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SOCIAL COST PRICING OF URBAN PASSENGER TRANSPORT

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Abstract

Social cost considerations are introduced in a theoretical pricing model of urban passenger transport services which builds upon Glaister and Lewis (1978). The model takes into account four main categories of external costs: congestion, air pollution, noise and accidents. Optimal price rules are determined for different circumstances: (i) no restrictions on prices, (ii) a transport sector budget constraint, or (iii) the introduction of restrictions on pricing.

THE PRICING PRINCIPLE

The increase in congestion and environmental problems caused by urban transport have induced economists to think about devising an appropriate pricing policy in order to limit the adverse effects of transport. The starting point of the argument is that the users of the different transport modes should be confronted with all private and external costs they cause. Only when they are charged for their external costs, will they take them into account in their transport decisions.

When prices are not used to reach distributional objectives and when there are no budgetary restrictions, economic theory suggests to charge transport users a price which exactly equals the marginal social costs, ie the sum of the marginal private and the marginal external costs. The marginal external costs consist *inter alia* of the valuation of the increase in congestion, air pollution and noise caused by the additional vehicle and of the costs associated with the increase in the accident risk. Several estimates exist of the marginal external costs of transport. Two problems are associated with their use. First of all, it is important that pricing is based on the marginal and not on the total or average costs. Secondly, prices should not be based on the marginal social costs corresponding with the existing traffic volumes, but on those corresponding with the optimal traffic volume. These two principles are illustrated in Figure 1 which describes the market of one single transport mode. In the present equilibrium A the traffic volume is XO. This is too high since the marginal social cost (given by the distance XO B) exceeds the marginal private cost (XO A). Usually, analysis is limited to the determination of the marginal social costs for the volume XO. However, charging this price gives rise to a traffic volume which is too low (XO*). The optimal traffic level is X1. For this level the marginal social costs are given by the distance X1 C.

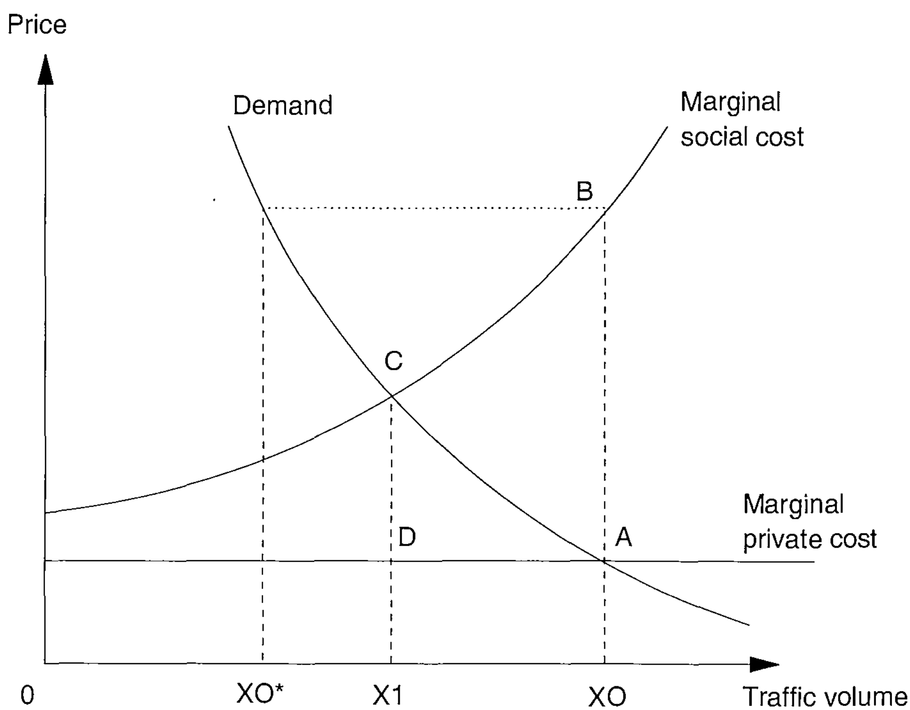

Figure 1 Marginal private and marginal external costs

In this paper we aim to determine the optimal prices of the different transport modes in an average Belgian city. The methodology and the theoretical model which underlie the exercise are discussed in a detailed way in De Borger et al. (1995) which also presents a number of simulations. Here we limit ourselves to a short description of the theoretical model followed by the presentation of some additional simulations.

THE MODEL

The model is based on Glaister and Lewis (1978), Viton (1983) and Small (1983). It is described in a detailed way in De Borger et al. (1995). The model distinguishes two transport modes: car and public transport. For each mode a distinction is made between peak and off-peak traffic. The demand for these four transport goods is interdependent. The demand curve in Figure 1 shifts when the price of another mode or the price in a different period is changed. For each transport market a private and an external cost function is determined. Using the model requires first of all the calibration of the demand functions in the initial equilibrium. Next, the demand functions and the marginal cost functions are used to determine simultaneously the optimal prices for the four transport goods. In terms of Figure 1, the model looks for point C starting in point A.

The model is based on a number of crucial assumptions. It is a partial equilibrium model which implies that no account is taken of feedbacks from the non-transport markets. Freight transport is not included. In an urban setting it can be considered to be of relatively small importance. Simplifying assumptions were made in the modelling of the supply side. The model does not incorporate an explicit network structure, but considers aggregate traffic flows in a homogeneous city. The traffic possibilities of the city are represented by one link with a given capacity. The speed-flow relationship for this link is based on more detailed network models. Public transport is assumed to exploit a given network and to adjust its services to long term demand changes. Public transport and cars use the same road infrastructure. The model determines optimal prices while other policy instruments are held constant. These include, eg spatial planning, road infrastructure, the quality of public transport, safety and environmental standards. The model is used to determine price levels only. The dimension of the price variable is the price per passenger km. The model does not yet allow to analyse eg whether prices have to be manipulated by means of the fuel tax or parking charges or how the public transport tariffs should be differentiated according to distance.

However, the model can be used to carry out second best exercises. Besides the basic optimum without budgetary or pricing restrictions, we present three additional simulations: (a) the impossibility of price discrimination for peak and off-peak car transport, (b) the restriction that the price of public transport may not exceed that of the initial equilibrium, and finally, (c) the introduction of a budget restriction for public transport which states that the deficit should be reduced by 50% with respect to the initial equilibrium. As was indicated before, it is assumed in all of the above simulations that there is a constant relationship between the demand of passenger km and the supply of vehicle km in the public transport sector. However, this assumption is not generally accepted, especially not for the off-peak period when the occupation rate is usually low. Therefore, in a final simulation we determine the optimum when the supply of public transport is held constant at the level of the initial equilibrium.

The model considers four types of marginal external costs: congestion, air pollution, noise and increased accident risk. They are determined on the basis of the methodology presented in Mayeres (1993). Table 1 gives the order of magnitude of the different marginal external costs in the initial equilibrium which corresponds with the observed traffic flows and prices of 1989. (In 1989 US$1 was worth BF39.43 and ECU1 was worth BF43.35.)

Table 1 The external costs of urban passenger transport in the initial equilibrium [BF(1989) per passenger km]

	Car traffic		Public transport	
	Peak	Off-peak	Peak	Off-peak
Air pollution	0.354	0.354	0.0469	0.0782
Noise	negligible		0.0690	0.3113
Accidents	0.9497	0.9497	0.1506	0.2509
Congestion	8.2292	0.5739	0.5590	0.0639
Variable resource-costs	1.6589	1.6589	3.7040	1.2570

Source: Mayeres (1993), Boniver (1993)

Note: In 1989, US$1 = BF39.43 and ECU1 = BF43.35

OPTIMAL PRICES AND TRAFFIC FLOWS

If there are no restrictions on the choice of price instruments it can be shown theoretically (De Borger et al. 1995) that prices should reflect the marginal social costs. Table 2 summarizes the results. It gives optimal prices, the corresponding traffic flows and the level of marginal costs in the optimum for each of the two periods. The optimum is compared with the initial equilibrium.

Table 2 The comparison of the basic optimum with the initial equilibrium

	Initial equilibrium	Optimum	
		Optimal value	% change w.r.t. the initial equilibrium
Prices in BF/pkm			
Car peak	2.67	6.67	150.17%
Car off-peak	2.67	3.46	29.88%
Bus peak	3.46	4.22	22.02%
Bus off-peak	3.46	1.95	-43.55%
Marginal social costs in BF/pkm			
Car peak	11.19	6.67	-40.43%
Car off-peak	3.54	3.46	-2.13%
Bus peak	4.53	4.22	-6.80%
Bus off-peak	1.96	1.95	-0.45%
Traffic volume in mil passenger km/day			
Car peak	47.31	37.85	-19.99%
Car off-peak	48.70	43.15	-11.39%
Bus peak	1.54	3.09	100.22%
Bus off-peak	1.30	2.52	94.52%
Total	98.85	86.62	-12.37%
Budget deficit public transport	1.43×10^7	1.34×10^7	-6.29%

Source: De Borger et al. (1995)

The optimal prices for car transport are substantially higher than the initial prices. The peak car price increases by 150%, ie more than doubles, while the off-peak price is 30% higher than in the initial equilibrium. Note that also public transport in the peak period gets 22% more expensive. This is not the case for off-peak public transport whose price is reduced. The imposition of the optimal prices results in a decrease of car transport (by 20% in the peak and by 11% in the off-peak) and to an almost doubling of public transport use. The marginal social costs of both transport modes in the optimum are lower than those in the initial equilibrium. Because of the reduction in car use the marginal social cost of an additional car passenger km is reduced by 40%. The marginal external cost of public transport in the peak decreases by 7%. These results are important because of two reasons. First of all, the imposition of optimal prices substantially reduces the total external costs of transport, especially in the peak period when they are the most disturbing. Secondly, the exercise illustrates a simple but essential characteristic of optimal prices, namely that they reflect the marginal social costs corresponding with the optimal traffic levels. These can deviate substantially from the marginal social costs at existing traffic levels. Referring back to Figure 1 there is a clear difference between the distances X0 B and X1 C.

We note that the solution in the base case scenario is not very sensitive to changes in the parameter values. An extensive sensitivity analysis (see De Borger et al. 1994) concluded that the optimal prices are quite robust. Only the own price elasticity of peak car transport influences the optimal price results strongly. The more price elastic car transport is, the lower are the optimal prices. The optimal traffic volumes on the contrary are very sensitive to the price elasticities, which makes infrastructure planning more difficult.

OPTIMAL TRANSPORT PRICES WITHOUT DIFFERENTIATION BETWEEN PEAK AND OFF PEAK CAR PRICES

A second exercise starts from the fact that because of technical or political reasons it may be difficult or even impossible to differentiate car prices according to the timing of the trip. This depends on the instruments which are deemed acceptable by the policy makers. Eg when prices are manipulated only through fuel taxes, a discrimination according to time period is impossible. If on the contrary, one can use instruments which do allow for a price discrimination according to time period (parking charges, etc.), then pricing at marginal social costs in each period is a potential solution. To study the impact of the impossibility of price discrimination, the optimal prices are calculated under the additional restriction of equal car prices in the peak and off-peak period.

Table 3 The optimum when no price discrimination is possible for peak and off-peak car transport: a comparison with the basic optimum

	Basic optimum	Optimum under the constraint car price peak = car price off-peak	
		Equilibrium value	% change w.r.t. the basic optimum
Prices in BF/pkm			
Car peak	6.67	4.64	-30.39%
Car off-peak	3.46	4.64	34.19%
Bus peak	4.22	1.18	-72.06%
Bus off-peak	1.95	1.87	-3.90%
Marginal social costs in BF/pkm			
Car peak	6.67	7.68	15.13%
Car off-peak	3.46	3.41	-1.59%
Bus peak	4.22	4.29	1.68%
Bus off-peak	1.95	1.95	-0.15%
Traffic volume in mil passenger km/day			
Car peak	37.85	40.84	7.90%
Car off-peak	43.15	35.64	-17.40%
Bus peak	3.09	3.39	9.71%
Bus off-peak	2.52	8.94	254.76%
Total	86.62	88.81	2.53%
Budget deficit public transport	1.34×10^7	1.98×10^7	47.76%

The results are summarized in Table 3 which also makes a comparison with the basic optimum. The prices for car traffic are a weighted average of the marginal social costs in the peak and off-peak. The prices are closer to the marginal social costs in the off-peak because off-peak car traffic is much more price elastic than peak car traffic. The distortion between the peak car price and the marginal social cost is corrected by a subsidy for peak public transport: its price is lower than the marginal social cost. The volume of off-peak car transport is reduced. The increase in peak car traffic is limited because of the low price for peak public transport. Of course this necessitates an expansion of the public transport supply. The public transport deficit increases by approximately 50%.

A MAXIMUM PRICE FOR PUBLIC TRANSPORT

As is clear from Table 2 the optimal price of public transport in the peak period is higher than the price in the initial equilibrium. Because of political reasons it may be unacceptable to raise the price of public transport above the current level. Therefore we have studied how the equilibrium changes when we introduce the restriction that public transport cannot be more expensive than in the initial equilibrium. The results are presented in Table 4 and correspond with our intuition. Since the maximum price of public transport is 3.46BF, the equilibrium price in the peak is lower than in the basic optimum and lower than the marginal social costs. In order not to favour public transport too much with respect to its two most important substitutes (peak car and off-peak public transport) the price of these two modes will also be lower than the marginal social costs. Since the traffic flows do not differ strongly from the basic optimum (except for peak public transport), the marginal social costs are only slightly higher than in the basic optimum. The public transport deficit increases by 18%.

Table 4 The optimum under the constraint that the price of public transport cannot exceed the price of the initial equilibrium: a comparison with the basic optimum

	Basic optimum	Optimum under the constraint that the price of public transport cannot exceed the price of the initial equilibrium	
		Equilibrium value	% change w.r.t. the basic optimum
Prices in BF/pkm			
Car peak	6.67	6.53	-2.17%
Car off-peak	3.46	3.45	-0.35%
Bus peak	4.22	3.46	-18.01%
Bus off-peak	1.95	1.91	-1.85%
Marginal social costs in BF/pkm			
Car peak	6.67	6.68	0.19%
Car off-peak	3.46	3.46	0.06%
Bus peak	4.22	4.22	0.07%
Bus off-peak	1.95	1.95	0.15%
Traffic volume in mil passenger km/day			
Car peak	37.85	37.86	0.02%
Car off-peak	43.15	43.19	0.09%
Bus peak	3.09	3.26	5.50%
Bus off-peak	2.52	2.54	0.79%
Total	86.62	86.85	0.27%
Budget deficit public transport	1.34×10^7	1.58×10^7	17.91%

OPTIMAL PRICES UNDER A BUDGET RESTRICTION FOR PUBLIC TRANSPORT

Up to now we have assumed that there is no budget restriction for public transport. With increasing returns to scale this gives rise to a deficit, as has become clear from the previous tables. In the cost function of public transport the model takes into account an important fixed cost which is responsible for approximately 60% of total costs in the initial equilibrium. This implies that there is a deficit for the public transport sector when price is set equal to marginal social cost. In the next simulation we determine the optimal price under the restriction that public transport revenue must allow to reduce the initial deficit by 50%. From Table 5 it becomes clear that the prices of all transport modes increase. Public transport prices rise substantially, especially in the peak period (an increase by 50%). This can be explained by the lower price elasticity of peak relative to off-peak demand, which is important when one wants to raise revenues at the lowest possible welfare cost. The increase of public transport prices in the off-peak is less pronounced (15%). But car transport also becomes more expensive. There are two reasons for this. The higher prices of public transport cause a change in modal choice in favour of car transport. The resulting increase in congestion and environmental problems means that external costs are higher. Secondly, car price is higher than the marginal social cost in order to reduce the price distortions in the public transport market. Peak car prices increase by 5%. In both periods and for both modes the prices are higher than the marginal social costs. Note that the budget restriction slightly reduces the total transport volume with respect to the basic optimum. This is mainly due to lower public transport use. The introduction of the budgetary restriction has only a minor impact on social costs.

Table 5 The optimum under a budget restriction for public transport: a comparison with the basic optimum

	Basic optimum	Optimum under a budget constraint for public transport[a]	
		Equilibrium value	% change w.r.t. the basic optimum
Prices in BF/pkm			
Car peak	6.67	7.04	5.55%
Car off-peak	3.46	3.51	1.42%
Bus peak	4.22	6.33	50.07%
Bus off-peak	1.95	2.24	14.82%
Marginal social costs in BF/pkm			
Car peak	6.67	6.61	-0.87%
Car off-peak	3.46	3.46	-0.09%
Bus peak	4.22	4.22	-0.05%
Bus off-peak	1.95	1.95	0.2%
Traffic volume in mil passenger km/day			
Car peak	37.85	37.74	-0.29%
Car off-peak	43.15	43.03	-0.28%
Bus peak	3.09	2.80	-9.39%
Bus off-peak	2.52	2.29	-9.13%
Total	86.62	85.86	-0.88%
Budget deficit public transport	1.34×10^7	7.14×10^6	-46.72%

[a] The deficit of the public transport cannot exceed 50% of the deficit in the initial equilibrium

OPTIMAL PRICES WITH A CONSTANT SUPPLY OF PUBLIC TRANSPORT IN THE OFF-PEAK PERIOD

The last simulation assumes that the supply of public transport in the off-peak period (measured in vehicle km) is held constant at the level of the initial equilibrium and is not adjusted to the number of passenger km as was assumed in the previous exercises. Indeed, it has been argued (Mohring 1972; Turvey and Mohring, 1975) that this assumption is unrealistic because an additional passenger can be transported at a very low marginal social cost in the off-peak period (because of the low occupation rates and the presence of sufficient capacity). He does not cause capacity costs, congestion, environmental or accident costs. However, when boarding or alighting he delays the other passengers. Contrary to the previous exercises the latter costs are included in the analysis. It is assumed that the average boarding and alighting cost of an additional passenger is 3.6 seconds. On the basis of the results of Hague Consulting Group (1990) for the valuation of time saving for public transport users, we get a marginal boarding and alighting cost equal to 0.031BF times the average number of copassengers. For peak public transport there is, as before, a fixed relationship between the supply of vehicle km and the number of passenger km demanded. But the marginal social costs now also include the boarding and alighting costs, so they are somewhat higher than before.

Table 6 A constant supply of public transport in the off-peak period: a comparison with the basic optimum

	Basic optimum	Model with a constant supply of public transport in the off-peak period	
		Equilibrium value	% change w.r.t. the basic optimum
Prices in BF/pkm			
Car peak	6.67	6.71	0.66%
Car off-peak	3.46	3.46	0.00%
Bus peak	4.22	5.78	36.85%
Bus off-peak	1.95	1.89	-3.28%
Marginal social costs in BF/pkm			
Car peak	6.67	6.71	0.66%
Car off-peak	3.46	3.46	0.00%
Bus peak	4.22	5.78	36.85%
Bus off-peak	1.95	1.89	-3.28%
Traffic volume in mil passenger km/day			
Car peak	37.85	38.10	0.66%
Car off-peak	43.15	43.14	0.00%
Bus peak	3.09	2.77	-10.35%
Bus off-peak	2.52	2.63	4.36%
Total	86.62	86.64	0.00%
Budget deficit public transport	1.34×10^7	9.36×10^6	-30.15%

The results are summarized in Table 6. Since there are no pricing restrictions, all prices equal marginal social costs. The price of off-peak public transport is 3% lower than in the basic optimum. In the peak period the price of public transport is 37% higher, which results in a lower demand. There is a shift from public to private transport. However, total transport volume remains more or less constant. Because of the lower supply of public transport the deficit decreases by 30%.

CONCLUSION

The development and application of a simple transport pricing model has made clear that there is still a long way to go before we have a fully realistic pricing model for urban transport. The model does not yet consider freight transport, it does not incorporate an explicit network structure and the different price components (purchase price, fuel price, insurance, maintenance costs, parking charges, road pricing, ...) are not made explicit. Moreover, the distributional impacts could not be analysed because of the use of aggregate data. Despite these shortcomings the model and its application have lead to useful insights in the complexity of the optimal pricing policy for urban transport. First of all, it shows how external effects can be incorporated in standard optimal pricing models. It illustrates under which conditions it is optimal to charge a price equal to marginal social costs. Moreover, it shows that these social costs should be evaluated at the optimal and not at the existing traffic flows. Secondly, the model allows to incorporate budgetary restrictions and restrictions on the policy instruments and illustrates how this results in deviations of optimal prices from marginal social costs. The model can also analyse the impact of different policy measures on the public transport budgetary deficit.

The results of the simulations suggest that taking into account the social costs of transport implies a drastic increase in the price of car traffic, especially (but not exclusively) in the peak period. This would lead to a reduction of the global transport volume and the marginal external costs of transport would decrease substantially. Although budgetary or other restrictions on pricing influence the optimal prices strongly, the increase in the price of peak car transport is a recurring conclusion of all simulations.

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REFERENCES

Boniver, V. (1993) Les coûts marginaux externes du transport public en milieu urbain, Estimation chiffrées pour la Belgique. Mimeo, CIRIEC, Liège.

De Borger, B., I. Mayeres, S. Proost and S. Wouters (1995) Optimal Pricing of Urban Passenger Transport: A Simulation Exercise for Belgium. *Journal of Transport Economics and Policy*, forthcoming.

De Borger, B., I. Mayeres, S. Proost and S. Wouters (1994) *Social Cost Pricing of Urban Passenger Transport: With an Illustration for Belgium.* SESO-Paper 94/301, SESO, Antwerpen and CES Public Economics Research Paper 34, C.E.S., Leuven.

Glaister, S. and D. Lewis (1978) An Integrated Fares Policy for Transport in London. *Journal of Public Economics*, 9, 341-355.

Hague Consulting Group (1990) *The Netherlands' 'Value of Time' Study: Final Report.* HCG, Den Haag.

Mayeres, I. and S. Proost (1995) *Optimal Tax and Investment Rules for Congestion Type of Externalities.* CES Public Economics Research Paper, C.E.S., Leuven.

Mayeres, I. (1993) The Marginal External Costs of Car Use - With an Application to Belgium. *Tijdschrift voor Economie en Management*, 38, 225-258.

Mohring, H. (1972) Optimization and Scale Economies in Urban Bus Transportation. *American Economic Review*, 62, 591-604.

Small, K. (1983) The Incidence of Congestion Tolls on Urban Highways. *Journal of Urban Economics*, 13, 90-111.

Turvey, R. and H. Mohring (1975) Optimal Bus Fares. *Journal of Transport Economics and Policy*, 9, 280-286.

Viton, P.A. (1983) Pareto-Optimal Urban Transportation Equilibria. In: *Research in Transportation Economics* (T.E. Keeler, ed.),Vol. I, 75-101. Greenwich.