tr>
<tr>
<td>Rigid</td>
<td>9.04</td>
</tr>
<tr>
<td>Artic</td>
<td>9.04</td>
</tr>
<tr>
<td>PSV pax</td>
<td>5.6</td>
</tr>
<tr>
<td>RAIL pax</td>
<td>7.52</td>
</tr>
</tbody>
</table>

3.4. Traffic speeds and speed flow relationships

For each case in our road traffic data we computed traffic flow per lane per hour using the passenger car unit (PCU, a standard measure of the use of road space by various vehicle types) and the relevant number of hours in the year. Speed flow relationships were provided by the DfT. We have 68 separate speed flow curves corresponding to a particular road in a particular area type. The speed flow curves are based on extensive studies of real road traffic conditions carried out by the DfT over many years. These relationships are crucial to the computation of the costs of congestion, because they represent the way that speeds are reduced as traffic increases.

3.5. External cost data

In order to implement our model we need detailed data on the marginal social costs of transport. The most comprehensive recent study of road and rail transport costs in Britain is by Sansom et al. (2001). They provide estimates of the external costs of road and rail travel specifying cost related to infrastructure operation and depreciation, external accidents, air pollution, noise, and climate change. Table 3 shows average national values for Great Britain for some of the external cost categories.

In fact we use the more detailed estimates that Sansom et al. (2001) provide separately for different vehicle types, area types and infrastructure types. We used estimates of external costs from Sansom et al., applying constant values per vehicle kilometre, but calculated our own congestion costs. The marginal social costs of congestion were computed numerically by adding one extra PCU to whatever was the current vehicle flow, using the speed-flow relationships to estimate the consequent reduction in speed and then summing the estimated delay costs to all road users affected.

3.6. Elasticities

The elasticities used in the model have been derived from a variety of sources. Graham and Glaister (2002a,b, 2004a) provide a survey of evidence on price elasticities of car traffic and freight traffic. Bus elasticities are taken from Dargay and Hanly (1999) and Rail elasticities from ATOC (2001). Table 4 lists the values and sources of the elasticities assumed at the national level.

<table>
<thead>
<tr>
<th>Cost category</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure operating costs and depreciation</td>
<td>0.42</td>
<td>0.54</td>
</tr>
<tr>
<td>External accident costs</td>
<td>0.82</td>
<td>1.40</td>
</tr>
<tr>
<td>Air pollution</td>
<td>0.34</td>
<td>1.70</td>
</tr>
<tr>
<td>Noise</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>Climatic change</td>
<td>0.15</td>
<td>0.62</td>
</tr>
</tbody>
</table>

*Source: Sansom et al. (2001).*
Local own and cross price elasticities will not necessarily be the same as a national average. For instance, if a particular area has very few rail services one cannot assume the national average percentage change in car trips as a result of a 1% change in rail fares. We modified national own and cross elasticities according to local market shares. Similarly, using evidence from de Jong and Gunn (2001), we allowed own-price elasticities for the car users to vary by trip purpose. Glaister and Graham (2003) detail the price elasticities, their sources and the ways in which we derived variation by market share and by journey purpose.

4. Application of the model

Using these data an equilibrium was established for the base situation. We then established new equilibria to represent the following policy scenarios:

(I) Environmental charges and congestion charges (EC&CC)—current fuel duties and other charges are at today’s levels but an additional charge is levied to fully reflect environmental costs and the incremental congestion cost that each vehicle imposes on all others.

(II) Zero fuel tax with environmental charges and congestion charges (zerotax, EC&CC)—all fuel taxes are removed (except that it is assumed that fuel would attract the standard rate of VAT) but an additional tax is added to fully reflect environmental costs and incremental congestion costs. This is the economically efficient scenario. In principle subsidies to public transport would also be eliminated but we found that it is not feasible to eliminate bus subsidies completely by raising fares. So bus fares were raised by 20%, and by 33% in London. Rail fares were raised 80%.

(III) Zero fuel tax with environmental charges and congestion charges with a revenue neutral mark-up (zerotax, EC&CC and revenue neutral mark-up)—as the previous case, but with the imposition of an equiproportionate mark-up on all environmental charges and congestion charges so as to return overall government income to today’s levels. For each type of vehicle and in each “case” the charges calculated under the previous scenario are all multiplied by the same factor.

Table 4
National elasticity values

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car traffic with respect to fuel price</td>
<td>-0.310</td>
<td>Graham and Glaister (2002b)</td>
</tr>
<tr>
<td>Bus (passenger km) with respect to bus fare</td>
<td>-0.900</td>
<td>Dargay and Hanly (1999)</td>
</tr>
<tr>
<td>Rail (passenger km) with respect to rail fare</td>
<td>-0.500</td>
<td>ATOC (2001)</td>
</tr>
<tr>
<td>Freight traffic with respect to fuel price</td>
<td>-1.070</td>
<td>Graham and Glaister (2004b)</td>
</tr>
<tr>
<td>Bus (passenger km) with respect to fuel price</td>
<td>0.035</td>
<td>Calculated</td>
</tr>
<tr>
<td>Rail (passenger km) with respect to fuel price</td>
<td>0.112</td>
<td>Calculated</td>
</tr>
<tr>
<td>Traffic (car km) with respect to bus fare</td>
<td>0.005</td>
<td>Calculated</td>
</tr>
<tr>
<td>Traffic (car km) with respect to rail fare</td>
<td>0.016</td>
<td>Calculated</td>
</tr>
<tr>
<td>Bus (passenger km) with respect to rail fare</td>
<td>0.340</td>
<td>Grayling and Glaister (2000)</td>
</tr>
<tr>
<td>Rail (passenger km) with respect to bus fare</td>
<td>0.918</td>
<td>Grayling and Glaister (2000)</td>
</tr>
</tbody>
</table>
In implementing our scenarios several numerical smoothing devices had to be employed to achieve convergence of the numerical algorithms, but approximate convergence was achieved in all cases. Some anomalies were noticed and dealt with as follows.

Some of the speed/flow relationships are specified as horizontal at very high traffic flows (beyond the normally expected rate of flow), implying that there would be no social cost from extra traffic in these circumstances and therefore no congestion charge. In the few cases where traffic flow was estimated to be so high as to be on the “flat” part of the speed/flow relationship, an artificial incremental speed reduction was imposed in order to create a congestion charge sufficient to bring the flow rate back to the sloping part of the curve, at which point normal charging principles would apply.

Vehicle operating costs increase rapidly with speed at high speeds. In a few circumstances, at high speeds, increasing congestion can reduce speeds sufficiently for savings in vehicle operating costs to dominate the additional time costs. While possible in reality, this “pathological” situation can cause instability in the search for an equilibrium so falling social costs with increasing congestion were neglected.

We also found in a few cases that the rate of charge implied by the model to cover travel costs, while economically efficient could be judged unacceptable. The increases were capped at the point where a vehicle type would experience a travel cost (excluding time costs in the case of cars) increase of 300%.

There are a number of limitations to our analysis. While we have used the best evidence we can find, many simplifying assumptions have been necessary. The aim has been to obtain a feel for the overall orders of magnitude of the implications of policy changes.

We do not address the important issues of technological or political feasibility. The crucial issue of the capital and operating costs of implementing any charging scheme is also outside the scope of this work. Our results are calculated relative to “today’s” conditions. We imagine that it would be possible to impose a taxing and charging scheme overnight, but a practical policy would have to work out an implementation date and measure effects relative to a base appropriate to that date, for which there would be growth in the underlying demand and some planned changes to the road and rail networks.

It is important to attempt to represent the distinction between peak and off-peak flows, as we have done, because of the non-linear nature of congestion and crowding. However, it is very hard to obtain reliable estimates of how traffic might shift between peak and off peak. People will, in practice, be able to respond by changing the time of day they travel so as to mitigate the effect on them of such things as congestion charges. Small (1982) and Lam and Small (2001) show that endogenous scheduling greatly reduces commuters’ values of time and for this reason time switching could represent a very important response to road pricing. We have made the simplifying assumption that there is no tendency to switch travel from one time of day to another, mainly because we could not find an objectively defensible way of modelling this. Our results may therefore exaggerate the overall traffic reduction for a particular level of congestion charge. Our predictions of the magnitude of charge increases necessary to achieve a better outcome depend crucially on the responsiveness of traffic at the most busy times and places. If the ability to switch means that this responsiveness is in fact greater than we have assumed, then our predictions of peak congestion charges will be higher than would actually be necessary.

Our model has no explicit transport network and makes no attempt to represent origin-to-destination trip patterns. It works in terms of flow rates per annum of passenger kilometres or vehicle
kilometres over typical roads at a variety of times and places. Therefore we are not able to distinguish between changes in numbers of trips and changes in average trip length; the historically observed responses to changes in costs and prices (the elasticities) are measures of a combination of both phenomena.

Similarly, this study concentrates solely on pricing measures on the current network. The observed elasticities represent the long term responses. They implicitly represent people’s propensity to change their travel patterns, trip lengths, including the propensity to change the densities of land use and the relationships between place of work and place of residence. However, we do not consider the part that active land use policies could play in altering traffic volumes and emissions.

The costs of environmental damages such as air pollution and climate change are uncertain but they are important determinants of the transport pricing policies discussed in this study. We accept without question the estimates of the several external and environmental costs of transport provided by Sansom et al. (2001). We recognise that making these estimates is difficult. Sansom et al. provide “low” and “high” environmental cost estimates and we make use of both to give an indication of how sensitive the policy conclusions might be.

There are some important factors that have not been—or cannot be—quantified. Some of these omitted factors may be detrimental: for example, community severance could result from the construction of new roads; accident rates could increase in some areas if road pricing reduces flows and increases speeds. Others are beneficial, for example better accessibility to family, leisure pursuits or employment opportunities. It is not apparent to us that we have necessarily underestimated or over-estimated the external costs and benefits of transport.

5. Results

The results are presented as follows. Table 5 gives a summary of the outcomes of the scenarios and Table 6 gives estimates of their economic performance, both tables use the low estimates of environmental costs. The results for each scenario are relative to the current base. Colour maps displaying an indication of the geographical incidence of speed changes and traffic changes are given in Graham and Glaister (2004c).

In Table 6 (column 2), we show estimates of benefits to passengers and freight. These are calculated on the basis of the simple “rule of one half”, which implicitly assumes the demand relationships are straight lines. If, however, they are not straight lines then this will be a source of error. It will be negligible for small perturbations from the base situation, but they will be larger for larger changes, but probably insignificant in relation to other sources of error and uncertainty.2

1 For instance Noland and Quddus (in press) have shown that congestion may be a mitigating factor of accident severity on high speed roads and motorways.

2 Bento and Perry (2001, 2002) have shown that the imposition of a congestion charge can interact with other existing taxes and create distortion that can change the expected welfare effect. For example, they note that congestion charging can reduce labour force participation by raising the cost of commuting to work, but on the other hand, if congestion tax revenues are used to reduce labour taxes then the net impact on labour supply can be positive. The interaction between new and existing taxes is not addressed in our study but we recognise that it is an important issue.
In Table 6 column (5) the direct revenue gain to the government is shown in terms of specific environmental charges, congestion charges and, under some scenarios, rebates per vehicle kilometre. There are additional financial implications for the government. It is assumed that changes in bus and rail subsidies ultimately pass to the government in full (a positive number in columns numbered (3) and (4) indicates a reduction in subsidy) and there are changes in fuel tax receipts (above changes in VAT on fuel) because of changes in the volume of fuel purchased. Column (7) summarises the overall government position.

Tables 6 and 7 repeat some of the results using the high estimates of the environmental costs. Concentrating first on the results given in Tables 4 and 5 we discuss each scenario in turn.

5.1. Environmental charges and congestion charges

Under this scenario, in addition to today’s fuel tax, every type of road user bears a charge per vehicle kilometre matching the estimated marginal environmental cost, which depends somewhat on vehicle type and location, and the congestion charge. Table 5 shows that under this scenario total road traffic falls by 9%, bus patronage increases by 7%, and rail patronage by 2%. Bus and rail finances improve: subsidy falls by just over 3%.

Note that the actual overall reduction in national traffic is only 9%, even though the environmental charges and congestion charges are in addition to today’s taxes. In fact the model results show that in some congested places, principally major urban areas and inter-urban routes, the new charges under this scenario are high and the reduction of traffic is substantial. But in many places and at many times there is little congestion so the increase in charges is only the relatively small environmental tax. The net result is that this full “optimum” can be achieved with a reduction of 9% in overall traffic levels—indicating the extent to which congestion is a localised problem. Indeed, we find that the imposition of environmental charges alone, without any congestion change, gives a traffic reduction of 6%, implying that congestion charges apply in relatively few time and places while environmental charges are by and large universal.
Table 6
Economic evaluation, low environmental costs

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Saving in environmental cost</th>
<th>Passenger and freight benefit</th>
<th>Reduction in bus subsidy</th>
<th>Reduction in rail subsidy</th>
<th>Env. tax, congestion charge revenue and rebates</th>
<th>Tax revenue correction</th>
<th>Net gain to government</th>
<th>Benefits net of all costs to government</th>
<th>Av. weighted ave. marg. cong. costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Column reference)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7) = (3 + 4 + 5 + 6)</td>
<td>(8) = (1 + 2 + 7)</td>
<td></td>
</tr>
<tr>
<td>1 EC&amp;CC</td>
<td>0.91</td>
<td>−7.99</td>
<td>0.05</td>
<td>0.08</td>
<td>11.9</td>
<td>−2.2</td>
<td>9.83</td>
<td>2.8</td>
<td>0.075</td>
</tr>
<tr>
<td>2 Zero tax, EC&amp;CC</td>
<td>−0.40</td>
<td>6.81</td>
<td>0.62</td>
<td>0.68</td>
<td>−7.9</td>
<td>+2.8</td>
<td>−3.80</td>
<td>2.6</td>
<td>0.062</td>
</tr>
<tr>
<td>3 Zero tax, EC&amp;CC and revenue neutral mark-up</td>
<td>0.32</td>
<td>0.15</td>
<td>0.63</td>
<td>0.77</td>
<td>0</td>
<td>+1.0</td>
<td>2.40</td>
<td>2.9</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Change relative to current situation (£ bn pa, 2003 prices).

Table 7
Summary results, high environmental costs

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Ratio of flow to the current value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Traffic</td>
</tr>
<tr>
<td></td>
<td>All</td>
</tr>
<tr>
<td>1 EC&amp;CC</td>
<td>0.81</td>
</tr>
<tr>
<td>2 Zero tax, EC&amp;CC</td>
<td>1.01</td>
</tr>
<tr>
<td>3 Zero tax, EC&amp;CC and revenue neutral mark-down</td>
<td>1.04</td>
</tr>
</tbody>
</table>
Table 6 shows that the addition of environmental and congestion charges would yield an extra direct revenue of £11.9 billion per annum and an overall increase in the government position of £9.8 billion per annum. There is a decrease in environmental damage costs of £0.91 billion per annum. The overall evaluation of benefits net of costs shows a gain of £2.8 billion per annum, with the overall disbenefit to passengers and freight of £8 billion per annum being offset by environmental benefits, improved public transport finances and tax revenues (which are largely a reflection of the value of improved travel conditions).

Instead of making the charges additional to the existing fuel tax it would in principal be possible to adjust the fuel tax so that the overall direct charge revenue is unchanged from today’s level. Below we develop a revenue neutral scenario along these lines as a variant of the economically efficient pricing scenario.

5.2. Zero taxes and subsidies, environmental and congestion charges

Under this scenario 67% of fuel duty is rebated leaving only standard rate Value Added Tax and both environmental charges and congestion charges are imposed. In principle this creates a “proper” or “efficient” set of road charges irrespective of where they happen to be set today. An attempt is also made to remove subsidies to public transport. In fact the commercial position of the bus and rail industries is so poor that it is not feasible to make them break even, short of shutting them down completely. We increased bus fares by 20% generally, and by 33% in London, where the bus market is stronger. We increased rail fares by 80% at which point the characteristics of our model imply that rail revenues would be approximately maximised.

Table 5 shows that under this scenario road traffic would increase by 12%, private cars by 6% and commercial vehicles by 16%. Bus patronage would increase by 12% and rail patronage decrease by 33%. Table 6 shows that compared with today’s levels it costs the government £7.9 billion per annum in charges and rebates and overall government revenues decrease by £3.8 billion per annum. The subsidy to the bus industry falls from £1.4 billion per annum to £0.8 billion and that for the rail industry falls from £1.6 billion per annum to £0.9 billion. Overall, there is a benefit to passengers and freight of £6.8 billion per annum, although there is an environmental damage cost of £0.4 billion per annum. The overall net benefit is estimated at £2.6 billion per annum.

These results illustrate the proposition that, on our assumptions, and given the environmental costs used (low estimates in this case), if charges were to be set in accordance with one set of economic principles, rather than by historical accident, then road users would pay less than they do today: average money costs per car kilometre would fall from 10.4 pence to 9.3 pence. There would be a net increase in economic efficiency.

5.3. Zero taxes and subsidies, environmental and congestion charge, revenue neutral mark-up

The previous scenario represents an idealised situation. In practice a revenue neutral scenario might be more politically attractive. Thus, here we take the idealised tax and charge structure as before but impose an equiproportionate mark-up so that the direct effect on government finances is neutral relative to today’s circumstances.
This scenario is particularly interesting because it achieves a redistribution of traffic away from congested times and places and away from those where environmental damage is greatest, while leaving total tax and charge revenues largely unchanged. Table 5 shows a slight increase in overall traffic of 4%, an increase in bus patronage of 13% and a decrease in rail patronage of 31%. Detailed results from the model show that traffic is reduced most in the big conurbations and it increases most in the country areas. The big cities enjoy a substantial speed improvement. Many of the places that have the biggest traffic volume increase (such as the North of England) have little or no speed reduction—because they are areas with spare capacity and therefore relatively little congestion. Thus, this scenario illustrates the proposition that at today’s overall rates of fuel tax, city areas are under-charged, while the country areas are significantly over-charged.

Table 6 shows that this scenario gives the best overall net benefit of all the scenarios we considered at £2.9 billion per annum. There is a net gain to the government of £2.4 billion per annum, largely due to a marked improvement in bus and rail finances (this, in turn, is partly due to the fares increases: of 20% and 80%). There is a reduction in environmental damage valued at £0.32 billion per annum. Passengers and freight users are slightly better off by £0.15 billion per annum.

It is interesting to note from Table 6 that the revenue neutral scenario appears to show a better overall economic return than the revenue-unconstrained case. On first principles one would expect the reverse. This may be a consequence of the “capping” that has been applied to ensure that no road user-type experiences more than a threefold increase in money costs per vehicle kilometre. This means that the “optimum” is, in fact, not a full economic optimum. It is also true that our incomplete representation of public transport could affect the results.

5.4. The effect of using high environmental estimates

Tables 7 and 8 repeat results for our scenarios using the high environmental costs estimates provided by Sansom et al. (2001). Our purpose here is to test the sensitivity of results to the view taken about the order of magnitude of costs.

Using high environmental cost for scenario EC&CC we find that overall traffic falls by 19% rather than 9%. The net gain to the government rises to £15 billion per annum from £9.83 billion and the saving in environmental costs increases from £0.91 billion per annum to £5.04 billion. These differences demonstrate that, as we have already noted, the high cost estimates are significantly different from the low ones, particularly with regard to air pollution and climate change.

Again, for the zero tax EC&CC scenario Tables 7 and 8 show rather different outcomes with the high environmental costs. Rather than a net loss to the government of £3.8 billion per annum there would be a net gain of £4.61 billion. Of course, this reflects the more aggressive stance towards charging for environmental effects: there is an estimated environmental gain of £1.6 billion per annum against the current base compared to a £0.4 billion per annum loss with low environmental costs. Average money costs per car kilometre would rise from 10.4 pence to 11 pence.

It turns out that if we assume the low environmental costs then the “proper” set of road user charges would yield less than today’s revenue from fuel duty, and if we assume the high environmental costs then they would yield more. Therefore, in terms of our simple model, the answer to the
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Saving in environmental cost</th>
<th>Passenger and freight benefit</th>
<th>Reduction in bus subsidy</th>
<th>Reduction in rail subsidy</th>
<th>Env. tax, congest. charge revenue and rebates</th>
<th>Tax revenue correction</th>
<th>Net gain to government</th>
<th>Benefits net of all costs to government</th>
<th>Av. weighted ave. marg. cong. costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 EC&amp;CC</td>
<td>5.04</td>
<td>−15.57</td>
<td>0.05</td>
<td>0.18</td>
<td>19.13</td>
<td>−4.36</td>
<td>15.0</td>
<td>4.47</td>
<td>0.082</td>
</tr>
<tr>
<td>2 Zero tax, EC&amp;CC</td>
<td>1.60</td>
<td>−1.92</td>
<td>0.63</td>
<td>0.77</td>
<td>3.03</td>
<td>+0.18</td>
<td>4.61</td>
<td>4.29</td>
<td>0.065</td>
</tr>
<tr>
<td>3 Zero tax, EC&amp;CC and revenue neutral mark-down</td>
<td>0.79</td>
<td>0.72</td>
<td>0.62</td>
<td>0.75</td>
<td>0</td>
<td>0.9</td>
<td>2.27</td>
<td>3.78</td>
<td>0.070</td>
</tr>
</tbody>
</table>

Change relative to current situation (£ bn pa, 2003 prices).
question whether road users in England are currently paying too much or too little depends upon what view is taken about where the “correct” environmental charges lie between our two extremes. The final scenario considered in Tables 7 and 8 is the Zero Tax EC&CC revenue neutral scenario. Under the assumption of high environmental costs the estimated environmental savings are greater as would be expected. There is a residual net gain to the government of £2.3 billion per annum and an overall economic benefit of £3.8 billion per annum. This is less than the overall benefit of £4.29 billion per annum under the revenue unconstrained case. Of course, there is less of a tendency to reduce charges in the non-urban area than under the low environmental cost case.

5.5. How widely should charging be implemented?

Throughout our work we have given little attention to the vital issue of what a practical scheme might look like. A proper treatment would require capital and operating costs of suitable technologies. Newbery (2002) discusses some of the subtleties of an economically effective design for a real scheme.

There may well be a case for considering a scheme that does not attempt to cover the whole country. As a charging scheme is progressively extended to less dense areas the costs are likely to rise while the traffic affected—and hence the benefits—are likely to rise less rapidly. Depending on the nature of the costs of the technology chosen to implement road-user charging it may be too troublesome to levy the smaller rates of charge or to attempt to cover all areas, except through a component of conventional fuel duty. We have made indicative estimates of what the effect might be of waiving low charges or restricting geographical coverage: an accurate analysis would require more modelling and information on the costs of the chosen technology.

Using the low environmental costs, we found that raising the charging threshold makes little difference between about 5 pence per car kilometre and 16 pence per car kilometre. Excluding rural and small urban areas would reduce the proportion of the traffic being charged from 92% to 45% but only reduce the revenues from £11.5 billion per annum to £9.2 billion per annum. Imposing a threshold of 5 pence per car kilometre further decreases the revenue to £5.3 billion per annum but it means that only about 10% of the traffic is experiencing any charge at all apart from fuel duty. This would achieve a 2% reduction in national traffic, but a much higher proportionate reduction in those congested circumstances to which the charges would apply.

If London and other big urban areas were included and if the threshold were to apply, the revenue would be over £4 billion per annum, but only 8% of national traffic would experience charging.

6. Summary and conclusions

In this paper we have developed a model to explore the potential effects of transport charging in England. We have run the model according to a range of policy scenarios including revenue raising and revenue neutral charging options and economically efficient pricing. For each scenario our
results have identified effects on traffic volumes, prices and fares, subsidies, environmental costs, benefits to consumers, revenue to the government, and overall net benefits.

We have shown that appropriate charging structures coupled with compensating reductions in motoring taxes could make a real difference to traffic growth, congestion and environmental damage and could relieve pressure to build new roads.

Our results confirm that it makes good economic sense to shift the burden of taxes and charges away from fixed taxes such as the tax disc (annual registration fee), towards charges that vary with usage. Whether a government following these principles would adjust fuel duty and other taxes so as to raise or lower total tax and charge revenue would be a matter of policy. Accordingly, we analysed a scenario that keeps the totals at roughly today’s levels. This illustrates that if the objective of policy is to address congestion then our current system of fuel duty is a blunt instrument which fails to distinguish those circumstances in which there is a case for reducing traffic from those in which people and industry could enjoy the benefits of greater mobility at lower cost. If on the other hand, the goal of policy is to reduce vehicle emissions then a flat rate fuel duty may be an appropriate and direct way to achieve this as has been shown in studies of the elasticities of fuel demand (e.g. Graham and Glaister, 2002a,b, 2004a).

If today’s rate of fuel duty were accepted as a foundation to which environmental and congestion charges were to be added then there would be some improvement of bus and rail finances and a substantial overall increase in government income. In some congested places, the charges would be high and the reduction of traffic would be substantial. But in many places and times there is little congestion so the increase in charges would be based only on the relatively small environmental charge. A policy along these lines could be combined with removal of the tax disc (annual registration fee).

Rather than increasing the total tax take a government might decide to concentrate on improving the balance of charges, keeping the total constant. We have shown that a revenue neutral package can achieve a redistribution of traffic away from congested times and places and away from those where environmental damage is greatest, while accommodating a slight increase in overall traffic. Traffic is reduced most in the big conurbations and it increases most in the rural areas. Thus, at today’s overall rates of fuel tax, city areas are under-charged while the country areas are significantly over-charged. Furthermore, the pressure to provide more road capacity would be significantly reduced because charging moderates traffic growth in just those places where capacity is exhausted.

Alternatively, suppose we rebuilt our system of transport charges from scratch, using first principles: abolish the present fuel duty, minimise subsidies to public transport and calculate appropriate charges for congestion and the other costs. We have shown that if they were introduced today the proper set of road-user charges might involve road-users paying more or less than currently. This would depend on a number of factors, including the valuation of the environment and people’s response to charging. But by 2010, increases in traffic and congestion would probably mean that, according to this set of principles, road-users should pay more. What is unambiguous from our analysis is that, leaving aside the issue of the overall level of charges, there would be benefits from changes to the structure of charges road-users face.

A crucial limitation of our model is that we are not able to allow users to switch the time of travel according to the level of charge. As we have acknowledged in the text, this is likely to be an important response to road pricing regimes. Building upon the model presented in this paper
our current research is attempting to address the time switching issue and is also concerned with the distributional, or equity, impacts of road user charging.

Four decades after the economic case for road user charging was fully articulated in the economics literature the visible success of the congestion charging scheme in central London has demonstrated to legislators that road user charging is a policy that could offer a real contribution towards one of the most intractable problems of public policy. In July 2003 the UK government announced a review of the feasibility of a national scheme. The estimates in this paper give some indications of how that might look and what it could achieve. But that leaves open a number of issues that will now have to be addressed such as choice of technology, exemptions, enforcement, and, crucially, who would set rates of charge, be accountable for the revenues and make decisions on expenditures.

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