Optimal Pricing and Regulation of Transport Externalities: A Welfare Comparison of Some Policy Alternatives

by

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ABSTRACT

The purpose of this paper is to present and apply a simple framework for studying optimal prices and regulations for passenger and freight transport, taking into account the heterogeneity of transport services, and capturing all major external costs, viz. congestion, air pollution, accident risks, and road depreciation. Based on a straightforward theoretical structure a simulation model is developed in which the heterogeneity of transport services (various modes, periods, fuel types etc...) is captured through the use of nested-CES utility and production functions. The authority chooses optimal taxes and decides which technologies have to be implemented from a social welfare viewpoint. In a first application of the model we consider both optimal pricing policies and the desirability of introducing improved engine technologies in cars. The results suggest that substantial welfare gains could be realised. Moreover, they clearly illustrate the importance of the set of instruments available to the government. For example, the absence of a toll or road pricing system that allows differentiation between peak and off-peak periods reduces the potential welfare gain of pricing policies by some 60%.

Optimal Pricing and Regulation of Transport Externalities:
A Welfare Comparison of Some Policy Alternatives[1]

0. Introduction

This paper presents a first effort to study optimal pricing policies and technology choices in interregional transport in Belgium on the basis of a disaggregate simulation model. The literature on optimal taxation in the presence of externalities (see, e.g., Sandmo (1975), Wijkander (1985), Oum and Thretheway (1988), Bovenberg and van der Ploeg (1994)), adapted for the specific case of congestion-type externalities (Mayeres and Proost (1996), De Borger (1996)), provides the theoretical basis for the simulation analysis. The specific treatment of congestion is necessary because, unlike many other external effects, congestion directly affects consumer demand for passenger transport and producer demand for freight transport. This results in complex feedback effects that have to be taken into account.

Unfortunately, although the theoretical models referred to above have substantially increased our understanding of the optimal pricing problem in the transport sector, their practical and policy implications remain somewhat limited. First, these models are obviously not designed to fully capture the heterogeneity of transport demand. Various modes have to be considered for both passengers and freight, the congestion contributions widely differ according to the period of the day, gasoline and diesel do not generate the same external pollution effects, etc. Second, congestion-type externalities imply that a full welfare optimum may not be attainable by the usual price and tax instruments (such as fuel taxes), since these do not allow spatial or temporal discrimination. Additionnal instruments, such as a toll system, may be required. Moreover, pricing policies are not the only instrument available to the authorities. Regulatory policies with respect to technologies can be implemented (e.g. norms with respect to catalytic converters), infrastructure policies can be developed, etc.

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To analyse optimal pricing policies that take account of these complications, a simulation model that allows to incorporate the relevant heterogeneity of transport services may be useful. In this paper, we describe the development of such a model and present some preliminary empirical results. The model looks for optimal prices (or taxes) and supply characteristics of the different transport services. A sufficient degree of heterogeneity of services is allowed by using nested utility and cost functions. The model is a standard welfare optimisation problem subject to relevant constraints on the policy instruments, it incorporates passenger and commodity transport, it takes account of all major external costs of the various transport modes, it captures the budgetary implications of government policies, and, finally, it allows general equilibrium effects of transport prices on other goods in the economy.

The model is very detailed in terms of transport services and externalities taken into account. To accomplish this some strong assumptions were made concerning other characteristics of the model. For example, location is assumed to be exogenously given, the road network is aggregated in one link, and the model is static in the sense that no explicit time dimension
is included.

Structure of this paper is as follows. In a first section we present the theoretical structure of the model, and we provide some insight in the resulting optimality rules. In Section 2 we discuss the structure of the simulation model used in the empirical analysis. We consecutively present the general characteristics of the model, provide details on the demand and the supply sides of the model, and we discuss the way the relevant external effects were incorporated. Section 3 deals with the results of a number of preliminary simulation exercises based on 1991 Belgian data on prices, taxes, and traffic volumes in interregional transport. Finally, Section 4 concludes.

1. The theoretical model

In this section we present the theoretical structure of the simulation model used to study optimal transport pricing and regulation. The model is in the tradition of previous optimal taxation models with externalities, but its specific characteristics are tailored towards the transport industry. A brief overview of the structure of the model is as follows. There are two production sectors in the economy: a private sector, producing an aggregate consumption good, and a transport sector. The transport industry provides both final goods to consumers (passenger transport) and intermediate goods to private producers (freight transport). The latter are used as inputs in the production process of final goods. The household sector is modeled by assuming a representative household; in other words, although this would be desirable from a policy viewpoint, the current version of the model ignores distributional considerations. The government is assumed to be interested in maximizing welfare, using public transport prices and taxes to be applied to private transport services as instruments. Moreover, it can impose norms on technologies (for example with respect to catalytic converters, airbags, etc.) to improve welfare. The objective function takes account of budgetary implications of tax and pricing policies, and it captures the impact of all important transport externalities.

Transport services produce two types of externalities. The first type consists of external effects that not only directly affect consumer welfare, but also have an impact on demand behavior. As previously suggested, congestion is the most obvious example. High traffic levels cause travel speed to decrease, and this directly affects the demands for the various transport modes. The second type of externality captures effects which certainly affect consumer utility, but probably do not influence demand behavior. Air pollution provides a good example. For most people, air pollution affects utility, but it is not an important determinant of their travel demand.

1.1. The behaviour of households

A representative household maximizes utility subject to a budget restriction. The demand for transport service i (expressed in passenger kilometer) is denoted by X_i^p (i=1,...,I). Other goods are aggregated in a composite commodity X. It is assumed that consumers take the prices of passenger transport q_i^p, the price of "other goods", q, and congestion C as exogenously given. Consumer income is denoted by R. Solving the corresponding utility maximisation problem yields the demand functions for passenger-km with the various modes, the demand for other goods, and the indirect utility function V(.),

$$X_i^p = X_i^p(q_1^p,...,q_I^p,q,C,R) \ \ \forall i$$

$$X = X(q_1^p,...,q_I^p,q,C,R)$$

$$V = V(q_1^p,...,q_I^p,q,C,R)$$

1.2. The private sector

The private sector consists of a large number of competitive firms. Without loss of generality, these firms are aggregated. This aggregate private sector produces the final good X according to a constant returns to scale technology using, among others, various freight transportation services as inputs. The number of ton kilometer with transport service (e.g., mode) j is denoted X_j^f (j=1,...J). Other inputs are aggregated in a composite input denoted X^o. It is assumed that congestion imposes a negative production externality, and that, for each level of X demanded by consumers, the firms minimize total cost. This implies the system of input demand functions

$$X_j^f = X_j^f\left(q_1^f,...,q_J^f,q^o,C,X\right) \ \ \forall j$$

$$X^o = X^o(q_1^f,...,q_J^f,q^o,C,X)$$

where q_j^f and q^o are the prices for freight transport and other inputs, respectively. Constant returns to scale in production combined with marginal cost pricing implies that output is demand-determined[2], and that the equilibrium price q of the final good can be written as

[2] Allowing for decreasing returns would imply the possibility of positive private sector profits. This substantially complicates the theoretical analysis, because account has to be taken of the distributional implications of profits (see, e.g. Yang (1993), De Borger (1996)).

$$q = q\left(q_1^f, \ldots, q_J^f, q^o, C\right)$$

1.3. The transport sector

The transport sector produces passenger- and tonkilometer using a large variety of transport alternatives. Moreover, on the supply side a number of different technologies are available. The number of passenger-kilometer (using alternative i) supplied with technology k is denoted by $Z_{i,k}^p$ (k=1,...,K). An example may be instructive. For instance, let X_1^p be the demand for passenger-kilometer with alternative 1, say big gasoline cars. Then $Z_{1,1}^p$ could be the supply of passenger-kilometer produced with cars of this type that are not equipped with a catalytic converter, and $Z_{1,2}^p$ could denote the corresponding number of passenger-kilometer of big gasoline cars that are equipped with a catalytic converter. The private cost of providing one pass-km for mode i with technology k is denoted $c_{i,k}^p$ and assumed constant. The externality cost (other than external costs associated with congestion) of one pass-km with mode i and technology k is denoted $e_{i,k}^p$ and also assumed constant[3]. Similarly, let X_j^f denote the demand for ton-kilometer with freight transport alternative j. Then $Z_{j,r}^f$, $c_{j,r}^f$ and $e_{j,r}^f$ are the supply of ton-km with freight transport alternative j using technology r, and the corresponding unit (private) cost and external cost, respectively. Obviously we have

$$X_i^p = \sum_{k=1}^{K} Z_{i,k}^p \quad \forall i$$

$$X_j^f = \sum_{r=1}^{R} Z_{j,r}^f \quad \forall j$$

Note that the choice of emission technology will also be determined in an optimal way by the authorities. Consider, for example, emission technologies for cars. Given the public good nature of cleaner technologies this would result in underprovision of emission reducing technologies. We therefore opted for an alternative approach, viz., the emission technology to be provided by suppliers will result from the overall optimisation and will be such as to minimise social costs.

[3] The constancy of private and external costs other than congestion is of course not necessary from a theoretical perspective. We made this assumption because data limitations forced us to impose it in the empirical application.

1.4. The nature of congestion

At its most general level, congestion is specified as a function of the use of all freight and passenger transport alternatives[4]

$$C = g(X_1^p,\ldots,X_I^p,X_1^f,\ldots,X_J^f)$$

As previously suggested, congestion differs from other external costs in that it explicitly enters all consumer demand functions as well as the production function in the private sector. This implies that changing transport prices generate complex reactions in congestion and demand. Consider for instance the effect of an increase in the price of the i-th passenger transport mode, q_i^p. Using the respective specifications of the demand functions and the definition of congestion, it is straightforward to show that the ultimate impact on congestion is given by

$$\frac{dC}{dq_i^p} = \frac{\sum_{n=1}^{I} \frac{\delta g}{\delta X_n^p}\frac{\delta X_n^p}{\delta q_i^p} + \sum_{m=1}^{J} \frac{\delta g}{\delta X_m^f}\frac{\delta X_m^f}{\delta X}\frac{\delta X}{\delta q_i^p}}{1-\eta}$$

where

$$\eta = \sum_{n=1}^{I} \frac{\delta g}{\delta X_n^p}\left(\frac{\delta X_n^p}{\delta q}\frac{\delta q}{\delta C} + \frac{\delta X_n^p}{\delta C}\right) + \sum_{m=1}^{J} \frac{\delta g}{\delta X_m^f}\left(\frac{\delta X_m^f}{\delta C} + \frac{\delta X_m^f}{\delta X}\left(\frac{\delta X}{\delta q}\frac{\delta q}{\delta C} + \frac{\delta X}{\delta C}\right)\right)$$

The numerator of the above expression measures the direct impact of the price increase on the level of congestion, both via passenger demand and freight demand. Changes in freight traffic demand are indirectly induced by changes in private good demand that lead to adjustments in production levels and, therefore, in the demand for inputs. The denominator of the above expression corrects the direct

[4] In practice, of course, some transport services (e.g., rail transport) do not contribute to congestion. In that case, just think of the partial derivative of g with respect to the use of this particular mode being equal to zero.

effect for the feedback effect. The change in the level of congestion C itself affects the demand for a variety of transport services. The feedback effect is typically negative so that the denominator is greater than one: the overall impact of a price change on congestion is smaller than the direct effect.

Similarly, the total impact on congestion of a change in the price of freight transport mode j can be written as

$$\frac{dC}{dq_j^f}=\frac{\sum_{n=1}^{I}\frac{\delta g}{\delta X_n^p}\frac{\delta X_n^p}{\delta q}\frac{\delta q}{\delta q_j^f}+\sum_{m=1}^{J}\left(\frac{\delta g}{\delta X_m^f}\left(\frac{\delta X_m^f}{\delta q_j^f}+\frac{\delta X_m^f}{\delta X}\frac{\delta X}{\delta q}\frac{\delta q}{\delta q_j^f}\right)\right)}{1-\eta}$$

Not surprisingly, freight rates affect congestion through two distinct channels, viz. directly through the demand for freight transport, and indirectly through their impact on private good prices.

1.5. The planning problem

The planner is assumed to choose all prices and the technologies to be implemented so as to maximise the following problem

$$\underset{\substack{q_i^p, q_j^f, Z_{i,k}^p, Z_{j,k}^f \\ \forall i,j,k}}{MAX} \quad W = \frac{1}{\mu_0} V\left(q_1^p,\ldots,q_I^p, q(q_1^f,\ldots,q_J^f,C),C,R\right)$$

$$+(1+\lambda)\left(\sum_{i=1}^{I}\sum_{k=1}^{K}(q_i^p - c_{i,k}^p)Z_{i,k}^p + \sum_{j=1}^{J}\sum_{r=1}^{R}(q_j^f - c_{j,r}^f)Z_{j,r}^f\right)$$

$$-\left(\sum_{i=1}^{I}\sum_{k=1}^{K} e_{i,k}^p Z_{i,k}^p + \sum_{j=1}^{J}\sum_{r=1}^{R} e_{j,r}^f Z_{j,r}^f\right)$$

$$s.t.$$

$$\sum_{k=1}^{K} Z_{i,k}^p = X_i^p\left(q_1^p,\ldots,q_I^p, q(q_1^f,\ldots,q_J^f,C),C,R\right) \ \forall i$$

$$\sum_{r=1}^{R} Z_{j,r}^f = X_j^f\left(q_1^f,\ldots,q_J^f, C, X(q_1^p,\ldots,q_I^p, q(q_1^f,\ldots,q_J^f,C),C,R)\right) \ \forall j$$

The objective function consists of three terms. The first term measures the representative consumer's indirect utility, normalized by the marginal utility of income in a reference situation so as to reflect consumer welfare in terms of real income. The second term measures tax revenue weighted by one plus the shadow cost of public funds[5]. The final term gives the monetary value of all external effects (e.g., environmental damage) other than congestion. Of course, the welfare effects of congestion are directly captured in the consumer's indirect utility function. Finally, the constraints indicate that for each transport alternative the sum of services produced by all available technologies should equal the corresponding demand for this particular service.

1.6. Optimal Taxation Rules

[5]Another possibility would be to maximize welfare subject to a budgetary constraint. The advantage of directly incorporating the budgetary implications of transport and environmental policies into the objective function is that the level of tax income is endogenously optimized. The disadvantage is that the choice of the shadow cost to be applied is difficult to determine a priori as it depends on what tax instruments the authorities have available.

To focus on the design of optimal taxes, suppose initially that only one technology is available for each transport service. In that case, we can rewrite the objective function as:

$$\underset{\substack{q_i^p, q_j^f \\ \forall i,j,k}}{MAX} W = \frac{1}{\mu_0} V\left(q_1^p, \ldots, q_I^p, q(q_1^f, \ldots, q_J^f, C), C, R\right)$$
$$+(1+\lambda)\left(\sum_{i=1}^{I} (q_i^p - c_i^p) X_i^p + \sum_{j=1}^{J} (q_j^f - c_j^f) X_j^f\right)$$
$$-\left(\sum_{i=1}^{I} e_{i,k}^p X_i^p + \sum_{j=1}^{J} e_j^f X_j^f\right)$$

The first-order conditions with respect to the prices of passenger mode i (q_i^p) and with respect to freight transport mode j (q_j^f) can be rearranged so as to yield

$$\sum_{n=1}^{I} \left(\frac{q_n^p - c_{n,k}^p - \dfrac{e_{n,k}^p + \left(\dfrac{MSDC}{1-\eta}\right)\dfrac{\delta C}{\delta X_n^p}}{1+\lambda}}{q_n^p} \right) \varepsilon_{X_n^p, q_i^p} \frac{X_n^p q_n^p}{X_i^p q_i^p}$$
$$+\sum_{m=1}^{J} \left(\frac{q_m^f - c_{m,r}^f - \dfrac{e_{m,r}^f + \left(\dfrac{MSDC}{1-\eta}\right)\dfrac{\delta C}{\delta X_m^f}}{1+\lambda}}{q_m^f} \right) \varepsilon_{X_m^f, X} \varepsilon_{X, q_i^p} \frac{X_m^f}{X_i^p} \frac{q_m^f}{q_i^p} = \frac{\dfrac{\mu}{\mu_0} - (1+\lambda)}{1+\lambda} \quad \forall i$$

$$\sum_{n=1}^{I}\left(\frac{q_n^p-c_n^p-\dfrac{e_n^p+\left(\dfrac{MSDC}{1-\eta}\right)\dfrac{\delta C}{\delta X_n^p}}{1+\lambda}}{q_n^p}\right)\varepsilon_{X_n^p,q}\varepsilon_{q,q_j^f}\frac{X_n^p q_n^p}{X_j^f q_j^f}$$

$$+\sum_{m=1}^{J}\left(\frac{q_m^f-c_m^f-\dfrac{e_m^f+\left(\dfrac{MSDC}{1-\eta}\right)\dfrac{\delta C}{\delta X_m^f}}{1+\lambda}}{q_m^f}\right)\left(\varepsilon_{X_m^f,q_j^f}+\varepsilon_{X_m^f,X}\varepsilon_{X,q}\varepsilon_{q,q_j^f}\right)\frac{X_m^f q_m^f}{X_j^f q_j^f}=\frac{\dfrac{\mu}{\mu_0}-(1+\lambda)}{1+\lambda}\quad\forall j$$

In these expressions μ is the marginal utility of income, and $\varepsilon_{z,t}$ denotes the elasticity of z with respect to t. Optimal pricing rules depend on own and cross-price elasticities of demand for passenger and freight transport and for the private good, on the output elasticity of freight transport demand, and on the elasticity of private goods prices with respect to freight rates. Finally, MSDC is the marginal social damage of congestion; it corresponds to the full external cost of an increase in congestion. It is given by

$$MSDC=-\left(\frac{1}{\mu_0}\frac{\delta V}{\delta C}\right)-\left(\frac{1}{\mu_0}\frac{\delta V}{\delta q}\frac{\delta q}{\delta C}\right)$$

$$-(1+\lambda)\left(\sum_{i=1}^{I}(q_i^p-c_i^p)\left(\frac{\delta X_i^p}{\delta q}\frac{\delta q}{\delta C}+\frac{\delta X_i^p}{\delta C}\right)+\sum_{j=1}^{J}(q_j^f-c_j^f)\left(\frac{\delta X_j^f}{\delta C}+\frac{\delta X_j^f}{\delta X}\left(\frac{\delta X}{\delta q}\frac{\delta q}{\delta C}+\frac{\delta X}{\delta C}\right)\right)\right)$$

$$+\left(\sum_{i=1}^{I}e_i^p\left(\frac{\delta X_i^p}{\delta q}\frac{\delta q}{\delta C}+\frac{\delta X_i^p}{\delta C}\right)+\sum_{j=1}^{J}e_j^f\left(\frac{\delta X_j^f}{\delta C}+\frac{\delta X_j^f}{\delta X}\left(\frac{\delta X}{\delta q}\frac{\delta q}{\delta C}+\frac{\delta X}{\delta C}\right)\right)\right)$$

It clearly consists of four identifiable terms. The first one is the direct effect of an increase in congestion on the consumers' utility. Note that this effect is expressed in monetary units by dividing by the marginal utility of income. The second term represents the welfare cost of an increase in the price of final goods, induced by a change in congestion level. The third term measures the impact of congestion on the government budget, multiplied by one plus the shadow externalities other than congestion due to increases in congestion.

Not surprisingly, the optimality rules are quite complex and provide little scope for direct interpretation. However, it is easy to show that under suitable restrictions they reduce to simple rules well-known from the literature. Suppose, for example, that the approximation of the marginal utility of income is perfect (i.e., $\mu=\mu_0$), and let all cross-price elasticities of demand for both passenger and freight transport be zero[6]. We find under those assumptions

$$\left(\frac{q_i^p - c_i^p - \dfrac{e_i^p + \left(\dfrac{MSDC}{1-\eta}\right)\dfrac{\delta C}{\delta X_i^p}}{1+\lambda}}{q_i^p} \right) = -\frac{\lambda}{(1+\lambda)\varepsilon_{X_i^p, q_i^q}} \quad \forall i$$

$$\left(\frac{q_j^f - c_j^f - \dfrac{e_j^f + \left(\dfrac{MSDC}{1-\eta}\right)\dfrac{\delta C}{\delta X_j^f}}{1+\lambda}}{q_j^f} \right) = -\frac{\lambda}{(1+\lambda)\varepsilon_{X_j^f, q_j^f}} \quad \forall j$$

[6] These assumptions are commonly used in the literature to ease the interpretation. Note, however, that especially with respect to freight transport they are quite unrealistic. Even if conditional demands are insensitive to prices of other freight transport services, a freight rate change implies an induced output effect as well.

If perfect tax instruments were available, i.e., $\lambda = 0$, these expressions simply boil down to marginal social cost pricing. If no lump-sum taxes can be used ($\lambda>0$) then the "markup" of price over marginal external cost varies inversely with the demand elasticity. However, the markup is not over social marginal cost nor over private marginal cost. It is a markup over private marginal cost plus a fraction of marginal externality cost. This result is well-known (see, e.g., Sandmo (1975), Bovenberg and van der Ploeg (1994), and Oum and Tretheway (1988).

1.7. Optimal choice of technologies

We now briefly consider the more general problem given before, in which not only taxes but also the choice of technologies can be used as policy instruments. It is easy to show that optimal taxation rules are identical to those presented in the previous subsection. With respect to the optimal choice of technology, note that, if the private and external costs were nonconstant and lump-sum taxes were available ($\lambda=0$), the first-order conditions with respect to $Z_{i,k}^{p}$ and $Z_{j,r}^{f}$ would require that the various technologies be implemented up to the level where all their respective relevant marginal social costs were equalized (see De Borger and Swysen (1996) for details). When $\lambda>0$, we would also have to consider the welfare effects of the tax revenues that are foregone by having a higher resource cost.

However, if one assumes that the marginal private and external cost of providing one passenger- or tonkilometer with mode i and technology k is constant, then it is clear that we obtain a corner solution. Optimally only one technology will be supplied for passenger transport and one for freight transport, viz. those technologies that produce the optimal traffic volumes at lowest social costs will be introduced. This of course implies that a technology with a higher resource cost can be implemented if it has comparatively lower external costs.

2. The simulation model

In this section we describe the construction of the simulation model used to determine optimal pricing policies for a large number of transport alternatives. However, before turning to the formulation of the model it is instructive to briefly review its most important limitations. First, it is a static model in the sense that the localisation of households and firms is assumed to be exogenously given. Second, the model provides a representation of an equilibrium situation with a fully adapted stock of transport means. This implies that automobile ownership is not explicitly treated as an independent variable. Although car ownership is endogenous, we use a reduced-form model of mode choice, applicable to a time frame long enough for car ownership to adjust to changes in other variables. After a policy change, the model calculates the new equilibrium outcome, but dynamic adjustments are not explicitly described. The results of the simulations should be interpreted in a medium-term perspective, i.e., for a time horizon that is long enough to have fully adapted stock of transport means, but not long enough to involve locational changes. Third, the model is not spatially disaggregated. In other words, transport is represented by one link per mode and there is no possibility of changing route[7]. Fourth, although this is desirable from a policy viewpoint, the version of the simulation model used in this paper does not yet capture neither the international dimensions of transport policies (e.g., the potential of tax exporting behavior) nor their distributional implications.

The simulation model is sufficiently detailed so as to distinguish between the peak and off-peak periods of the day, it includes all relevant modes (for passengers: the private car, bus, and rail; for freight: truck, rail, inland waterways), it takes account of different types of cars as well as various fuel types (gasoline, diesel). Moreover, the model captures most relevant externalities associated with transport services, including congestion, road surface depreciation, accident risks (i.e., safety), and various emissions. The latter include transport's contribution to the greenhouse effect (CO_2-equivalent), to the ozon problem (VOC, NO_x), its contribution to acid rain (SO_2, NO_x), and to local

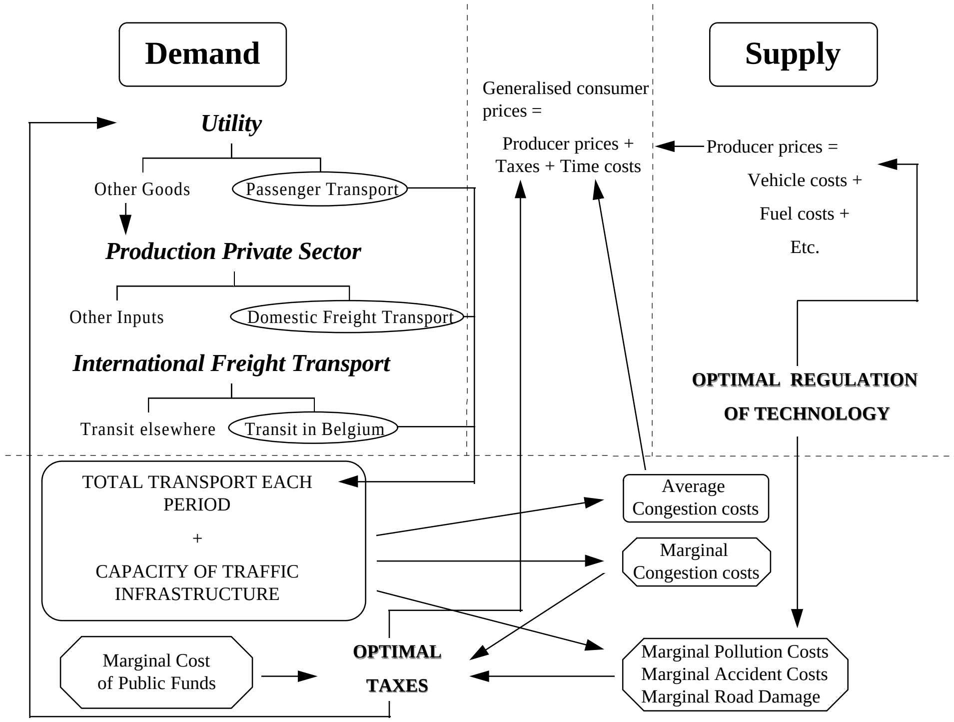
[7] Spatial differences in social costs and transport flows were taken into account within the TRENEN project by developing two companion models: the interregional model discussed here, and the urban model. The interregional transportation market is characterized by lower market shares for public transport, less congestion and noise costs, and a much greater importance of freight transport (see De Borger et al (1995)).

air quality (CO, particulates).

The overall model structure is represented in figure 1[8]. We now briefly turn to the specification of the demand and supply sides of the transport market.

[8]See De Borger B., Ochelen S., Proost S. and Swysen D.(1995) for more details.

Figure 1: Structure of the Interregional Model



2.1. Structure of the demand side of the transport market

2.2.1 Demand for passenger transport: Consumers' Behavior

To structure transport demand decisions with a large number of alternatives we used nested CES-utility functions to represent consumer preferences (see Keller (1976)). The homothetic nature of the CES implies that, at each level, quantity and price indices can be constructed as functions of lower-level quantities and prices, respectively. Moreover, each quantity index has a subutility interpretation. The CES-approach assumes that at each level subutility is separable in the different goods. Calibration of this function is based on estimates of substitution elasticities at the different levels combined with observations on prices and quantities at the lowest level of the tree structure.

The nested structure used for the simulation exercises is represented on Figure 2. At the highest level total utility depends on two aggregate goods, viz. transport and other goods. At the second level, the transport subutility component contains transport demands in two periods of the day (peak and off-peak) as arguments. At the third level, peak transport demand includes "private" and "public" peak demand. At the fourth level, public transport can be either bus or train. Furthermore, private transport (i.e car) consists of "carpooling" and "driving solo". Carpooling is considered as a particular mode in order to allow different prices (per car km) according to the car's occupancy rate. Furthermore, two car sizes are being considered, viz. big and small. Finally, there are two possible fuels, gasoline and diesel.

Figure 2: Multi-Level Decision Structure for Passenger Transport

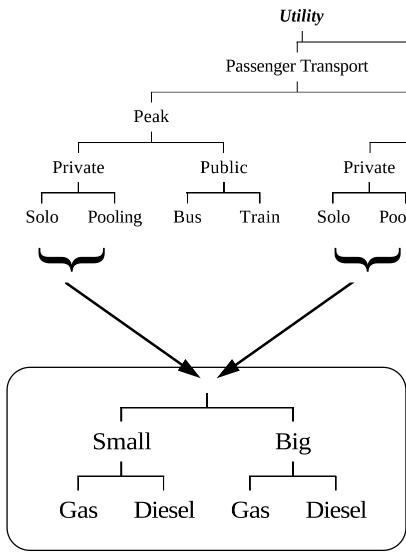
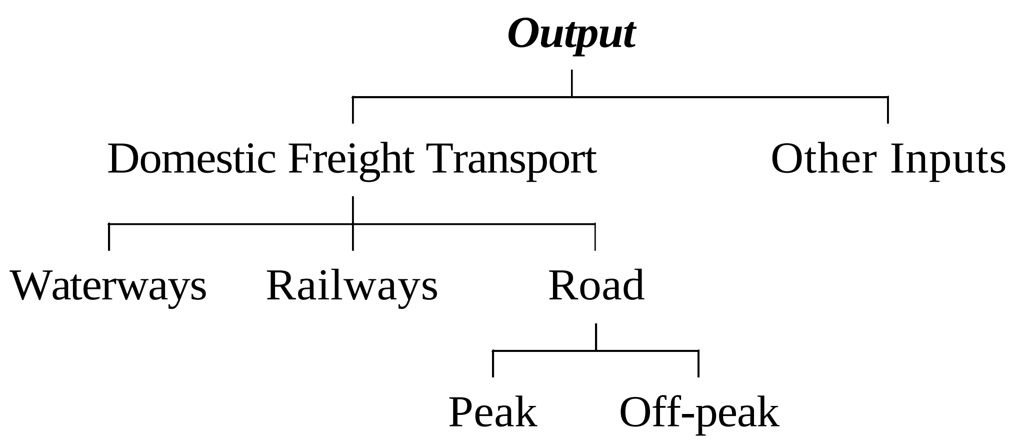


Figure 3: Multi-Level Decision Structure for Domestic Freight Transport



At each level aggregate price and quantity indices can be constructed. The aggregate quantity index of service i belonging to a given level n is given by

$$X_{n,i} = \left(\sum_{j\in i} \alpha_{n-1,j}^{\rho_{n,i}} . X_{n-1,j}^{\rho_{n,i}}\right)^{\frac{1}{\rho_{n,i}}}$$

$$where \ \ \rho_{n,i} = \frac{\sigma_{n,i}-1}{\sigma_{n,i}}$$

The sigma refer to elasticities of substitution, and the notation j∈i means that all disaggregates j are considered that branch off from alternative i at level n-1. The corresponding aggregate price index related to $X_{n,i}$ is given by

$$q_{n,i} = \left(\sum_{j\in i} \alpha_{n-1,j} . q_{n-1,j}^{\tilde{\rho}_{n,i}}\right)^{\frac{1}{\tilde{\rho}_{n,i}}}$$

$$where \ \ \tilde{\rho} = \frac{\tilde{\sigma}_{n,i}-1}{\tilde{\sigma}_{n,i}} \quad ; \quad \tilde{\sigma}_{n,i} = \sigma_{n,i}^{-1}$$

With the above-described structure, it is easy to show that the utility maximising demand functions for commodity i can be written as (see Keller (1976))

$$X_i = \frac{R}{q_{N,i}} \prod_{n=1}^{N} \alpha_{n-1,i} \left(\frac{q_{n,i}}{q_{n-1,i}}\right)^{\sigma_{n,i}}$$

where, as before, R is the consumer's income. Note that the demand for an arbitrary good is a function of all prices via the aggregate price indices at the various levels.

In order to introduce congestion into the model, it will be assumed in the application that demands depend on generalised prices, defined as the sum of monetary and time expenditures. The demand for passenger kilometer with a given mode is assumed to depend on prices and speeds of all transport modes. Further details are given below.

The choice of the nested CES demand structure implies that the income elasticity equals one; moreover, it imposes some restrictions on the substitution possibilities between goods in different branches of the tree. In particular, it implies that a price change in one branch will affect the demands for all goods in a given other branch in the same way. This implies, e.g., that the elasticity of the demand for off-peak car transport and for off-peak public transport with respect to the price of peak bus transport are equal. Given these restrictions, the substitution elasticities were chosen such that the resulting price elasticities were close to those available in the literature (see, e.g., Oum, Waters and Yang (1992) and Goodwin (1994)). The price elasticities that were used are given in Table 1[9].

[9] A number of sensitivity analyses were carried out to see how sensitive the results were with respect to the assumed elasticity values. We found that the optimal transport volumes were quite sensitive to differences in elasticities. However, the optimal prices were found to be much less affected, except for extremely large changes in own price elasticities. Results are available from the authors.

Table 1Passenger Transport's Price Elasticities

		Peak demand		Offpeak demand	
		Private	Public	Private	Public
Peak prices	Private	-0.423	0.084	0.084	0.084
	Public	0.003	-0.311	0.003	0.003
Offpeak prices	Private	0.089	0.089	-0.512	0.089
	Public	0.004	0.004	0.004	-0.369

2.2.2 Demand for Freight Transport

Freight transport demands are treated like derived demands for inputs by a private sector producing an aggregate private consumption good. This good enters the utility function of the representative consumer at the highest level. Consumer demand for this good generates production by the private sector, in which freight transport is one among several inputs. The demand for freight transportation is then assumed to be the result of cost minimising behavior by producers, conditional on the output level of the final good to be produced.

Again, a tree structure is used to represent producers' decisions with a large number of transport alternatives. The tree considered in the simulation model is shown on Figure 3. It is developed in less detail than in the case of passenger transport, as the number of relevant alternatives is much smaller. For example, the peak versus off-peak decision is probably only relevant for road transportation, almost all road freight transport uses diesel, etc. We therefore simply distinguish the three relevant modes (road, rail, inland waterways), and make a further distinction for road transport according to period of the day. No further refinements have been considered. Again, cost functions were assumed to be of the CES-type. In other words, for each level price and quantity indices are constructed along the same lines as for passenger transport. The price elasticities that were used are shown in Table 2. The substitution elasticities were choosen such that the resulting own-price elasticities for road and rail are close to those given by Oum, Waters and Yong (1992).

Table 2Freight Transport's Price Elasticities

	Demand Road	Demand Rail	Demand Waterways
Price Road	-0.561	0.017	0.017
Price Rail	0.004	-1.456	0.004
Price Waterways	0.002	0.002	-1.302

Finally note that here as well generalized prices are being used, see below.

2.2. Representation of Supply

The supply of the various transport modes is introduced in the model via cost functions for the different modes and alternatives. For freight transport and public passenger transport, resource costs include expenditures on labor, energy, materials, rolling stock etc. For private passenger transport (i.e, car) resource costs consist of depreciation expenditures, insurance, energy, parking costs, maintenance, etc.

As previously suggested, the choice of emission technology is also captured as part of the supply component. The emission technology to be provided by suppliers will result from the overall optimisation and will be such as to minimise social costs. The decision variables here are the quantities supplied of vehicles equipped with a certain type of emission technology. Note, however, that in the simulation exercises reported below, choice between different technologies is only available for passenger transport by car.

2.3. Externalities taken into account

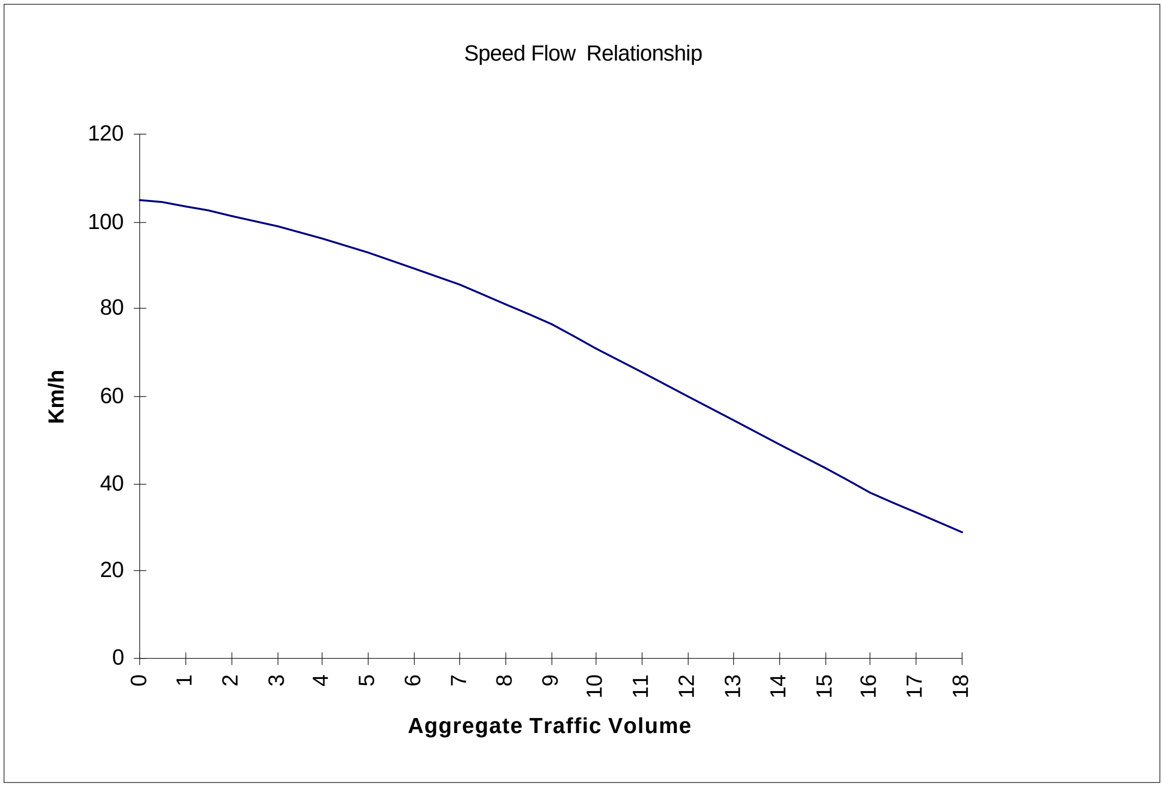
We considered the following external costs caused by transport: congestion, air pollution, accident risks, and road depreciation. First consider congestion. It was introduced in the model by specifying all demand functions for both passenger and freight transport in terms of generalized prices per kilometer, which include monetary expenditures as well as the monetary value of the time needed to travel one kilometer. The monetary value of travel time per kilometer is simply the value of time[10] per hour times the inverse of the speed in kilometers per hour. The generalized prices assume that speed of road traffic is endogenously determined according to a speed-flow relationship. This gives the speed of private car transport as a function of the number of Passenger Car Units (PCU)[11] per hour for each period considered. It was assumed that large and small cars

[10] The values of time used are taken from from Hague Consulting Group (1992).

[11] A car is equal to one PCU, while busses and trucks equal two PCUs.

have the same impact on congestion. Bus and truck speeds on the other hand were assumed to be a constant fraction of cars' speed. Other modes' (rail, inland waterways) speeds were assumed to be constant and independent from the overall level of traffic. The speed-flow relation was constructed by calibrating the parameters of the functional form suggested by Kirwan, O'Mahony and O'Sullivan (1995) on the basis of observable information on Belgian interregional speeds and flows. The use of aggregate data for a one-link network is reflected in the slope of the speed-flow relationship, which is graphically depicted in Figure 4.

Figure 4: Speed-Flow Relationship



All externalities other than congestion were assumed to have a constant cost per kilometer. Air pollution is caused by vehicles' emissions. We considered six pollutants: SO_2, NO_x, HC, CO, CO_2, and PM. Both the emission levels and the appropriate valuations were derived from available studies in the literature (we refer to Mayeres (1993) for more details on the valuation of CO2, HC, SO2 and NOx, and to Small and Kazimi (1995) for CO and PM). Accident costs were supposed constant per vehicle-km. They were derived using the methodology described in Mayeres, Ochelen and Proost (1996); they take into account both material and physical damages. Finally, consistent with Newbery (1988), road depreciation was fully attributed to trucks.

3. Some Simulation Results

In this section, we illustrate the use of the model with Belgian data for 1991 on interregional transport flows and prices. The data concerning resource cost, demands, prices, emissions, values of time, etc., were derived from a large number of sources. More details about the data are available in De Borger and Swysen (1996).

Solution of the model runs in two steps. First, using the available data we calibrate all remaining model parameters (utility function parameters, cost function parameters, ...)[12]. The reference situation can then be interpreted as reflecting an initial market equilibrium consistent with observable information on prices and flows. The most relevant information with respect to the reference solution is presented in Table 3[13]. It suggests that all transport services are priced substantially below their corresponding marginal social costs in the peak period. In the off-peak, taxes and marginal external costs are quite similar, with the exception of large cars; they actually pay more that the external costs. The reason is that in 1991 relatively little congestion existed on

[12] Note that in order to close the model at the calibration stage a third (untaxed) consumer good was introduced in the utility function apart from passenger transport and the aggregate private good produced by the private production sector. Although this commodity has no impact on the optimal pricing results of the simulations it may be interpreted as a good the production of which does not generate any demand for freight transport (say, services).

[13] In order to make the presentation and the interpretation of different transport outcomes more transparent, not all transport markets have been incorporated in the tables that will be presented.

interregional traffic flows. Also note that, with the exception of bus transport in the off-peak period, public transport is heavily subsidised.

In a second step, once the model parameters have been determined we look for the values of the policy variables (prices, taxes, ...) that maximise the objective function. Importantly, note that we took the particular case of a zero shadow cost of public funds in the preliminary application reported here. This specification is equivalent to assuming lump-sum taxation. The objective function under these circumstances consists of just two components. First, it includes the indirect utility of the representative consumer, normalised by the marginal utility of income in the reference situation. Congestion is directly captured in utility via the generalised prices of transport services. It is assumed that tax revenues generated on the transport sector are lump-sum redistributed to the consumer. Tax income changes are thus explicitly taken care of in the welfare calculation via the representative consumer's indirect utility. A second component captures the external costs other than congestion.

To get some insight into the possible range of problems the model can handle we therefore simulated several different applications of the model. The applications differ according to the pricing instruments one assumes the government has available to differentiate between prices of the various transport services, and according to whether or not one allows optimal technology choice. In a first exercise (subsection 3.1) we studied optimal pricing under the assumption that the government has sufficient policy instruments (for example, vehicle taxes, fuel taxes, and tolls) available to optimally price all transport alternatives considered[14]. However, we ignore in this first application the optimal choice of technologies. Second, we analysed a model that determines optimal prices when optimal taxes cannot be varied according to peak versus off-peak period because no tolls can be implemented (see subsection 3.2). Again the optimal choice of technologies was ignored. Third, we illustrate the logic of the model with respect to the choice of optimal technologies using a very simple and specific example (subsection 3.3). Fourth, we investigate the effectiveness of public transport pricing (subsection 3.4). Finally, we determine the

[14] These three instruments suffice to implement the full pricing optimum. See De Borger and Swysen (1996) for details. Note that we use the toll as a possible instrument that allows price diferentiation between peak and off-peak periods.

full optimum, in which all price instruments are available, and, in addition, the possibility of introducing specific new technologies are optimally selected (subsection 3.5).

3.1. Pricing Optimum

We first consider a 'pricing' optimum. We solve the model to determine the set of prices that maximizes the objective function without considering the choice of technologies, where it is assumed that each mode and period can be priced differently. The pricing optimum so obtained is given in Table 4.

The results are easily summarized. First, all prices in the peak period for both passenger and freight transport in the peak have risen compared with the reference situation. Moreover, it is proportionately larger for small cars, resulting in a smaller price difference between small and big cars. Also note that the price differential between gasoline and diesel decreases relative to the reference situation. These findings can be explained by the fact that, especially in the peak period, the main external cost of cars is the contribution to congestion and that, in the model, this contribution is assumed to be exactly the same for different types of cars. Moreover, differences in pollution costs are quite small, and accident costs were assumed to be the same for all car types (Mayeres, Ochelen, and Proost (1996)). While differences in social external costs cannot justify large tax differences between large and small cars, this results may of course change once distributional issues are taken into account.

In the off-peak period, several car prices actually decline as a consequence of the fact that in the 1991 reference situation they paid more in taxes than the external cost they imposed. The price increases for public transport of both passengers and freight can be explained by the fact that subsidies in the reference situation implied that users did not even pay the private costs. On the contrary, the price of inland waterway transport would slightly decline. Finally note that optimal pricing would have a non-negligible impact on transport flows. Peak car transport would decline by some 11%, off-peak car traffic would increase by 7%. Moreover, both public transport use and especially peak truck traffic would go down.

Finally, Table 4 also summarizes the impact of the optimal prices on consumer utility, on various external effects, and on tax revenues. All external costs of the transport sector are lower in the optimum as compared to the reference situation, although the relatively small reduction in overall traffic flows implies modest reductions in pollution. Tax revenues rise substantially, especially those generated on freight flows. Importantly, the results indicate that the implementation of the optimal pricing policies would yield a welfare gain of approximately 0.87 million ECU per day.

3.2. Optimal pricing when no toll is available

It is possible that pricing instruments that allow optimal differentiation between peak and off-peak prices (tolls, road pricing) is not implementable. In this subsection we assume that no such toll is available. Moreover, we also assumed that it was not feasible to charge different public transport prices in peak and off-peak periods.

The resulting optimum is described in Table 5. Although the general trends are similar to those of the previous case, there are some obvious differences. The absence of a toll no longer allows the fine-tuning of the tax system according to temporal variations in externalities. The remaining instruments serve as very imperfect tools to correct for both congestion and environmental damage. Note that all prices rise as compared to the reference situation, but differences between periods vanish. Prices exceed marginal social costs in the off-peak period, and travellers in the peak pay a tax which is much smaller than the corresponding marginal external cost. Moreover, Table 5 suggests that the additional restriction on available tax instruments reduced the welfare gain from 0.87 to 0.20 million ECU per day. In other words, the absence of a toll reduces the potential welfare gain dramatically.

3.3. Introducing new technologies

In a third exercise, we introduced the possibility of allowing the government to implement specific new technologies. For illustrative purposes we only consider a very simple example. Regarding gasoline cars the desirability of subsidising the introduction of catalytic converters was evaluated[15]. For diesel cars we considered subsidising an improved engine technology (turbo-cooler, installation of an oxydation cat). These cleaner technologies imply higher resource costs, but they are less pollutant. Should the new technology be subsidized, prices would remain unchanged, but tax revenue and pollution costs would be different.

The results, reported in Table 6 suggest that, evaluated at 1991 figures, it would be interesting to subsidize installation of catalytic converters on all gasoline cars. The reduction in pollution obtained by this policy would more than compensate for the reduction in overall tax revenues associated with the subsidies. However, the reduction in pollution due to improved diesel technology does not outweigh the higher resource cost. Note that prices and taxes are the same as in the reference situation. The results further suggest that the policy being considered would substantially reduce pollution associated with passenger transport at almost constant traffic flows. However, it was found that it would imply a welfare gain of only 0.11 million ECUs per day. This amounts to only 13% of the welfare gain at the full pricing optimum.

3.4. Optimal Public Transport Pricing

In this exercise, we let the model optimally determine public transport (train and bus) prices, keeping all other prices unchanged at their reference level. Results are given in Table 7. Public transport prices rise, but by less than in the pricing optimum. There remain subsidies for passenger transport by train, but they are less important than in the reference situation. This is a classic second-best result: as other modes are underpriced (as compared to the optimum), it is optimal not to make public transport users pay the the full marginale social cost. Table 7 reveals, however, that using only public transport prices is not an efficient policy: it attains only 13% of the welfare gain that is attainable in the full pricing optimum.

[15] TRENEN can include a large number of different car technology options. The major problem up to now was not the modelling but the cost data for alternative emission technologies.

3.5 Full Optimum: Optimal pricing and choice of technology

We finally consider the case where the government has all pricing instruments available and, in addition, it can freely decide whether or not to subsidize catalytic converters and improved diesel technologies. The results are given in Table 8. Not surprisingly, they combine the results found under subsections 3.1 and 3.3. Taxes are identical to those of subsection 3.1, except for some minor differences related to big gasoline cars, and catalytic converters are introduced for all gasoline cars. The welfare gain amounts to 0.99 million ECU per day.

4. Conclusions

In this paper we looked for optimal pricing and regulatory policies in the transport sector within the framework of a standard welfare maximisation problem. First, a simple theoretical model was developed. We then constructed a simulation model consistent with the theoretical framework to study a variety of policies using data on Belgian interregional transport. The model allowed for a large number of transport alternatives through the use of nested CES utility and cost functions, and it captured the most important external effects associated with transport services. The model was used to determine optimal taxes and public transport prices, optimal choice of technologies, and combinations of the two policies.

An advantage of the type of model developed here is that it directly provides a monetary measure of overall welfare. As a consequence, the model could be used to compare the welfare implications of, e.g., implementing a toll system (pricing policy), priority bus lanes (traffic management), investment in inland waterways capacity (infrastructure policies), imposing environmental standards, introducing new technologies, etc...

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REFERENCE SITUATION 1991

PASSENGER TRANSPORT

			Passengers km/day (million)	Price (ECU per passenger-km)	Tax (ECU per passenger-km)	Marginal Ext. Cost (ECU per passenger-km)	Speed (Km/h)	Market-share
PRIVATE TRANSPORT								
PEAK	Big	Gasoline	18.110	0.353	0.117	0.235		
		Diesel	11.572	0.282	0.082	0.231	55	40.9%
	Small	Gasoline	27.510	0.216	0.072	0.232		
		Diesel	16.867	0.180	0.054	0.227		
		Total	74.059					
OFF-PEAK	Big	Gasoline	18.639	0.357	0.120	0.064		
		Diesel	11.910	0.285	0.084	0.060	95	42.1%
	Small	Gasoline	28.314	0.223	0.077	0.062		
		Diesel	17.360	0.186	0.058	0.057		
		Total	76.223					
TECHNOLOGY	Big	Gasoline			Standard			
		Diesel			Standard			
	Small	Gasoline			Standard			
		Diesel			Standard			
PUBLIC TRANSPORT								
PEAK	Bus		5.462	0.030	-0.0117	0.0128	42.3	3.0%
	Train		8.502	0.046	-0.0600	0.0003	70.0	4.7%
		Total	13.964					
OFF-PEAK	Bus		6.503	0.030	0.0030	0.0055	73.1	3.6%
	Train		10.123	0.046	-0.0084	0.0007	70.0	5.6%
		Total	16.625					
	TOTAL PASS-KM		180.872					

FREIGHT TRANSPORT

		Ton-km /day (million)	Price (ECU/ton-km)	Tax (ECU/ton-km)	Marginal Ext. Cost (ECU/ton-km)	Speed (Km/h)	Market-share
Road	Peak	14.026	0.058	0.0077	0.0403	35.7	67%
	Offp	61.303	0.058	0.0077	0.0095	61.7	
Waterways		14.307	0.029	0.0035	0.0016	10.0	13%
Railways		22.337	0.038	0.0000	0.0012	55.0	20%
	TOTAL TON-KM	111.973					

WELFARE COMPONENTS

	(in million ECU/day)
Utility	706.7488
Pollution Passenger Tr.	1.56223
Pollution Freight Tr.	0.24498
Accident Costs	4.59839
Road Damage	0.10598
Social Welfare	700.2372

OPTIMAL PRICING

PASSENGER TRANSPORT

			Passengers km/day (million)	Price	% change wrt ref	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU per passenger-km)					
PRIVATE TRANSPORT									
PEAK	Big	Gasoline	18.630	0.408	16%	0.172	0.172		
		Diesel	10.532	0.368	30%	0.168	0.168	63.7	38%
	Small	Gasoline	23.330	0.313	45%	0.169	0.169		
		Diesel	13.123	0.290	61%	0.165	0.164		
		Total	-11%						
OFF-PEAK	Big	Gasoline	22.199	0.303	-15%	0.066	0.066		
		Diesel	12.756	0.262	-8%	0.061	0.061	94.2	47%
	Small	Gasoline	29.569	0.210	-6%	0.064	0.063		
		Diesel	16.768	0.187	1%	0.059	0.059		
		Total	7%						
TECHNOLOGY	Big	Gasoline				Standard			
		Diesel				Standard			
	Small	Gasoline				Standard			
		Diesel				Standard			
PUBLIC TRANSPORT									
PEAK	Bus		6.412	0.051	71%	0.0094	0.0094	49	4%
	Train		4.797	0.107	130%	0.0003	0.0003	70	3%
		Total	-20%						
OFF-PEAK	Bus		6.680	0.032	9%	0.0056	0.0056	72.6	4%
	Train		9.426	0.055	19%	0.0007	0.0007	70.0	5%
		Total	-3%						
	TOTAL PASS-KM		-4%						

FREIGHT TRANSPORT

		Ton-km /day (million)	Price		Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU/ton-km)				
Road	Peak	12.258	0.080	37%	0.0292	0.0292	41	65%
	Offp	60.464	0.061	4%	0.0098	0.0098	61	
Waterways		16.420	0.027	-7%	0.0016	0.0016	10	15%
Railways		22.257	0.039	3%	0.0012	0.0012	55	20%
	TOTAL TON-KM	-1%						

WELFARE COMPONENTS

	(% change wrt ref)		(% change wrt ref)
Utility	0.11%	Tax Income Pass Tr	40%
Pollution Passenger Tr.	-0.10%	Tax Income Freight Tr	59%
Pollution Freight Tr.	-1.65%		
Accident Costs	-2.52%		
Road Damage	-3.46%		
Welfare Gain	0.87 **million ECU/day**		

NO TOLL SYSTEM AVAILABLE

PASSENGER TRANSPORT

			Passengers km/day (million)	Price	% change wrt ref	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
					(ECU per passenger-km)				
PRIVATE TRANSPORT									
PEAK	Big	Gasoline	18.305	0.379	7%	0.143	0.220		
		Diesel	10.557	0.334	18%	0.134	0.217	56.8	42%
	Small	Gasoline	27.416	0.239	11%	0.095	0.217		
		Diesel	16.015	0.212	17%	0.086	0.213		
		Total	-2%						
OFF-PEAK	Big	Gasoline	18.761	0.385	8%	0.148	0.063		
		Diesel	10.522	0.342	20%	0.141	0.059	95.7	42%
	Small	Gasoline	27.540	0.250	12%	0.104	0.061		
		Diesel	15.512	0.225	21%	0.097	0.056		
		Total	-5%						
TECHNOLOGY	Big	Gasoline				Standard			
		Diesel				Standard			
	Small	Gasoline				Standard			
		Diesel				Standard			
PUBLIC TRANSPORT									
PEAK	Bus		6.059	0.039	32%	-0.0021	0.0120	44	4%
	Train		6.236	0.078	68%	-0.0285	0.0003	70	4%
		Total	-12%						
OFF-PEAK	Bus		6.820	0.039	32%	0.0125	0.0054	73.7	4%
	Train		7.724	0.078	68%	0.0231	0.0007	70.0	5%
		Total	-13%						
	TOTAL PASS-KM		-5%						

FREIGHT TRANSPORT

		Ton-km /day (million)	Price		Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU/ton-km)				
Road	Peak	13.802	0.063	9%	0.0127	0.0378	37	65%
	Offp	58.182	0.063	9%	0.0127	0.0093	62	
Waterways		16.660	0.027	-8%	0.0013	0.0016	10	15%
Railways		22.583	0.039	2%	0.0008	0.0012	55	20%
	TOTAL TON-KM	-1%						

WELFARE COMPONENTS

	(% change wrt ref)		(% change wrt ref)
Utility	-0.01%	Tax Income Pass Tr	44%
Pollution Passenger Tr.	-3.27%	Tax Income Freight Tr	52%
Pollution Freight Tr.	-1.89%		
Accident Costs	-3.91%		
Road Damage	-4.44%		
Welfare Gain	0.20 **million ECU/day**		

OPTIMAL CHOICE OF TECHNOLOGY

PASSENGER TRANSPORT

			Passengers km/day (million)	Price	% change wrt ref	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU per passenger-km)					
PRIVATE TRANSPORT									
PEAK	Big	Gasoline	18.095	0.353	0%	0.108	0.224		
		Diesel	11.563	0.282	0%	0.082	0.231	55.1	41%
	Small	Gasoline	27.491	0.216	0%	0.063	0.223		
		Diesel	16.857	0.180	0%	0.054	0.227		
		Total	-0.07%						
OFF-PEAK	Big	Gasoline	18.621	0.357	0%	0.111	0.052		
		Diesel	11.898	0.285	0%	0.084	0.060	95.0	42%
	Small	Gasoline	28.287	0.223	0%	0.068	0.052		
		Diesel	17.344	0.186	0%	0.058	0.057		
		Total	-0.10%						
TECHNOLOGY	Big	Gasoline				Improved			
		Diesel				Standard			
	Small	Gasoline				Improved			
		Diesel				Standard			
PUBLIC TRANSPORT									
PEAK	Bus		5.461	0.030	0%	-0.012	0.013	42	3%
	Train		8.491	0.046	0%	-0.060	0.000	70	5%
		Total	-0.08%						
OFF-PEAK	Bus		6.497	0.030	0%	0.003	0.005	73.2	4%
	Train		10.112	0.046	0%	-0.008	0.001	70.0	6%
		Total	-0.10%						
	TOTAL PASS-KM		-0.09%						

FREIGHT TRANSPORT

		Ton-km /day (million)	Price		Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU/ton-km)				
Road	Peak	14.022	0.058	0%	0.008	0.040	36	67%
	Offp	61.245	0.058	0%	0.008	0.010	62	
Waterways		14.291	0.029	0%	0.004	0.002	10	13%
Railways		22.313	0.038	0%	0.000	0.001	55	20%
	TOTAL TON-KM	-0.09%						

WELFARE COMPONENTS

	(% change wrt ref)		(% change wrt ref)
Utility	-0.09%	Tax Income Pass Tr	-7%
Pollution Passenger Tr.	-49.26%	Tax Income Freight Tr	0%
Pollution Freight Tr.	-0.09%		
Accident Costs	-0.09%		
Road Damage	-0.08%		

OPTIMAL PUBLIC TRANSPORT PRICES

PASSENGER TRANSPORT

			Passengers km/day (million)	Price	% change wrt ref	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU per passenger-km)					
PRIVATE TRANSPORT									
PEAK	Big	Gasoline	18.167	0.353	0%	0.117	0.237		
		Diesel	11.605	0.282	0%	0.082	0.233	54.8	42%
	Small	Gasoline	27.581	0.216	0%	0.072	0.234		
		Diesel	16.906	0.180	0%	0.054	0.230		
		sum	0%						
OFF-PEAK	Big	Gasoline	18.708	0.357	0%	0.120	0.064		
		Diesel	11.954	0.285	0%	0.084	0.060	95.0	43%
	Small	Gasoline	28.418	0.223	0%	0.077	0.062		
		Diesel	17.423	0.186	0%	0.058	0.057		
		sum	0%						
TECHNOL(	Big	Gasoline				Standard			
		Diesel				Standard			
	Small	Gasoline				Standard			
		Diesel				Standard			
PUBLIC TRANSPORT									
PEAK	Bus		5.765	0.046	55%	0.005	0.013	42	3%
	Train		5.135	0.099	114%	-0.007	0.000	70	3%
		sum	-22%						
OFF-PEAK	Bus		6.861	0.028	-3%	0.002	0.005	73.1	4%
	Train		9.604	0.051	9%	-0.004	0.001	70.0	5%
		sum	-1%						
	sum PASS-KM		-2%						

FREIGHT TRANSPORT

			Ton-km /day (million)	Price		Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU/ton-km)					
Road	Peak		13.998	0.058	0%	0.008	0.041	36	67%
	Offp		61.335	0.058	0%	0.008	0.010	62	
Waterways			14.323	0.029	0%	0.004	0.002	10	13%
Railways			22.362	0.038	0%	0.000	0.001	55	20%
		sum	0%						

WELFARE COMPONENTS

	(% change wrt ref)		(% change wrt ref)
Utility	0.02%	Tax Income Pass Tr	7%
Pollution Passenger Tr.	0.31%	Tax Income Freight Tr	0%
Pollution Freight Tr.	0.02%		
Accident Costs	0.33%		
Road Damage	0.01%		
Welfare Gain	0.11 **million ECU/day**		

FULL OPTIMUM

PASSENGER TRANSPORT

			Passengers km/day (million)	Price	% change wrt ref	Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU per passenger-km)					
PRIVATE TRANSPORT									
PEAK	Big	Gasoline	18.714	0.405	15%	0.161	0.161		
		Diesel	10.506	0.367	30%	0.168	0.168	63.7	38%
	Small	Gasoline	23.250	0.313	45%	0.160	0.160		
		Diesel	13.099	0.290	61%	0.164	0.164		
		Total	-11%						
OFF-PEAK	Big	Gasoline	22.388	0.300	-16%	0.054	0.054		
		Diesel	12.685	0.262	-8%	0.061	0.061	94.2	47%
	Small	Gasoline	29.633	0.209	-6%	0.054	0.053		
		Diesel	16.678	0.187	1%	0.059	0.059		
		Total	7%						
TECHNOLOGY	Big	Gasoline				Improved			
		Diesel				Standard			
	Small	Gasoline				Improved			
		Diesel				Standard			
PUBLIC TRANSPORT									
PEAK	Bus		6.404	0.051	71%	0.0094	0.0094	49	4%
	Train		4.787	0.107	130%	0.0003	0.0003	70	3%
		Total	-20%						
OFF-PEAK	Bus		6.666	0.032	9%	0.0056	0.0056	72.6	4%
	Train		9.408	0.055	19%	0.0007	0.0007	70.0	5%
		Total	-3%						
	TOTAL PASS-KM		-4%						

FREIGHT TRANSPORT

		Ton-km /day (million)	Price		Tax	Marginal Ext. Cost	Speed (Km/h)	Market-share
				(ECU/ton-km)				
Road	Peak	12.257	0.080	37%	0.0292	0.0291	41	65%
	Offp	60.392	0.061	4%	0.0098	0.0098	61	
Waterways		16.403	0.027	-7%	0.0016	0.0016	10	15%
Railways		22.233	0.039	3%	0.0012	0.0012	55	20%
	TOTAL TON-KM	-1%						

WELFARE COMPONENTS

	(% change wrt ref)		(% change wrt ref)
Utility	0.01%	Tax Income Pass Tr	31%
Pollution Passenger Tr.	-50.75%	Tax Income Freight Tr	59%
Pollution Freight Tr.	-1.75%		
Accident Costs	-2.50%		
Road Damage	-3.56%		
Welfare Gain	0.99 **million ECU/day**		