AN ECONOMIC MODELLING APPROACH FOR THE REFORM OF URBAN TRANSPORT PRICING

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Abstract

In this model various transport options for the household are represented. These options differ in social costs and in (generalised) prices. Transport demand is represented by a nested CES function. Transport supply is represented with constant returns to scale cost functions, except for the Mohring effect in public transport. The urban road network is represented as one congested link. The model is calibrated to a reference equilibrium. It is then used to assess the social welfare impact of alternative sets of policy instruments (public transport pricing, environmental regulation, fuel taxes, road pricing and parking charges).

INTRODUCTION

Road transport generates different types of external costs. These include air pollution, noise and external costs more specific to urban transport, such as congestion and accident externalities. Those problems are most often dealt with by piecemeal or indirect policies. In Europe, the overall level of car traffic is limited through high excise taxes on motor fuels[1], parking policies and subsidies to public transport. Air pollution problems are tackled mainly by emission standards for cars and by differentiated excises on fuels (leaded versus unleaded gasoline). There is a need for integration of these policy actions in a consistent framework because they all contribute to the same objectives. One can indeed reduce air pollution through emission standards on cars, but also via subsidies to public transport or higher taxes on car use. We present a partial equilibrium model of urban transport markets, in which the different external cost aspects are integrated, as a tool for integrated policy assessment.

In the TRENEN-URBAN model, transport activities in an urban area are represented as a set of interrelated transport markets. A 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 offpeak) in a homogenous city. Demand on each market is a function of the generalised costs on all markets. The generalised cost of trips consists of resource costs, time costs and different types of taxes. The markets interact through changes in the generalised costs that are either exogenous (tax changes) or endogenous: time costs depend on the total volume of transport on the network. This detailed representation of the transport market allows to represent explicitly congestion, air pollution, noise and accident externalities.

A market equilibrium is reached through maximisation of a welfare function under a set of constraints on the policy instruments. Relaxing the policy constraints allows to construct counterfactual equilibria and to assess the relative merits of different pricing and regulatory policy instruments.

The TRENEN-URBAN model extends a previous urban transport model (DE BORGER, MAYERES, PROOST, WOUTERS (1996)) that focused only on optimal pricing policies, did not use an explicit welfare criterium and had a strongly simplified demand and supply structure. The principal contribution of TRENEN-URBAN is in the explicit computation of optimal taxes and regulations that internalise different types of externalities, in a second best framework. First results of the TRENEN model were presented in DE BORGER, OCHELEN, PROOST, SWYSEN (1997). This paper presents the second version of TRENEN-URBAN, with improvements in the representation of parking, public transport costs and treatment of tax revenues.

In terms of degree of detail, the TRENEN-URBAN model is an intermediate solution between a general equilibrium model and a typical transport model. In a general equilibrium model, transport is just one of the goods considered and optimal direct and indirect taxes can be computed in a second best framework à la MAYERES and PROOST (1997). In a typical transport model[2] the transport operations of the different modes are represented in detail on a network and the main goal is the correct simulation of the flows on the network. Our approach drops, on the one hand, the explicit network representation of the transport flows by assuming a homogeneous zone, while retaining the detailed representation of transport volumes by mode. The relevant information of the network model is summarised in an aggregate flow-speed relationship. On the other hand, optimal taxes are computed only for transport markets 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 marginal cost of public funds is a parameter which can be supplied by a general equilibrium model.

In this paper the emphasis is on the presentation of the intuition and the capabilities of the model. The mathematical description of the model can be found in OCHELEN, PROOST, VAN DENDER (1998). This paper also briefly discusses an application of the model to Brussels. The TRENEN-URBAN model has been applied to different European cities and has been used to study the reform of transport pricing in the EU. A comparison of policy results can be found in PROOST et al. (1998).

Section 2 presents the intuition of the model in graphical terms. Section 3 is on the operationalisation of the different model components. Section 4 discusses some preliminary model results for Brussels. Section 5 concludes.

THE INTUITION OF THE MODEL

The transport sector is an important cause of external costs specific to transportation like congestion, but also of other external costs like air pollution and accidents. Several types of policies can tackle the external costs problem. There is a need for integration of these policy actions in a consistent framework. A way to achieve this is to use equilibrium models for the transport market in which external cost aspects are integrated.

The basic idea of TRENEN URBAN is to look for the optimal combination of price and regulatory policies in the transport and environment domain via the optimisation of a welfare function. This optimum will be implemented as a market equilibrium with different types of taxes, public transport prices and environmental standards.

In general, the optimum is the situation where the difference between the total benefits and the total costs is maximised. Consider as an example the market for carkm in a particular city as depicted in FIGURE 1. This figure represents the market for carkm in one particular period (peak) with one particular type of car (small gasoline car with catalytic converter). For each type of vehicle or means of transportation one has such a market diagram, and all markets are interrelated. Demand for a particular type of transport depends on the prices of all other types of transport means available. In Figure 1, however, other variables influencing the demand function are kept constant.

The demand function expresses the consumers' total marginal willingness to pay at each volume of carkm. The surface under the curve is therefore a measure of the total benefits of car use: at a very high price only the strictly necessary carkm would be demanded, but as prices drop more and more households will use the car for all types of purposes.

The marginal resource cost curve gives the marginal resource cost of a carkm at each volume, such that the underlying surface is the total resource cost. In the figure the marginal resource cost (r) is constant and equals OC. The resource cost contains fuel costs, maintenance costs, vehicle depreciation, parking costs, and cost of other inputs, all on a per carkm basis.

If there were no congestion and no externalities, the equilibrium volume of traffic is V_{A1}, where car users' marginal willingness to pay equals the marginal resource costs. This would also be a welfare optimum because the difference between total benefits and total costs is maximised. The net benefit is measured by area DA_1C. A different type of pricing, giving a higher or a lower volume of transport would generate a smaller difference between total benefits and total costs, because the willingness to pay decreases to a level below the resource cost when the volume increases beyond V_{A1} and vice versa.

Due to the limited capacity of the road network, time costs per carkm increase when traffic volume increases. When car users only have to pay the resource cost and the average congestion cost, which is usually the case, we get an equilibrium point A_2.

There are however externalities in this situation. Externalities are costs generated by car users, which they do not pay for. The first externality is congestion. A car user pays the average congestion cost (the time required to drive a carkm) but not the marginal congestion cost (the time loss caused to other drivers). Other types of externalities like air pollution, noise and accidents costs are taken as independent of traffic volume in the diagram. A constant cost per carkm is added to the marginal resource and time costs. The highest cost curve is the social marginal cost of a carkm. The optimal point then is equilibrium point B where all car users pay the marginal social cost of a carkm. Implementing point B rather than point A_2 generates a welfare gain equal to the area BEA_2. Total welfare is now equal to the area DBF.

The TRENEN model assesses instruments, like prices and standards, that bring the equilibrium from A_2 closer to B. Stricter emission standards tend to lower the air pollution costs (downward shift of the marginal air pollution costs) at the expense of higher resource costs (upward shift of the marginal resource costs). In fact several taxes on transport already exist, but these are not necessarily optimal.

A model is required because of two type of complications. First, not one single market but a set of minimally 4 interrelated transport markets (2 modes such as car and bus and 2 periods such as peak and off peak) have to be studied. With several types of fuels, cars and public transport modes, TRENEN II URBAN consists of 20 interacting transport markets. The interactions work through money prices and time costs, because the same network is shared by the different transport modes (except metro). Second, policy instruments are not perfect and are subject to several types of constraints : cars can not always be taxed in function of their emissions and in function of the level of congestion. A comparison of second best situations requires a quantitative approach trading off different types of inefficiencies.

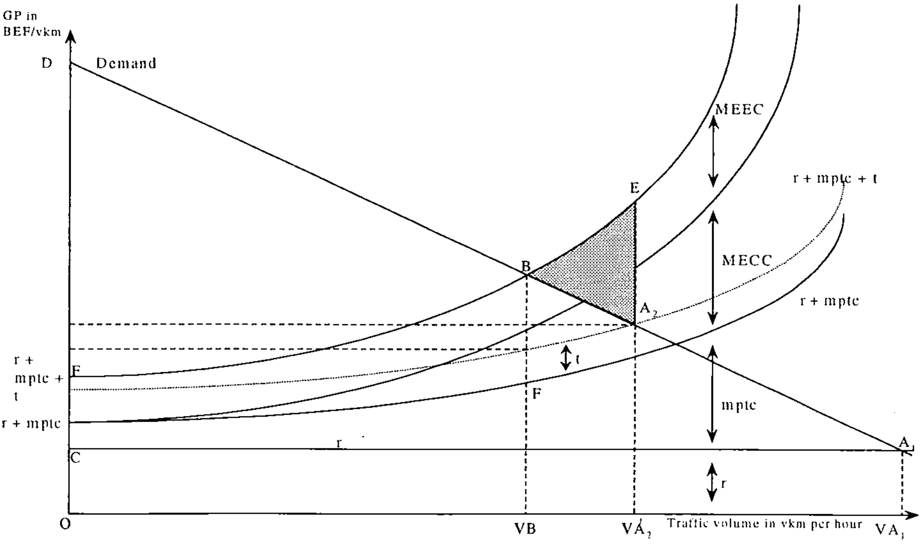

Figure 1 Representation of a Transport Market (e.g. peak car use with a small petrol vehicle equipped with a catalytic converter)

OPERATIONALISATION OF THE MODEL CONCEPTS

We discuss the representation of demand, supply, external costs, the congestion function and the marginal cost of public funds. The model application discussed here is for Brussels, a city of medium size with an extensive road and public transport network. The predicted transport situation in 2005 for unchanged policy conditions with respect to 1991 will serve as reference equilibrium. The applications discussed in section 4 do not include freight transport in the analysis.

Demand representation

Four groups of representative consumers are distinguished. First we distinghuish between inhabitants and commuters. For each of these categories a further distinction is made between those who have access to free parking and those who do not.

Passenger transport demand is represented using a nested CES function (KELLER (1976)). The CES function is easy to calibrate and requires a minimum of behavioural information: prices and quantities in a reference equilibrium together with substitution elasticities at each level. Nested logit functions are in theory a superior way to represent transport demand, but they are more data intensive and can not easily be used for the computation of optimal taxes.

The specific nested CES utility function used contains seven nests. The elasticities of substitution are are determined assuming that the lower we go down the tree, the easier one can substitute between the alternatives, such that they yield price elasticities consistent with the literature.

The full structure is shown in Figure 2 in the form of a utility tree.

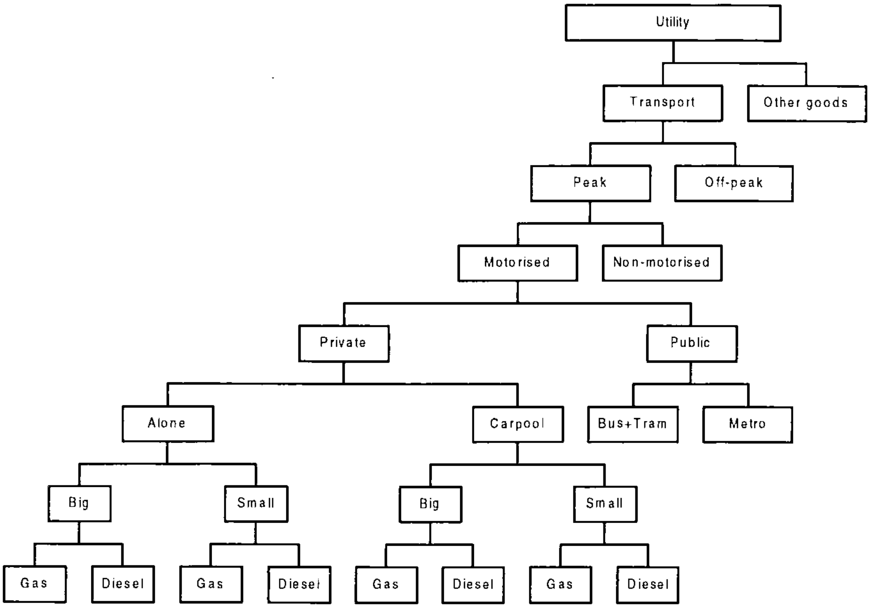

Figure 2 Utility tree for urban passenger transport in TRENEN II URBAN - Elaboration of peak-

In determining the order of the nests one should bear in mind the assumption of separability underlying the nested structure. All goods located on the same branch of a tree will react identically to a price change of a good on another branch of the tree.

Car pooling is considered as a separate mode because in this way the overall occupancy rate for cars becomes endogenous. The non-motorised modes are aggregated into one mode because we emphasise congestion and air pollution problems. Most of the branches have only two choices, but they can be extended to any number.

Supply representation

The supply part is kept very simple in this model. Its main function is to represent the resource costs of alternative transport modes. We distinguish between public and private transport.

Private transport modes

For private passenger transport modes, a distinction is made between large and small cars, between diesel and petrol cars and between pooled and non-pooled cars. Resource costs are taken as constant per vehicle kilometer for each of these categories. This implies that the costs of ownership and of use of cars are not addressed separately. This is acceptable in a static implementation of a model that represents a long run adjustment.

For petrol cars two technological options are distinguished: standard technology which includes a normal 3 way catalytic converter and improved technology containing a pre-heated 3 way catalytic converter. The latter is more efficient in reducing harmful emissions in urban areas. For diesel cars there are also two possibilities. The improved technology adds a particulates filter to the standard technology.

For private transport modes, six inputs are required to produce a carkm. There is no substitution possible between these inputs. To obtain one km in period X by individual of type Y with cartype Z, a fixed amount of fuel and parking time is needed. The other costs are vehicle depreciation costs, insurance costs, and maintenance costs. When the different types of taxes and the time costs are added to the resource costs, one obtains generalised prices.

The majority of car users do no pay for parking at the trip destination. This is due to two reasons : (1) high transaction costs, and, (2) free parking is a tax free benefit to employees. In TRENEN II URBAN parking is modeled as follows. A parking firm supplies parking space at a constant marginal cost. Payers for parking pay this marginal resource cost. Non-payers for parking pay nothing. The losses of the parking firm are paid, for 40% by government (lost tax revenue due to the tax free benefit), and for 60% by all consumers (see CALTHROP et al. (1999) for more details).

Public transport modes

We consider two types of public transport, busses and trams, and underground. Busses and trams are defined as one mode because they are perceived by users as transport modes with the same quality. Busses and trams also (largely) use the same network and contribute to overall road congestion. Both public transport modes are represented by a linear cost function that contains a fixed cost and a proportional variable cost which differs by period: vehicle investment costs are fully allocated to the peak period. For the representation of economies of density in public transport, we adapt MOHRINGs' (1972) framework to the requirements of TRENEN-URBAN.

The congestion function

The model represents the city as a hypothetical one link system with homogenous congestion conditions. The congestion function is exponential. The precise functional form is based on extensive tests with detailed urban network models (O'MAHONY et al, 1997).

External costs

The methodology used in the estimation and valuation of the major external costs of transport is in detail described in MAYERES, OCHELEN, PROOST (1996). We briefly discuss the valuation assumptions for the external congestion, air pollution, noise and accident costs.

In the peak period congestion is the dominant external cost. The values of time used are based on HAGUE CONSULTING GROUP (1990).

The marginal external cost of air pollution caused by transport includes the damages linked to particulates, ozone formation, climate change and acidification. For the pollutants mentioned all external damages are taken into account: not only at the level of Brussels but also at EU or world level.

Marginal external air pollution costs per vehicle km have been assumed constant in the model. Total air pollution costs can be reduced by choosing a cleaner car, a smaller car, a different, cleaner, transport mode or by reducing the volume of transport. More fuel-efficient cars were not introduced as a specific option.

The external costs of noise contain the subjective discomfort of all inhabitants of a city caused by vehicle noise. Using a detailed study of the noise production by traffic in Brussels we derived a formula giving the average sound level over a given period as a function of the volume and composition of the traffic flow. This allows the computation of the marginal noise contribution of an extra vehicle km. The basis for the monetary valuation is the loss of value of houses in more noisy areas. The marginal external cost of noise is higher in the offpeak than in the peak. No possibility was foreseen to reduce the noise level of cars or busses by technical means.

In the accident costs one takes into account three types of costs: the willingness to pay of the victim to avoid an accident, the willingness to pay of the victims' family and friends to avoid an accident, and the direct economic costs of an accident (output loss for society, medical costs). The total social accident cost of adding an additional vehicle consists of two elements: the total accident costs for the occupants of the extra vehicle and also increase in accident costs for all other road users, due to the increased accident risk. The first category of social costs is internalised to a large extent by insurance premia and because people take their own utility loss due to accident risk into account when deciding to make a trip. The only social costs of this category not internalised, are the costs to society which are not recovered from insurance companies (ambulance costs, some medical costs etc.). Their magnitude depends on the insurance contracts. In Belgium, only costs related to the driver (not the passenger) are therefore included in the marginal external accident cost.

Whether the second category, increased accident costs for other road users, is internalised or not, is an empirical matter. This external cost is zero when adding more cars does not affect the accident risk. This is an accepted assumption for accidents between motorised road users.

The external costs are computed on the basis of observed accident risk, taking into account three different types of accidents (fatal, serious injury and light injury).

In this approach, total accident costs can only be reduced by affecting the total volume of traffic. One could imagine a more complex setting where the accident costs are linked to car design and drivers' behaviour. The total accident risks can then be reduced by linking insurance premia and taxes to these two elements. Of course also other elements linked to infrastructure are of importance, but they are kept fixed in this study.

The marginal cost of public funds

For the exercises in this paper it was assumed that all increases in indirect tax revenue are used to decrease labour taxes. Using the survey on marginal costs of public funds by SNOW and WARREN (1996), on marginal and effective tax rates from OECD (1996), and on labour supply elasticities from HANSSON and STUART (1985), a value of 1.2 was calculated for the marginal cost of public funds in Belgium. Since the share of labour income in total income equals 70% approximately, the value of • used in the applications is 0.066.

The reference equilibrium in Brussel, 2005

The Brussels region has 0.95 million inhabitants and 0.65 million commuters. For both categories, it was assumed that 30% pay for parking in the reference situation (figure taken from HALCROW FOX (1996)). The peak period is 5 hours long (morning and evening peak), the offpeak is spread over 17 hours. The reference equilibrium is obtained by calibrating the model to the projected

transport flows and prices in 2005, using the behavioural information contained in the elasticities of substitution.
The reference situation is described in table 2. The money price is the sum of resource costs and taxes. The generalised cost is the money price plus time costs. Costs and prices are expressed per passenger km, using an occupancy rate of 1 for solo driving and 2.5 for carpooling in private transport, and 40 passengers per vehicle in peak hours versus 9 in offpeak hours, in public transport.

From a pure efficiency point of view, the relation between social costs (resource costs plus marginal external cost) and private costs in all markets is what matters. In table 2, large deviations between marginal external costs and tax levels are present. The largest difference is found in the peak period, for car users with access to free parking. These users do not pay the full resource cost of their trips, and cause a large external congestion cost when driving in peak hours. The resource cost of parking per km is larger for inhabitants than for commuters, because parking costs are per trip costs, and average trip distances are shorter for inhabitants. The inefficiencies concerning parking and congestion dominate other issues, like choice of fuel or carsize.

Table 1 **Characterisation of the Reference Situation (Brussels, 2005)**

Prices and costs (ECU/pkm)	**Resource cost**	**Tax**	**Money price**	**Marginal external cost (per vkm)**	**Generalised price**
Peak					
car, solo, small, petrol, free parking					
Inhabitants	0.361	0.089	0.280	1.834	0.614
Commuters	0.261	0.089	0.280	1.834	0.614
car, solo, small, petrol, paid parking					
Inhabitants	0.361	0.089	0.450	1.834	0.784
Commuters	0.261	0.089	0.350	1.834	0.684
car, solo, small, diesel, free parking					
Inhabitants	0.326	0.083	0.271	1.863	0.547
bust/tram (inhabitants)	0.080	0.039	0.12	0.092	0.587
Offpeak					
car, solo, small, petrol, free parking					
Inhabitants	0.359	0.083	0.271	0.047	0.419
bus/tram (inhabitants)	0.271	-0.151	0.12	0.014	0.521
Volume and composition of traffic	**mio pkm**	**Share (%)**	**% carpool**	**Speed (km/h)**	
Peak, private	3.846	41.6	29.6	23.1	
Peak, public	1.839	19.9		20.6	
Offpeak, private	2.839	30.7	25.4	49.7	
Offpeak, public	0.727	7.9		44.2	
Tax revenue (mio ECU/day)					
Private	0.508				
Public	-0.010				
External costs (mio ECU/day)	0.432				

RESULTS OF A CASE STUDY

In this case study we compare, for 2005, the results of the reference equilibrium with an optimised pricing case. In the reference equilibrium the instruments used by government are fuel taxes, circulation taxes and subsidies to public transport covering the fixed cost, and part of the marginal costs (cfr. table 1). In the optimised policy case all existing taxes are abolished, and replaced by a combination of road pricing with several cordons, fuel taxes and new public transport prices. The level of all these new taxes can be chosen freely, without any tax revenue constraint.

Table 2 gives optimal taxes for Brussels in 2005, as well as the changes with respect to the reference situation, for a small petrol car driven alone (private transport) and for busses (public transport). Two situations are reported : optimal taxes when the reference system of parking charges remains unchanged (opt. A), and optimal taxes in the case where all drivers pay the full resource cost of parking (opt. B). We summarise the main results :

Optimal taxes are in general much higher than reference taxes. Taxes differ from marginal external costs for several reasons.
Perfect instruments are not feasible in practice. In particular, we do not allow tax differentiation between payers and nonpayers for parking. This characteristic is assumed to be unobservable at the time of the automated toll collection. Differentation between inhabitants and commuters, and between types of cars, is assumed to be feasible. The imperfectness of instruments may lead to taxes exceeding marginal external costs.in some markets, and to the opposite effect in other markets.
Next to internalisation of external costs, revenue raising is a second objective of the transport taxation system. Since transport taxes are less distortionary than labour taxes, and since we assume that transport tax revenues are used to decrease labour taxes, a positive weight (of 6.6%) is used for transport tax revenues, in the welfare objective function. Using a positive marginal cost of public funds for transport taxes will lead to transport taxes which exceed the marginal external costs of transport.
As a check on the correctness of the model setup, the optimal taxes were calculated in a situation where parking is charged at resource cost to all consumers, where no constraints on instruments are present, where there are no economies of density in public transport, where the marginal cost of public funds is zero, and where the tax rate on other goods is zero. In this model setup, the optimal taxes are equal to marginal external costs.
Optimal taxes are much more differentiated between peak and offpeak periods. This is necessary to address the congestion externality.
Taxes are higher for inhabitants than for commuters. We have assumed that this differentiation is feasible, because it amounts to a spatial differentiation of the tax, which is possible when using electronic tax collection systems. The tax is higher for inhabitants because they pay a higher price for transport per km in the reference situation (since their parking cost is higher on a per km basis). Equal absolute tax increases will consequently have a smaller relative effect for inhabitants. An equal reduction in traffic demand for inhabitants will hence require a larger price increase.
The optimal tax increase is smaller when all drivers pay for the resource cost of parking.
Public transport prices increase as well as private transport prices. In an optimal pricing system there is no incentive to subsidise public transport (except for the fixed costs). The increase here is higher in the offpeak period, which follows from the low occupancy rates in that period.
The tax system leads to drastic decreases of marginal external costs during peak hours. In offpeak hours there is a slight increase of marginal external costs, due to increased congestion, but the level of these costs remains low.

Table 2 Optimal Taxes and Marginal External Costs, Without (OPT A) and With (OPT B) Improved Parking Charges, Brussels 2005 (ECU/pkm and % change w.r.t. reference situation)
(for a small petrol car driven alone, and for busses)

		OPT A				**OPT B**			
		Tax	**% change**	**MEC**	**% change**	**Tax**	**% change**	**MEC**	**% change**
Private									
Peak	**free prk**								
	inh.	0.658	639	0.407	-78	0.533	499	0.407	-78
	comm.	0.546	513	0.407	-78	0.497	452	0.407	-78
	paid prk								
	inh.	0.658	639	0.407	-78	0.533	499	0.407	-78
	comm.	0.546	513	0.407	-78	0.497	452	0.407	-78
Offp.	**free prk**								
	inh.	0.316	281	0.047	0	0.188	126	0.047	0
Public									
Peak	**inh.**	0.082	110	0.020	-75	0.080	105	0.020	-75
Offp.	**inh.**	0.111	-	0.016	12	0.104		0.016	12

A welfare gain of more than 1% is reached by the optimal pricing policy (this is illustrated for optimal pricing cum improved parking charges, in table 3). This global welfare gain follows from a strong reduction of external costs and from an increase in the weighted average consumer surplus. It may be noted that all consumer groups except inhabitants not paying for parking in the reference situation, experience a gain of consumer surplus. Different definitions of the groups, with possibly other tax redistribution systems, could lead to other results. In the welfare computation no account was taken of implementation costs of road pricing and improved parking charges. For road pricing, implementation costs amount to 20 to 40% of the total welfare gains from road pricing. The implementation costs for improved parking charges are expected to be relatively small.

Given the size of the price increases, the sharp drop in traffic levels is not unexpected. Traffic decreases in the peak as well as in the offpeak. Peak traffic is discouraged mainly because the high external congestion costs are now internalised. Offpeak traffic decreases because the average tax level is increased, because former nonpayers for parking now pay the resource cost of parking, and because offpeak public transport is no longer subsidised. Offpeak public transport was strongly subsidised in the reference situation. The share and the level of public transport increases during peak hours, since this mode contributes less to congestion on a per passenger km basis. In the new modal distribution of traffic, peak and offpeak private traffic have lost market share, all to the advantage of public transport during peak hours.

Table 3 Key Results of Optimal policy (case, 2005 ; opt. B)

	welfare level	% welfare gain	% maximal welfare gain	traffic level (mio/ pkm)	% pea private traffic	% peak, public traffic	% offpeak private traffic	% offpeak, public traffic	Other external costs (mio ECU/day)
RF	54.60	0	0	9.252	41.6	19.8	30.6	7.8	0.432
FO	55.31	1.30%	97.3%	8.410	35.3	28.2	29.1	7.4	0.374

CONCLUSIONS

In this paper we have presented a partial equilibrium model for the study of optimal transport pricing in urban areas. The model addresses simultaneously the different types of externalities. It is theoretically consistent, but can be extended in a number of directions to make it more relevant to policy. It would, e.g., be useful to represent the network by several links instead of one, to introduce heterogenous consumers, and to introduce dynamics.

The first case studies with this model show interesting and encouraging results. General conclusions are that optimal transport taxes seem to be much higher than present taxes, that optimal taxes include corrections for unpaid parking resource costs, and that optimal public transport prices exceed the marginal social costs.

ENDNOTES

[1] In general fuel taxes are levied for government budget considerations rather than for external cost internalisation.

[2] See Small (1992) for an overview.

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