Public transport subsidies versus road pricing:

An empirical analysis for interregional transport in Belgium

Bruno DE BORGER and Didier SWYSEN[1]

University of Antwerp
UFSIA

ABSTRACT

The purpose of this paper is to investigate when subsidies for public transport are justified. We first theoretically identify the key parameters in determining the desirability of public transport subsidies. We then use a detailed numerical optimisation model, calibrated with data on interregional transport in Belgium in 2005, to empirically determine second-best level and structure of public transport fares under a number of assumptions. We compare them to the reference situation, and to the first-best solution where each transport mode is priced at marginal social costs. The results show that subsidies for public transport turn out to be optimal in most second-best situations. Moreover, free bus service turned out to be optimal in the peak period if car prices for some reason cannot be manipulated, and if a fair amount of substitution between bus and car use exists.

---

[1] Department of Economics (AEC), University of Antwerp (UFSIA), Prinsstraat 13, B2000 Antwerpen, Belgium.
Author for correspondence: B. De Borger, tel: +32 3 220 40 57; fax: +32 3 220 40 26; e-mail: bruno.deborger@ufsia.ac.be

0. Introduction

To cope with the increasing social damage associated with transport activities, policy makers have suggested the use of both pricing policies (e.g., fuel taxes, public transport subsidies, road pricing, parking fees) and regulatory instruments (emission norms, speed limits, traffic regulations, etc.)[2]. Without denying the importance of other policies, the main focus of this paper is on public transport subsidies as a means to alleviate externality costs in the transport sector. Although many economists argue that there exist more efficient ways to internalise (especially congestion) externalities, public transport subsidies are often considered a useful component of second-best policy packages in case more sophisticated pricing instruments such as road pricing are either not feasible or politically unacceptable (see, e.g., Button (1993)). The argument in favour of public transport subsidies is that lower public fares will encourage a shift from private vehicles to public transport modes, thereby alleviating the social costs associated with congestion, air pollution and accident risks. Apart from this efficiency argument, subsidies have under some conditions also been justified on distributional grounds (see, e.g., Bös (1986) and Dodgson an Topham (1987))[3].

Of course, there is a large literature dealing with the theoretical principles underlying second-best public transport fares as well as with the costs and benefits of public transport subsidies. For example, Glaister and Lewis (1978) developed a model incorporating three modes (rail, bus and car) and two periods (peak and off-peak), and determined welfare-optimal prices for rail and bus transport, conditional on given private transport prices. They emphasised the role of the social costs of the private and public transport modes together with both the own price and cross price elasticities for the optimal pricing structure. More recently, Glaister (1984) analysed the costs and benefits of different subsidy levels, assuming that the subsidies were used to either finance fare reductions or increases in service levels. Building upon Turvey and Mohring (1975), Jansson (1979), Else (1985) and Jansson (1993) studied optimal prices of scheduled transport services, incorporating optimal adjustment of frequencies. Finally, Dodgson and Topham (1987) incorporated distributional arguments in their rigorous analysis of the conditions under which public transport subsidies can be justified in a welfare-theoretic framework; moreover, they stressed the importance of the shadow cost of public funds.

Although the above studies have carefully identified the key parameters (elasticities, external costs, shadow cost of public funds, etc.) upon which both optimal public transport fares and the economic justification of public transport subsidies depend, they provide -- with the exception of Glaister and Lewis (1978) -- little empirical evidence on a number of important issues. For example, what does the second-best level and structure of public transport fares look like? Under what conditions are public transport subsidies welfare-improving? Can free public transport be justified

---

[2] A good overview of relevant measures is provided in, e.g., Button (1993).

[3] An extreme form of subsidies is simply to provide public transport at a zero fare. In Belgium, e.g., as of July 1,1997 the city of Hasselt grants free bus transport to the local population. Moreover, the president of the Flemish public transport firm 'De Lijn' also recently proposed to provide free public transport.

from a welfare viewpoint? What are the welfare implications of optimal public transport fares relative to those of a detailed system of road pricing that allows private as well as public transport prices to be optimally differentiated according to peak and off-peak traffic levels? How does the shadow cost of public funds affect the results?

The purpose of this paper is to empirically investigate these questions using data on Belgian interregional traffic. Although some of the relevant questions have been analysed before, the model we use is richer than previous empirical models in at least two respects. First, we use a detailed numerical optimisation model (described in detail in De Borger et al. (1997)) that disaggregates transport services according to transport mode, that distinguishes peak and off-peak travel, that takes account of both passenger and freight traffic, and that allows different car types and fuel types as well as the possibility of introducing new vehicle technologies. Second, the model incorporates all major external costs associated with the various transport services, including congestion, pollution, and accident risks.

A limitation that this paper shares with most previous applied studies is that we ignore distributional issues. We do so for several reasons. First, the model we use contains a very detailed transport sector but is highly aggregated as far as other sectors of the economy are concerned. Since our primary purpose was to analyse transport policies in view of the social costs of congestion, accidents and air pollution, we opted for a detailed transport sector at the expense of less detail elsewhere. As a consequence the model is not very well suited to derive firm statements about the distributional implications of alternative policies. Second, a recent study based on a general equilibrium model for Belgium with a much more aggregated transport sector but including a labour market and a number of other consumption goods concluded that better and politically acceptable distributive instruments exist than subsidies to the public transport industry (Mayeres and Proost (1997)).

The structure of this paper is as follows. To set the stage, we review in a first section a few crucial determinants of the potential desirability of public transport subsidies, using the simplest possible theoretical framework. In Section 2 we briefly describe the detailed simulation model that was designed to compute optimal transport prices under a variety of circumstances. The model was calibrated using data on interregional transport in Belgium. In the third section, we apply the model and compare the effects of various pricing scenarios. As a point of reference we first present the full optimal pricing scenario in which it is assumed that all transport services can be priced at their corresponding social costs; this presupposes the availability of instruments such as road pricing that allow differentiation of private transport prices according to peak and off-peak traffic. Next we analyse a number of second-best public transport policies, and compare the welfare implications with both the reference scenario and the full optimum. These exercises provide evidence on the level and structure of optimal public transport prices depending on the constraints policy makers face. Moreover, they also indicate under what conditions second-best prices involve subsidies, and under what conditions (if any) free public transport can be considered a valid second-best policy. The analysis is performed for a variety of substitution elasticities between private and public transport, and the role of the shadow cost of public funds is explicitly investigated. Section 4 concludes.

1. When are public transport subsidies justified ? A simple theoretical analysis

The only purpose of the simple theoretical model presented in this section is to highlight some essential parameters that determine whether or not subsidies for public transport are justified. As the model serves a purely illustrative purpose, we do not claim neither generality nor originality. A more general (but because of its complexity somewhat less intuitive) treatment is given in Dodgson and Topham (1987).

Suppose for simplicity that there are only two modes, the private car and a publicly operated bus system. Both private and public transport generate external costs; all marginal external costs are assumed to be constant per kilometre. Since no distributional concerns are taken into account, we assume the existence of a representative consumer. We use the following notation ($i \in \{a,b\}$, with a = car and b = bus)

X_i	number of passenger-km travelled using mode i
P_i	unit price of X_i
C_i	the marginal cost (assumed constant) of producing X_i
E_i	the marginal external cost (assumed constant) of mode i
V(.)	the indirect utility function of the representative consumer

Suppose a public authority is responsible for public transport policy, and that the only instrument it has available is the price P_b. Then the authority's planning problem can be formulated as

$$\underset{P_b}{Max}\ W = \frac{1}{\mu_0} V(P_{a,}P_b, R) - (E_a X_a + E_b X_b) + (1+\lambda)\left[(P_a - C_a) X_a + (P_b - C_b) X_b\right]$$

where $X_i = X_i\ (P_a\ ,P_b\ ,R)$ is the demand function for mode i, and R is the representative consumers' income. The first term of the objective function is a money-metric indicator of the consumer's indirect utility. It is obtained by normalising indirect utility by μ_0 , the marginal utility of income in an arbitrary reference situation. The second term captures total external costs. Finally, the third term represents the social value of the tax income generated by the transport sector. It is given by multiplying tax income by one plus λ, the shadow cost of public funds[4].

[4] The shadow cost of public funds is, by definition, the welfare loss associated with the collection of 1 ECU of tax revenue. In partial equilibrium models, a shadow cost of public funds equal to one means that the planner is indifferent between one ECU of government revenue and 1 ECU of consumer surplus. Compared to the traditional sectoral budget constraints imposed on the transport sector, the use of a value larger than one is a more appropriate way of taking into account the financial constraint of the government.

The first order condition of this problem gives

$$\frac{\delta W}{\delta P_b} = \frac{1}{\mu_0}\frac{\delta V}{\delta P_b} - E_a\frac{\delta X_a}{\delta P_b} - E_b\frac{\delta X_b}{\delta P_b} + (1+\lambda)\left[(\mathrm{P}_a - C_a)\frac{\delta X_a}{\delta P_b} + X_b - (P_b - C_b)\frac{\delta X_b}{\delta P_b}\right] = 0$$

Using Roy's identity and rearranging terms, this expression can be manipulated to yield[5,6]

$$\frac{P_b - C_b - \dfrac{E_b}{1+\lambda}}{P_b} = \frac{1}{\left|\varepsilon_{b,b}\right|}\left[\frac{\lambda}{1+\lambda} + \left(\frac{P_a - C_a - \dfrac{E_a}{1+\lambda}}{P_a}\right)\varepsilon_{a,b}\frac{P_a X_a}{P_b X_b}\right]$$

where $\varepsilon_{i,j}$ is the elasticity of X_i with respect to P_j.

This expression nicely summarises some crucial parameters determining the optimal public transport price. It indicates that the mark-up over private marginal cost plus a fraction of marginal external cost is inversely proportional to the own price elasticity of public transport demand; the proportionality factor depends on the shadow cost of public funds, on the mark-up for car traffic, and on the cross-price elasticity between private and public transport. This result is well-known (see e.g. Sandmo (1975), Bovenberg and van der Ploeg (1994), and Oum and Tretheway (1988)). It implies that the optimal public fare positively depends on the shadow cost of public funds, on the marginal external cost of public transport, and on the cross-price elasticity between private and public transport. It is negatively affected by the own price elasticity of public transport demand and by the marginal external cost of car traffic.

Notice two further implications of the optimal pricing rule. First, if the cross-price elasticity is zero, then the higher λ, the closer the optimal price will be to monopoly pricing. Second, social cost pricing for car transport does not imply social cost pricing for public transport. Simple algebra shows that setting car price equal to marginal social cost ($P_a=C_a+E_a$) implies

$$\frac{P_b - C_b - E_b}{P_b} = \frac{\lambda}{1+\lambda}\left[-E_b + \frac{1}{\left|\varepsilon_{b,b}\right|} + E_a\varepsilon_{a,b}\frac{P_a X_a}{P_b X_b}\right]$$

In other words, the optimal public transport price deviates from its marginal social cost as long as the shadow cost of funds is nonzero. Public fares may be above or below marginal social cost depending on the relative magnitude of the external costs of public and private transport, and on the own and cross price elasticities of demand. The absolute value of the deviation positively depends on the cost of public funds itself.

---

5 Assuming that the approximation of the marginal utility of income is perfect, i.e. $\delta V/\delta R=\mu_0$

6 When car price is a decision variable as well, a similar expression is obtained for private transport. Combining these two expressions yield marginal social cost pricing for both modes (assuming λ is zero).

The same parameters identified above obviously also determine under what conditions subsidies to public transport (defined as a price P_b beneath the marginal production cost C_b) are justified. Slightly rewriting the above equation shows that subsidies can be optimal if and only if

$$P_a - C_a < \frac{E_a}{1+\lambda} - \frac{E_b}{1+\lambda}\frac{\left|\varepsilon_{b,b}\right|}{\varepsilon_{a,b}}\frac{X_b}{X_a} - \frac{\lambda}{1+\lambda}\frac{P_b X_b}{P_a X_a}\frac{1}{\varepsilon_{a,b}}$$

For a given tax on car transport (P_a - C_a) the likelihood that public subsidies are justified positively correlates with the marginal external cost of car traffic, with the relative importance of car transport, and with the cross price elasticity of private car demand with respect to the price of public transport. If private transport is taxed way below social cost then a reasonable second-best policy is to subsidise public transport, especially if the reduction in car traffic the subsidies induce is large. On the other hand, the optimality of subsidies is less likely the higher the marginal external costs generated by public transport itself, the higher the marginal cost of public funds, and the larger the price elasticity of public transport demand. Indeed, a highly elastic public transport demand implies that subsidies generate a large distortion on the public transport market itself.

Note that if we assume that λ=0 (i.e., the case of lump-sum taxes being available), then optimal public transport pricing is described by the expression

$$\frac{P_b - C_b - E_b}{P_b} = \frac{\varepsilon_{a,b}}{\left|\varepsilon_{b,b}\right|}\left(\frac{P_a - C_a - E_a}{P_a}\right)\frac{P_a X_a}{P_b X_b}$$

In this case it is clear that if car transport is priced at its social cost then social cost pricing must also apply for bus transport. The same holds if the cross-price elasticity is zero. Indeed, in that case deviation from social cost pricing of public transport have no effect whatsoever on private car traffic. Finally, it follows in this case that subsidies for public transport are optimal if

$$P_a - C_a < E_a - E_b\frac{\left|\varepsilon_{b,b}\right|}{\varepsilon_{a,b}}\frac{X_b}{X_a}$$

This illustrates the intuitive result that subsidies for public transport can only be justified when private transport does not fully cover its social costs.

2. The numerical optimisation model

In this section we briefly describe the optimisation model used to calculate optimal public transport fares under a variety of different assumptions on the basis of detailed information for interregional traffic in Belgium. In order to capture the heterogeneous nature of transport markets, the empirical model is much richer than the theoretical structure described in the previous section. We use the interregional version of the Trenen-model described in detail in De Borger et al. (1997)[7]. It distinguishes passenger and freight transport, it considers various modes (car, bus and railroad for passenger traffic; truck, inland waterways an rail for freight flows), it captures both peak and off-peak traffic, and it allows different car and fuel types. Moreover, it can handle the introduction of new engine technologies. An overview of the structure of the model is given in Figure 1. As a detailed description of the model can be consulted elsewhere (De Borger et al. (1997)), we restrict the presentation to a general intuitive overview.

On the demand side, passenger transport is treated as a final good that is further disaggregated through the use of a nested CES indirect utility function for the representative consumer (see, e.g., Keller (1976)). Freight transport is considered to be a derived demand; it is treated as an input into the production of an aggregate consumption good. The demand for freight is further disaggregated by assuming a nested CES cost function for the production of this aggregate good. The nested CES structure allows the analysis of the consumer's choices and the producer's input choices in a series of consecutive steps; at each step aggregate price and quantity indices can be constructed based on the prices and quantities of the goods at the next (lower) step in the decision process. Note that all prices are to be interpreted as 'generalised' prices, incorporating the value of time spent in traffic (see below).

The overall structure of the household's preferences is represented in Figure 2. At the highest level of the tree structure he is assumed to trade off transport versus other goods based on an aggregate price index for transport and other goods. The transport aggregate is then further disaggregated by allowing the consumer to choose between alternative modes, between peak and off-peak travel, between two different types of cars (small or large), and between different types of fuel (gasoline and diesel) on the basis of their subjective preferences and on the basis of the relative prices and speeds of the different transport alternatives available. A similar idea holds for the demand for freight services. Cost minimising producers first decide on the overall demand for freight transport. Demand is then disaggregated towards different modes and periods.

The supply side of the model is kept very simple. Assuming perfect competition supply will be delivered at marginal resource costs plus producer taxes. In the absence of producer taxes, producer prices will therefore simply equal the marginal resource cost.

[7] Apart from a general description of the model structure of both the urban and the interregional versions of the model, De Borger et al (1997) contains a number of other applications of the model as well.

In the equilibrium module 'generalised' equilibrium prices are computed for the different types of transport services. The generalised price is the sum of three elements:

a) a producer price for the different types of vehicle kilometres - this price is determined by the supply module;

b) a time cost equal to the average congestion cost; the latter is a function of the total traffic volume;

c) a tax (or subsidy) that has two policy functions: to raise tax revenue and to correct for the external costs of transport. This tax will obviously be differentiated for the different types of transport goods. The magnitude of the taxes[8] will strongly depend on the level of the marginal externality costs and on the shadow cost of public funds.

The operation of the model runs in two steps. First an initial reference situation is constructed. This is selected so as to be representative of the expected traffic situation in Belgium for 2005 under the assumption of unchanged transport pricing and regulatory policies. Interpreting this situation as a market equilibrium and making reasonable assumptions about demand elasticities allows us to calibrate all remaining model parameters. Once the parameters are determined the model can be used in a second step to calculate welfare-optimal pricing and regulatory policies by maximising a welfare function under various constraints on the availability of price and regulatory instruments. The objective function being maximised is the following

$$W = \frac{1}{\mu_0} V + \lambda T - E$$

It consists of three terms. The first one measures the representative consumer's indirect utility V normalised by μ_0 , the marginal utility of income in the reference situation, so as to reflect consumer welfare in terms of real income. Congestion is directly captured in utility via the generalised prices of the various transport services. Moreover, it is assumed that tax revenues are lump-sum redistributed to the representative consumer. The second term evaluates the tax revenues T at the shadow cost of public funds λ. The intuition is the following: if lump-sum taxes are available, the model simply reimburses tax revenues directly to the consumer (i.e., tax payments are added to exogenous consumer income). In that case λ is zero and the second term drops out of the welfare evaluation. If the shadow cost of public funds is positive, however, tax revenues are worth more in welfare terms than their lump-sum value to consumers, because the extra revenues allow the government to reduce distortionary taxes elsewhere in the economy. This effect is measured by the second term. Finally, the third term captures the monetary value of all external costs other than congestion.

[8] Apart from taxes, the policy maker can also impose certain technology regulations under the form of ad hoc constraints on the supply part of the model: minimum energy efficiency requirements, emission abatement technologies etc. As the focus in this paper is on public transport subsidies, we do not discuss this aspect furthermore and refer to De Borger et al (1997) for more details.

The above description implies that different externalities are introduced in the model in different ways. Congestion is assumed to vary with the traffic level and is incorporated by defining demands in terms of generalised prices that incorporate the value of time spent in traffic. Congestion is therefore directly captured via the generalised prices in the indirect utility function. All other marginal external costs, including air pollution (CO, NOx, CO2, HC, PM10, and SO2), accidents and road depreciation, are assumed to be independent of traffic levels. They are evaluated in monetary terms and enter the objective function with a minus sign. For more details on the evaluation of external costs we refer to Mayeres, Ochelen, and Proost (1996).

Figure 1: Structure of the model

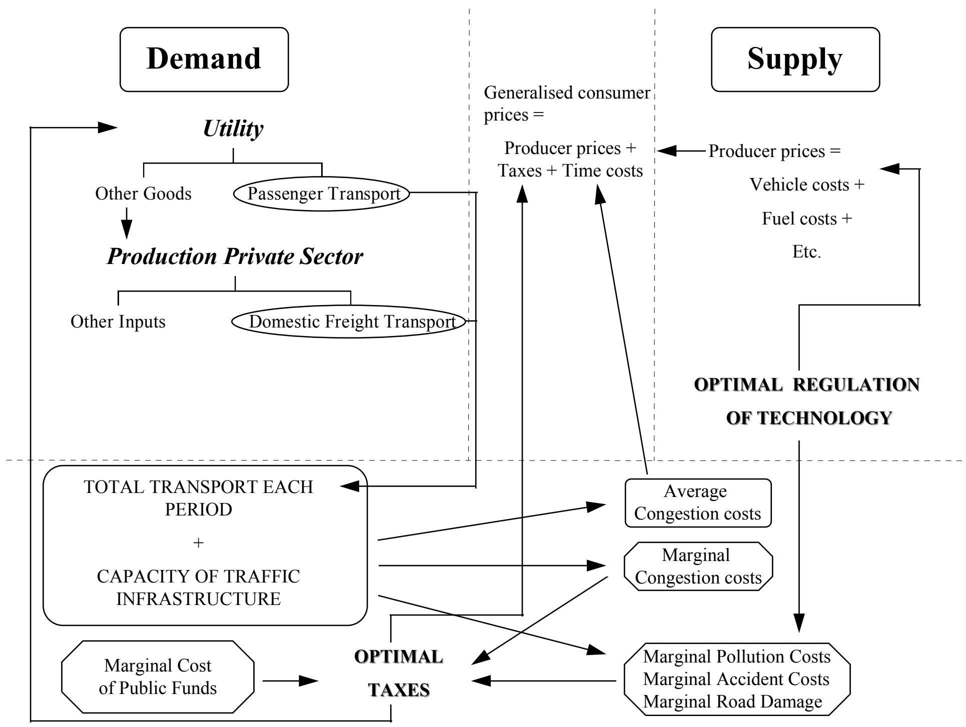
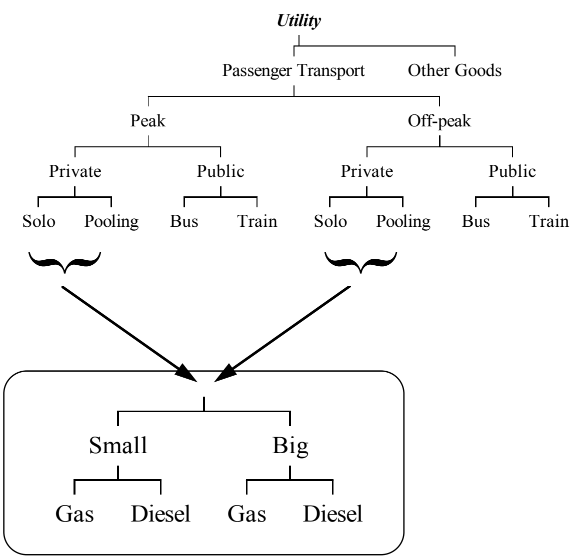


Figure 2: Multi-level decision structure for passenger transport



3. Optimal public transport pricing: empirical results

In this section we turn to empirical results for interregional transport in Belgium. We first describe two benchmarks cases with which the outcomes of second-best public transport pricing policies can be compared, viz. the calibrated reference situation for 2005 (subsection 3.1) and a full welfare optimum (subsection 3.2) in which it is assumed that there are no restrictions on the available pricing instruments. This implies that prices of the various public and private transport services can be optimally differentiated according to fuel type, period of the day (peak versus off-peak), etc. This requires new pricing technologies such as electronic road pricing. We then consider optimal second-best public transport fares for a variety of situations. First we assume that pricing instruments are limited to fuel taxes and public transport fares (subsection 3.3). Second, we look at the optimal public transport fares when car prices are kept at their reference level (subsection 3.4). Finally (subsection 3.5), we repeat the last exercise but with the additional constraint that public transport fares cannot discriminate between the peak and off-peak period of the day (which is the case in the reference situation).

As the theoretical part of the paper identified the shadow cost of public funds and the relevant price and cross-price elasticities as important determinants of the optimal public transport fare, we carried out a sensitivity analysis with respect to these two sets of parameters. However, the nested CES structure implies that it is much more convenient to analyse variations in elasticities by focusing on different values for the substitution elasticities between private and public transport. Although many other sensitivity analyses were performed, we report in this paper results for two different values for the shadow cost of public funds (λ=0 and λ=0.05) and four different values of the substitution elasticity between private and public transport (SE=0.8, 1.6, 2.4 and 4). In Appendix 1 more details are provided on the relation between price and substitution elasticities within the framework of the model.

3.1 The reference situation: Belgium 2005

The reference situation corresponds to the expected prices, transport flows and vehicle regulations in 2005 in Belgium, assuming unchanged policy. For clarity sake we provide all relevant numerical information on the reference situation in Appendix 2. More details concerning its construction (determination of prices, costs, etc.) be found in De Borger et al. (1997). We limit the discussion here to a few relevant observations.

3.1.1 Generalities

-For all transport markets considered, taxes are below the marginal external costs in the peak period. In the off-peak period, however, private transport prices more or less correspond to the social costs.

-Substantial subsidies exist for public transport, especially for rail. There is a small tax on bus use in the off-peak period.

-Public transport's market share is quite small. In 2005, it only accounts for 15% of the total number of passenger-km; passenger transport by bus represents less than 6% of total passenger traffic, the share of rail accounts for 9%.

-For the determination of standard vehicle technologies in 2005, we refer to recent EC regulations (directive 91/441/EEC). We are assuming that, by the year 2005, Belgium will have fully implemented these standards. This implies that in 2005 all gasoline cars are equipped with 3-way catalytic converters and that diesel can have improved engine technology (i.e. direct injection, turbo-supercharger, charge cooling and exhaust gas recirculation) and are equipped with an oxidation catalyst. Trucks and buses are also equipped with improved engines and improved tyres.

3.1.2 Prices, taxes, and marginal private costs

The tax (or subsidy) on any given transport service is defined as the difference between the price and the marginal resource cost. The price of one passenger-km by car was calculated to be 9.7 and 7.7 BEF for gasoline and diesel cars, implying respective unit taxes of 3.3 BEF and 2.2 BEF.

Public transport prices were computed using statistical information from the respective public transport firms. They amount to 1,254 and 1,972 BEF per passenger-km for bus and rail services, respectively. Note that there is no peak-off-peak price discrimination in the reference situation. Marginal resource costs of public transport in the off-peak period were approximated by the average variable cost. The latter consists of expenditures on labour, on energy (insofar as related to rolling stock operations), and on materials; it includes maintenance costs. The same components constitute costs in the peak period. However, in order to approximate long-run marginal cost, we allocated the marginal cost of rolling stock completely to this period. We finally used the relevant occupancy rates to approximate the marginal private cost per passenger-kilometres.

Importantly, note that the method used to approximate the marginal cost of public transport services implies that costs strongly differ between peak and off-peak period, but that there are no scale economies or diseconomies within a given period. Obviously, these are very strong assumptions that should, however, be interpreted in view of the aggregate nature of the numerical optimisation model, and taking into account the implicit assumption of passive adaptation of public transport supply. Although on individual lines Mohring-effects (Mohring (1972), Jansson (1979)) may yield very small marginal costs of extra passengers, this will not necessarily be the case at the network level where some lines incur high rates of capacity utilisation even in the off-peak period. Given the current highly concentrated spatial demand structure demand increases at the network level do have non-negligible effects on long-run operating costs. Of course, the calculation of costs implies that the empirical results should be viewed as nothing more than illustrations of the impact of restrictions on pricing instruments for optimal public transport prices. In other words, the comparison of different second-best policies is more important than the absolute price levels themselves.

Application of the above-described procedure yielded marginal private costs of 1.753 and 1.128 BEF/passenger-km for bus services in the peak and off-peak periods, respectively. For public rail transport, the marginal private costs amounted to 4.52 and 2.33 BEF/passenger-km for peak and off-peak, respectively. These figures imply subsidies in the peak period of 0.49 and 2.54 BEF/passenger-km for public transport by bus and by train, respectively. In the off-peak period, we find that there is a subsidy for rail transport (0.35 BEF/passenger-km) but a small tax for public bus services (0.12 BEF/passenger-km).

3.1.3 Marginal external costs

Table 1 summarises the marginal external costs per passenger-km in the reference situation. the dominant external cost for interregional transport in Belgium in 2005 is peak congestion. It amounts to nearly 30 BEF/passkm and accounts for more than 90% of the total marginal external costs of peak car traffic. Marginal external costs of (peak) congestion are about 15 times smaller for public transport by bus, and are zero for public transport by train. In the off-peak period, however, marginal external congestion costs are small. Marginal external accident costs are quite important: they amount to 1.6 BEF/passkm for car traffic, and are about 20 times smaller for public transport by bus. Maybe surprisingly, the calculated marginal external pollution costs are somewhat less important. The reason is that by 2005 standard technologies for cars will be far less pollutant than in the 1990's. Private cars' marginal external costs of pollution will be comparable to those of public transport and represent less than 1BEF per passenger km.

Table 1. Marginal External Costs in the Reference Situation (BEF/passenger-kilometre)

	Congestion	Accidents	Air pollution	TOTAL
Peak gasoline car	27.942	1.616	0.282	29.840
Peak diesel car	27.942	1.616	0.631	30.189
Peak bus	1.815	0.072	0.330	2.217
Peak train	0.000	0.000	0.226	0.226
Offp gasoline car	0.275	1.616	0.318	2.209
Offp diesel car	0.275	1.616	0.668	2.559
Offp bus	0.030	0.086	0.560	0.676
Offp train	0.000	0.000	0.452	0.452

3.2 Optimal Pricing

In this subsection, we turn to the results of the first optimisation exercise. We report a 'full optimum' obtained under the assumption that perfect pricing instruments are available. This includes, among others, the possibility to tax car traffic and public transport differently according to the period of the day (peak versus off-peak). The optimal prices are presented in Table 2. Complete results (including the impact on external costs, traffic volumes, and summary information on the welfare implications) are given in Appendix 3.

Table 2. Full optimal prices

			lambda=0				lambda=0.05			
		reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	gas. car	9.68	17.58	17.49	17.38	17.16	19.10	19.01	18.93	18.75
	diesel car	7.68	16.71	16.62	16.51	16.29	18.12	18.04	17.96	17.78
	bus	1.25	2.76	2.75	2.75	2.73	3.54	3.53	3.52	3.50
	train	1.97	4.75	4.75	4.75	4.75	5.70	5.70	5.70	5.70
offpeak	gas. car	9.75	8.85	8.86	8.86	8.86	10.13	10.14	10.14	10.14
	diesel car	7.73	8.12	8.12	8.12	8.13	9.29	9.30	9.30	9.30
	bus	1.25	1.85	1.85	1.85	1.85	2.39	2.39	2.39	2.39
	train	1.97	2.78	2.78	2.78	2.78	3.49	3.49	3.49	3.49

First consider the case where the shadow cost of public funds is zero. It then follows that marginal social cost pricing is optimal for all transport modes (including freight transport). Consequently, private transport prices[9] sharply rise in the peak (increase of some 80% and 116% for gasoline and diesel cars, respectively. In the off-peak period, there is a small price increase (+5%) for diesel cars, but a price decrease for gasoline cars (-9%). This is explained by the fact that for gasoline (off-peak) car users the tax in the reference situation already exceeded the relevant marginal external cost.

Compared to the reference situation, at the optimum the existing subsidies for public transport are replaced by small taxes equal to their respective marginal external costs. This entails sharp increases for public transport prices (+121% and + 48% for bus users during the peak and off-peak period respectively; +141% and 41% for transport by train). Public transport modes, however, do remain cheaper than car travel.

As can be seen in Table 2, when all prices can be optimally adjusted they hardly depend on the substitution elasticity (SE) that is being used. This is not suprising: in the full optimum, all taxes have to be equal to the marginal external costs, whatever the elasticities that are used. Now note that in our applications, the marginal external costs of pollution and accidents were assumed to be constant. Only marginal external congestion costs depend on traffic levels. In the absence of congestion it is clear that the optimal taxes would equal the (constant) mec, and the elasticities would not matter for the determination of taxes as long as the shadow cost of public funds equals zero. As a consequence, in the off-peak period when congestion is limited taxes are nearly independent of the relevant elasticities. In the peak period, however, we do

[9] As the emphasis in this paper is on public transport prices, we only present the results for an average gasoline car and an average diesel car, in both the peak and the off-peak period. However, the simulation model is more disaggregated as it includes different sizes (big, small) and occupancy rates for cars. Complete results are available from the authors.

notice small differences in the optimal taxes depending on the substitution elasticity that is being used.

The full results reported in Appendix 3 indicate that the optimal prices induce large shifts in traffic volumes. Moreover, volumes are much more sensitive to variations in substitution elasticities than the optimal prices and taxes. For a low substitution elasticity we find that total passenger transport demand would decline by some 4.4%. Car transport would decrease by 16% in the peak period but increase by 7.6% during the off-peak period. Public transport demand decreases by 6.9% in the peak and by 5% during the off-peak period. These aggregate figures hide an important difference between bus and rail, however. Indeed, bus demand rises by some 33% whereas the use of rail services declines substantially (-33%). This is explained by the higher price increase for transport by train than by bus, and by the decrease in peak congestion that benefits bus travellers.

For the highest substitution elasticity between private and public transport, total traffic demand decreases by 3.4%, mainly due to private car use. Indeed, the demand for private transport decreases by 18% during the peak and increases by some 10% during the off-peak period. Again, the reactions of the two public modes are very different. Although the overall demand for public transport rises by 48.8% in the peak this is largely due to an enormous increase in transport by bus (+115%); rail transport only marginally rises (+6%). Note that public transport demand declines in the off-peak period.

The overall welfare gain of this optimal pricing scenario amounts to some 81 to 84.3 billion BEF/year (see Appendix 3). First, consumer utility rises substantially. The negative effect of higher prices is more than compensated by the decrease in congestion and by the positive effect engendered by the sharp increase in tax income[10]. Second, the increase in tax revenues is indeed substantial. Tax income would rise by some 129% (low substitution) to 120% (high substitution) for passenger transport, and by some 274% for freight transport[11]. This increase in tax revenues corresponds to 270 to 250 billion BEF/year or 26000 to 24500 BEF/year per inhabitant. Third, note that all external costs would sharply decrease. Air pollution caused by passenger and freight transport would decrease by 6.5% and 10.5%, respectively, yielding a welfare gain of approximately 5.3 billion BEF/year. Accidents costs would decrease by some 5% (6 billion BEF/year).

As a final observation, note that when the shadow cost of public funds is positive, optimal taxes do no longer correspond to marginal external costs. This is explained by the fact that one now gives an explicit weight to tax revenues in the objective function. In general, the tax rate will be higher for those transport modes for which the own-price elasticity is smaller; moreover, marginal external costs become somewhat less important in the determination of the optimal taxes[12]. As a

---

[10] Remember that the tax revenue is redistributed to the (representative) consumer.

[11] In the full optimum, freight transport prices sharply rise (+105% and +25% for peak and off-peak road transport respectively; +19% for rail and +20% for waterways), leading to a decrease in traffic flows (-11% for road transport, -7% for rail and -4% for waterways).

[12] Technically, the mark-up is not over social marginal cost but over private marginal cost plus a fraction of externality costs. It can be explained as follows: "Marginal social cost pricing gives a signal to consumers to recognise externalities and reduce their demand. When price are marked up over

consequence of higher transport prices, traffic volumes decrease more than in the previous case.

3.3 Optimal public transport pricing and optimal fuel prices

Implementing the optimal prices derived in the previous subsection requires pricing techniques such as electronic road pricing that are not currently used in Belgium. In this subsection, we look at the optimal public transport prices in the case where perfect road pricing cannot be implemented, so that more traditional price instruments have to be used. In particular, we assume that fuel taxes are now the only variable instruments available for taxing car traffic. In addition public transport prices can be optimally determined[13].

The resulting prices are presented in Table 3. Complete results can be found in Appendix 4.

Table 3. Optimal public transport pricing and optimal fuel prices

			lambda=0				lambda=0.05			
		reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	gas. car	9.68	14.10	14.04	13.95	13.76	15.83	15.77	15.68	15.48
	diesel car	7.68	13.35	13.29	13.20	13.01	14.96	14.91	14.82	14.62
	bus	1.25	2.79	1.59	1.27	1.09	3.75	2.50	2.14	1.91
	train	1.97	4.55	3.48	3.18	3.00	5.52	4.35	4.02	3.80
offpeak	gas. car	9.75	14.54	14.47	14.38	14.20	16.39	16.33	16.24	16.04
	diesel car	7.73	13.93	13.87	13.78	13.59	15.70	15.65	15.55	15.34
	bus	1.25	1.73	2.69	3.11	3.47	2.28	3.33	3.79	4.19
	train	1.97	2.64	3.84	4.37	4.83	3.36	4.69	5.27	5.77

When the shadow cost of public funds is zero, the results can be summarised as follows. Since the main inconvenience of fuel taxes is that they cannot discriminate between periods of the day, we find taxes on car traffic that are in between peak and off-peak marginal external costs. This is a classic second-best result. Again, there is not much variation in car traffic prices in function of the substitution elasticity that is used. In comparison to the reference situation, sharp price increases for car traffic (about +44% for gasoline cars, and +72% for diesel cars) are observed. In comparison with the full optimum of the previous section, price increases are less dramatic in the peak period, but more important in the off-peak period. Note that the underlying fuel price increases are quite drastic: from 31 to approximately 111 BEF/litre for gasoline, and from 24 to approximately 185 BEF/litre for diesel.

The impossibility of correctly charging for congestion implies that public transport prices are now much more dependent on the substitution possibilities between private and public transport. When the substitution elasticity is low, public transport prices are very close to marginal social costs, no matter how 'distorted' car prices are. When

private costs in order to cover a budget deficit, demand is choked off. This makes it less important to introduce a further mark-up over private costs as a specific signal to consumers to reduce demand because of externalities. The deficit mark-up by itself is already choking off demand. Allowing both factor to choke off demand would be an overkill, and would result in lower social welfare." (Oum and Tretheway (1988, p.313))

[13] In this exercise, we assume that all freight transport prices remain unchanged at their reference level.

there are more substitution opportunities, however, peak public transport prices are below the corresponding marginal social cost. The consequence is that at high substitution elasticities public transport subsidies are economically justified (see Appendix 4). This is a classical second best result as well: when peak car traffic is underpriced and in the presence of cross-price effects, it is optimal not to charge public transport users the full social cost. Since the reference situation was characterised by large subsidies, this does not necessarily imply lower prices than in the reference case. Indeed, peak public transport prices do increase in comparison with the reference situation, except for bus transport when the substitution elasticity assumes its highest value. In the off-peak period, the opposite reasoning holds: as car traffic is priced above its marginal social costs, so are public transport prices. The higher the substitution elasticity, the higher the off-peak public transport prices.

The effects on traffic volumes can be summarised as follows. As taxes on peak car traffic are smaller than in the full optimum, the decrease in car use is smaller (-6 to -10%). However, while off-peak car traffic increased in the full optimum, it now sharply decreases (by some 18%) due to the high price increases that occur in the off-peak period. Off-peak public transport volumes strongly depend on substitution elasticities: at low values volumes decrease less than in the full optimum, while the opposite holds for high substitution possibilities.

The welfare effects are summarised as follows. First, the utility of the representative consumer increases as compared to the reference situation. Again, the higher transport prices are more than compensated by the decrease in congestion (peak traffic speed rises from 41 to a little more than 50 km/h) and the increase in tax income (corresponding to some 300 billion BEF/year, approximately 30000 BEF/year per inhabitant). Second, tax income increases more than in the full optimum. Third, as the decrease in passenger traffic levels is more important than in the full optimum, pollution and accident costs become even smaller. However, social costs caused by freight transport increase. This is mainly due to an increase in the demand for freight transport by trucks related to the reduction in congestion. This negative side effect illustrates the need to co-ordinate passenger and freight transport policies.

In total the welfare gain of this policy scenario amounts to 29 to 33 billion BEF/year according to the substitution elasticity used. This represents 35 to 40% of the maximum welfare gain that was obtained in the full pricing optimum of the previous section. The welfare costs of not implementing a road pricing scheme that allows to discriminate between car traffic in the peak and in the off-peak period appear thus to be high[14].

When the shadow cost of public funds is positive, we observe again that the prices increases are even more important. The optimal fuel prices are now of the order of 142 BEF/l for gasoline, and 235 BEF/l for diesel. Moreover, subsidies for public transport by bus seem no longer to be justified, even for high substitution elasticities. Interestingly, note that the welfare gain amounts now to 47 to 50% of the maximum welfare gain that is obtained in the full optimum. This percentage is remarkably higher than when the shadow cost of public funds is zero. This illustrates the fact that

[14] Of course, this lower welfare gain is also due to the fact that we didn't optimise freight transport prices in this scenario.

fuel taxes are a much more efficient instrument for raising tax revenue than for solving congestion problems.

3.4. Optimal public transport pricing

Suppose, as was the case in the theoretical model presented in Section 2, that the only instruments available to policy makers are public transport fares. In other words, we keep all prices fixed at their reference level, and let the model determine optimal public transport fares which can differ between peak and off-peak periods. The results of this scenario are presented in Table 4. Complete results are given in Appendix 5.

Table 4. Optimal public transport pricing

OPTIMAL PUBLIC TRANSPORT PRICES

			lambda=0				lambda=0.05			
		reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	bus	1.25	1.44	0.00	0.00	0.00	1.98	0.00	0.00	0.00
	train	1.97	3.49	2.08	1.60	1.19	3.95	2.33	1.81	1.37
offp	bus	1.25	1.09	1.48	1.64	1.78	1.34	1.64	1.75	1.86
	train	1.97	1.83	2.32	2.52	2.69	2.17	2.54	2.68	2.81

As could be expected, the optimal public transport prices are now very sensitive to the assumed substitution elasticities between private and public transport. First note that the higher the substitution elasticity between public and private transport, the lower the prices for public transport (and the larger the subsidies) in the peak period, while the opposite holds in the off-peak period. As car traffic is severely underpriced in the peak period, it is optimal to lower public transport prices. However, in the off-peak period of the day, car traffic prices are much closer to their marginal social costs, so that subsidies for public transport are less justified. The lower the cross-price elasticities the closer the taxes will be to marginal external costs.

Second, note that a zero price for public transport by bus in the peak period turns out to be optimal for some sets of elasticities. When peak car traffic is priced much below its marginal social cost and cross-price effects are sufficiently important, the welfare costs of charging bus prices that do not reflect their social costs are more than compensated by the reduction of external costs caused by a switch from private to public transport.

However, this does not apply to transport by train, nor to public transport in the off-peak period[15]. Although we do find subsidies to be optimal for rail services, zero fares are not justified: the resource costs of peak public transport by train are higher than for bus, so that making trains free would induce a too high distortion. At high substitution elasticities, the price of public transport by train in the peak period does become cheaper than in the reference situation. In the off-peak period, as said above, car traffic is more or less correctly priced, so that there is no need for public transport subsidies. While subsidies for public transport are always justified in the peak period, there can be taxes in the off-peak period. However, taxes on public transport are always below marginal external costs.

Third, note that the subsidies are always greater (the taxes are always smaller) for transport by train than for transport by bus, mainly because of lower marginal external costs. Transport by train however remains more expensive than transport by bus because of higher resource costs.

Fourth, depending on the set of elasticities that is used, peak public transport prices may be higher or lower than the off-peak prices. This is related to our first point. If the substitution elasticity between public and private transport is high, lower public transport prices induce a shift from private to public transport. This shift is desirable in the peak period in order to reduce congestion, but not in the off-peak period since private transport is more or less correctly price in this period. Lowering peak public transport prices has two main effects. First, it attracts peak car users, which is desirable; second, it attracts off-peak public transport users, which is not desirable. The former effect dominates the latter when the substitution elasticity gets higher.

If substitution is limited optimal public transport prices in the peak period are higher than in the reference situation, leading to a 12% decrease of the total demand for public transport (+3% for bus, -22% for train). In the off-peak period, the opposite holds: the optimal prices are lower than in the reference situation and the total demand for public transport rises by some 3% (+3.6% for bus, +2.1% for train). The effect on car traffic is very small. On the other hand, if the substitution elasticity is high, optimal peak public transport prices are below their reference level, leading to a 84% increase in the demand for public transport (+92% for transport by bus and + 79% for transport by train). The demand for private transport by car in the peak decreases by 2.4%. In the off-peak period, the opposite again holds: public transport prices rise and demand decreases by 37% (demand for private transport rises by 1.8% in the off-peak period).

[15] Other simulation exercises revealed that free public transport (buses and trains in both periods) might be welfare improving if and only if the consecutive enormous increase in demand can be satisfied at low costs. While it could be the case in the off-peak period, when occupancy rates are lower, it is probably unfeasible in the peak period. If more vehicles are needed to "absorb" the increase in the number of passengers, it will involve higher costs for the authorities (and therefore for the consumers if free public transport is to be paid by a lump sum amount as it was proposed in Flanders) and an increase in the pollution and accident levels that might offset the lowering of external costs caused by the switch from public to private transport. It must be stressed that free public transport seems to be insufficient to markedly alleviate peak congestion: in our most favourable scenario, the average speed in the peak period rose from 41 to 49 km/h. This has to be compared with the peak speed of 66 km/h obtained in the full pricing optimum scenario...

In total, optimal public transport pricing would yield a welfare gain ranging from 0.7 to 5.6 billion BEF/year depending on the assumed substitution elasticity between private and public transport. This only represents 0.9 to 6.7% of the maximum attainable welfare gain in the optimal pricing scenario.

Depending on the set of elasticities used, the tax income (generated by passenger transport) would either marginally increase (by 3% for the lowest value) or, what is more likely, decrease (by 8.4% for the highest value). Consequently, optimal public transport pricing could lead either to a lump sum reimbursement of 530 BEF per inhabitant per year, or to a lump sum tax of 1480 BEF. In the former case, the (very small) increase in consumers' utility is mainly due to higher transfers from the government to consumers, and to the lower off-peak public transport prices. In the latter case, the negative income effect (lower transfers to the consumers) is dominated by the positive effect of lower peak public transport prices, and lower congestion .

The effects on air pollution and accidents caused by passenger traffic are very small. However, note that the decrease in congestion caused by the switch from private car to public transport would induce an increase in the demand for freight transport by road, and thereby an increase in pollution caused by the freight transport sector.

Finally, we once again observe that subsidies for public transport modes are less justified when there exist other distortionary taxes elsewhere in the economy. If the shadow cost of public funds equals 0.05, the role of public transport prices as a mean of alleviating transport social costs becomes less important as compared to its role in raising tax revenue. However, peak car traffic prices are so much underpriced that subsidies for peak public transport continue to be optimal. In most cases, they even are below their reference level.

3.5 Optimal public transport pricing (no peak-off-peak discrimination)

In this scenario, we let all prices at their reference level, except public transport prices. However, contrary to the previous exercise, we assume that public transport fares are the same in the peak and in the off-peak period. The resulting prices are presented in Table 5, complete results are in Appendix 6.

Table 5. Optimal public transport pricing (no peak-offp discrimination)

			lambda=0				lambda=0.05			
		reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	bus	1.25	1.22	0.84	0.75	0.70	1.56	1.01	0.87	0.78
	train	1.97	2.61	2.19	2.04	1.93	3.00	2.41	2.22	2.06
offp	bus	1.25	1.22	0.84	0.75	0.70	1.56	1.01	0.87	0.78
	train	1.97	2.61	2.19	2.04	1.93	3.00	2.41	2.22	2.06

A first observation is that subsidies for public transport continue to be justified. Importantly, note that the optimal public transport prices are actually quite close to their reference levels. This suggests that the reference public transport fares are approximately welfare-optimal if it is not feasible (or one is not willing) to affect car traffic prices and it is not possible (or one is not willing) to differentiate public transport fares according to peak and off-peak periods.

According to our results, however, subsidies for trains could be a little bit lowered while the opposite holds for buses. As a consequence, the demand for transport by bus would increase while the demand for transport by train would decrease. The effect on private car traffic is negligible. In total, welfare effects are nearly zero; they amount to less than one percent of the maximum attainable welfare gain.

3.6 Summary of results

By way of conclusion it is instructive to summarise the optimal public transport prices obtained for the various scenarios. In Table 6 an overview is given for a common value of the elasticity of substitution (2.4). The price elasticities consistent with this value are close to those found in the literature (see Appendix 1).

Table 6. Summary of public transport prices

			lambda=0				lambda=0.05			
		reference	I	II	III	IV	I	II	III	IV
prices (BEF/passkm)										
peak	bus	1.25	2.75	1.27	0.00	0.75	3.52	2.14	0.00	0.87
	train	1.97	4.75	3.18	1.60	2.04	5.70	4.02	1.81	2.22
offp	bus	1.25	1.85	3.11	1.64	0.75	2.39	3.79	1.75	0.87
	train	1.97	2.78	4.37	2.52	2.04	3.49	5.27	2.68	2.22

I: Full optimum / II: Optimal public transport prices + optimal fuel prices / III: Optimal public transport prices / IV: Optimal public transport prices (no peak-offp discrimination)

One obvious conclusion that can be drawn from this table is that there is no such thing as "the" optimal public transport price. It depends on the available pricing instruments and on the shadow cost of public funds. When the shadow cost of public funds is zero, and when perfect price instruments are available for all modes, then social marginal cost pricing applies. In that case subsidies for public transport are not justified; they should be replaced by (small) taxes corresponding to the marginal external costs (see case I in Table 6). In second-best situations where car traffic is not "correctly" priced, subsidies for public transport may well be justified (see cases II, III and IV). This is especially the case for bus transport due to the much lower resource costs involved in comparison with rail transport. Note that free buses may be optimal if car prices for some reason cannot be manipulated.

When the shadow cost of public funds is positive, however, subsidies for public transport are less justified. The possibility of decreasing other distortionary taxes results in higher optimal public transport prices.

4. Conclusions

In this paper, we first reviewed the conditions under which public transport subsidies may be justified from a welfare economic viewpoint. To do so, we presented a very simple theoretical optimal pricing model in which both private and public transport generated external costs. Not surprisingly, the shadow cost of public funds, the relative marginal external cost of public and private transport, and the cross-price elasticity between private and public transport were identified as crucial parameters in determining the desirability of public transport subsidies.

A detailed numerical optimisation model was used to study optimal public transport prices in interregional transport in Belgium under a variety of assumptions with respect to the available pricing instruments. This yielded a number of interesting results. First, although subsidies for public transport can obviously not be justified when car traffic prices can be optimized as well, in a number of second-best situations subsidies did turn out to be optimal. Second, depending on the elasticity of substitution between private and public transport the second-best optimal subsidies may be quite large. Indeed, free bus service in the peak period turned out to be optimal if car prices for some reason cannot be manipulated, and if a fair amount of substitution between bus and car use exists. Third, it was observed that the reference price structure in Belgium is approximately optimal if one is willing to assume that prices for car use cannot be adjusted and in addition no price discrimination between peak and off-peak public transport is possible. Fourth, it was shown that a higher shadow cost of public funds makes subsidies for public transport less desirable.

Finally, it was clearly shown that second-best public transport pricing policies only yield a small fraction of the welfare gains obtained when marginal social cost pricing is applied to all modes. Using fuel taxes and public transport prices yield some 36% of the maximum welfare gain. Optimal public transport pricing only yields 2.5% the maximum gain, and less than 1% is attained when public transport prices cannot discriminate among periods of the day.

Bibliography

- Bös (1986), *Public sector economics*, North Holland, Amsterdam.
- Bovenberg L. and van der Ploeg R. (1994), "Environmental Policy, Public Finance and the Labour Market in a Second-Best World", *Journal of Public Economics*, 55, 349-390.
- Button (1993), *Transport Economics*, Aldershot, UK; Elgar.
- De Borger B., Mayeres I., Proost S. and Wouters S. (1996), "Optimal Pricing of Urban Passenger Transport - A Simulation Exercise for Belgium", *Journal of Transport Economics and Policy*, 31-54.
- De Borger B. and Swysen D. (1997), "Optimal Pricing and Regulation of Transport Externalities: A Welfare Comparison of Some Policy Alternatives", *Working Paper 13.97*, Fondazione Eni Enrico Mattei.
- De Borger B., Ochelen S., Proost S. and Swysen D. (1997), "Alternative Transport Pricing and Regulation Policies: a Welfare Analysis for Belgium in 2005", *Transportation Research D*, Vol.2, No 3, 177-198.
- Dogson and Topham (1987), "Benefit-cost rules for urban transit subsidies", *Journal of Transport Economics and Policy*, 57-71.
- Else P.K. (1985), "Optimal Pricing and Subsidies for Scheduled Transport Services", *Journal of Transport Economics and Policy.*
- Glaister D. and Lewis D. (1978), "An Integrated Fares Policy for Transport in London", *Journal of Public Economics*, vol.9, 341-355.
- Glaister (1984), "The Allocation of Urban Public Transport Subsidy", in: Le Grand J (ed.), Privatisation and the Welfare State", London, Allen & Unwin, 177-200.
- Jansson J.O (1979), "Marginal Cost Pricing of Scheduled Transport Services - A Development and Generalisation of Turvey-Mohring's Theory of Optimal Bus Fares", *Journal of Transport Economics and Policy*.
- Jansson K. (1993), "Optimal Public Transport Price and Service Frequency", *Journal of Transport Economics and Policy*, 27(1), 33-50.
- Mohring (1975), "Optimisation and Scale Economies in Urban Bus Transportation", *American Economic Review*, vol.62, 591-604.
- Oum T.H. and Tretheway M.(1988), "Ramsey Pricing in the Presence of Externality Costs", *Journal of Transport Economics and Policy*, 22(3), 307-317.
- Oum T.H., Waters, W.G. and Yong J.S (1992), "Concepts of Price Elasticities of Transport Demand and Recent Empirical Estimates", *Journal of Transport Economics and Policy*, Vol. 26, 139-154.
- Sandmo A. (1975), "Optimal Taxation in the Presence of Externalities", Swedish Journal of Economics, 77-86-98.
- Small (1992), *Urban Transportation Economics*, Fundamentals of Pure and Applied Economics Series, 51, Chur, Harwood Academic Publishers.
- Turvey and Mohring (1975), "Optimal Bus Fares", *Journal of Transport Economics and Policy*.

APPENDIX 1 own- and cross-price elasticities in the reference situation

Elasticities used in the numerical optimisation model were obtained by adapting estimates taken from the literature (see, e.g., Oum, Waters and Yong (1992)) to the nested CES-structure of the model (see De Borger et al. (1997)). This demand structure indeed imposes some restrictions on the substitution possibilities between goods in different branches of the utility tree. In particular, it implies that a price change in one branch will affect the demand for all goods in a given other branch in the same way. For example, the cross-price elasticity of demand for off-peak car transport and for off-peak public transport with respect to the price off-peak public transport price are necessarily equal in this demand structure.

Given these restrictions, the substitution elasticities were initially chosen such that the resulting price elasticities were close to those available in the literature. We then varied the elasticity of substitution SE between private and public transport so as to obtain 4 different sets of elasticities. They are given below. When SE rises, the cross-price effects become more important. Moreover, note that set 3 is closest to the estimates available in the literature.

Elasticity of substitution between private and public transport: 0.8

		peak		offp	
		private	public	private	public
peak	private	-0.3294	0.06888	0.06888	0.06888
	public	0.0021	-0.18347	0.0021	0.0021
offp	private	0.07331	0.07331	-0.48988	0.07331
	public	0.00269	0.00269	0.00269	-0.2650

Elasticity of substitution between private and public transport: 1.6

		peak		offp	
		private	public	private	public
peak	private	-0.35383	0.44271	0.06888	0.06888
	public	0.01349	-0.35765	0.0021	0.0021
offp	private	0.07331	0.07331	-0.53026	0.59612
	public	0.00269	0.00269	0.02189	-0.5136

Elasticity of substitution between private and public transport: 2.4

		peak		offp	
		private	public	private	public
peak	private	-0.37827	0.81655	0.06888	0.06888
	public	0.02487	-0.53183	0.0021	0.0021
offp	private	0.07331	0.07331	-0.57064	1.11894
	public	0.00269	0.00269	0.04108	-0.7621

Elasticity of substitution between private and public transport: 4

		peak		offp	
		private	public	private	public
peak	private	-0.42715	1.56421	0.06888	0.06888
	public	0.04765	-0.88018	0.0021	0.0021
offp	private	0.07331	0.07331	-0.65141	2.16456
	public	0.00269	0.00269	0.07947	-1.2591

APPENDIX 2 reference situation (interregional transport in Belgium in 2005)

PASSENGER TRANSPORT

				Passengers km/day (million)	Price	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
					(BEF per passenger-km)				
			PRIVATE TRANSPORT						
PEAK	Solo	Big	Gasoline	14.179	15.214	5.117	35.861		
			Diesel	12.996	11.541	3.256	36.361		
		Small	Gasoline	21.539	9.214	3.085	35.758		
			Diesel	18.944	7.605	2.280	36.126		
	Pooling	Big	Gasoline	5.453	6.130	2.075	14.354	41.3	41.9%
			Diesel	4.999	4.645	1.319	14.565		
		Small	Gasoline	8.284	3.729	1.261	14.312		
			Diesel	7.286	3.061	0.923	14.470		
			total	93.680					
OFF-PEAK	Solo	Big	Gasoline	14.593	15.111	5.053	2.691		
			Diesel	13.376	11.517	3.243	3.130		
		Small	Gasoline	22.168	9.438	3.224	2.622		
			Diesel	19.497	7.725	2.347	3.020		
	Pooling	Big	Gasoline	5.613	6.079	2.043	1.081	98.7	43.1%
			Diesel	5.145	4.626	1.308	1.267		
		Small	Gasoline	8.526	3.800	1.305	1.054		
			Diesel	7.499	3.118	0.955	1.221		
			total	96.418					
TECHNOLOGY		Big	Gasoline			Standard			
			Diesel			Standard			
		Small	Gasoline			Improved			
			Diesel			Standard			
			PUBLIC TRANSPORT						
PEAK	Bus			5.971	1.254	-0.497	2.217	31.8	2.7%
	Train			9.295	1.972	-2.549	0.227	70.0	4.2%
			total	15.266					
OFF-PEAK	Bus			7.109	1.254	0.128	0.707	76.0	3.2%
	Train			11.067	1.972	-0.357	0.448	70.0	5.0%
			total	18.176					
		TOTAL PASS-KM		223.540					

FREIGHT TRANSPORT

			Ton-km /day (million)	Price	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
					(BEF/ton-km)			
Road	Peak		18.205	2.485	0.327	6.919	26.9	73%
	Off-Peak		79.564	2.485	0.327	0.946	64.2	
Waterways			10.403	1.233	0.149	0.388	10.0	8%
Railways			26.242	1.603	0.000	0.299	55.0	20%
		Sum	134.415					

WELFARE COMPONENTS

	(in million BEF/day)
Utility	35748.055
Pollution Passenger Tr.	100.35823
Pollution Freight Tr.	77.065675
Accident Costs	326.44718
Road Damage	5.845875
Social Welfare	35238.338

APPENDIX 3 Full optimal pricing (optimisation results)

			lambda=0				lambda=0.05			
		reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	gas. car	9.68	17.58	17.49	17.38	17.16	19.10	19.01	18.93	18.75
	diesel car	7.68	16.71	16.62	16.51	16.29	18.12	18.04	17.96	17.78
	bus	1.25	2.76	2.75	2.75	2.73	3.54	3.53	3.52	3.50
	train	1.97	4.75	4.75	4.75	4.75	5.70	5.70	5.70	5.70
offpeak	gas. car	9.75	8.85	8.86	8.86	8.86	10.13	10.14	10.14	10.14
	diesel car	7.73	8.12	8.12	8.12	8.13	9.29	9.30	9.30	9.30
	bus	1.25	1.85	1.85	1.85	1.85	2.39	2.39	2.39	2.39
	train	1.97	2.78	2.78	2.78	2.78	3.49	3.49	3.49	3.49
taxes (BEF/passkm)										
peak	gas. car	3.25	11.06	10.97	10.86	10.64	12.58	12.50	12.42	12.24
	diesel car	2.23	11.30	11.21	11.11	10.88	12.71	12.63	12.55	12.38
	bus	-0.50	1.01	1.00	1.00	0.98	1.79	1.78	1.77	1.75
	train	-2.55	0.23	0.23	0.23	0.23	1.18	1.18	1.18	1.18
offpeak	gas.car	3.30	2.28	2.28	2.29	2.29	3.56	3.57	3.57	3.57
	diesel car	2.26	2.62	2.62	2.62	2.63	3.79	3.80	3.80	3.80
	bus	0.13	0.72	0.72	0.72	0.72	1.26	1.26	1.26	1.26
	train	-0.36	0.46	0.46	0.45	0.45	1.16	1.16	1.16	1.16
marg.ext.cost (BEF/passkm)										
peak	gas. car	29.84	11.03	10.94	10.84	10.61	10.11	10.04	9.97	9.82
	diesel car	30.19	11.27	11.17	11.07	10.85	10.35	10.29	10.22	10.07
	bus	2.22	1.00	1.00	0.99	0.98	0.94	0.94	0.93	0.92
	train	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
offpeak	gas. car	2.21	2.25	2.26	2.26	2.26	2.21	2.21	2.21	2.22
	diesel car	2.56	2.58	2.59	2.59	2.60	2.54	2.54	2.55	2.55
	bus	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	train	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
traffic level (Mpasskm/day)										
peak	car	93.680	-16.2%	-16.7%	-17.1%	-18.2%	-17.9%	-18.2%	-18.6%	-19.4%
	bus	5.971	33.3%	51.7%	71.6%	115.4%	28.7%	42.4%	56.8%	87.6%
	train	9.295	-32.8%	-23.9%	-14.5%	5.9%	-37.3%	-30.9%	-24.3%	-10.2%
offpeak	car	96.418	7.6%	8.4%	9.1%	10.3%	2.0%	2.9%	3.7%	4.9%
	bus	7.109	-4.2%	-15.8%	-26.1%	-43.2%	-9.2%	-20.7%	-30.8%	-47.4%
	train	11.067	-5.5%	-16.9%	-27.1%	-43.9%	-11.2%	-22.4%	-32.2%	-48.5%
Speed car traffic (km/h)										
	peak	41.349	65.410	65.829	66.280	67.261	67.446	67.761	68.093	68.794
	offp	98.749	98.392	98.344	98.303	98.239	98.777	98.731	98.691	98.627
Welfare components (MBEF/day)										
	utility	35748	0.53%	0.54%	0.55%	0.56%	0.46%	0.47%	0.48%	0.49%
	accidents	326.447	-5.11%	-4.91%	-4.78%	-4.70%	-8.69%	-8.43%	-8.24%	-8.01%
	pollution pass.tr	100.358	-6.26%	-6.54%	-6.73%	-6.87%	-10.01%	-10.36%	-10.63%	-10.96%
	pollution freight.tr	77.066	-10.49%	-10.47%	-10.44%	-10.38%	-13.94%	-13.92%	-13.90%	-13.86%
	road depreciation	5.846	-11.17%	-11.15%	-11.12%	-11.03%	-14.34%	-14.33%	-14.30%	-14.24%
	tax income pass tr	500.712	129.08%	127.15%	125.02%	120.29%	174.10%	172.70%	171.18%	167.86%
	tax income freight tr.	33.542	274.21%	273.98%	273.70%	272.99%	344.37%	344.17%	343.93%	343.35%
Welfare (MBEF/day)		35238	35461	35463	35465	35469	35530	35532	35534	35537
Welfare Gain wrt ref (MBEF/day)			222	225	227	231	265	267	269	272

APPENDIX 4 Optimal public transport prices and optimal fuel prices

			lambda=0				lambda=0.05			
		reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	gas. car	9.68	14.10	14.04	13.95	13.76	15.83	15.77	15.68	15.48
	diesel car	7.68	13.35	13.29	13.20	13.01	14.96	14.91	14.82	14.62
	bus	1.25	2.79	1.59	1.27	1.09	3.75	2.50	2.14	1.91
	train	1.97	4.55	3.48	3.18	3.00	5.52	4.35	4.02	3.80
offpeak	gas. car	9.75	14.54	14.47	14.38	14.20	16.39	16.33	16.24	16.04
	diesel car	7.73	13.93	13.87	13.78	13.59	15.70	15.65	15.55	15.34
	bus	1.25	1.73	2.69	3.11	3.47	2.28	3.33	3.79	4.19
	train	1.97	2.64	3.84	4.37	4.83	3.36	4.69	5.27	5.77
taxes (BEF/passkm)										
peak	gas. car	3.25	7.70	7.64	7.56	7.38	9.44	9.38	9.29	9.10
	diesel car	2.23	7.99	7.93	7.85	7.67	9.62	9.57	9.48	9.28
	bus	-0.50	1.04	-0.16	-0.48	-0.66	2.00	0.75	0.39	0.16
	train	-2.55	0.03	-1.04	-1.34	-1.52	1.00	-0.17	-0.50	-0.72
offpeak	gas.car	3.30	8.01	7.94	7.85	7.67	9.84	9.79	9.69	9.49
	diesel car	2.26	8.45	8.39	8.30	8.11	10.22	10.16	10.07	9.86
	bus	0.13	0.60	1.56	1.98	2.35	1.15	2.20	2.67	3.06
	train	-0.36	0.31	1.51	2.04	2.50	1.03	2.36	2.94	3.44
marg.ext.cost (BEF/passkm)										
peak	gas. car	29.84	20.72	20.69	20.37	19.36	18.38	18.39	18.16	17.43
	diesel car	30.19	20.88	20.85	20.53	19.54	18.57	18.58	18.35	17.62
	bus	2.22	1.63	1.63	1.61	1.54	1.48	1.48	1.47	1.42
	train	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
offpeak	gas. car	2.21	2.10	2.10	2.10	2.11	2.09	2.08	2.08	2.09
	diesel car	2.56	2.44	2.43	2.43	2.44	2.42	2.41	2.42	2.42
	bus	0.71	0.70	0.70	0.70	0.70	0.69	0.69	0.69	0.69
	train	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
traffic level (Mpasskm/day)										
peak	car	93.680	-6.6%	-7.1%	-7.8%	-9.9%	-8.8%	-9.1%	-9.8%	-11.5%
	bus	5.971	15.2%	44.8%	79.1%	163.2%	13.0%	38.4%	67.0%	134.8%
	train	9.295	-26.0%	-7.6%	12.7%	59.5%	-31.4%	-16.4%	-0.1%	36.4%
offpeak	car	96.418	-18.9%	-19.1%	-18.5%	-17.1%	-23.0%	-23.1%	-22.5%	-21.1%
	bus	7.109	2.0%	-7.6%	-18.3%	-37.7%	-3.7%	-13.2%	-23.7%	-42.3%
	train	11.067	-0.6%	-9.9%	-20.4%	-39.2%	-6.7%	-16.0%	-26.1%	-44.1%
Speed car traffic (km/h)										
	peak	41.349	50.260	50.625	51.396	53.562	53.158	53.435	54.070	55.835
	offp	98.749	99.744	99.756	99.737	99.681	99.925	99.934	99.914	99.860
Welfare components (MBEF/day)										
	utility	35748	0.07%	0.07%	0.08%	0.11%	0.02%	0.02%	0.02%	0.05%
	accidents	326.447	-12.49%	-12.75%	-12.82%	-13.01%	-15.52%	-15.73%	-15.73%	-15.76%
	pollution pass.tr	100.358	-14.63%	-14.76%	-14.66%	-13.92%	-18.01%	-18.23%	-18.24%	-17.79%
	pollution freight.tr	77.066	2.77%	2.81%	2.89%	3.15%	3.57%	3.60%	3.67%	3.87%
	road depreciation	5.846	3.26%	3.32%	3.43%	3.76%	4.19%	4.23%	4.33%	4.58%
	tax income pass tr	500.712	167.71%	164.72%	160.75%	150.83%	218.44%	216.20%	212.77%	204.07%
	tax income freight tr.	33.542	3.02%	3.06%	3.16%	3.45%	3.88%	3.91%	3.99%	4.22%
Welfare (MBEF/day)		35238	35317	35317	35320	35330	35392	35391	35394	35401
Welfare Gain wrt ref (MBEF/day)			78.45	78.44	81.86	91.64	126.86	126.20	128.69	136.14
Welfare Gain in % of max. gain			35.29%	34.93%	36.10%	39.67%	47.80%	47.23%	47.85%	50.01%

APPENDIX 5 Optimal public transport prices

		reference	lambda=0				lambda=0.05			
			SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)										
peak	gas. car	9.68	9.68	9.67	9.67	9.66	9.68	9.67	9.67	9.66
	diesel car	7.68	7.68	7.68	7.68	7.67	7.68	7.68	7.68	7.67
	bus	1.25	1.44	0.00	0.00	0.00	1.98	0.00	0.00	0.00
	train	1.97	3.49	2.08	1.60	1.19	3.95	2.33	1.81	1.37
offpeak	gas. car	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75
	diesel car	7.73	7.73	7.73	7.73	7.73	7.73	7.73	7.73	7.73
	bus	1.25	1.09	1.48	1.64	1.78	1.34	1.64	1.75	1.86
	train	1.97	1.83	2.32	2.52	2.69	2.17	2.54	2.68	2.81
taxes (BEF/passkm)										
peak	gas. car	3.25	3.25	3.25	3.25	3.24	3.25	3.25	3.25	3.25
	diesel car	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23
	bus	-0.50	-0.31	-1.75	-1.75	-1.75	0.23	-1.75	-1.75	-1.75
	train	-2.55	-1.03	-2.44	-2.92	-3.33	-0.57	-2.19	-2.71	-3.15
offpeak	gas.car	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
	diesel car	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
	bus	0.13	-0.04	0.35	0.51	0.65	0.22	0.51	0.63	0.73
	train	-0.36	-0.49	-0.01	0.19	0.36	-0.16	0.21	0.35	0.48
marg.ext.cost (BEF/passkm)										
peak	gas. car	29.84	30.00	29.94	29.44	28.03	30.03	30.06	29.61	28.36
	diesel car	30.19	30.35	30.29	29.79	28.38	30.39	30.42	29.97	28.72
	bus	2.22	2.23	2.22	2.19	2.10	2.23	2.23	2.20	2.12
	train	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
offpeak	gas. car	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.22
	diesel car	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
	bus	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	train	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
traffic level (Mpasskm/day)										
peak	car	93.680	0.1%	-0.2%	-0.8%	-2.3%	0.1%	-0.2%	-0.6%	-2.0%
	bus	5.971	2.8%	24.4%	39.6%	91.9%	-2.0%	23.2%	36.0%	81.4%
	train	9.295	-21.8%	0.0%	23.5%	79.4%	-25.7%	-5.8%	15.0%	63.7%
offpeak	car	96.418	0.2%	0.3%	0.8%	1.8%	0.3%	0.6%	1.2%	2.2%
	bus	7.109	3.6%	-7.9%	-18.6%	-37.1%	-0.9%	-12.6%	-23.2%	-41.1%
	train	11.067	2.1%	-9.2%	-19.8%	-37.9%	-2.8%	-14.2%	-24.6%	-42.1%
Speed car traffic (km/h)										
	peak	41.349	41.255	41.529	42.078	43.773	41.177	41.419	41.901	43.384
	offp	98.749	98.738	98.737	98.712	98.666	98.731	98.722	98.692	98.641
Welfare components (MBEF/day)										
	utility	35748	0.01%	0.01%	0.02%	0.04%	0.00%	0.01%	0.02%	0.04%
	accidents	326.447	0.12%	0.03%	0.03%	-0.22%	0.21%	0.19%	0.26%	0.12%
	pollution pass.tr	100.358	-0.06%	-0.27%	-0.40%	-0.04%	-0.55%	-0.68%	-0.83%	-0.60%
	pollution freight.tr	77.066	0.01%	0.02%	0.09%	0.31%	0.01%	0.01%	0.07%	0.27%
	road depreciation	5.846	0.00%	0.03%	0.12%	0.42%	0.00%	0.01%	0.09%	0.36%
	tax income pass tr	500.712	3.00%	-0.74%	-2.76%	-8.44%	5.62%	0.77%	-1.14%	-6.13%
	tax income freight tr.	33.542	0.00%	0.03%	0.10%	0.36%	0.01%	0.01%	0.08%	0.30%
Welfare (MBEF/day)		35238	35240	35240	35244	35254	35268	35267	35270	35279
Welfare Gain wrt ref (MBEF/day)			1.93	2.14	5.60	15.45	3.01	2.14	5.11	13.64
Welfare Gain in % of max. gain			0.87%	0.95%	2.47%	6.69%	1.14%	0.80%	1.90%	5.01%

APPENDIX 6 Optimal public transport prices

(no peak-off-peak discrimination)

		lambda=0				lambda=0.05			
	reference	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4	SE2=0.8	SE2=1.6	SE2=2.4	SE2=4
prices (BEF/passkm)									
peak gas. car	9.68	9.68	9.68	9.67	9.67	9.68	9.68	9.68	9.67
diesel car	7.68	7.68	7.68	7.68	7.68	7.68	7.68	7.68	7.68
bus	1.25	1.22	0.84	0.75	0.70	1.56	1.01	0.87	0.78
train	1.97	2.61	2.19	2.04	1.93	3.00	2.41	2.22	2.06
offpeak gas. car	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75	9.75
diesel car	7.73	7.73	7.73	7.73	7.73	7.73	7.73	7.73	7.73
bus	1.25	1.22	0.84	0.75	0.70	1.56	1.01	0.87	0.78
train	1.97	2.61	2.19	2.04	1.93	3.00	2.41	2.22	2.06
taxes (BEF/passkm)									
peak gas. car	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25
diesel car	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23
bus	-0.50	-0.53	-0.91	-1.00	-1.05	-0.19	-0.74	-0.88	-0.97
train	-2.55	-1.91	-2.33	-2.48	-2.59	-1.52	-2.11	-2.30	-2.46
offpeak gas.car	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30	3.30
diesel car	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
bus	0.13	0.09	-0.28	-0.38	-0.43	0.43	-0.11	-0.26	-0.34
train	-0.36	0.29	-0.14	-0.29	-0.40	0.67	0.08	-0.11	-0.27
marg.ext.cost (BEF/passkm)									
peak gas. car	29.84	30.00	29.91	29.76	29.43	30.07	30.03	29.92	29.67
diesel car	30.19	30.36	30.26	30.11	29.79	30.42	30.38	30.28	30.03
bus	2.22	2.23	2.22	2.21	2.19	2.23	2.23	2.22	2.21
train	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
offpeak gas. car	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2.21
diesel car	2.56	2.56	2.56	2.56	2.55	2.56	2.56	2.56	2.56
bus	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
train	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
traffic level (Mpasskm/day)									
peak car	93.680	0.1%	0.0%	-0.2%	-0.5%	0.1%	0.1%	0.0%	-0.3%
bus	5.971	2.6%	6.2%	10.8%	20.7%	-0.1%	2.4%	5.8%	13.3%
train	9.295	-10.7%	-4.5%	0.9%	11.0%	-15.3%	-9.7%	-5.1%	3.1%
offpeak car	96.418	0.2%	-0.1%	-0.5%	-1.5%	0.3%	0.3%	0.0%	-0.8%
bus	7.109	4.1%	13.0%	20.4%	34.7%	-2.3%	6.0%	12.1%	23.4%
train	11.067	-10.1%	-4.4%	2.1%	15.4%	-14.2%	-9.9%	-5.0%	5.3%
Speed car traffic (km/h)									
peak	41.349	41.250	41.359	41.522	41.879	41.171	41.226	41.344	41.616
offp	98.749	98.737	98.747	98.770	98.823	98.731	98.730	98.746	98.785
Welfare components (MBEF/day)									
utility	35748	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
accidents	326.447	0.13%	-0.01%	-0.26%	-0.85%	0.21%	0.19%	0.01%	-0.43%
pollution pass.tr	100.358	-0.41%	0.28%	0.83%	1.87%	-0.91%	-0.25%	0.22%	1.04%
pollution freight.tr	77.066	0.00%	0.00%	0.02%	0.07%	0.01%	-0.01%	0.00%	0.04%
road depreciation	5.846	0.00%	0.00%	0.03%	0.10%	0.00%	-0.01%	0.00%	0.05%
tax income pass tr	500.712	2.95%	-0.16%	-1.70%	-3.88%	5.43%	1.68%	0.09%	-1.87%
tax income freight tr.	33.542	0.00%	0.00%	0.02%	0.09%	0.00%	-0.02%	0.00%	0.04%
Welfare (MBEF/day)	35238	35239	35239	35239	35240	35267	35266	35266	35266
Welfare Gain wrt ref (MBEF/day)		0.82	0.45	0.68	1.48	1.87	0.65	0.49	0.77
Welfare Gain in % of max. gain		0.37%	0.20%	0.30%	0.64%	0.71%	0.24%	0.18%	0.28%