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TOWARDS MARGINAL COST PRICING : A COMPARISON OF ALTERNATIVE PRICING SYSTEMS

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ABSTRACT

European urban areas are marred by the problems of congestion and environmental degradation due to the prevailing levels of car use. Strong arguments have thus been put forward in support of a policy based on *marginal cost pricing* (European Commission 1996). Such policy measures – which would force private consumers to pay for a public service that was previously provided «for free» – are, however, notoriously unpopular with the general public and hence also with their elected representatives – the politicians.

There is thus an obvious tension between economic theory, which suggests that marginal cost pricing is the welfare maximising solution to urban transport problems, and practical experience, which suggests that such pricing measures are unwanted by the affected population and hence hard to implement through democratic processes.

The *AFFORD* Project for the European Commission has aimed to investigate this paradox and its possible solutions, through a combination of economic analysis, predictive modelling, attitudinal surveys, and an assessment of fiscal and financial measures within a number of case study cities in Europe. In this paper the methodology and results obtained for the Edinburgh case study are reported in detail. The study analyses alternative road pricing instruments and compares their performance against the theoretical first best situation. It discusses the effect of coverage, location, charging mechanism and interaction with other instruments. The paper shows that limited coverage in one mode may lead to a deviation from the user pays principle in other modes, that location is as important as charge levels and that assumptions about the use of revenues are critical in determining the effect on equity and acceptability. Finally the results show that a relatively simple smart card system can come close to providing the economic first best solution, but that this result should be viewed in the context of the model assumptions.

1. INTRODUCTION

There have been growing concerns over sustainability and how to achieve sustainable mobility as advocated by the EU's Common Transport Policy (COM(98)716). Producing integrated land use-transport strategies has been viewed as a solution to the problem, however in its 2001 review for the Council of Ministers (ECMT, 2001), the joint ECMT/OECD study group concluded that "implementing multi-sectoral, integrated policy packages has proved easier said than done".

Road pricing is seen as a key instrument in forming an integrated strategy and has been proposed as a practical means of reducing the externalities arising from road use in urban areas for almost four decades (Ministry of Transport, 1964). Practical designs, existing designs and on-desk studies around the world have demonstrated the requirement of the judgmental design to produce a closed cordon system (Holland and Watson, 1978; Dawson and Brown, 1986; Larsen, 1988; Richards et al, 1996; and recently GOL, 2002). More theoretical studies have considered second-best tolling systems whereby a limited subset of links can be charged and compared with the results of first-best systems where all links may be tolled (Verhoef 2000); the approach was adopted by Shepherd et al (2001) and used to investigate the optimal location of toll points. None of these studies have considered the integration of road pricing with other instruments.

A recent paper by May et al (2000)[1] has described a procedure for finding optimal urban transport strategies and its application in nine European cities. The underlying aim of FATIMA was to devise and apply a method for estimating optimal transport strategies within a context of limitations on public finance, and it included consideration of the use of private finance. Central to all nine optimal transport strategies was an element of pricing applied to the private car. This was in the form of either parking charges (short and long stay) and/or a road pricing cordon with prices optimised for peak and off-peak. There have been relatively few similar research projects. The most relevant are TRENEN II STRAN (1999), which sacrificed network detail in order to optimise using a simple single link model of a number of cities to identify optimal combinations of policies, and earlier work by TRL with their Strategic Policy Model, which indicated the relative merits of policies based on public transport and demand management in five UK cities, but made no attempt at optimisation (Dasgupta et al, 1994). A separate strand of research has been the use of system dynamics models to reflect the longer term response to a range of policy measures (Bell, (1998); Schade and Schade, 2001), but again they have included no attempt at optimisation, and doubts have been cast on the ability of such modelling approaches to reflect fully the complexity of demand and supply-side responses (Simmonds et al, 2001).

This paper builds on the work of May et al (2000) for the City of Edinburgh. The previous study found optimal levels for a number of policy instruments but it only considered one road pricing system (an inner cordon). Recent research has suggested that distance-based charging is likely to out-perform conventionally-developed cordon schemes (May and Milne, 2000), yet virtually all current proposals envisage the use of simple cordons (GLA, 2001; Edinburgh City Council, 2000). The current UK legislation has permitted local authorities to develop proposals for road pricing as a means of reducing congestion and environmental impact, and to retain the revenues for use in enhancements to the transport system. However, the regulations only permit low technology cordon and area-based schemes. In contrast to this the Dutch are proposing a zone based system with variable charges per kilometre depending on the zone location (Bovy, 2000).

The aim of this paper is to see if the use of alternative road pricing instruments including an alternative cordon location, the use of fuel taxes and the use of a hypothetical smart card system

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[1] carried out within a related project FATIMA ("Financial Assistance for Transport Integration in

in the context of an integrated strategy can improve upon the inner cordon results of May et al (2000). The research was conducted within the project AFFORD ("Acceptability of Fiscal and Financial measures and Organisational Requirements for Demand management") which aimed to investigate the gap between the economic theory of marginal cost pricing and real world applications which are restricted by current technology and acceptability of pricing systems. To measure the gap between economic theory and practical applications each system is compared against the theoretical first best benchmark where it is assumed that all marginal external costs can be charged to the user.

The analysis presented here concentrates on the private car mode, other instruments are taken directly from the previous FATIMA optimisation process. However the public transport fares and frequencies are also considered via sensitivity tests and "optimised" under the first best and smart card cases.

Section 2 deals with the methodology, section 3 introduces the concept of policy settings and describes the basis for the study and the alternative pricing instruments considered. Section 4 presents the results, comparing the welfare gains to the first best case and then analysing the other impacts on travel, mode split, and revenue use. Section 5 provides conclusions and recommendations for further work.

Metropolitan Areas") as part of the European Union's Fourth Framework Research Programme.

2. METHODOLOGY

2.1 Model Used

The study of integrated strategies requires a multi-modal transport model. The START strategic model for Edinburgh was developed by the MVA Consultancy (Bates et al 1991). It contains two sub-models : an *external forecast model*, used to predict changes of demand due to factors such as land-use, household structure and income, and a *transport model* to represent travel choices. The latter in turn contains two sub-models : a *demand model,* which calculates changes in travel patterns based on changes in generalised cost, and a *supply model* which deals with both system and operator effects.

The supply model produces cost information for the demand model and the two iterate until equilibrium is achieved. The demand model is based on a set of incremental hierarchical logit models covering travel choice for destination, mode and sub-mode, time of day and route. Origins and trip frequencies are assumed to be fixed. The supply model covers car and public transport but excludes non-motorised trips. Road travel costs are calculated using an aggregate cost-flow based network and the route choice available for each origin to destination movement is limited to a small number of pre-determined alternatives. Car parking is subject to capacity constraints, affecting travel cost through changes in time spent both searching for a space and accessing the final destination. In-vehicle costs for road-based public transport are affected by changes in cost on the aggregate road network. All public transport costs are affected by service frequencies, fares, number of stopping points and effects related to patronage.

The Edinburgh model consists of a network including 25 zones. Five modes of travel are considered: private car, heavy rail, bus, light rail, and guided bus, of which the last two are new modes. The market is segmented between six travel purposes (commute, education, visit, business, non-home based, and leisure) and three time periods (two peaks and the rest of the day).

A single scenario analysis is used whereby land use patterns and car ownership rates are fixed for the forecast year of 2010.

2.2. Cost-benefit analysis

The general methodological framework adopted in the modelling exercise is an adaptation of cost-benefit analysis. Cost-benefit accounts are drawn up relative to a base case scenario, and subdivided between various institutional sectors. The general optimisation principle applied in the AFFORD project is that of maximising an economic efficiency function extended to include environmental benefits termed EEFP.

Economic Efficiency Function (EEFP)

The formula for EEFP is given by:

$$EEFP = B - I + \lambda \ PVF - EC \qquad (1)$$

where: B, I, PVF and EC are defined below;

$1+\lambda$ is the shadow price of public funds.

The rationale for assigning an extra value to each unit of public revenue raised is the assumption that the alternative forms of taxation invariably are distortionary – they distort the price signals of the economy by allowing the cost perceived by private decision makers to differ from the marginal social cost. In such a case the resource allocation becomes inefficient, i.e. the total output of goods and services becomes smaller than it could have been, had all individual decision makers been facing the true marginal social cost**.** Minken (1998) indicates that 0.25 has been a standard value for λ in a number of practical planning exercises, citing a review by Snow and Warren (1996) concerning the theory and estimates of shadow price for the use of public funds.

In the following all results have a shadow price of 1.25 applied, though the implications of reducing this to unity is discussed in section 4.

The net present value of benefits (B)

The present value of net benefits, B, consists of net benefits to travellers, operators and the government, over a 30 year time horizon but ignoring year 0 investment costs. The transport model is run for one forecast year (or target year 2010) and a neutral assumption is made about the profile of benefits over time such that the benefits for this target year are assumed to represent the average benefit over the evaluation period.

The generalised cost of travel is defined as the monetary costs (fuel, fares, tolls, parking charges), plus in-vehicle time cost (in-vehicle time multiplied by the value of time), plus other elements of travel time costs, such as waiting time cost (related to service levels and patronage), access and egress time costs, and search time for parking. Note that all the latter time costs are factored to reflect how travellers perceive them, typically this factor has been set equal to two.

The net benefits to travellers are evaluated as the generalised consumer surplus from the change in generalised costs on all travel movements, assuming that the demand functions are linear in the relevant region of generalised costs. This is a standard evaluation procedure in cost benefit analyses of transport usually termed the "rule of a half" (see MVA et al, 1994).

The present value of net benefits, B, is given by:

$$B = \sum_{i=1}^{30} \frac{1}{(1+r)^i}(f+u) \qquad (2)$$

where:

u is the net benefit to transport users in the target year, compared with the do-minimum scenario;

f is the net financial benefit to transport suppliers in the modelled target year, compared to the do-minimum scenario, taking into account both revenue and operating costs;

r is the annual (country specific) discount rate. For Edinburgh the discount rate was taken as 8%.

Present Value of Finance (PVF)

The Present Value of Finance (PVF) of a set of instruments is defined as the net financial benefit to government and other providers of transport facilities, both public and private, over a 30 year time horizon, relative to the do-minimum.

Again, where only one future target year was modelled, PVF was defined as:

$$PVF = -I + \sum_{i=1}^{30} \frac{1}{(1+r)^i} f \qquad (3)$$

where:

I is the present value of the cost of public transport infrastructure investment, compared to the do-minimum scenario (it is assumed that all investment takes place immediately in year 0);

f and r are as defined above for Equation (2).

External costs EC

The external cost indicator for each mode is the change in veh-kms (compared to the do-minimum) in the modelled year, factored by the sum of the accident, noise and pollution costs per veh-km, and summed over a 30 year period.

Let γ_{am}, γ_{nm} and γ_{pm} be the costs per vehicle kilometre for mode m due to accidents, noise and pollution respectively. Let k_m be the change in the vehicle kilometres by mode m in the target year (compared to the do-minimum strategy). The external cost indicator EC is defined as:

$$EC = \delta \sum_m \gamma_m k_m \tag{4}$$

where $\gamma_m = \gamma_{am} + \gamma_{nm} + \gamma_{pm}$

and $$\delta = \sum_{i=1}^{30} \frac{1}{(1+r)^i} \tag{5}$$

Default γ values were based upon costs given by Tinch (1995) as shown in Table 2.1.

	Pollution	Noise	Accidents	Total cost
Car	0.028	0.037	0.022	0.087
Bus	0.218	0.075	0.045	0.338
Tramway	0.0	0.062	0.045	0.108
Total	0.245	0.174	0.113	0.532

Table 2.1: Pollution, noise and accident costs in euros per veh-km (γ values) given by Tinch (1995)

To find the optimal («*best practice*») combination of second-best policy instruments, the transport models are used to calculate the elements of the cost-benefit accounts, and an optimisation procedure is used to tune the policy instruments available to the levels that maximise the overall economic efficiency function. Policy instruments considered include cordon toll charges, parking charges, fuel tax, and public transport level-of-service and fares. In addition the

Edinburgh case study included a new guided bus system and low cost increases in road capacity which formed part of the optimal strategy in the FATIMA project.

Best practice second-best solutions are compared with the theoretical first-best «benchmark», which – although impossible to implement in practice with today's technology and legislation – is perfectly computable in a network assignment model (see Fridström et al, (2000) or Sheffi(1985)). In the first-best solution, road users are made to pay a charge exactly equal to the marginal external cost in equilibrium. This charge varies continuously in space and time, so as to reflect instantaneous fluctuations in congestion costs.

3. POLICY PACKAGES

The AFFORD project divided the modelling studies into thematic scenarios or settings as follows.

Policy scenario
Base case – Do-minimum
First-best marginal cost pricing
Narrowly first-best
Broadly first-best
Second-best marginal cost pricing
Second-best under current institutions
Second-best after institutional reform
«Acceptable» pricing

Table 3.1: Policy scenarios

For this case study all scenarios include the shadow price on public funds unless stated otherwise.

3.1. The base case scenario

In order to assess any type of policy or situation, the analyst or planner has to define a reference scenario or «base case», to which the various policy scenarios can be compared.

In the Edinburgh case study foreseen or committed strategies are defined for the year 2010 and are termed the Do-minimum. This base case scenario anticipates large increases in private car use in response to income and population growth. The Edinburgh model simulations therefore presuppose congestion levels far in excess of the present situation. Hence, one might expect a relatively large benefit to be attainable from marginal cost pricing.

3.2. The first-best policy

The AFFORD study distinguishes between «first-best» and «second-best» road pricing policy packages. By definition, the first-best pricing policy is the unconstrained welfare optimum, in which one imagines that each traveller is charged the true marginal social cost of road use, as given by the level of congestion, environmental and accident costs – and of any other external or internal cost, such as vehicle operating costs and time costs – generated by the marginal road user exactly *there* and *then*.

Depending on the perspective, two interpretations are possible.

Narrowly first-best marginal cost pricing, and

Broadly first-best marginal cost pricing.

The *narrowly first-best* policy assumes that all pricing instruments reflect the principle of marginal cost pricing, and that charging itself is costless. The *broadly first-best* package represents optimisation of social welfare while taking account of the costs of implementation and regulation. If the equipment necessary for charging fully flexible and differentiated prices is too expensive, it could mean that it is broadly first-best to apply second-best taxes.

By equating the marginal private cost to the marginal social cost, the first-best pricing policy induces all individual decision makers to make the socially most profitable choice, whenever they maximise their own utility or profit. As shown by (Milne et al 2000), first-best marginal cost pricing is able to provide the correct incentives for long-term as well as short-term decision-making, not only in regard to route and mode choice, but also in relation to road capacity provision, technology choice, spatial behaviour, and sustainability.

This first-best pricing solution, however, presupposes a very sophisticated, real-time revenue collection and information system, in which road user charges vary instantaneously in space and time, i.e. between all road links and for every single minute, depending on the current level of congestion etc. This ideal road pricing scheme is, unfortunately, only a theoretical construct, infeasible in practice (at least with the present state of technology and legislation).

It can, however, be mimicked to some extent in a network simulation model, so that one may derive the theoretically optimal level of road user charges and their hypothetical effect on traveller behaviour. This is done by running a network assignment task in which, *rather than the generalised (private) unit cost of road use, we use the marginal social cost function as the volume-delay relationship*. The latter function can be derived simply by differentiation of the aggregate social cost function. The equilibrium solution thus generated will be interpretable as the *system optimum under marginal cost road pricing with elastic demand*, i.e. as the solution after the imposition of an optimal road charge (see Fridström et al (2000) or Sheffi (1985) for details).

This theoretical first-best solution is used as an interesting benchmark case, against which the various *second-best* solutions – based on real-world policy instruments – can be judged. How far in the direction of the ideal, first-best solution are we able to move, when constrained by the pricing instruments actually available to planners and politicians?

For the Edinburgh model an approximation to narrow first best was applied to the private car mode and sensitivity tests were used to optimise the level of public transport fares and frequencies (see section 4.1 for results). The first best solution was said to be an approximation as the START model does not represent all the dimensions of behaviour and driver or vehicle attributes which could be differentiated in theory. For example the version of the model used did not differentiate users by income group or vehicles by vehicle type and so could not be used to study the effects of differing values of time or to differentiate the emissions by vehicle type; both of which could be used in theory to differentiate optimal prices.

3.3. Second-best policies

As second best scenarios are considered the array of relevant policy packages becomes rather more complex.

In general, a second-best policy package is said to be the *optimal («best practice») combination of policy instruments under the constraints represented by technology, geography, legislation, and institutional barriers*.

Second-best scenarios are considered under current and future institutions. As public transport is currently de-regulated in Edinburgh the main assumption regarding current institutions is that the local authority has no control over fares and frequencies and so there is no change from the foreseen strategy. So under current institutions the setting can be viewed as a private car setting or intra-modal setting.

For the second best after institutional reform, the local authority is considered to have control over fares and frequencies and thus the scenario could be viewed as a multi-modal (inter-modal) setting.

3.4 Acceptable Pricing

The purpose of this setting is to demonstrate the effect of limiting charges on road users to some "acceptable" level. Following the FATIMA consultation process it was suggested that parking charges be limited to a 300% increase in real terms and that the maximum road pricing charge for any trip be limited to 5 Euro. As will be seen later the interpretation of these limits depends upon the type of charging system considered.

3.5 Basis for the study and interaction with other instruments

The strategic model START was used building on previous work carried out by May et al (2000) which found optimum levels for a given package of instruments (again maximising EEFP) as shown in table 3.2.

peak fare	Off-peak fare	peak freq.	off-peak freq.	capacity	peak cordon charge	off-peak cordon charge	parking charge long stay	parking charge short stay	guided bus
-90%	-35%	+85%	+70%	+10%	2 euro	2 euro	+300%	+300%	Yes

Table 3.2 : Optimal levels of instruments from May et al (2000).

This package of instruments resulted in an EEFP of +**2344** million Euro calculated with respect to the Do-minimum over a 30 year period.

Note here that the cordon is a City centre cordon with a 2-way charge. All other instruments are defined in terms of changes from the do-minimum.

The aim of this study is to look at the effect of using alternative pricing instruments in place of the city centre cordon charge. The changes in capacity, parking charges and guided bus are taken as given in table 3.2 in all that follows. The fares and frequencies are varied according to the institutional setting, so under the current institutional framework, no changes in fares or frequencies are assumed whereas under the future institutional setting fares and frequencies are assumed to be controlled by the local authority and the values in table 3.2 are taken unless stated otherwise.

The pricing instruments considered were as follows :-

1. An approximation to first best marginal cost pricing
2. City Centre Cordon around the CBD of Edinburgh : 2-way charges in Euro (as used in May et al 2000).
3. Outer Ring-Road Cordon : 2-way charges in Euro.
4. Fuel Tax in Euro/km for private car[2].
5. A Smart Card system which charges by distance but allows minimum and maximum charges to be applied. (Described later in section 4.4)

Note that estimates of implementation and operational costs of each system were not available and so these costs were assumed to be equal for all systems and equal to those used by May et al

[2] A distance based charge for the whole study area is used as a proxy for fuel tax assuming a fixed fuel consumption per km. It is also assumed to be under National control.

for the city centre cordon. Obviously this assumption is unrealistic and the benefits of more complex systems will have to be considered in light of this assumption.

4. Results

Sections 4.1 to 4.4 describe the basic results by system for each thematic package whereas sections 4.5-4.6 give an overview and interpretation of key indicators. Note that in the following all settings include a range of other instruments which remain fixed, these are the guided bus, parking charges and low cost capacity increases and are set as in table 3.2.

4.1 Approximation to first best marginal cost pricing

Here the first best optimal prices have been approximated for car users across the whole study area of the Edinburgh model. The prices were determined by shifting the original speed-flow curves to represent marginal costs of congestion and by adding an optimal toll/km which represented the environmental externalities (which in the START model evaluation of EEFP were calculated on the basis of changes in vehicle-km by mode). The resulting optimal prices were converted from minutes per link by time period to euro per route by time period and applied with the original speed flow curves in place.

The first best "pattern" of charges was applied along with the guided bus infrastructure, capacity increases and parking charge increases to aid comparison to May et al (2000). The "pattern" was tested for "car-only" first best charges (with no changes in public transport fares and frequencies) and with various increases in fares and frequencies as marginal cost pricing theory suggests to find the first best multi-modal set of charges and service levels. The results are shown in table 4.1 for the car only and multi-modal first best solutions.

Pattern of Charges	Public transport changes	EEFP (million euro)
First Best (Car only)	No change in fares/frequencies	4361
First Best (Multi-modal)	Fares +50%, Frequencies +75%	4626

Table 4.1 : Approximation to first best pricing : EEFP results.

The first best solutions approximately doubled the EEFP value of 2344 million Euro found by May et al (2000) using the instruments in table 3.2. The marginal cost pricing (MCP) theory suggests that modes should be independent of one another (each mode should pay for itself) and this is borne out by the fact that the first best multi-modal solution is to increase fares for public transport resulting in an increased EEFP value. This first best multi-modal solution is now taken as the true first best benchmark solution for the Edinburgh strategic model.

4.2 Second-best under current institutions (Intra-modal)

The possible measures in the near future were considered as follows :-

- As public transport is currently de-regulated the assumption is no control over fares and frequencies and so no change from the Do-minimum is allowed.
- Simple road pricing systems become available (cordon toll systems 2 and 3).

The results for no road pricing system and fuel tax increases are included in the discussion of results to provide comparisons to no charges and to full coverage of users via fuel tax. With no road pricing system available the optimum package is (as before with an inner cordon) to set the parking charges to their upper limit of +300% along with the capacity increases and guided bus infrastructure. This run is reported in table 4.2 along with the optimal charges for the two cordon systems given no change in fares and frequencies.

Road Pricing System	Charge (Euro or euro/km)	EEFP (Million Euro)	Percentage of first-best solution
0. No road pricing system	0	1089	24
2. City Centre cordon Toll	2.5	2002	43
3. Outer Ring Road Cordon Toll	4.0	2421	52
4. Fuel tax increase	0.15	3876	84

Table 4.2 : Optimal charges and benefits compared to the first best solution.

Introducing any of the road pricing systems considered increases the benefits significantly displaying the key role to be played by pricing car use in the formation of an integrated strategy. Implementing the city centre cordon toll (with a higher charge than that used in table 3.2) almost doubles the EEFP value obtained with no road pricing (i.e. guided bus, parking charges and capacity changes only), but this value remains lower than the optimal combination with fare reductions and frequency increases which gave an EEFP value of 2344 reported in section 3.5. However the Outer Ring-Road cordon produces an improvement over the city centre cordon due to the greater coverage of trips. Finally the application of fuel tax increases (in this case assumed to be applied at the national level and therefore applies to the whole study area) gives a substantial increase in the EEFP achieving 84% of the first best solution. It should be noted that this increase is equivalent to almost a 170% increase in fuel price which may not be acceptable as discussed in section 4.4.

4.3 Second-Best after Institutional reform (multi-modal)

Essentially the institutional reform is to allow regulation of public transport fares and frequencies. A second best multi-modal package is found by using the levels of fares and frequencies in the peak and off-peak as shown in table 3.2. Each road pricing instrument is then modelled in turn and the charge levels optimised. Table 4.3 shows the results for the cordons and fuel tax. Note that the optimal charges for the cordon systems are lower than those where no fare reductions or frequency changes were allowed. This shows that a certain optimal "gap" between car and public transport costs may exist and that the “carrot” and “stick” may be used to better effect than a simple “stick” approach.

Road Pricing System	Charge (Euro or Euro/km)	EEFP (Million Euro)	Percentage of first-best solution
2. City Centre cordon Toll	2.0	2344	51
3. Outer Ring Road Cordon Toll	3.25	2585	56
4. Fuel Tax increase	0.15	3647	79

Table 4.3 : Optimum charges with fare reductions and frequency increases

Note that the effect of the fare reductions across the whole study area is beneficial to the cordon toll systems 2 and 3 in terms of increasing EEFP values and reducing charges for car users, though for the fuel tax system applied to the whole study area the reduced fares results in a decrease in EEFP value (only 79% of first best compared with 84% in table 4.2).

This result shows the importance of the spatial coverage of the charging instruments in determining not only the effects on the charged mode but also upon the alternative modes and their optimal instruments. In other words once the chargeable area for car-users is restricted in some way, then the measure is by definition a second best measure (spatially) and this then implies the measures for alternative modes may have to compensate for this sub-optimality.

Hence fare reductions accompany cordon tolls which attract car-users to public transport in the non-charged areas which serves to increase the EEFP value by reducing the environmental costs associated with car-kilometres. As shown in table 4.1 the first best multi-modal option for public transport was to increase fares and frequencies as all car users faced increases in charges in line with Marginal Cost Pricing theory. In this way the modes were independent and users' paid their own costs. The fuel tax results confirm that fare reductions are not necessary when all car-users can be charged.

4.4 Acceptable Pricing

Following the FATIMA consultation process with local authorities it was suggested that the maximum road pricing charge for any trip be limited to 5 Euro. Thus a strategy is deemed acceptable when the increases in charges are limited or constrained to be less than 5 Euro. This was simple to apply for the cordon systems and in fact the optimal second best charges are lower than 5 Euro and hence acceptable. The application of such a limit to a fuel tax increase had to be converted into a maximum rate per km based on the longest trip in the study area. The longest trip within the study area was 80 km which implied a maximum rate per km of 0.06 Euro/km. This is obviously an approximation to an acceptable solution as trips out of the study area may be longer than 80km. The concept of maximum charges gave rise to an alternative approach based on a theoretical smart card which imposes a minimum and maximum charge for a trip with a distance based charge between the minimum and maximum. Figure 1 shows the Smart card system charges by trip length given a rate of 0.15 Euro/km and minimum and maximum charges of 1 and 4 Euro respectively.

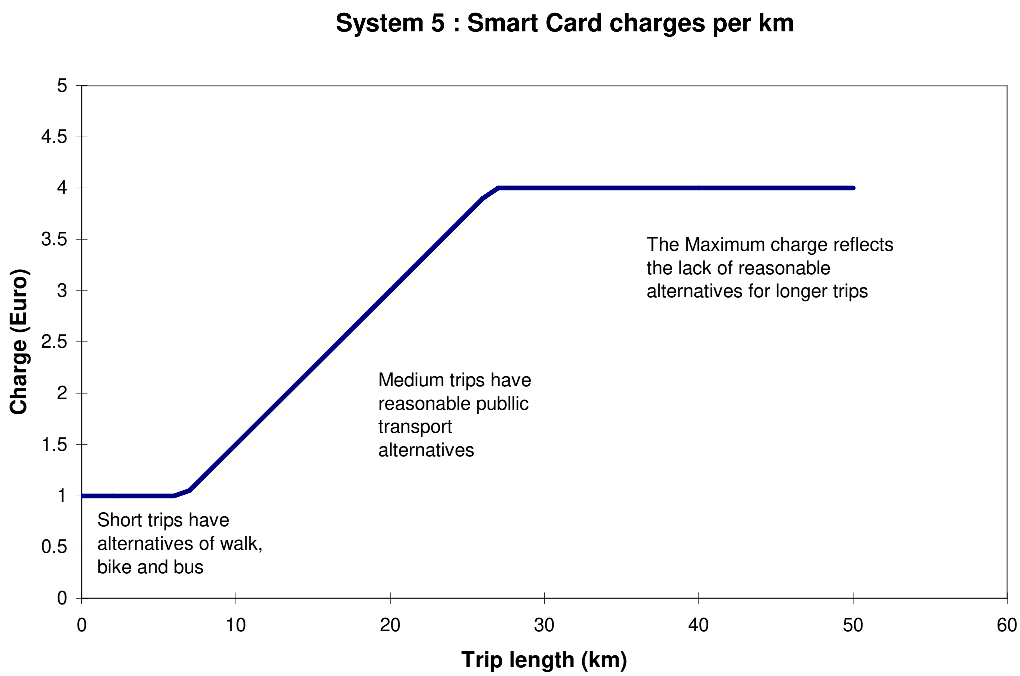

Figure 1 : Smart card charges by trip length.

The design of the charging system reflects the alternatives available in the Edinburgh study area (and could be easily modified to other cities). The minimum charge of 1 Euro is applied to trips less than 7 km where reasonable alternatives are walking, cycling and public transport. From 7 km to 27 km the charge increases to the maximum level of 4 Euro. Within this range there should be a reasonable public transport alternative, at least in the Edinburgh area (within the outer ring-road). Trips which are longer than this are generally to or from the surrounding areas which have fewer reasonable public transport alternatives and contribute less to congestion per kilometre travelled.

This slightly more complex system reflects the general problems of providing alternatives for longer trips and would be more acceptable to rural residents. It charges more per km for inefficient short trips by car aiming to reduce emissions caused by "cold starts"[3]. In the mid-range it charges by use and so retains the major principle of marginal cost pricing. The capping of the charge (to 4 Euros) for longer trips is intended to improve acceptability.

Table 4.4 shows the Acceptable package results for the cordons, limited fuel tax and the smart card with service changes as in table 3.2 with fare reductions (system 5) and fare increases (system 5a).

Road Pricing System	Charge (Euro or Euro/km)	EEFP (Million Euro)	Percentage of first-best solution
2. City Centre cordon Toll	2.0	2344	51
3. Outer Ring Road Cordon Toll	3.25	2585	56
4. Fuel Tax Increase	0.06	3172	69
5. SMART Card (Fare reductions)	0.15	4108	89
5a. SMART Card (Fare increases)	0.15	4463	96

Table 4.4: Simple "acceptable" optimal values

Reducing the fuel tax increase to a more acceptable level has reduced the benefits to 69% of the first best solution with the longest chargeable trip paying an extra 5 Euro in fuel tax. The smart card system applied a minimum charge of 1 Euro per trip and a maximum of only 4 Euro per trip yet it achieves 96% of the first best solution. One has to bear in mind the limitations of the model here – the nature of the strategic model meant that the first best system was restricted to use a combination of flat rate charges per km for externalities and link specific charges for congestion applied in three time periods. As congestion was only present in the central area of the model, this "limited" first best system allows a complex "second best" system such as that based on a smart card to mirror the charging pattern and hence almost reproduce the first best results. A more complex model coupled with a more complex first best application e.g. charging different rates for different vehicle types, including a more complex model of externalities and taking into

[3] Note that the effects of cold starts are not modelled and as such any benefits from a reduction in cold

account the "dynamics" within a peak-period more accurately would imply that the relatively simple smart card system would fall far shorter of a true first best than reported here.

4.5 Impact on travel indicators and make up of the benefits

The previous sections have compared the systems and packages solely in terms of the total welfare gain as measured by EEFP and the optimal charge levels. This section takes the best scenario for each system considered and compares the impact on demand for trips, mode split and average trip lengths.

Figures 2 and 3 show the change in demand for trips and corresponding changes in average trip lengths for total trips, car trips and public transport trips for each type of pricing system considered. All systems reduce car trips and increase public transport trips. All systems reduce the average trip-length by car except the city centre cordon which induced routing around the centre. The average trip length by public transport is increased for all systems. The fuel tax increases have the largest effect on mode split as it affects all trips in proportion to their trip length, whereas the first best and smart card system have lower charges for the longer trips within the study area.

Figure 4 shows the composition of the welfare gain EEFP by the main categories and translated into Euros per capita per annum. This illustrates the benefit for the first best system as around 390 Euro per capita per annum compared to 198 euro per capita per annum for the inner cordon.

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starts would be in addition to those estimated within the EEFP calculations.

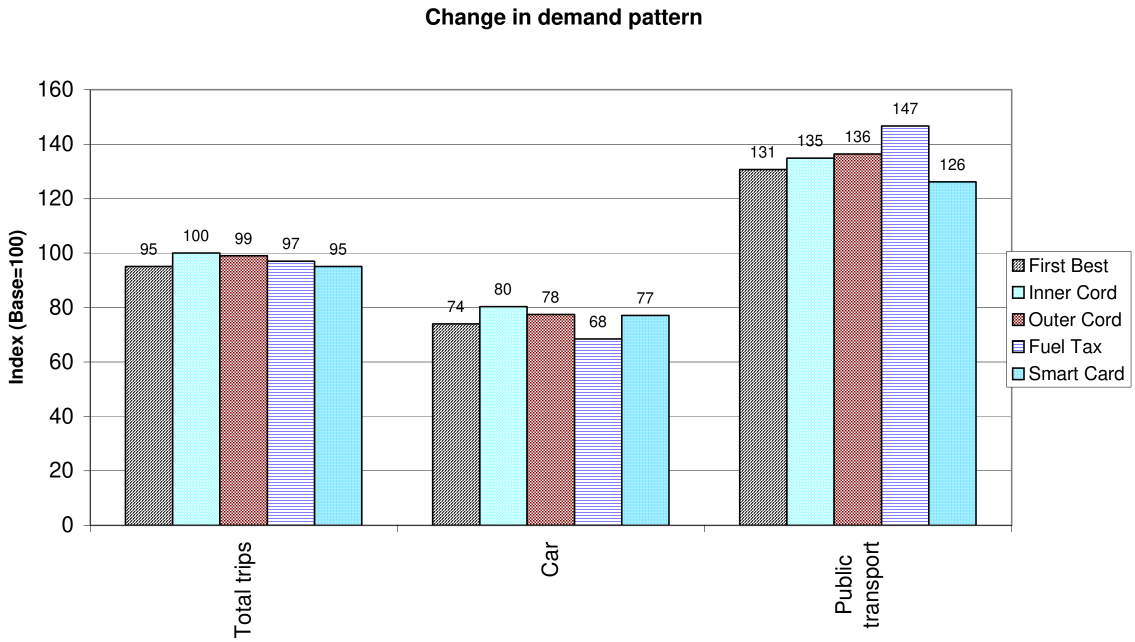

Figure 2 : Change in demand for trips

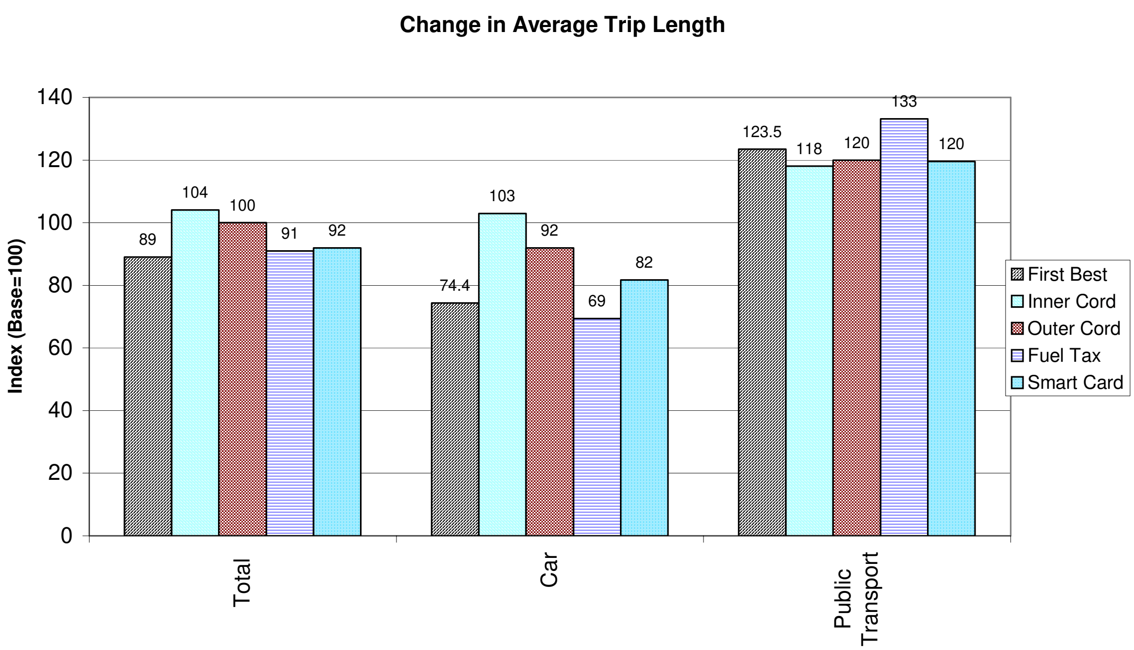

Figure 3 : Changes in average trip lengths for car and public transport

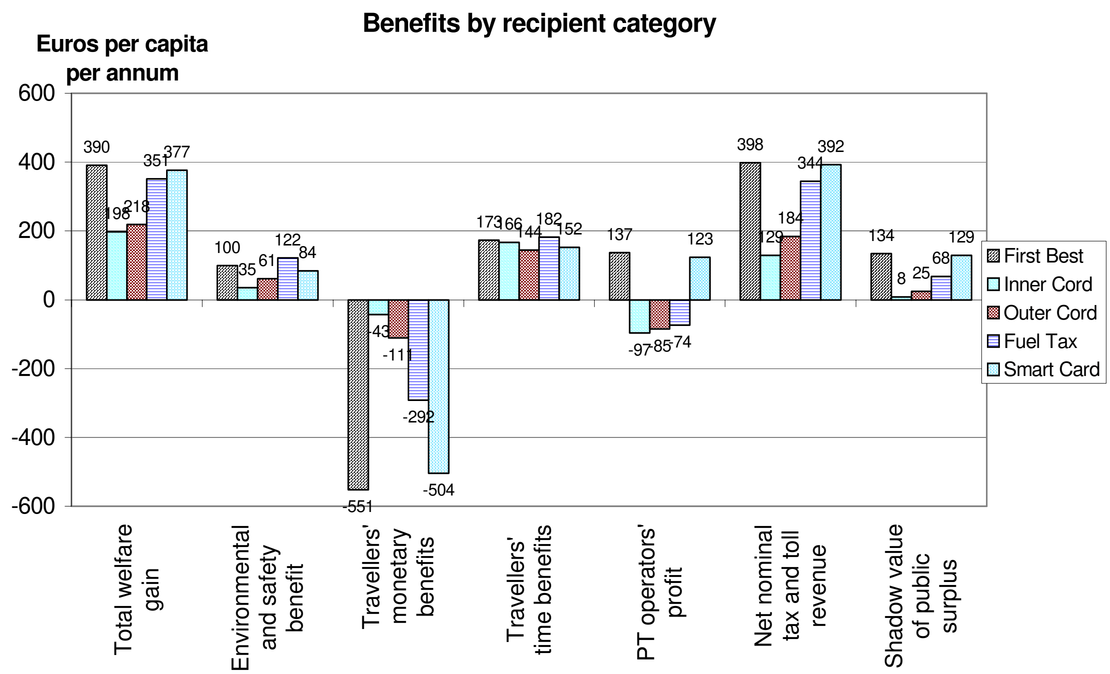

Figure 4 : Benefits by recipient category

The environmental and safety benefits are positive for all scenarios and systems and represent between 20-30% of the total net welfare gain. The environmental benefits are closely related to the reduction in car-kms and hence increase with increased coverage of the charging system.

Travellers' monetary benefits are negative and increase with coverage of the system, however these become less significant in aggregate as they cancel out with the transfer to government and operators. The graph shows the magnitude of the money transfer from travellers to government under first best conditions. Thus the success of such a system would depend largely on the assumptions about revenue recycling to ensure acceptability of the charges imposed. An analysis which takes the total monetary benefits alone hides the distributional issues between modes and between car users themselves, e.g. with the inner cordon fares are reduced and only those drivers passing the cordon pay an extra charge.

All systems give positive and similar time benefits though this does not distinguish between public transport and car user time benefits. The public transport operators' profit is positive for the first best and smart card systems which increased fares and services whereas the profits are negative where fares have been reduced and thus require some subsidies from the toll revenues collected.

The shadow value of public funds surplus forms a significant element of the welfare gain for the first best system and for the smart card system. The value is related to the amount of revenue generated which in turn is dependent upon the coverage of the systems. Sensitivity tests showed that if the shadow price were reduced to zero then the total welfare gain is reduced by over 30% in the first best case, however the time and environmental benefits remained almost constant.

4.6 Other impacts

In terms of spatial effects, the first best system should by definition be the most equitable system as each user pays their own marginal costs. The effect of tolled cordons is to create boundary effects with the small city centre cordon hitting those who reside within the cordon more than those who reside outside of the cordon; basically the cordon is small enough to allow routing around the charged area. The larger cordon affects those outside the cordon as the cordon is large enough to allow free movement within the area and to limit the opportunities for re-routing around the cordon. The fuel tax system affects all areas but the effect increases with average trip length or for those living in the outermost zones. The use of subsidies for public transport services in general appears to be equitable if it is assumed that the lower income groups are the majority of the public transport users.

The effect on “other sectors” is largely dependent upon the assumptions made about the method of recycling of revenues generated and upon the amount of revenue generated by any system. Table 4.5 shows the present value of finance (PVF) and the equivalent amounts which would have to be recycled on average to each household per annum if all the surplus was ear-marked for the study area.

Road Pricing System	Charge (Euro or Euro/km)	PVF (Million Euro)	Amount recycled per household per annum (Euros)
2. City Centre cordon Toll	2.0	377	65
3. Outer Ring Road Cordon Toll	3.25	1172	201
4. Fuel Tax Increase	0.06	1026	176
5a. SMART Card (Fare increases)	0.15	6110	1050
1. First Best	Variable	6341	1089

Table 4.5 : Comparison of PVF and amounts recycled per annum.

The amounts recycled to each of the 517 thousand households in the study area under each package or system are directly related to the magnitude of the Present Value of Finance (PVF) so that under the first best system a household would receive over 1000 euro per annum compared to 65 euro per annum under the inner cordon system. This shows that the system used can influence whether or not the transport sector should be considered as a means of reducing the distortions in the tax system.

The revenue generated under the first best solution and the smart card system is far greater than that under the cordon or acceptable fuel tax solutions and the assumption that all revenues should be recycled into transport projects (as suggested in the UK) would clearly be impractical. One suggestion is to limit spending on transport projects to those which are economically justified e.g. the guided bus infrastructure development as modelled in this case study and to use all other revenues to either reduce labour taxes or to in some way compensate users via some lump sum.

In addition the large amounts which would have to be recycled under the first best system have implications for modelling any behavioural responses (as all households may expect to receive a significant lump sum or tax reduction). Ideally the revenue recycling should be modelled within a consistent framework, however this was not feasible with the current model and so the users could not use any recycled revenue to pay for their intended trips.

5. Conclusions

The introduction of a road pricing system has been shown to significantly increase the social welfare of the residents of Edinburgh and to play a key role in creating an "integrated" strategy. However forming the optimal "integrated" strategy requires alternative systems to be considered. Whilst optimisation procedures can find the optimal strategy for a given set of instruments, it has been shown that the selection of which instruments to include in the process can be more important than the optimisation process itself.

The first best multi-modal solution gives substantial welfare benefits to the system as a whole and can be used as a benchmark to judge other more practical systems. Simplifying the charging systems to be cordon based provides opportunities for realistic implementations but not without pitfalls. Limiting the spatial coverage of the charging measures by implementing cordons, by definition creates second best systems. Different sized cordons have been shown to have different effects on those living inside and outside the cordon. The use of small city centre toll cordons can create boundary effects and increase average trip lengths due to re-routing effects. Larger toll cordons can also have boundary effects, though if large enough they have little adverse effect on those residing within the area.

Where coverage of private car is limited, the use of fare reductions and frequency increases in conjunction with these second best cordon systems can improve the social welfare further and allow lower optimal charges to be applied. However use of such subsidies is straying from the principle of the user pays. The choice of system for one mode may imply another mode should become second-best to increase welfare for the system as a whole.

Applying a simple rise in fuel tax provided results which were 84% as effective as the first best system. This simple system would be easy to implement but would mean adding approximately 1.5 Euro to the price of one litre of fuel (almost 170% increase) which is unacceptable in the current political climate. The major criticism of the fuel tax increase would come from rural residents and long distance goods operators.

Applying simple acceptable limits on the parking charges and road pricing charges reduces the social benefit for all systems compared to an unconstrained package as expected. The introduction of more complex systems with minimum and maximum charge levels increases the benefits to 96% of the first best total welfare gain whilst maintaining the same acceptable maximum charges. This suggests that using a minimum and maximum charge level via a smart card system is perhaps the way forward rather than using some simple cordon structure.

However the nature of the strategic model meant that the first best system was restricted to use a combination of flat rate charges per km for externalities and link specific charges for congestion applied in three time periods. As congestion was only present in the central area of the model, this "limited" first best system allows a complex "second best" system such as that based on a smart card to mirror the charging pattern and hence almost reproduce the first best results.

In addition the large amounts which would have to be recycled under the first best (or near) system have implications for modelling any behavioural responses (as all households may expect to receive a significant lump sum or tax reduction). Ideally the revenue recycling should be modelled within a consistent framework, however this was not feasible with the current model and so the users could not use any recycled revenue to pay for their intended trips.

Further research is required in terms of modelling the behaviour of users post-recycling in conjunction with research into the actual possibilities for revenue uses under different assumptions about the levels of revenues collected. Furthermore the generation of alternative instruments to be considered within an integrated strategy requires further work as key instruments such as those presented here for road pricing can give significantly different results in terms of welfare gain.

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