EXTERNAL COST INTERNALISATION OF URBAN TRANSPORT: A CASE STUDY OF DUBLIN

(Short Running Title: External Cost Internalisation of Urban Transport)

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ABSTRACT

Transport imposes significant costs on the environment and the community, particularly in the form of air pollution, noise, accidents and congestion. Transport users do not currently pay the full costs of their transport activities and in particular do not pay the marginal external costs. A model, developed under the EU DGVII Transport Program by CES at the Catholic University of Leuven to quantify the marginal external costs of transport, was used in a case study of Dublin. The model can be used for prioritisation of urban transport policies using welfare as an indicator.

The paper presents the results of a Do Nothing scenario for the year 2005 and of a Full Optimum Scenario for the same year where in the latter case all external costs are internalised. This assumes that policy makers have very sophisticated pricing instruments available to them. The comparison between the reference and full optimum scenario indicates that taxes on all transport modes in Dublin should be increased substantially, particularly in the morning and evening peak periods. As a result of the price increases, travel demand is reduced. The tax revenue objective and the congestion externality, by far the major externality, strongly influence model optimisation. Road use pricing using current available technology is a second-best method of internalising the marginal external costs of transport i.e. it does not

internalise precisely the marginal external costs. The charge levels presented in this paper are currently being used in a road use pricing trial in Dublin the results of which were published in O'Mahony, Geraghty and Humphreys (2000).

Key Words: Transport, environment, external costs, economics.

INTRODUCTION

The TRENEN model was developed as a tool to address the interfaces between transport, the environment and energy as part of a project funded under the EU DGVII Transport Programme. Pigou (1920) proposed that congestion could be regulated by imposing charges for road use, known as road use pricing. When congestion exists and in the absence of road use pricing, all users who are willing to pay the marginal private cost of a trip make their journey. However, due to congestion, the marginal social cost exceeds the marginal private cost. To reach a situation where the marginal social costs are absorbed by the car user who imposes them, a Pigouvian charge (Pigou, 1920) is required to be imposed on that car user; a charge equal to the difference between the marginal social cost and marginal private cost.

The TRENEN model estimates the marginal external costs associated with different policies, enabling a value to be placed on these costs for transfer to the transport user. In other words, the model determines what a transport user should pay if the marginal external costs of congestion, air pollution, noise and accidents were to be included. The European Commission's Green Paper on Fair and Efficient Pricing in Transport (CEC, 1996) is a more recent endorsement of policies aimed at imposing the full costs of travel on transport users.

The TRENEN model was developed by Van Dender, Proost and Ochelen (1997) as part of a research project and several case studies on six European cities were conducted. The paper presents the results of one of those case studies on Dublin, the capital of Ireland. A brief description of the model is first presented followed by the results of the reference situation (Do Nothing) and a full optimum scenario for the year 2005. The full optimum scenario represents the situation where the policy maker has sophisticated pricing instruments available allowing precise internalisation of the external costs of transport. The comparison between the reference and optimum scenarios allows one to observe the substantial differences between the Do Nothing situation and that where all costs are paid by the user.

TRENEN MODEL

In the TRENEN model, transport activities are represented as a set of interrelated transport markets (Van Dender, Proost and Ochelen, 1997). Each market corresponds to the use of a particular transport mode (e.g. small petrol car) with a given occupancy rate (pooled or not) in a particular time interval (peak or off-peak) in a homogenous city. Demand is a function of the generalised costs on all markets. The generalised cost of trips consists of resource costs, time costs and taxes. A market equilibrium is reached by maximisation of a welfare function under a set of constraints on the policy instruments.

The TRENEN model is a partial equilibrium model. It differs from a typical transport network model as it is not based on a network with spatial characteristics. For the TRENEN model, the relevant information from a network model is summarised in an

aggregate flow-speed relationship where the model works with one link representing the city. Optimal taxes are computed only for transport markets by assuming separability with the non-transport goods and using a marginal cost of public funds approach to trade-off the welfare cost of raising taxes in the transport sector versus other sectors. The partial equilibrium approach means that the feedback on non-transport markets is neglected and prices on other markets are fixed. Tax revenue is assumed to be returned to the consumer, and the valuation of externalities depends on changes in the transport market.

Supply and Demand

The supply and demand market in one particular period (peak or off-peak) for one particular type of car (small/large, petrol/diesel) is represented in Figure 1 (Van Dender, Proost and Ochelen, 1997). Each type of vehicle or means of transportation can be represented on such a market diagram. All of the market diagrams are interrelated since the demand for a particular type of transport depends on the prices of all the other types of transport modes available.

Insert Figure 1 here

The demand function in this market expresses the marginal willingness to pay at each volume of traffic. The resource cost consists of items such as fuel cost, maintenance cost, tyres and vehicle depreciation. If there were no external costs, there would be an equilibrium volume of traffic VA_1 where car users pay the marginal resource costs. Due to the presence of congestion, the average time spent on the road network increases. The car user pays the average congestion cost but not the marginal congestion cost. When the average congestion cost is added to the resource cost, an equilibrium point A_2 is reached.

The external costs are those costs generated by car traffic but that are not paid by the car user. The highest cost curve in Figure 1 is the marginal social cost of car use, where social cost is defined as the sum of the private and external costs. The socially optimum flow of traffic is that associated with point B since the marginal social costs of car use equal demand. For all trips over and above point B, the benefit to the driver is less than the cost they are imposing on other drivers (the marginal external cost). It is better for society if these trips are not made. Implementing point B rather than point A_2 generates a welfare gain equal to the area BEA_2 . In the TRENEN model one tries to find instruments, such as pricing methods that move the equilibrium from A_2 to B. Regulatory instruments, such as improved vehicle technology, will have the effect of increasing the resource cost while lowering the social cost.

Framework of the TRENEN Model

The TRENEN model is explained in detail in Van Dender, Proost and Ochelen (1997), but can be summarised diagrammatically as shown in Figure 2. The model consists of three components: a demand module, a supply module and an equilibrium price module. Each of the modules is described in more detail below. The model is calibrated for a given reference equilibrium. Observed or forecasted money prices and quantities for all modes of transport are used for the calibration together with information on the ease of substitution between transport and other goods as well as between the different modes of transport.

Insert Figure 2 here

Demand Module

The market demand refers to the demand for transport relative to other (non-transport) sectors of the economy. It is assumed that a transport user optimally allocates

spending between passenger transport and other goods. All transport options available to the consumer are examined as there may exist strong substitution possibilities between the different modes of travel.

Demand is derived from the optimisation of a nested Constant Elasticity of Substitution (CES) utility function. The utility function can be illustrated by means of a utility tree. The assumption of separability which underlies the nested tree structure plays a role in determining the order of the levels of the tree (Van Dender, Proost and Ochelen, 1997). The utility function used in the TRENEN model contains seven levels of decision making, which result in a wide range of options available to the transport user. For example, an individual can choose whether to travel in the peak or off-peak period and whether or not to choose a motorised mode of travel. Whereas public transport users have the option of travelling by bus or train, the private transport user can choose the size of car and the type of fuel as well as solo driving or car pooling. The utility function requires information on the prices and quantities in a reference equilibrium together with substitution elasticities at each level. The elasticity of substitution was chosen assuming that the lower down the tree the easier it is to substitute between the alternatives.

Supply Module

The main function of the supply part of this model is to represent the resource costs, subsidies to producers, environmental and safety regulations of alternative transport modes. The producer can be forced by regulation to supply a particular car technology. The assumption of perfect competition for the private transport modes ensures that producers will minimise total costs. For example, in the absence of

pollution regulation or taxation, producers will typically supply vehicles without catalytic converters in deference to vehicles with catalytic converters. Producer prices will thus equal marginal resource costs. Supply of private and public transport is assumed to take place under constant returns to scale, implying that changes in volumes have no effect on the marginal production costs. This assumption is simplistic and will need to be addressed in the future development of the model.

A distinction is made between large and small cars, between petrol and diesel cars and between pooled and non-pooled cars. Resource costs are taken as constant per vkm for each of these categories. An option of improved technology is available for both petrol and diesel cars.

The public transport options available in Dublin are bus and rail. The resource costs for the bus service were based on the operating costs taken from the Annual Report of Dublin Bus (1995). Operating costs were proportioned between peak and off-peak periods on the basis of the demand in each period. However, to further differentiate between peak and off-peak periods, costs relating to non-use related depreciation and exceptional operating costs were assigned totally to the peak period. Total travel demand was proportioned between peak and off-peak periods according to the proportions of peak and off-peak period demand forecasted for 2006 in the Dublin Transportation Initiative Model i.e. 14,290,467 vehicle kilometres (vkm) in the peak period and 36,827,533 vkm in the off-peak period. The corresponding resource costs were 53,128,350 Euro for the peak period and 85,390,549 Euro for the off-peak period. These resource costs were then calculated on a per passenger km basis, as presented in Table 1. The walking times to public transport stops and waiting times

contribute to the generalised cost of public transport. Within the model the waiting times are allowed to vary as a function of public transport volumes.

Insert Table 1 here

Equilibrium Price Module

This part of the model calculates the generalised prices for the different types of transportation modes. The generalised price is the sum of three elements as follows:

1. A producer price - determined by the supply module
2. A transportation time cost - this will be a function of the total volume of traffic at equilibrium. This cost contains the average congestion cost and in the case of public transport, the value of walking and waiting times.
3. A tax (or subsidy) - to raise tax revenue (or subsidise certain modes of transport) and to correct for external costs. This tax will be differentiated for the different types of transport goods.

As previously stated, the tax revenues for transport are calculated as well as tax revenues from indirect taxes on non-transport goods. Substantial increases or decreases in the tax revenue raised in the transport markets will have an effect on the tax revenues from consumption of other goods. A large tax increase for transport can generate more tax income from transport taxes, but will also reduce the consumption of other taxed goods, because of negative income effects. The magnitude of taxes on transport will depend on the cost of public funds and on the level of the marginal external costs.

Price and Substitution Elasticities

Price elasticities of transport demand are, in general, rather crude and approximate measures of aggregate responses in a market. The direct impact of a price change is used to compute the short-run elasticities, while the long-run elasticities are computed by allowing for the full impact of a price change (Oum et al, 1992). Since the TRENEN model is static by nature it is suitable for addressing optimal short-run pricing of infrastructure.

Price elasticities for goods may be derived from substitution elasticities using the relationship between price and substitution elasticities (Keller, 1976):

$$EL_{AA} = (-SE_{AB} + W_A(SE_{AB} - 1)) \frac{MQ_A}{Q_A}$$

where EL_{AA} is the price elasticity of demand for transport mode A

SE_{AB} is the elasticity of substitution between mode A and mode B

W_A is the expenditure share on mode A

MQ_A is the money price of mode A

and Q_A is the generalised price for mode A.

The estimates of relevant elasticities from literature are summarised in Table 2.

Insert Table 2 here

Each element in Table 2 represents the price elasticity of the transport mode in the column with respect to the price of the transport mode in the row. The elements on the diagonal give the own price elasticities. The cross price elasticities are either zero (since a price change in one period does not affect demand in another period) or positive. It can be seen that changes in car price have a greater effect on demand for buses than vice versa. However, given that they are all still less than one, means that demand is inelastic.

The assumptions regarding the way people behave in their transport choices are reflected in the elasticities of substitution at each level of the utility tree. Substitution elasticities relate to preferences and not to market conditions. They can take a value between zero and infinity - the larger the substitution elasticity means the more willing people are to substitute one option for another. The substitution elasticities are shown in Table 3.

Insert Table 3 here

Transport is generally demanded only when necessary and therefore the ease of substitution between transport and other goods, at 0.6, is quite low indicating that consumers do not have much choice. Consumers are more willing to substitute between peak and off-peak transport but to an even greater extent the size of car and type of fuel used. Low levels for walking and cycling indicate that it is difficult to get consumers to switch from motorised and non-motorised modes of transport. This is reflected in the small values for the related substitution elasticities. For the other alternatives available (private or public travel, solo or pooled travel, bus or rail travel) consumers are more willing to substitute between these alternatives in the off-peak period than in the peak period.

EXTERNAL COSTS

Congestion

Congestion is an ever increasing problem within the urban environment and it results in longer journey times, increased fuel consumption and greater wear and tear on vehicles. There are over 1,338,600 licensed vehicles on Irish roads with of which 1,057,000 are private cars. The number of private cars licensed in the Greater Dublin area totals 300,941 (DOE, 1996).

The cost of congestion in the EU amounts to four times more than is spent on public transport in the EU (Commission of the European Communities, 1996). Quinet (1994) estimates the external congestion cost of transport at 2% of GDP. Barret et al (1997) state that this 'is probably an over-estimate for Ireland given the relatively low population and small urban areas in Ireland'. The marginal congestion costs are calculated endogenously in the TRENEN model. The costs consider the time losses of other road users but do not include the effect of the marginal change in speed on operating costs and on air pollution. Congestion is also assumed not to influence the demand of other road users (Mayeres et al, 1997).

The TRENEN model requires a congestion function to describe how average speed is influenced by traffic flow. The congestion function allows the time loss suffered by other road users to be computed if an additional passenger car unit (PCU) joins the traffic flow. This is then combined with information on the value of time to calculate the marginal external congestion cost of an additional PCU kilometre. The congestion function was derived using a series of network model runs at different levels of demand. The functions used in this project were

$T = 1.35 + 0.12e^{0.97x}$ for the peak period and

$T = 1.43 + 0.03e^{1.57x}$ for the off-peak period

where T = the time taken to travel 1 km on the network (minutes) and

x = total distance travelled in million pcu-kms.

More detail on the congestion function characteristics are presented in O'Mahony, Kirwan and McGrath (1997).

Air Pollution

Transport is now considered to be the biggest source of air pollution in Ireland (EPA, 1996). The major sources of atmospheric pollution from motor vehicles comes from exhaust gases. Modern vehicle technology will have a major impact on reducing emissions in the coming years. However, the impact of new technologies could well be reduced by the dramatic increase in the number of vehicles on the road.

Diesel and petrol engines produce different types of pollutants, and each pollutant has a different impact on human health. 71% of the national vehicle fleet use petrol, 29% operate on diesel and only 0.11% use an alternative, such as LPG (DOE, 1996). 86% of the total private car fleet use petrol, whereas diesel engines are used by a variety of different vehicles including heavy goods vehicles (HGVs) and buses. The high occupancy rate of buses means that emissions per passenger kilometre are substantially lower than those associated with a car kilometre.

Monitoring results by Dublin Corporation (city authority) indicate that pollutants such as smoke, sulphur dioxide (SO₂), lead and carbon monoxide (CO) do not currently present a problem for Dublin's air quality. Compulsory installation of catalytic converters in all new cars has been in place since 1989 and there has been widespread scrappage of cars greater than 10 years old under a Government-run scheme. However, a remaining 54% of licensed private cars are 6 years old and over (DOE, 1996).

The external air pollution costs used in the TRENEN model are extrapolated from the ExternE Transport project (Bickel et al, 1998). The ExternE project uses an 'impact pathway' approach i.e. a sequence of events which links a 'burden' to an 'impact'. The main stages of the impact pathway were emission modelling, dispersion modelling, estimation of physical impacts using exposure-response functions and finally monetary valuation of impacts (Bickel et al, 1998). The results obtained by ExternE take into account the impact of pollutant emissions on local concentration levels and refer to the external costs of air pollution on human health, materials, crops and global warming. The marginal external air pollution costs for the different types of vehicle considered in the TRENEN model are shown in Table 4. The values shown for the car are in EURO per vkm, while the values for the public transport modes are in EURO per passenger km.

Insert Table 4 here

Accidents

The costs to society incurred by road accidents are an indicator of accident occurrence and severity. The two principal methodologies employed for the estimation of accident costs are the human capital and the willingness to pay approaches. Jones-

Lee (1990) suggests that the latter could add 40 – 50% to the value of a life. The human capital method estimates the cost to the economy arising from the lost output of persons killed and injured. Willingness to pay on the other hand includes an additional component based on what society would be prepared to pay to reduce the risk of an accident. The value of a statistical life (VOSL) refers to the marginal willingness to pay to avoid the risk of a fatal accident aggregated over a large number of people. Cost estimates from the NRA (1997) for fatal accidents are based on the willingness to pay method while the remaining accident categories employ the human capital approach. The estimated cost of a fatal accident in 1996 was 1080000 Euro, while 39375 Euro and 3813 Euro apply to a serious and minor injury accident respectively. The cost of a material damage accident is estimated to be 1400 Euro. The total cost of reported road accidents in Ireland in 1996 is estimated to be 567 Euro million (NRA, 1997).

The difference between the marginal social cost of an accident and the average private cost is the marginal external cost. There are three stages in computing the external costs of accidents: the first involves identifying the cost elements of traffic accidents, the second involves considering whether and to what extent these costs are externalised and the third involves placing money values on those cost elements which are externalised (Maddison et al, 1996).

Where road transport insurance is compulsory, the road user takes account of the average private accident costs. This includes their own utility loss due to the accident risk and possibly also the utility loss of relatives and friends. Material costs are internalised through third party insurance. The marginal external accident cost arises

in a number of situations: (1) where transport users are not adequately insured, (2) where the insurance system does not deal with all costs related to accidents (such as police, administration and certain medical costs) and (3) where insurance spreads the cost of accidents among all motorists (4) increased risk to other road users, especially vulnerable road users. The output lost to the state in the form of taxes paid by the individual is also an external cost.

The Commission of the European Communities (1995) estimate the external cost of road traffic accidents as 1.5% of GDP. In calibrating the TRENEN model for Dublin the values presented in Table 5 were used because the necessary accident data for Dublin was not available. The willingness to pay of relatives and friends of the victim to avoid the accident was not included in the cost estimate.

Insert Table 5 here

Noise

The cost of noise generated by road traffic is difficult to evaluate and no estimates currently exist for Dublin. Various studies have put forward estimates of the value such as Quinet (1994) who suggests a value of 0.3% of GNP, while the Commission of the European Communities, in their Green Paper 'Towards Fair and Efficient Pricing', (1995) estimate the external cost of noise at 0.2% of GDP. In calibrating the Dublin model and in the absence of Dublin data the values for Brussels were used (Mayeres et al, 1997). However, densities and incomes are not similar in Dublin and Brussels and therefore this should be taken as a simplifying assumption that requires further work. In summary, the total external noise cost was calculated by multiplying the monetary value per dB by the noise level above the threshold of 50 dB(A) by the length of road where a noise externality is generated. The monetary value of noise

was calculated at 0.6 EURO per 1dB(A) per kilometre (Mayeres et al, 1997). The algorithm used (Mayeres et al, 1997) is as follows:

$$\text{Marginal external noise cost} = \text{value of noise /dB} \left[\frac{10}{\ln 10} \frac{1}{Q_{vl} + 10Q_{pl}} \right]$$

where Q_{vl} = volume of light vehicles (<3.5 tonnes) in veh/h

Q_{pl} = volume of heavy vehicles (>3.5 tonnes) in veh/h.

RESULTS

The results presented are for the reference scenario and the full optimum scenario for the year 2005. The TRENEN model distinguishes between four types of consumers on the basis of two characteristics. Residents within a close proximity of the city centre are classified as inhabitants, whereas residents of the peripheral area of Dublin city are classified as commuters. The zoning system in the Simulation and Assignment of Traffic to Urban Road Networks (SATURN) (Van Vliet, 1991) network model of Dublin was used to categorise the consumer type according to inhabitant and commuter. Trips originating in the zones which lie more or less within the canal ring of Dublin (CBD) were classified as inhabitant trips. The 367 zone trip matrices were compressed into two zone matrices - one zone representing total trips generated by inhabitants, the other zone representing total trips generated by commuters.

Consumers must be further distinguished according to those who pay for parking and those who do not. Inhabitant and commuter demands are further broken down into 'payers' and 'non-payers' by means of an additional parking model. A study within the Custom House Docks Area in Dublin (Dublin Corporation, 1996) showed that up to

73% of people who travel to work by car do not pay to park and this compares well with an estimated EU average of 70%. Apart from the travel demand data and proportion of people who pay for parking, information on the money price of private transport and average parking costs are input to the parking model. The parking model splits total demand between 'payers' and 'non-payers'. The split in demand is a population-weighted average between the different user groups. The prices that the different user groups face is taken into account by the reaction of drivers to a change in prices which is represented in the price elasticity of demand.

Reference Scenario

A summary of the monetary values determined in the reference scenario are presented in Table 1. The resource cost for commuters is lower than that for those individuals living in the city centre (inhabitants) due to the fact that the cost is spread over a longer distance for commuters. The negative tax on public transport in the peak period, in the reference scenario, indicates that this transport mode is subsidised. The marginal external cost of public transport per passenger km is considerably lower than that of private transport due to the higher occupancy rate of the public transport vehicles. The average car occupancy rate was 1.37 (DTI, 1995) and it was assumed that 20% of all cars were pooled. An average occupancy rate of 2.85 was used for pooled vehicles. The occupancy of buses in peak periods was assumed to be 37 (Dublin Bus, 1995) and in the off-peak period an occupancy rate of 20 was used.

Figure 3 indicates that in the case of a small (840-1400cc) petrol car – driver only - by an inhabitant not paying for parking, the tax charges amount to only 12% of the full cost of the journey. As a result, the total marginal external cost, accounting for 47%

of the total cost, is higher than the monetary price. The marginal external cost due to congestion accounts for 92% of the total marginal external cost. In the case of an inhabitant, as described above, who pays the parking charge, this additional cost comprises 14% of the total cost. The external costs are high for this consumer at 41%. In the case of the commuter payer, the time cost and resource costs are slightly higher than in the case of the inhabitant payer but the parking cost is lower due to the charge being spread over a longer distance.

Insert Figure 3 here

Figure 4 shows the generalised price of a selection of vehicle types. One may observe that diesel vehicles are priced lower than petrol (gasoline) vehicles in the reference situation. The generalised price is generally lower in the off-peak period as one would expect, given the lower time costs.

Insert Figure 4 here

When one examines the reference scenario demand results in Figure 5, one may observe that the demand for travel for petrol vehicles is higher than diesel. This represents the fact that petrol is the predominant fuel currently used in Ireland. One may also notice that the demand for travel in petrol cars in the off-peak period is considerable. The speed of travel in the peak period is quite low at 19.6 km/hr but this rises to 35.6km/hr in the off-peak period.

Insert Figure 5 here

The corresponding reference scenario public transport results are presented in Table 6. In this case, as one would expect, generalised prices are the same for all inhabitants and the same for all commuters. The generalised price in the off-peak period is higher due to the lower occupancy rates of public transport during these periods. The demand for public transport by inhabitant payers is higher than for non-payers. This

reflects the current situation in Dublin where those who pay for parking are more likely to use public transport. Bus speeds are slightly lower than private transport in both the peak and off-peak periods but train speeds remain at 38km/hr. It should be noted that there are limited train services available for commuters in Dublin and they are limited to a few corridors only.

Insert Table 6 here

Full Optimum Scenario

The full optimum scenario assumes that a policy maker has sophisticated pricing instruments available which can be used to internalise externalities precisely. The interesting aspects of the results of this scenario enable one to see the difference between the reference situation and what transport users should be paying in terms of the marginal external costs of their transport activities. The TRENEN model can be constrained to replicate second-best type policies such as congestion pricing or fuel taxation but for the purposes of this paper the full optimum is compared with the reference scenario.

A summary of the taxes in both scenarios are presented in Table 7. One may observe that the taxes in the full optimum rise considerably for all modes of transport. The subsidies on public transport in the reference scenario are removed in the full optimum scenario. Subsidies are considered by the TRENEN model as inefficiencies. The tax applied is much smaller than the tax increase on private transport so one would expect public transport to attract its share of demand. The tax increases in the off-peak period are much less than in the peak period. This can be attributed to lower traffic congestion in the off-peak period with lower marginal external congestion costs arising as a result.

Insert Table 7 here

A selection of results for private transport in the full optimum scenario are presented in Figure 6. They can be easily compared with the reference scenario in Figure 3. There are some notable points of interest in these results. In general, all types of private transport vehicle are priced higher in the full optimum scenario. This shows that in the reference situation externalities are not internalised and so in the full optimum taxes rise to account for this shortcoming e.g. 49% compared with 12% for the inhabitant non-parking-payer. In the case of a large petrol vehicle with driver only in the peak period the generalised price in the full optimum is 1.06 Euro/vkm (commuter payer) compared with 0.81 Euro/vkm in the reference situation. As congestion is the largest externality the TRENEN model taxes the vehicles at the same rate as that in the reference situation.

The increases in generalised price for diesel vehicles are generally larger than for corresponding petrol vehicles in the peak period. This is due to the fact that diesel vehicles currently contribute more to air pollution than petrol vehicles. The TRENEN model strives to rectify the price levels accordingly in the full optimum scenario.

Demand for private transport decreases in the full optimum scenario as a result of the increases in generalised price. The largest decrease in demand in the peak period is for small petrol vehicles as a result of the increase in tax imposed due to the congestion externality. Decreases in demand are also evident in the off-peak period again as a result of the price increases. Speed rises markedly in the full optimum scenario as a result of the reduction in demand with speed rising to 29.9 km/hr. In

Figure 6, one may observe the sizeable proportion of the costs now attributed to tax and a noticeable reduction in external costs.

Insert Figure 6 here

The full optimum public transport results are presented in Table 8 where the most notable findings have been mentioned earlier, i.e. the generalised price increases when compared with the reference situation. The speed of buses in the peak period increases significantly while in the off-peak period it increases slightly.

Insert Table 8 here

SENSITIVITY TESTING

Sensitivity tests were carried out (Gibbons, 1998) on the 2005 model with the reference parking charge and standard technology options included. The model was run for each of the sensitivity tests under the reference and full optimum policy scenarios. The objective of running the model under the reference scenario was to test the accuracy of the model. The aim of running the tests was to examine the sensitivity of the model. Six tests were carried out as described in Table 9.

Insert Table 9 here

Reference Scenario Tests

Since transport demands are constrained to their reference level in the reference scenario, it is expected that the results from each test will produce the same overall levels of demand for the different transport modes. The passenger kilometres demanded over the total population of Dublin are shown in Figure 7. The largest percentage change from the original 2005 reference scenario is for public transport in the peak period. This occurs in Test 4 where demand is lower than in the original scenario by 0.09%. In Tests 1 to 4, differences in the range of -0.08% to 0.08% are observed for peak private transport. Differences in the off-peak period are smaller

than those in the peak period, with the largest differences of 0.05% and -0.05% occurring for public transport in Tests 1 and 2 respectively. Overall, the differences in the test results and the original reference scenario are small and thus confirm the numerical precision of the model.

Insert Figure 7

Full Optimum Scenario

The full optimum policy scenario was run for each of the sensitivity tests described in Table 9. The full optimum scenario does not put any constraint on policy instruments in the model and the results from this scenario, therefore, show the greatest changes from the results produced in the reference scenario.

The percentage change in transport demands in the full optimum scenario with respect to the 2005 reference scenario model (with no change to original input parameters), are presented in Figure 8. The greatest reduction in demand for private transport in the peak period occurs in Test 2 (reducing by 21%) where the value of time for private and public transport has been doubled. The decrease in demand for public transport in the peak period is considerable in Test 2 and at 9%, the increase in demand for public transport in the off-peak period is significant. In Test 1, where the value of time is halved, the largest reduction in demand for public transport occurs in both peak and off-peak periods. The values of time are over 50% lower for public transport than private transport in the peak period but equal in the off-peak period. From the results produced in Tests 1 and 2, it would appear that the value of time has an important impact in the TRENEN model in determining the demand for a particular mode of travel.

Insert Figure 8 here

The percentage changes in speed for the reference situation sensitivity tests with respect to the original reference scenario are presented in Table 10. The improvements in speed are at their lowest for Test 1, at 28% for private transport and 2% for public transport. This is only to be expected since the levels of private transport in Test 1 indicate that this is the most popular mode of transport. In Test 4, the improvements in speed, in the peak period, are also at the lower end of the scale. This test assumes that consumers are less willing to substitute between peak and off-peak periods. Hence, demand in the peak period remains high. Test 2 achieves the highest increase in speed (36% for private transport and 3% for public transport) as a result of the decrease in demand for private transport (see Table 10). Test 3 produces the second highest results with improvements almost as high as those in Test 2. This is because the consumer finds it easier to substitute between peak and off-peak periods in Test 3.

Insert Table 10 here

Table 11 provides a summary of the overall results produced from the sensitivity tests. The largest welfare gain, of 0.51%, occurs in Test 1. This may be attributed to the reduction in marginal external congestion costs. The tax revenue generated by private transport in Test 1 is also affected by the reduction in external congestion costs, since the tax required to internalise the marginal social cost has also reduced. This observation is reversed for Test 2, with higher marginal social costs leading to higher levels of tax revenue.

Insert Table 11 here

Overall it can be seen, from each sensitivity test, that a decrease in transport demand is more likely to occur than a shift from peak to off-peak or private to public transport. It would appear, therefore, that one of the primary objectives of the TRENEN

optimisation procedure is to maximise tax revenue, by internalising the social costs of all transport modes. Promotion of public transport or travel in off-peak periods has a lower priority. The external costs, apart from congestion, are relatively less important. The limited changes in welfare may be explained by the fact that transport is only a small share of total expenditure. Full details of the results are available from the authors.

CONCLUSIONS

The price paid for many journeys does not reflect the social costs involved. Charging road users on the basis of full social costs is a key element in an efficient and sustainable transport system. By making all transport users more aware and more accountable for the full cost of their actions, individuals will be able to make more informed judgements about the costs and benefits of transport alternatives. This means that the overall use of transport resources will be more efficient.

Current taxes do not represent the full external costs of the different transport modes. The tax on vehicle purchase and annual motor tax are not well related to the external cost generated by vehicles and although fuel taxes differ according to fuel type they do not always favour those which are least harmful to the environment e.g. tax on diesel in Ireland is lower than tax on unleaded petrol. With any economic policy the transparency of costs and prices is important so that users can see that the price paid for a given journey is fair in relation to the costs generated and not merely a source of government revenue generation. Since costs often vary across space, time and modes, there is also a need for differentiation in prices.

The results from the TRENEN model indicate that the success of policy measures depend upon the consumer being charged a higher price for transport than is currently the case and the degree to which that price may be differentiated over space and time. The associated rise in welfare from the reduction in congestion and pollution combined with the reimbursement of tax payments outweighs the utility loss due to the price increases of transport services.

The results from the reference pricing scenario highlighted the inefficiencies present in the current pricing system. The resource cost of parking is not paid in over 70% of cases and external costs are much higher than the taxes paid. The ideal prices which transport users should be paying, as output by the full optimum scenario, further emphasise these inefficiencies. Optimal pricing implies that large increases are required in the price of both peak and off-peak private transport by imposing taxes on consumers which internalise the external costs of their transport demands. The costs of implementation of road use pricing was not examined in this project. The optimal scenario also suggests an increase in the price of public transport although not as high as that for private transport.

Overall the TRENEN model has shown that by making all road users pay for parking can be a very effective instrument. Not only does this charge correct the parking inefficiency, it also reduces the congestion externality. Improved car emission technologies, on the other hand, reduce air pollution effects. This is an important aspect but many commentators suggest that much of the gains to be realised have already been achieved.

In the application of the TRENEN model to Dublin, account was not taken of the implementation costs of new pricing technologies like road use pricing. Assuming that an electronic cordoning system, similar to that used in Singapore, would be the most useful type for Dublin, the implementation costs consist of the costs of extra equipment in vehicles, sensor equipment along roads and operating costs. These costs are an important issue in the implementation of any road pricing scheme and they would need to be considered in the overall evaluation of any policy measures.

The issue of freight transport has also not been considered. Goods vehicles have a strong negative impact on the urban environment in terms of air pollution since they not only emit high levels of pollutants but the majority of vehicles have diesel engines. Large numbers of goods vehicles on city streets increase the risk of accidents among the most vulnerable road users. They create an element of fear and intimidation for residents and other road users in the city centre as well increased levels of congestion. Freight transport is to be included in further applications.

The model does not directly induce a modal transfer to public transport which in real terms is seen as a positive step. Although large tax increases were observed, the overall reduction in travel demand was not as high as might be expected. This would suggest that in order to achieve a reduction in transport demand, pricing policies must be considered in the long-run and that in the short-run transport demand is inelastic.

According to Button (1994) an important pre-requisite to reducing negative externalities from transport is to obtain a good estimate of the actual cost. The work carried out in Dublin to date on the evaluation of costs associated with the external

effects of transport has been limited. This was in part due to inadequate levels of data collection directly related to transport. However, increased measurements of air pollutants and monitoring of noise levels are currently underway. This information would provide a basis for further work in the area of evaluating these costs for Dublin.

The sensitivity tests indicated that the value of time is an important factor in determining an individual's preference for mode of travel. The values used in the TRENEN model were those derived for Dublin during the Dublin Transportation Initiative (DTI, 1995).

The TRENEN application to Dublin has shown that the true costs of road transport are far greater than the sum of individual benefits. However, the positive aspects of road vehicles should not be disregarded in the drive to control road transport. Motor vehicles can bring economic benefits to isolated communities and bring amenities within the reach of all citizens as long as they exist within an integrated system of public transport and town planning. The positive aspects of road use would not be sacrificed if the amount of traffic on the roads were to be reduced, rather they would be enhanced and negative effects would be diminished.

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Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure Legends

Figure 1 Supply and Demand in the TRENEN Model

(Van Dender, Proost & Ochelen, 1997)

Figure 2 Structure of the TRENEN Model (Van Dender, Proost and

Ochelen, 1997)

Figure 3 2005 Reference Scenario

**Figure 4 Differences between prices in Reference and Full Optimum cases
for commuter payers.**

**Figure 5 Differences in demand between Reference and Full Optimum cases
for commuter payers.**

Figure 6 2005 Full Optimum Pricing Scenario – small petrol vehicle

Figure 7 Sensitivity of demand results for reference case

Figure 8 Change in demand compared with Reference (base) scenario

<u>Prices and costs (EURO/pkm)</u>	Res ource Cost	Tax	Money Price	Marginal External cost (per vkm for car, per pkm for public transport)	Generalised Price
Peak					
Car, solo, small, petrol, free park					
inhabitants	0.39	0.12	0.34	0.5	0.55
commuters	0.31	0.12	0.34	0.5	0.55
Car, solo, small, petrol, paid park					
inhabitants	0.39	0.12	0.52	0.5	0.73
commuters	0.31	0.12	0.43	0.5	0.65
Car, solo, small, diesel, free park					
inhabitants	0.37	0.1	0.3	0.52	0.51
Bus (inhabitants)	0.11	-0.06	0.05	0.03	0.21
Off-peak					
Car, solo, small, petrol, free park					
inhabitants	0.39	0.12	0.33	0.09	0.48
Bus (inhabitants)	0.12	0.01	0.13	0.01	0.57

Table 1 Monetary values in the Reference Situation

	Peak Car	Off-peak Car	Peak Public Transport	Off-peak Public Transport
Peak Car	-0.3	0.049	0.708	0
Off-peak Car	0.05	-0.6	0	0.578
Peak Public Transport	0.03	0	-0.35	0.036
Off-peak Public Transport	0	0.02	0.03	-0.87

Table 2 Price elasticities (De Borger et al, 1995)

Transport and other goods	0.6	
Peak and off-peak transport	0.8	
Big and small cars	1.5	
Fuel types	1.5	
	<i>Peak</i>	<i>Off-Peak</i>
Motorised and non motorised travel	0.3	0.3
Private and public travel	1.05	1.95
Solo and pooled travel	0.6	1.6
Bus and rail travel	1.1	1.65

Table 3 Substitution elasticities (Gibbons, 1998)

Vehicle Type	Cost
Diesel Car	0.04 Euros/vkm
Petrol Car	0.006 Euros/vkm
Diesel Bus	0.04 Euros/pkm
Train	0.006 Euros/pkm

Table 4 **Marginal external air pollution costs averaged for urban conditions (ExternE, 1997)**

Vehicle Type	Cost (EURO per vehicle km)
Car	0.03
Bus	0.02
Train	0.003

Table 5 **Marginal external accident costs (Van Dender, Proost and Ochelen, 1997)**

	Inhabitant	Inhabitant	Commuter	Commuter
	Non-Payer	Payer	Non-Payer	Payer
Generalised				
Price				
(EURO/vkm)				
Peak bus	0.21	0.21	0.18	0.18
Peak train	0.14	0.14	0.09	0.09
Off-peak bus	0.57	0.57	0.5	0.5
Off-peak train	0.59	0.59	0.52	0.52
Demand				
(Pass.km/individual)				
Peak bus	0.7	0.73	0.8	0.82
Peak train	0.44	0.46	0.71	0.73
Off-peak bus	3.41	3.59	1.58	1.63
Off-peak train	2.18	2.29	0.75	0.77
Speed (km/hr)				
Peak bus	17.5	17.5	17.5	17.5
Peak train	38.0	38.0	38.0	38.0
Off-peak bus	31.7	31.7	31.7	31.7
Off-peak train	38.0	38.0	38.0	38.0

Table 6 2005 Reference Scenario public transport results

	Inhabitant	Commuter
	Non-Payer /	Non-Payer /
	Payer	Payer
REF1		
Peak, car	0.12	0.12
Peak, bus	-0.06	-0.06
Off-peak, car	0.12	0.12
Off-peak, bus	0.01	0.01
FO2		
Peak, car	0.58	0.46
Peak, bus	0.15	0.08
Off-peak, car	0.38	0.28
Off-peak, bus	0.18	0.11

Table 7 Taxes in Reference and Full Optimum scenarios (EURO/pass.km)

	Inhabitant	Inhabitant	Commuter	Commuter
	Non-Payer	Payer	Non-Payer	Payer
Generalised				
Price				
(EURO/vkm)				
Peak bus	0.4	0.4	0.3	0.29
Peak train	0.22	0.22	0.15	0.15
Off-peak bus	0.74	0.74	0.59	0.59
Off-peak train	0.77	0.77	0.67	0.67
Demand				
(Pass.km/				
individual)				
Peak bus	0.43	0.44	0.56	0.56
Peak train	0.34	0.35	0.5	0.51
Off-peak bus	3.47	3.37	1.65	1.63
Off-peak train	2.2	2.13	0.68	0.68
Speed (km/hr)				
Peak bus	23.1	23.1	23.1	23.1
Peak train	38.0	38.0	38.0	38.0
Off-peak bus	32.5	32.5	32.5	32.5
Off-peak train	38.0	38.0	38.0	38.0

Table 8 2005 Full Optimum Pricing Scenario public transport results

Test 1	Values of time for private and public transport are halved
Test 2	Values of time for private and public transport are doubled
Test 3	Substitution elasticity between peak and off-peak transport increased from 0.8 to 1.2
Test 4	Substitution elasticity between peak and off-peak transport decreased from 0.8 to 0.4

Table 9 Sensitivity Tests for the 2005 TRENEN Model

	Base	Test 1	Test 2	Test 3	Test 4
% Peak Private Speed	32.45	28.06	36.17	34.95	29.03
% Peak Public Speed	32.49	28.08	36.22	34.96	29.05
% Off-Peak Private Speed	2.76	2.36	3.23	2.61	2.95
% Off-Peak Public Speed	2.71	2.34	3.22	2.59	2.90

Table 10 Change in speed compared with Reference Scenario

	Base	Test 1	Test 2	Test 3	Test 4
% Welfare	0.46	0.51	0.40	0.47	0.45
% Total External Cost	-14.30	-14.33	-14.67	-14.26	-14.38
% Tax Revenue Private	139	103	211	135	145
% Tax Revenue Public	658	502	957	663	647

Table 11 Change in summary results compared with Reference Scenario