The Control of Externalities in the Transport Sector:  
An Applied General Equilibrium Model *

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Abstract

The paper uses an applied general equilibrium model, calibrated to the situation in Belgium in 1990, to evaluate the efficiency effects of small policy changes in the presence of externalities. The model incorporates three types of externalities: congestion, which has a feedback effect on the behaviour of the economic agents, air pollution and accidents. Balanced budget incidence analysis shows that the ranking of tax instruments in terms of their marginal cost of public funds (MCF) changes significantly when the effect of the reform on the externalities is taken into account. The effects of the changes in congestion and air pollution are the most important. Secondly, differential incidence exercises make a link with the double dividend literature.

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I. Introduction

The paper uses an applied general equilibrium (AGE) model, calibrated to the situation in Belgium in 1990, to evaluate the efficiency effects of small policy changes in the presence of externalities. The model focuses on externalities generated by the transport sector, though air pollution caused by non-transport energy use is also taken into account. It considers the most important externalities of transport use, namely those related to congestion, air pollution, global warming and accidents [see, e.g., Mayeres, Ochelen & Proost (1996)]. Other, relatively less important, external cost categories such as noise and road damage externalities are not taken into account. The externalities which are included in the model share the property of being characterized by a feedback effect, i.e., the level of the externality affects the behaviour of the economic agents. E.g., the congestion level affects the use of cars and trucks; the same is true for the accident risk, which in addition, also influences the consumption of medical care or the use of safety devices.

The paper presents two types of exercises, which differ because they consider a different type of policy package. The balanced budget incidence simulations involve an increase in separable government spending which is financed by a change in a tax instrument such that government budget balance is maintained. The paper considers four alternative instruments for financing the increase in government spending: a lump sum tax, the labour income tax, the fuel taxes and peak road pricing. For each of these instruments a marginal cost of public funds (MCF) is calculated. The results of the model are compared with those of a model without externalities, in order to assess the importance of incorporating the externalities in the analysis. It is shown that the inclusion of the impacts on the externalities changes the policy recommendations significantly. The information provided by this type of exercises is useful for two purposes. First of all, it serves as an input in cost-benefit analyses. The non-tax costs of a public project should be multiplied by the marginal cost of public funds of the instrument used to finance the project, in order to make a correct comparison with its benefits [see e.g., Stiglitz & Dasgupta (1971), Atkinson & Stern (1974)]. Secondly, the MCF is a useful tool in deciding whether a revenue neutral policy reform is welfare improving or not. From the theory of optimal taxation in the presence of externalities\(^1\), we know that when taxes are set optimally, the MCF is equalized across all tax instruments. Starting from a non-optimal tax system, social welfare is increased (decreased) when the tax with the highest welfare cost per additional unit of government revenue is reduced (increased) and when simultaneously the tax with the lowest welfare cost per additional unit of government revenue is raised (reduced).

In the second type of exercises, the so-called differential incidence simulations\(^2\), one type of

\(^1\) The optimal taxation in the presence of externalities is treated e.g., in Sandmo (1975) and Bovenberg & van der Ploeg (1994). The literature was adapted for the specific case of externalities with a feedback effect in De Borger (1997) and Mayeres & Proost (1997). The last paper derives optimal tax and investment rules for a second-best taxation model with income distribution aspects and illustrates the theoretical insights by means of a simple AGE model calibrated to Belgium.

\(^2\) The terminology is based on Musgrave (1959).
government instrument is altered, and the original level of government revenue is maintained by changing another policy instrument. More particularly, we compare the welfare change of a small increase in the fuel tax and the introduction of peak road pricing for two different ways of revenue recycling: an increase in the poll transfer and a decrease in the labour income tax rate. This provides a link with the double-dividend literature. The double dividend hypothesis claims that the gross welfare costs of an externality tax can be compensated by two types of dividends. The first dividend is obtained by the decrease of the externality. The second dividend is the efficiency gain that can be obtained by using the externality tax revenue to reduce existing distortionary taxes. The strong double dividend hypothesis states that a revenue-neutral tax reform which consists of the substitution of the externality for distortionary taxes results in zero or negative gross welfare costs. This implies that no information is needed about the benefits of the externality reduction in order to justify the externality tax. A general discussion of the issue is presented in e.g., Goulder (1995). An analytical treatment can be found in e.g., Bovenberg & de Mooij (1994) and Parry (1995). A numerical investigation for Belgium in the case of a carbon-energy tax is given in Proost & Van Regemorter (1995).

It is clear that the general equilibrium approach offers a clear advantage over the partial equilibrium models which are commonly used to study policies for the control of transport externalities\(^3\). This it because it allows to consider transport policies from the broader perspective of a global policy change. Therefore, it becomes possible to examine e.g., the double dividend issue.

This paper is closely related to Ballard & Medema (1993), Bovenberg & Goulder (1995) and Brendemoen & Vennemo (1996). The difference with Bovenberg & Goulder (1995) is that they consider only the gross welfare costs of environmental policy measures. The motivation for introducing environmental policies is assumed to be external to the model. In this respect their approach is similar to that of a number of other AGE models which are used for the evaluation of environmental policies [see, e.g., Stephan (1989), Conrad & Schröder (1990), Hazilla & Kopp (1990), Jorgenson & Wilcoxen (1990), Bergman (1991), Nestor & Pasurka (1995)]. Though these models go slightly further in that they model the generation of the externalities, they do not model their impact on the economic system. In Ballard & Medema (1993) and Brendemoen & Vennemo (1996) the evaluation of a policy change depends not only on its costs but on the relation between its costs and benefits. In both models the level of the externality has an impact on economic welfare directly through the utility function of the representative household. However, the externality is introduced as providing a separable contribution to the household’s welfare. Other AGE models which use this approach are Bergman (1993), Perroni & Wigle (1994) and Proost & Van Regemorter (1995). The present paper relaxes the separability assumption in the case of the congestion externality: the households’ allocation of expenditure over the different goods is affected by the level of congestion. In the literature a limited number of studies can be found in which the separability assumption is relaxed. Examples are Beaumais & Schubert (1994), Espinosa & Smith (1995), Pireddu

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\(^3\) Examples of partial equilibrium models are e.g., Glaister & Lewis (1978), Small (1983), Viton (1980,1983), De Borger et al. (1996) and De Borger et al. (1997). These models determine optimal transport policies in the presence of externalities.
The modelling of the congestion externality in our paper is based on DeSerpa (1971) and Bruzelius (1979). In the case of air pollution and accidents however, the model continues to assume that household preferences are separable in these two externalities, though in reality they have a feedback effect similar to that of congestion. The indirect impact on economic welfare through the productivity of inputs at the production side is modelled in Ballard & Medema (1993). Another example is Bergman (1993). In our study we assume that the productivity of inputs is related negatively to the level of congestion.

The structure of the paper is as follows. First, we describe the general characteristics and specification of the AGE model which is used for the calculations, with a particular attention to the modelling of the externalities. After a brief description of the initial equilibrium, which corresponds with the situation in Belgium in 1990, we discuss the results of two types of simulation: the balanced budget incidence and the differential incidence simulations. The final section concludes and describes some extensions to the model.

II. The Applied General Equilibrium Model

The AGE model is a static model for a small open economy. It is used to simulate the effects of policy changes and in doing so it assumes that flows can adjust immediately in order to clear markets. This implies that the time horizon of the model is longer than the short term, since in the short run slow price adjustments can prevent markets from clearing or inflexibilities can result in excess profits or non-optimal allocations. On the other hand, the reference period is shorter than the long run. This is because the stock of the flexible capital good is assumed to be fixed, i.e. independent from savings, which results in a fixed supply of capital services. The flexibility of the stock of capital goods means that their services can be shifted between sectors without costs. Savings are modelled as purchases of capital goods which add to the stock of the capital goods only in a future period which is not considered by the model. This is a common procedure in AGE modelling. Examples can be found in e.g., Keller (1980), Dervis et al. (1982) and Serra-Puche (1984). The approach poses an upper limit to the time horizon of the model. The upper limit should be such that the increase in the capital stock is small compared to the level of the stock in the initial equilibrium. We conclude that the time horizon is the medium term. This implies that only durable goods with a long lifespan should be considered as capital goods. As a consequence, our analysis assumes that transport vehicles do not belong to the category of capital goods. The medium term horizon is also motivated by the assumption that economic agents cannot change their location in response to policy changes.

The model focuses on transport issues, which implies that transport is modelled in a quite

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4 In Beaumais and Schubert (1994) environmental quality affects the choice between green and standard consumer goods. Espinosa & Smith (1995) assume that the choice between medical care and other consumption goods is affected by morbidity which is determined by the level of air pollution. In Pireddu (1996) the pollution level determines the demand for a composite defensive commodity. Mayeres & Proost (1997) assume that the congestion level determines the demand for the congestion generating goods.
detailed way. A distinction is made between different transport modes (road, rail, inland navigation),
between vehicle types and between two periods of time in the case of road transport (peak and off-peak
road transport). In contrast to the network models which are often used in the transport literature, the
AGE model is not spatially disaggregated. For each transport mode (road, rail, inland navigation) the
basic premise is that the network has homogeneous traffic conditions and can be represented as if it were
a one-link system. The model includes three types of transport externalities: congestion, air pollution and
accidents. Four types of economic agents are considered: the households, the production sectors, the
government and the foreign sector. The next section discuss first in general terms how the behaviour of
the economic agents is modelled. The presentation focuses on the way in which the externalities are
modelled. For a more detailed description of the model, the reader is referred to Mayeres (1998a).
Afterwards, we turn to the model specification and implementation.

1. A General Description of the Applied General Equilibrium Model

There are \( J \) goods in the economy \((j=1,\ldots,J)\). A distinction is made between transport and non-
transport goods \((r=TP,NTP)\). There are \( M \) transport goods \((r=TP; m=1,\ldots,M)\) and \( K \) non-transport goods
\((r=NTP; k=1,\ldots,K)\) with \( M+K=J \). The \( K \)th non-transport good is taken to be the capital good\(^5\).

a. The Households

There are \( I \) identical households. Each household has a fixed endowment of capital goods, which
provides a fixed supply of capital services \((c)\). Each household is also endowed with a fixed amount of
time \((T)\). The utility of each household is given by:

\[
U = f_U(x_{TP}, x_{NTP}, \theta h_{TP}, lh) + f_{EM}(EM) + f_{ACC}(ACC)
\]  

(1)

Utility \( U \) is determined by three components. The first component is direct utility \( f_U \) derived from goods
consumption and time use. The second component is the utility related to the emission level of air
pollutants and is represented by \( f_{EM}(EM) \). \( EM \) is the vector of emissions of different air pollutants.
Finally, utility is a function of the number of transport accidents which is reflected by \( f_{ACC}(ACC) \). \( ACC \) is
a vector of accidents occurring to the different transport modes. The exact form of \( f_{EM}(EM) \) and
\( f_{ACC}(ACC) \) is discussed in a later section. It is assumed that the household’s preferences are separable in
\( EM \) and \( ACC \), i.e. the allocation of expenditure over goods consumption and time use is independent of
\( EM \) and \( ACC \). \( EM \) and \( ACC \) are assumed to affect the welfare of the households negatively \((\frac{\partial U}{\partial EM}<0, \frac{\partial U}{\partial ACC}<0)\). In its behaviour each household is assumed to ignore its own impact on \( EM \) and \( ACC \). It
considers itself to be infinitely small compared to society.

The separability assumption which is maintained for air pollution and accidents, is relaxed in the
case of congestion. Our approach is based on the theoretical reasoning introduced by Becker (1965)
which was elaborated, inter alia, by Johnson (1966), Oort (1969), DeSerpa (1971) and Bruzelius (1979).

\(^5\) Appendix 1 provides a list of symbols.
Here we adapt the exposition of DeSerpa (1971) and Bruzelius (1979). The function \( f_U \) is defined as a function not only of goods but also of time allocated to the consumption of goods and to leisure. It is assumed to be quasi-concave in its arguments, continuous and twice differentiable. \( xh_{NTP} \) is a \( K \) vector of non-transport goods consumed by the household. The household’s consumption of the non-transport good \( k \) is denoted by \( xh_{NTP,k} (xh_{NTP,k} \geq 0) \). The \( K \)-th non-transport good is the capital good which is used to model the savings decision. Since we use the static equilibrium approach intertemporal decisions such as savings and investment can be modelled only in a very crude way. Following e.g., Keller (1980), Dervis et al. (1982) and Serra-Puche (1984) consumer savings are modelled by means of the demand for the capital good, the services of which will be sold in the future to earn a rental as a compensation for the postponement of consumption. The consumers can also save by purchasing government bonds, which are assumed to be a perfect substitute for the physical capital good (cf. infra). \( xh_{TP} \) is an \( M \) vector of transport goods \((xh_{TP}=(xh_{TP,1},...xh_{TP,M}) \) with \( xh_{TP,m} \geq 0 \). Total leisure consumed by the household is denoted by \( lh \ (lh \geq 0) \). Total time allocated to transport good \( m \) is denoted by \( 2h_{TP,m} \). It is assumed that all transport goods are consumed one at a time and that all available time is spent either in the consumption of the transport goods, or in leisure or labour.

Utility is assumed to be maximized subject to two types of constraints: the budget constraint and the time allocation constraints. The budget constraint is given by expression (2).

\[
U = f_U (xh_{TP}, xh_{NTP}, \theta h_{TP}, lh) + f_{EM} (EM) + f_{ACC} (ACC) \tag{2}
\]

It states that the sum of the money costs of consumption and the cost of leisure time and of time allocated to transport cannot exceed full income. The consumer price of the non-transport and transport goods is given by \( q_{NTP,k} \) and \( q_{TP,m} \) respectively. The net domestic wage rate is denoted by \( wh \). Full income consists of non-labour income \((P+qh_c)\) and wage income which would have been obtained if the households devoted all their available time to labour \((wh (T-LABEXP) + wabh \ LABEXP)\) minus net international transfers \((\text{INTTF})\) which are assumed to be constant. \( P \) is the uniform poll transfer received from the government. \( c \) gives the capital services rendered by the capital stock owned by the household. The capital services are sold at a price \( qh_c \). It is assumed that \( c \) is a constant. \( T \) is the total time available to each household and is also constant. It is assumed that each consumer group devotes a fixed amount of time \((LABEXP)\) to labour abroad for which it receives a net wage rate \( wabh \).

The time allocation constraints for the transport goods, given in (3), state that for each transport good, the total time allocated to it should be at least as large as the minimum time requirement.

\[
\theta h_{TP,m}^*(Z) x_{TP,m} - \theta h_{TP,m} \leq 0 \quad (m=1,...,M) \tag{3}
\]

The minimum time requirement is defined as the product of the total consumption of the transport good by the household (e.g., the number of pkm travelled) and the time requirement per unit of the transport good \((2h_{TP,m}^*)\). The latter depends on the level of congestion \( Z \), which is a function of the capacity of the road infrastructure and of total traffic volume, as will be discussed later. It is assumed that each household considers the minimum time requirement to be given exogenously, and therefore does not take into account the effect of its own transport decisions on this minimum requirement.
From the first order conditions of the household’s maximization problem it can be derived that the marginal value of time spent in leisure is given by the net wage, on condition that there are no restrictions on labour time:

\[
\frac{\partial U}{\partial h} = wh
\]  

(4)

\(\lambda\) is the Langrange multiplier associated with the budget constraint and is interpreted as the marginal utility of income.

Secondly, the value of a marginal time saving in transport can be shown to equal the difference between the marginal value of time spent in leisure and the marginal value of the satisfaction of time allocated to transport.

\[
\frac{\gamma_{TP,m}}{\lambda} = wh - \frac{\partial U/\partial h_{TP,m}}{\lambda} = \frac{\partial U/\partial h}{\lambda} - \frac{\partial U/\partial h_{TP,m}}{\lambda}
\]  

(5)

\(\gamma_{TP,m}\) is the Langrange multiplier of the time allocation constraint for good \(m\) and can be interpreted as the marginal utility of saving time in transport. The value of a marginal time saving in transport will be nonzero if the time allocation constraint is binding for the transport good. In that case the marginal value of leisure time is higher than the marginal value of time devoted to the transport good and utility can be increased by transferring time from transport to leisure. If the time allocation constraint is nonbinding for transport, utility cannot be increased by transferring time from transport to leisure and the marginal value of a time saving in transport is zero. In the model it will be assumed that the time allocation constraints are binding for all transport activities, or, in other words, that the households wish to spend less time on transport than what is required. From (5) it is clear that the value of a marginal time saving is determined endogenously in the model. This contrasts with the generalized cost approach which is commonly used in transport models. In this approach, the demand for transport is a function of the generalized cost, which is the sum of the money price of the transport good and the time requirement multiplied by an exogenous value of time.

Maximizing the utility function subject to the budget constraint and the time allocation constraints gives rise to the following general demand functions. They indicate that the level of congestion \(Z\) has an effect on the behaviour of the households, in contrast to the level of \(EM\) or \(ACC\). This is because of the fact that air pollution and accidents are assumed to make a separable contribution to the household’s welfare, while this assumption is dropped for congestion.

\[
xh_{r,n} = xh_{r,n} (qh , qh_C , wh , wabh , P , Z) \quad (n=1,...,M \text{ for } r=TP; n=1,...,K \text{ for } r=NTP)
\]  

(6)

\[
\theta_{h_{TP,m}} = \theta_{h_{TP,m}} xh_{TP,m} \quad m=1,...,M
\]  

(7)

\[
lh = lh (qh , qh_C , wh , wabh , P , Z)
\]  

(8)

The indirect utility function can be defined as:

- 7 -
\[ V = V (q_h, q_{h_c}, w_h, w_{abh}, P, Z, EM, ACC) \] (9)

b. The Domestic Production Sectors

In each domestic production sector \( j \) we consider a representative firm which is assumed to maximize its profits under the hypothesis of perfect competition. Each representative firm produces gross output under a constant-returns-to-scale production technology. Production requires the input of capital services, labour, transport and non-transport goods. The productivity of the inputs is assumed to be affected negatively by the level of congestion \( Z \). However, air pollution and accidents do not affect the production side of the economy. In the optimization problem it is assumed that each firm considers the level of congestion \( Z \) to be exogenous, i.e. it believes not to contribute itself to the level of \( Z \).

The domestic production sectors do not only sell their goods in the domestic market but also abroad. The export of domestically produced goods requires an additional input of transport goods and transport labour. Each export producing sector \( j \) is assumed to minimize its costs of producing a given amount of exports subject to the production function. Also in this case the productivity of the transport goods and labour is negatively related to the congestion level \( Z \).

c. The Foreign Sector

Following Armington (1969) foreign goods are assumed to be different from domestic goods, though they might be close substitutes for one another. Homogeneity of domestic and foreign goods would lead to a tendency towards specialization when coupled with the small country assumption, which is not observed in reality, and would give rise to unrealistic trade elasticities. Therefore, we follow the approach used in many other models [see, e.g., Keller (1980), Dervis et al. (1982)] and adopt the Armington formulation which allows one to keep aggregative commodity categories across countries but specifies product differentiation by country of origin into the structure of demand. The approach constructs an aggregate or composite commodity for each tradeable which is a function of the imported and domestic variety of the good. Given the prices of the two varieties, the combination of the imported and domestic variety is chosen such that the cost of producing a given amount of the composite good is minimised. The Armington assumption is not without cost. It gives individual producers some monopoly power over their prices, leading to relatively large terms of trade effects. When goods become more differentiated, each country has more control over its own prices. Another consequence is that each economy is better insulated against shocks from abroad since imperfect substitution dampens the effect of changed import prices on the domestic prices system.

The import of goods and services requires transport in Belgium. This causes the import price to be different from the cif-price (i.e., the import price which includes all costs up to the border of the importing country). In the AGE model the cif-price of the imported goods is taken to be fixed and acts as a numéraire. The foreign sector which imports the goods in Belgium is assumed to choose the input of foreign transport goods and foreign labour for transport in Belgium such that the costs of delivering a given amount of imports in Belgium are minimised. The productivity of transport labour and the transport
goods is assumed to be affected negatively by the level of congestion in Belgium.

On the export side, remaining faithful to the small-open-country assumption would entail that the country’s export prices are fixed in the world market and do no depend on the quantities exported. But this is inconsistent with the assumption that products are differentiated by country of origin and imperfect substitutes for one another. This assumption leads to less than infinitely elastic demand functions for the country’s exports. Based on Dervis et al. (1982) we use the following constant elasticity demand function to determine the export demands \( \text{ex}_j \) for each good \( j \):

\[
\text{ex}_j = \hat{\text{ex}}_j \left( \frac{\text{pw}_j}{\text{px}_j} \right)^{\eta_j}
\]  

(10)

\( \text{pw}_j \) is the world price (expressed in terms of the domestic currency) and is treated as fixed, given the fact that the domestic country is small. The export price of the domestic products is denoted by \( \text{px}_j \), \( \eta_j \) equals minus the price elasticity of export demand. \( \hat{\text{ex}}_j \) is a positive constant representing total world demand for good \( j \). A change in \( \text{px}_j \) is assumed not to affect the world price of good \( j \), nor the total demand for the good, but it does have an impact on the country’s market share.

Transit transport in the domestic country is transport unconnected to domestic production, import or export. It is included in the model because of its contribution to congestion, air pollution and accidents. The demand for transit transport (tt) in the country is determined in the following way:

\[
\text{tt} = \bar{\text{tt}} \left( \frac{\text{ptt}_w}{\text{ptt}} \right)^{\eta_t}
\]  

(11)

where \( \text{ptt}_w \) is the price of transit transport abroad, which is assumed to be constant, \( \text{ptt} \) is the price of transit transport in the country, \( \bar{\text{tt}} \) is a constant representing total demand for international transport by foreign firms. \( \eta_t \) equals minus the elasticity of transit transport in the country with respect to \( \text{ptt} \). Transit transport in Belgium is produced with as inputs foreign transport goods and foreign labour. The transit sector is assumed to minimise its costs of producing a given amount of transport in Belgium subject to a CRS production technology. The productivity of the input factors is related negatively to the level of congestion \( Z \) in Belgium.

d. The Government

A single government includes government activities at all levels: federal, regional and local. The government is modelled as if it were a single consumer, which maximizes a utility function defined over the \( K \) non-transport goods, subject to a budget constraint. The spending of the government on the \( K \) non-transport goods is assumed not to enter the utility function of the consumers as public goods. Government income consists of the sum of tax revenue and revenue from the sale of capital services rendered by the capital stock owned by the government, minus the poll transfers paid to the household groups, the remuneration of capital services, subsidies paid by the government to the domestic production sectors and net government transfers to the rest of the world (which are assumed to be constant). The government may spend more than this income. If this is the case, the government deficit appears as a positive endowment
of capital tomorrow in its budget constraint. Implicitly, it is assumed that the government can run a deficit by selling bonds which the households consider as perfect substitutes for physical capital as savings instruments [see, e.g., Kehoe & Serra-Puche (1983)].

The government can make use of several tax instruments. First of all, it levies an income tax on the labour and capital income of the households. Secondly, it can levy excises on the input of transport and non-transport goods by the domestic production sectors and the households and indirect taxes on the households’ consumption. Furthermore, it can make use of externality taxes on the consumption of non-transport energy goods and transport goods. For the transport goods, the externality taxes can also be levied on the use of transport goods by foreign firms (associated with import or transit transport).

e. The Determinants of Congestion, Air Pollution and Accidents

The model considers three types of externalities: those related to congestion (Z), air pollutant emissions (EM) and accidents (ACC). The previous sections already discussed the way in which these three phenomena affect the economic agents. This section describes in general terms the determinants of Z, EM and ACC.

The congestion level is determined by the relationship between the traffic flow F and the capacity of the transport infrastructure CAP. The congestion level increases with traffic flow and decreases with the capacity of the infrastructure.

\[ Z = Z \left( F, \text{CAP} \right) \quad \text{with} \quad \frac{\partial Z}{\partial F} > 0, \quad \frac{\partial Z}{\partial \text{CAP}} < 0 \]  

(12)

We define the total use of transport good \( m \) \( (X_{TP,m}) \) as

\[ X_{TP,m} = I x_{h_{TP,m}} + \sum_{j=1}^{J} \left( x_{p_{TP,m}} + x_{x_{TP,m}} + x_{ab_{TP,m}} \right) + x_{t_{TP,m}} \quad (m=1,...,M) \]

(13)

It equals the sum of the total use of the transport good \( m \) by the households \((I x_{h_{TP,m}})\), by the domestic production sectors for the transport of domestically demanded goods \((\sum x_{p_{TP,m}})\), by the domestic production sectors for export related transport in Belgium \((\sum x_{x_{TP,m}})\), by the foreign sectors for import related transport in Belgium \((\sum x_{ab_{TP,m}})\) and by transit transport in Belgium \((x_{t_{TP,m}})\). Defining \( X_{TP} \) as \( X_{TP}=(X_{TP,1},...,X_{TP,M}) \), the traffic flow relevant for the determination of the congestion level is obtained in the following way:

\[ F = F \left( X_{TP} \right) \]

(14)

In the present version of the AGE model CAP is assumed to be constant. This assumption will be relaxed in later versions of the model.

The emissions of the different air pollutants are a function of the total use of transport goods and non-transport energy goods. We define the total consumption of the non-transport energy good \( en \) as

\[ X_{NTP,en} = I x_{h_{NTP,en}} + \sum_{j=1}^{J} x_{p_{NTP,en}} \quad en=1,...,EN \]

(15)

It equals the sum of the consumption of the good by the households \((I x_{h_{NTP,en}})\) and by the domestic production sectors \((\sum x_{p_{NTP,en}})\). The level of emission of air pollutant \( po \) is defined as
\[ EM_{po} = \sum_{m=1}^{M} emtp_{po,m} X_{TP,m} + \sum_{en=1}^{EN} emen_{po,en} X_{NTP,en} \quad po = 1, \ldots, PO \]  

(16)

\( emtp_{po,m} \) and \( emen_{po,en} \) are emission factors which give the emissions of pollutant \( po \) per unit of consumption of the transport good \( m \) and the non-transport energy good \( en \) respectively. The function \( f_{EM} \) in (1) is defined as:

\[ f_{EM} = \sum_{po=1}^{PO} mu_{AP,po} \left( EM_{po}^{ref} - EM_{po} \right) \]  

(17)

\( mu_{AP,po} \) is the marginal utility to the household of a decrease in the emissions of pollutant \( po \). \( EM_{po}^{ref} \) gives the total emissions of pollutant \( po \) in the reference equilibrium.

The number of accidents depends on the total use of the transport goods. \( ACC_{m,n} \) gives the number of accidents of type \( n \) in which transport mode \( m \) is the victim. A distinction is made between four accident types: fatality, serious injury, light injury and material damage. \( ACC_{m,n} \) is defined as

\[ ACC_{m,n} = \sum_{n} ar_{m,v}^{n} X_{TP,m} \]  

(18)

As before, the index \( m \) stands for the transport modes. So does the index \( v \), but in addition this index includes external objects (such as a wall or a tree) as a category. \( ar_{m,v}^{n} \) is the probability that an accident of type \( n \) occurs between transport modes \( m \) and \( v \) in which \( m \) is the victim.

The function \( f_{ACC} \) is defined as follows:

\[ f_{ACC} = \sum_{n} mu_{ACC,n} \sum_{m} \left( ACC_{m,n}^{ref} - ACC_{m,n} \right) \]  

(19)

It is the sum over all accident type categories \( n \) of the marginal utility of a decrease in the number of accidents of type \( n \) \( (mu_{ACC,n}) \) times the total reduction in the number of accidents of type \( n \) with respect to the initial equilibrium.

**f. The Market Equilibrium Conditions**

In the equilibrium, the following market equilibrium conditions must hold:

(i) on the labour market: the sum of labour supplied by the households and by the rest of the world should equal the sum of total labour demanded by the domestic production sectors and the export of domestic labour.

(ii) on the market for capital services: the total supply of capital services by the households and the government should equal total demand of capital services by the domestic production sectors and the government.

(iii) on the market for the capital good: the sum of the supply of capital goods by the domestic production sectors and by the government (which sells bonds in order to finance its government deficit) and the import of capital goods should equal the demand by the households, the government and the rest of the world.

(iv) on the other goods markets: the sum of the supply of the good by the domestic production sectors and the import of the good should equal the demand by the domestic production sectors, the
households, the government and the rest of the world

(v) on the balance of payments: the total outflow of funds to the foreign sector should equal the total inflow. The outflow of funds consists of the value of imports, the value of imported labour, the net international transfers by the government and by the households. The inflow of funds equals the sum of the value of exports, the value of exported labour and the value of the externality taxes levied by the Belgian government on the use of transport in Belgium by foreign economic agents. A trade deficit on the part of the foreign sector is assumed to be offset by the sale of capital goods to the domestic households such that the balance of payments is in equilibrium. This good is considered by them as a perfect substitute for physical capital.

g. Investment

Although the model is static, we have to take into account the investment that takes place during the period which is considered. Total physical investment in the economy is defined as the sum of household savings and government investment (modelled as their demand for the capital good) minus the government deficit and the trade surplus.

2. The Model Specification

This section discusses in more detail the specification of the model presented in the previous sections. Table 2 gives an overview of the goods considered in the model. The table makes a distinction between four types, which refer to the different production technologies of the sectors in which they are produced, as will be explained later. However, first we turn to the specification of the households’ utility function.
Table 1: Classification of the domestic production sectors

<table>
<thead>
<tr>
<th>no.</th>
<th>Type I</th>
<th>no.</th>
<th>Type II</th>
<th>no.</th>
<th>Type III</th>
<th>no.</th>
<th>Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Capital goods</td>
<td>5a</td>
<td>Peak bus tram metro</td>
<td>2a1</td>
<td>Electricity</td>
<td>3a</td>
<td>Transport vehicle services</td>
</tr>
<tr>
<td>2a</td>
<td>Electricity</td>
<td>5b</td>
<td>Off peak bus tram metro</td>
<td>2a2</td>
<td>El. electricity sector</td>
<td>3b</td>
<td>Gasoline car</td>
</tr>
<tr>
<td>2b</td>
<td>Solid fuels</td>
<td>2a3</td>
<td>Solid fuels</td>
<td>3a</td>
<td>El. production sectors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2c</td>
<td>Petrol products</td>
<td>5b</td>
<td>Electricity</td>
<td>3b</td>
<td>El. households</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2d</td>
<td>Gas</td>
<td>2a4</td>
<td>Solid fuels</td>
<td>3c</td>
<td>LPG car</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Transport</td>
<td>6a</td>
<td>Peak passenger rail</td>
<td>3d</td>
<td>Gasoline van</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Transport services</td>
<td>6b</td>
<td>Off Peak passenger rail</td>
<td>3e</td>
<td>Diesel van</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Maintenance</td>
<td>2b1</td>
<td>Solids electricity</td>
<td>3f</td>
<td>Truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Other goods and services</td>
<td>2b2</td>
<td>Solids production</td>
<td>3g</td>
<td>Bus, tram, metro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>2b3</td>
<td>houses</td>
<td>3h</td>
<td>Passenger train</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td>3i</td>
<td>Freight train</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>2c1</td>
<td>Petrol products</td>
<td>3j</td>
<td>River vessel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**a. The Households**

The direct utility function $f_U$ of each household is a nested function with 10 levels ($w=0,...,9$) defined over the excess quantities of the different goods and time uses. The nested structure is presented in Figures 1a and 1b. At the top level ($w=0$) the utility component is a Cobb-Douglas type of function. At this level the households allocate their resources between present goods and time consumption on the one hand and future consumption on the other hand. Modelling this decision with the help of a Cobb-Douglas type of function implies a fixed marginal propensity to save. All other utility components, with the exception of those at level 8, are specified as linear homogeneous Modified Constant Elasticity of Substitution (MCES) functions [Keller (1976)] of the associated utility components at the next level.

Figures 1a and 1b do not require a lot of additional information, except about levels 6 to 8. At $w=6$ the utility component corresponding with passenger kilometres travelled by different car types is
modelled as a MCES function of committed and supplementary mileage. This way the simultaneous decision about car ownership and car use is introduced in the AGE model. This is important if we want to look at the differential impact of taxes on the purchase of vehicles and taxes on their use. The approach is based on Koopman (1995) and Conrad & Schröder (1991) who consider the joint choice of the ownership of a durable and its use in an aggregate model. In contrast to the disaggregate models [e.g., Train (1986), De Jong (1990)] which explain behaviour at the level of the decision making unit, the aggregate models try to describe the aggregate demand of durables and their associated nondurables as a function of a number of variables that describe the goods or their consumers. The approach of Conrad & Schröder (1991) is based on the assumption that ownership of a durable (a car) implies a minimum consumption of nondurables (fuel, maintenance etc.). The cost per unit of the durable then consists not only of the price of the durable itself but also of the sum over all associated nondurables of the price of the nondurable times the amount of the nondurable needed per unit of the durable. In addition to the minimum consumption of the nondurables complementary to the use of the durable, the consumers may decide to consume more than the minimum of the nondurable. This part of the consumption of the nondurable is termed the substitutable part. Conrad & Schröder give an interpretation of this approach for the case of cars: they say that ownership of a car implies a minimum fuel input which results from the maximum fuel efficiency which can be obtained by driving carefully. But the driver can choose to consume more fuel by changing his driving style. Koopman (1995) uses a similar approach and provides an intuitively more appealing interpretation. He starts from the assumption that owning a car implies a certain minimum mileage, or, in other words, that people will only decide to buy a car when they know that they will drive at least a minimum number of miles with it. The minimum mileage is termed the committed mileage. The assumption is corroborated by evidence from the disaggregate models. For the Netherlands, e.g., it is found that this minimum mileage is approximately 69% of average annual mileage [De Jong (1990)]. The costs of the vehicle are completely assigned to the committed mileage. In addition, the cost per unit of committed mileage includes the fuel, maintenance and time costs. The consumer can choose to drive more than the minimum kilometrage. This is called the supplementary mileage. The cost per unit of supplementary mileage does not include the vehicle costs. At \( w=7 \) committed and supplementary mileage are a MCES function of physical \( \text{pkm} \) and transport time. At \( w=8 \), committed mileage is a Leontief-type function of vehicle \( \text{km} \) (vkm), fuel and maintenance. In the case of supplementary mileage \( \text{pkm} \) is a Leontief function of fuel and maintenance only.

As was indicated before the households are assumed to maximize this utility function subject to their budget constraint and the time allocation constraints. These last constraints state that both for the peak and the off-peak period the time devoted to transport mileage should at least be as high as some minimum time requirement, which depends on the level of congestion in the period considered.

b. The Domestic Production Sectors

A distinction is made between four types of production sectors. An overview is given in Table 2. The technology of production in the Type I and Type II production sectors is represented by a nested CES-Leontief production function. Figures 2a and 2b show the nested production structure of the type I
sectors. The tree structure has eight levels ($w=0,...,7$). For $w=0$ to 5 (except for rail business transport) the production components are defined as MCES functions of the associated production components at the next level. At level 6 the transport mileage component is a Leontief-type function of the production components at the next level, which correspond with the input of fuel, maintenance and labour. In the case of committed transport mileage the production components also include transport vehicle services. The input-output coefficient of transport labour is assumed to depend on the level of congestion.

The production structure of the type II production sectors is similar except for the transport subproduction function. Figure 3a presents the transport production structure for peak public passenger transport (goods 5a and 6a). The structure of off-peak passenger transport (goods 5b and 6b) is similar but for one exception: it is assumed that no vehicle services are required to produce mileage. This way the costs of vehicle services are allocated completely to peak public transport. The amount of transport labour required for bus, tram and metro transport depends on the level of congestion. Passenger rail transport is assumed to be unaffected by congestion. Figure 3b gives the structure of the transport component for the freight rail sector (good 7). The production structure of inland navigation (good 8) is similar to that of the freight rail sector.

The third type of production sectors combines basic energy products (electricity, solid fuels, petrol products and gas) with transport, capital, non-transport labour, energy and other goods to produce specific energy products (e.g. gasoline in the case of petrol products). The production structure is similar to that of type I production sectors. However, at the top level gross output is a Leontief type function of the basic energy product and a capital, non-transport labour, transport, energy and other goods component. The fourth type of sector transforms generic transport vehicle services into specific vehicle services according to a Leontief type production function.

We now turn to the production of export. The economy exports the following goods: capital goods, electricity, solid fuels, petrol products, transport vehicle services, rail freight services, inland navigation services and other goods and services. The export production function is assumed to be of the nested Leontief-CES type and combines the domestically produced good with transport. No transport is required for electricity, rail freight services and inland navigation services. The tree structure is represented in Figure 4. Congestion influences the input-output coefficient of road transport labour.

c. The Foreign Sector

As was discussed previously, goods are assumed to be differentiated according to country of origin. We adopt the Armington formulation and construct a composite commodity for each tradeable which is a CES function of the imported and the domestically produced goods. Given the prices of the imported and the domestic goods, their combination is chosen such that the cost of producing a given amount of the composite good is minimized. The elasticity of substitution of the CES function can be interpreted as the trade substitution elasticity. If it is high, the domestic and imported goods are close substitutes.

The country imports the following goods: capital good, electricity, solid fuels, petrol products, gas, transport vehicle services, inland navigation services and other goods. As was indicated above the
import production function combines the imported good with transport in Belgium. Transport is not required for electricity, gas and inland navigation services. The production structure is of the nested Leontief-CES type and is presented in figure 5.

The production structure for transit transport in Belgium is described in Figure 6.

d. The Congestion Function

The model includes a time-flow relationship which gives the minimum time requirement per unit of transport as a function of the traffic flow \( F \) and the capacity of the transport infrastructure (\( CAP \)). The time flow relationship is based on the one derived by Kirwan et al. (1995) from simulations with a network model, which is used to compute the impact on average speed of a proportional increase in all trips. Kirwan et al. (1995) conclude that the exponential type of time-flow relationship is the most satisfying. They propose the following general form:

\[
\theta_{TP,m}^{d} = A_{1,m} \left[ A_{2}(CAP) + A_{3}(CAP) \exp \left( A_{4}(CAP) \times F^{d} \right) \right]
\]

\( \theta_{TP,m}^{d} \) is the minimum time requirement for transport good \( m \) in period \( d \) (\( d = \) peak, off-peak). \( F^{d} \) is the traffic flow in period \( d \) in millions of passenger car units (PCU). For the road transport goods the traffic flow depends on the number of cars, road public transport vehicles and trucks. Other transport goods are assumed not to contribute to congestion on the road network. \( A_{1,m}, A_{2}, A_{3}, A_{4} \) are the parameters of the time flow relationship. For rail transport and inland navigation \( A_{3} \) and \( A_{4} \) are assumed to be zero, which implies a constant speed.

3. The Implementation of the Model

The starting point of the exercises is a reference equilibrium calibrated to the situation in Belgium in 1990\(^6\). The calibration of the model starts with the selection of parameters. The uncompensated labour supply elasticity equals 0.54 in the benchmark equilibrium, while the compensated labour supply elasticity equals 1.1. This implies a higher sensitivity than what is generally assumed in AGE models\(^7\). However, it is in line with evidence found by Hansson & Stuart (1985) who derive a median aggregate wage and total income elasticity on the basis of a survey of the literature. By taking a weighted average over estimates of labour supply elasticities of the more sophisticated studies in the literature, they obtain an aggregate medium wage and total income elasticity of 0.44 and -0.08 resp. This evidence is corroborated by later work of the same authors [Hansson & Stuart (1993)]. Fitting a

\(^{6}\) For details on the construction of the data set and on the calibration of the model, see Mayeres (1998b).

\(^{7}\) The large AGE models in the Shoven-Whalley tradition generally have a central estimate of 0.15 for the uncompensated wage elasticity [see e.g., Ballard et al. (1985)]. Ballard & Medema (1993) use 0.1 and 0.25 as their central estimate.
simplified general equilibrium model to aggregate data from a cross-section of 22 OECD economies, they derive an uncompensated wage elasticity of 0.66 and a compensated wage elasticity of 1.36 (with a standard error of 0.15 and 0.14 respectively) which is in line with their earlier findings. The authors also present uncompensated and compensated wage elasticities for the representative household in each of the OECD countries. For Belgium this gives an uncompensated and compensated wage elasticity of resp. 1.1 and 1.7. The central value assumed in our AGE model is lower than this value for Belgium, but is line with the central estimates of both studies by Hansson & Stuart.

The uncompensated own-price and income elasticities of the different consumer goods in the initial equilibrium are presented in Table 2.

Table 2: The Uncompensated Own Price Elasticities and the Income Elasticities in the Initial Equilibrium

<table>
<thead>
<tr>
<th>Own price elasticity</th>
<th>Income elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
</tr>
<tr>
<td>Car mileage (gasoline car)</td>
<td></td>
</tr>
<tr>
<td>Committed mileage</td>
<td>-0.16</td>
</tr>
<tr>
<td>Supplementary mileage</td>
<td>-0.43</td>
</tr>
<tr>
<td>Public transport pkm</td>
<td></td>
</tr>
<tr>
<td>Bus, tram, metro</td>
<td>-0.15</td>
</tr>
<tr>
<td>Rail</td>
<td>-0.54</td>
</tr>
<tr>
<td>Non-transport energy</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>-0.77</td>
</tr>
<tr>
<td>Solid fuels</td>
<td>-0.40</td>
</tr>
<tr>
<td>Petrol products</td>
<td>-0.40</td>
</tr>
<tr>
<td>Gas</td>
<td>-0.40</td>
</tr>
<tr>
<td>Capital goods</td>
<td>-0.69</td>
</tr>
<tr>
<td>Other goods and services</td>
<td>-0.78</td>
</tr>
</tbody>
</table>

On the producer side, the elasticities of substitution are based on Capros et al. (1997). The elasticities of substitution for freight transport are chosen on the basis of the elasticity estimates presented in Oum, Waters & Yong (1992).

The valuation of the externalities is based on the following sources. For the households, the value of a marginal time saving in transport is based on a willingness-to-pay study for the Netherlands [Hague Consulting Group (1990), Bradley (1990), Bradley & Gunn (1990)]. Table 3 gives an overview of the VOT in the initial equilibrium.
Table 3: The Value of a Marginal Time Saving in the Initial Equilibrium [BF(1990)/h]

<table>
<thead>
<tr>
<th></th>
<th>Car</th>
<th>Bus, tram, metro</th>
<th>Rail</th>
<th>Non-motorized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>212</td>
<td>168</td>
<td>205</td>
<td>112</td>
</tr>
<tr>
<td>Off-peak</td>
<td>188</td>
<td>137</td>
<td>177</td>
<td>112</td>
</tr>
</tbody>
</table>

Source: based on Hague Consulting Group (1990), Bradley (1990), Bradley & Gunn (1990)

The calibration of $\mu_{AP,po}$ and $\mu_{ACC,n}$ is based on the value for the marginal external air pollution and accident costs. Table 4 summarizes the marginal external air pollution costs in the initial equilibrium. The model includes the following air pollutants: NOx, SO2, HC, CO, CO2 and particulate matter with a diameter smaller than 10 and 2.5 microns (PM10 and PM2.5 resp.). The methodology for the calculation is to a large extent similar to the one presented in Mayeres, Ochelen & Proost (1996). However, we have chosen to integrate as much as possible recent information provided by the Extern-E project [Bickel et al. (1997), Hurley et al. (1997), Holland (1997)]. The marginal social air pollution costs consist mainly of health damage costs.

Table 4: The Marginal External Costs of Air Pollution in the Initial Equilibrium

NOTE: all values are expressed in BF(1990)/g; the values for CO and CO2 are expressed in BF(1990)/kg.

<table>
<thead>
<tr>
<th></th>
<th>Marginal external air pollution costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>0.0830</td>
</tr>
<tr>
<td>SO2</td>
<td>0.2372</td>
</tr>
<tr>
<td>HC</td>
<td>0.0101</td>
</tr>
<tr>
<td>CO</td>
<td>0.0918</td>
</tr>
<tr>
<td>CO2</td>
<td>0.5221</td>
</tr>
<tr>
<td>PM2.5</td>
<td>9.2330</td>
</tr>
<tr>
<td>PM10</td>
<td>0.8746</td>
</tr>
</tbody>
</table>

The methodology for calculating the marginal external accident costs is similar to that presented in Mayeres, Ochelen & Proost (1996). In the initial equilibrium these costs equal 0.972 BF/vkm for cars, 3.846 BF/vkm for buses, 0.005 BF/vkm for trams, 0.553 BF/vkm for trucks and 7.47 BF/pkm for nonmotorized transport. The high costs for motorized transport are explained by the relatively high accident risks of non-motorized transport users.

On the basis of these values we can calculate the marginal external costs of the different transport modes in the initial equilibrium. Table 5 gives an overview of these costs and compares them with the taxes which are paid. It is clear that for most transport modes and periods the marginal external costs are much lower than the taxes. In the peak the most important external cost category is congestion, in the off-peak air pollution and accidents are relatively more important.
Table 5: The Marginal External Costs of Road Transport in the Initial Equilibrium

<table>
<thead>
<tr>
<th></th>
<th>Marginal External Costs (BF(1990)/vkm)</th>
<th>Taxes as Percentage of Marginal External Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
<td>Off-peak</td>
</tr>
<tr>
<td><strong>Passenger transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-business car vkm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline car</td>
<td>9.53</td>
<td>3.13</td>
</tr>
<tr>
<td>Diesel car</td>
<td>11.36</td>
<td>4.96</td>
</tr>
<tr>
<td>LPG car</td>
<td>9.31</td>
<td>2.91</td>
</tr>
<tr>
<td><strong>Business car vkm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline car</td>
<td>9.53</td>
<td>3.13</td>
</tr>
<tr>
<td>Diesel car</td>
<td>11.36</td>
<td>4.96</td>
</tr>
<tr>
<td>LPG car</td>
<td>9.31</td>
<td>2.91</td>
</tr>
<tr>
<td><strong>Bus, tram, metro vkm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric vehicles</td>
<td>15.84</td>
<td>3.04</td>
</tr>
<tr>
<td>Diesel vehicles</td>
<td>38.44</td>
<td>25.64</td>
</tr>
<tr>
<td><strong>Road freight transport</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline van</td>
<td>9.41</td>
<td>3.01</td>
</tr>
<tr>
<td>Diesel van</td>
<td>11.63</td>
<td>5.23</td>
</tr>
<tr>
<td>Truck</td>
<td>29.65</td>
<td>16.85</td>
</tr>
</tbody>
</table>

III. Simulations

Once the parameters of the AGE model have been determined, it is used to undertake simulations. First, the reference equilibrium is replicated. Next, the model performs so-called revised case simulations. The difference between the two is that in the revised case simulations the policy instruments are changed. Two types of simulations are performed: balanced budget incidence and differential incidence simulations.

1. Balanced Budget Incidence Exercises

In the balanced budget incidence exercises we introduce a small increase in the level of separable government expenditure. The separability assumption is crucial. If it were relaxed, the analysis should have to take into account the relationship between taxed private goods and the change in government expenditure. The change in government spending is accompanied by a change in the tax system such that government budget balance is maintained. The paper considers several ways to finance the increase in government expenditure. For each alternative instrument $g$ the marginal cost of public funds ($MCF_g$) is computed. The $MCF_g$ gives the marginal cost in terms of welfare of the representative household of raising an additional unit of government revenue by means of instrument $g$. It is defined as the negative ratio of the change in welfare of the representative household and the change in government revenue brought about by instrument $g$. The change in welfare is measured by means of the concept of the...
equivalent gain [see King (1983)]. So,

\[ MCF_g = - \frac{EG_g}{dREV_g} \]  

(21)

For comparability, the real change in government revenue \((dREV_g)\) is assumed to be the same for all instruments. The equivalent gain associated with instrument \(g\) \((EG_g)\) is defined as that sum of money which the household would have accepted in the initial equilibrium as equivalent to the impact of the reform. It equals the change in equivalent income with respect to the initial equilibrium. The equivalent income is defined here as that level of income which, at the reference price vector and the reference levels of congestion, emissions and accidents, allows one to reach the same level of utility as can be attained under the initial price vector and level of congestion, emissions and accidents. The calculations say nothing about the social value of the change in government spending. This is because of the purpose of the MCF exercises. On the one hand, when the MCF calculations are used in cost-benefit analyses, the purpose is to compare the consumers’ welfare loss with the amount of revenue collected for the government. If the MCF is larger than one, the calculations indicate that the incremental government spending must generate more than a dollar of social value per dollar of costs in order to be socially worthwhile. It is the benefit side of the analysis which takes into account the utility that the increase in government spending provides to the households. On the other hand, the tax reform exercises aim to compare the MCF of two tax instruments in order to assess the possibility of revenue neutral tax reforms.

For the analysis of the results it will prove useful to decompose the marginal cost of public funds of each instrument \(g\) into three terms.

\[ MCF_g = MCF_g^A + MCF_g^B + MCF_g^C \]  

(22)

The first term \((MCF_g^A)\) is defined as the marginal cost of funds when emissions of air pollutants and accidents are assumed to remain at their reference level. However, given the way in which congestion is modelled, this term does take into account the welfare effect of the changes in speed. The second term \((MCF_g^B)\) presents the marginal welfare impact associated with the change in emissions. Finally, the last term \((MCF_g^C)\) is the marginal welfare impact of the change in accidents caused by the tax reform.

Our findings for the model with externalities will be contrasted with MCF calculations for the same model without externalities. In these calculations, the second and third term of \(MCF_g\) drop out and the first term does not include the welfare effects of the change in the minimum time requirements since these are assumed to be fixed. In the rest of the paper the MCF calculated by the model without externalities is referred to by the symbol \(MCF^\ast\).

The AGE model is used to compute the MCF and its components for four alternative instruments. These instruments are used to finance a 0.2% real increase in separable government expenditures. More particularly, we consider:

1. a lump sum tax: this instrument consists of a decrease in the poll transfer to the households, which accounts for 11.6% of generalized household income in the initial equilibrium. The poll transfer is decreased by 0.17% with respect to reference situation.
2. *an increase in the tax rate on labour income*: the income tax rate, which equals 44.80% in the initial equilibrium is increased by 0.1%.

The results for these two more conventional revenue generating tax instruments, are compared with those for instruments aimed specifically at the transport sector:

3. *an increase in the fuel tax*: this instrument consists of an increase in the excise on fuel used for road transport. In the initial equilibrium the excise on gasoline, diesel and LPG, expressed as a percentage of producer prices, equal 125.6%, 85.2% and 0% respectively. The increase in the excise equals 3 percentage points for all fuel types. The fact that the excise, rather than the VAT rate, is raised makes that the use of fuel for road transport both by the households and the domestic producers is taxed. Foreign road transport users are not to subject to this tax. The tax on fuel used by rail transport and inland navigation is assumed to remain constant in real terms.

4. *peak road pricing*: this instrument consists of the introduction of a tax of 0.1 BF per vkm for peak road transport. Both domestic and foreign road transport users are subject to this tax, regardless of the vehicle type.

Table 6 gives an overview of the results of balanced budget incidence exercises and compares the results of the AGE model with externalities with those of the AGE model without externalities.

The first part of Table 6 gives the $MCF^*$ and the corresponding ranking of the four policy instruments found for the AGE model without externalities. The MCF of all policy instruments is larger than one. E.g., the $MCF^*$ of the labour income tax equals 1.163. This means that the additional government expenditures should be undertaken only if their marginal benefits are at least 16.3% higher than the non-tax costs, if they are financed through an increase in the tax on labour income. The lump sum tax has the lowest $MCF^*$ because it has only revenue effects, while the other taxes have distortionary effects as well, caused by substitution away from the tax base.

The revenue effect of the lump sum tax

---

8 The change in the policy instruments is different for the model with and without the externalities, as is the exact change in government revenue. The values are summarized in the following table:

<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>AGE model with externalities</th>
<th>AGE model without externalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poll transfer</td>
<td>-0.1679%</td>
<td>-0.1645%</td>
</tr>
<tr>
<td>Labour income tax</td>
<td>+0.10382%</td>
<td>+0.1019%</td>
</tr>
<tr>
<td>Peak road pricing</td>
<td>+0.1 BF/vkm</td>
<td>+0.1 BF/vkm</td>
</tr>
<tr>
<td>Fuel tax</td>
<td>+2.9815 percentage points</td>
<td>+2.9589 percentage points</td>
</tr>
<tr>
<td>Real government expenditures</td>
<td>+0.1962 %</td>
<td>+0.1928%</td>
</tr>
</tbody>
</table>

9 In addition to the revenue and the distortionary effect, the literature also identifies the spending or budget effects as determinants of the value of the MCF. These reflect the influence of public spending on the size of the tax base. Since in our exercises the tax change is used to finance the level of separable government spending, this third effect is absent here.
increases labour supply, but decreases the consumption of the other taxed goods. This explains why the MCF of the lump sum tax is larger than 1. The welfare costs of the other instruments range from 1.158 for fuel taxes and 1.163 for the labour income tax to 1.187 for peak road pricing. The MCF of the labour income tax is high because the initial labour income tax rate is high and labour supply is elastic, which implies erosion of the tax base. The MCF for peak road pricing is the highest, because its tax base is small and raising the government revenue implies a relatively large increase in the tax on peak road transport and higher distortions.

Table 6: Balanced Budget Incidence Simulations: The Marginal Cost of Public Funds

<table>
<thead>
<tr>
<th></th>
<th>Lump sum tax</th>
<th>Labour income tax</th>
<th>Fuel tax</th>
<th>Peak road pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model without externalities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCF</td>
<td>1.093</td>
<td>1.163</td>
<td>1.158</td>
<td>1.187</td>
</tr>
<tr>
<td>Ranking</td>
<td>(1)</td>
<td>(3)</td>
<td>(2)</td>
<td>(4)</td>
</tr>
<tr>
<td><strong>Model with externalities</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MCF</td>
<td>1.074</td>
<td>1.113</td>
<td>0.805</td>
<td>0.692</td>
</tr>
<tr>
<td>Ranking</td>
<td>(3)</td>
<td>(4)</td>
<td>(2)</td>
<td>(1)</td>
</tr>
<tr>
<td>MCF^A</td>
<td>1.080</td>
<td>1.139</td>
<td>0.966</td>
<td>0.795</td>
</tr>
<tr>
<td>MCF^B</td>
<td>-0.001</td>
<td>-0.021</td>
<td>-0.124</td>
<td>-0.078</td>
</tr>
<tr>
<td>MCF^C</td>
<td>-0.004</td>
<td>-0.005</td>
<td>-0.037</td>
<td>-0.025</td>
</tr>
</tbody>
</table>

Acknowledging the presence of externalities changes the ranking of the policy instruments significantly, as is clear from the second part of Table 6. Peak road pricing now has the lowest MCF, followed by the excise on fuel for road transport. In these two cases the value of the MCF is below one. E.g., in the case of peak road pricing, the MCF equals 0.692. This means that, because of the efficiency effects of the tax, the increase in government spending financed with this instrument would still be welfare improving with a social benefit of only 70% of non-tax costs. The MCF of the lump sum tax and the labour income tax is higher than one. First, we discuss the results for the lump sum tax and the labour income tax and then we turn to the other instruments.

In the case of the lump sum tax and the labour income tax, the MCF is lower than the MCF. The reason for this is that the instruments have an impact on the level of congestion. In order to explain the impact of the policy changes on the level of the externalities, it is useful to decompose these marginal externality impacts into three components. They are summarized in Figure 1.

Figure 1: The Components of the Marginal Externality Impact

The first two components are the activity and the composition effect [see e.g., Bovenberg and van de Ploeg (1994)]. The activity effect consists of the impact on the level of economic activity. A reduction in the level of economic activity can be expected to lead to a lower use of externality generating goods and therefore to reduce the level of the externalities. The composition effect refers to the effect of the change in the composition of the economic activity. The composition of the economic activity may change because of the switch in private and public sectors between activities with different impacts on the externalities. Secondly, there is the effect of the switch from private to public consumption, which will reduce the externality level if public consumption generates less externalities than private consumption. Adding these two effects gives the gross composition effect. Bovenberg & van der Ploeg (1994) include the public abatement effect as the second determinant of the composition effect. However, since the present version the AGE model does not include the possibility of public abatement, this effect is zero in our case. The third determinant of the composition effect is the feedback effect. It is associated with the impact on the behaviour of the economic agents induced by the change in the level of the externality. In our model the feedback effect is present only for congestion, since this is the only externality which
provides a non-separable contribution to the households’ welfare and has an impact on the productivity of inputs at the production side of the economy. The feedback effect can be expected to counteract the first two components of the composition effect. This is because a decrease in the level of congestion will induce the economic agents to use more transport, which increases the level of congestion again. The feedback effect is absent in models where the level of the externality does not influence the behaviour of the economic agents. This explains why it was not included in Bovenberg & van de Ploeg (1994).

The final component of the marginal externality impact is related to the impact of the policy change on the monetary valuation of the different externalities. We term this the valuation effect. In the model the monetary value of a marginal time saving, of a change in emissions and of a change in accident costs is affected by the policy changes and will therefore influence the value of the MCF.

In the case of the labour income tax the activity level of the economy is reduced because public consumption rises less than private consumption falls. This can be explained as follows. The increase in the labour income tax rate reduces the real after tax wage rate, which leads to a lower labour supply. The resulting decrease in generalised income reduces the demand for all goods by the households, except nonmotorized transport. The activity effect is also present at the production side of the economy. The decrease in household demand leads to a reduction of production levels and to a reduction in the total number of tkm transported in Belgium by the domestic production sectors. The switch from private to public consumption strengthens the activity effect, since the public consumption generates no externalities. However, the combination of these two effects is mitigated to some extent by the feedback effect: the increase in speed causes the representative household to use more road transport. The same phenomenon is present at the production side of the economy where for the domestic production sectors, the increase in speed of road freight transport causes tkm transported by this mode to fall less than tkm transported by freight rail and inland navigation. Moreover, the use of road freight transport of imports and transit transport increases because of the same reason. Still, even when the feedback effect is taken into account, the overall impact is that the level of congestion is lower than in the initial equilibrium.

We now turn to the two other components of the MCF. MCF\textsuperscript{A} reflects the additional welfare costs associated with the change in emissions. For both instruments, air pollutant emissions are lower than in the initial equilibrium. The labour income tax has a larger impact on transport emissions than the
lump sum tax. This can be explained as the result of the combined activity and composition effects which were described above. The non-transport related emissions consist of the emissions caused by the use of energy for non-transport purposes by the household and the production sectors. In the case of the labour income tax the activity effect leads to a decrease in the use of non-transport energy. It is reinforced by the gross composition effect: total domestic demand for solid fuels is reduced slightly more than the demand for the other non-transport energy products. The feedback effect is absent, while the shift from private to public consumption reduces emissions further. This also holds when the lump sum tax is used. However, in that case the activity effect leads to an increase in the emissions which is also reinforced by the gross composition effect. The use of all non-transport energy goods except electricity increases. However, the percentage increase in the use of solid fuels is larger than that of petrol products and gas.

MCF<sup>c</sup> reflects the change in transport accident costs, which is of relatively small importance in both cases. The combined activity and feedback effect are counteracted by the gross composition effect: though the shift from private to public consumption reduces accident costs, the representative household switches from motorized to nonmotorized transport which is characterized by higher marginal external accident costs.

In all components of the MCF the valuation effect is present. The value of a marginal time saving is slightly lower in the new equilibrium. This causes the welfare gain of a decrease in congestion to be lower than if the VOT had remained constant. The difference is appr. -0.05% when the lump sum tax is changed and -0.075% when the labour income tax is used instead. The change in the monetary valuation of emissions and accidents is 0.057% lower when the labour income tax is used and 0.045% lower for the lump sum tax. One can conclude that the valuation effect does not impact the results of the exercises significantly for small changes in the lump sum tax and labour income tax.

b. Balanced Budget Incidence: Peak Road Pricing and the Fuel Tax

The fact that peak road pricing is a very efficient instrument to tackle the congestion problem is reflected in the large difference between MCF<sup>A</sup> and MCF<sup>B</sup>. It is because of this change that peak road pricing becomes the most efficient instrument to finance the increase in government expenditures when externalities are taken into account. The gross composition effect is the main explanation for this result. The imposition of a tax on peak road transport induces the representative household and the domestic production sectors to switch from peak car to off-peak car transport, and to the other transport modes. The percentage changes are smaller for business than for non-business transport. As regards freight transport, there is a switch from peak to off-peak road freight transport and from road freight transport to inland navigation and freight rail. However, the effect on transit transport is relatively larger than for domestic and import related transport given the high price sensitivity of this type of transport. The gross composition effect is offset to a small extent by the feedback effect.

The real after tax wage rate decreases. This is because the tax on peak road transport acts as an implicit tax on labour income. Moreover, the input of transport in the production sectors is reduced. This decreases the productivity of the other inputs in the production process. Part of the burden will be borne by labour. However, the negative effect of the decrease in the real wage rate on labour supply is offset by
the fact that time devoted to transport falls (because of the speed increase and the reduction in the consumption of transport) and is devoted instead to labour and leisure. The net effect is that both leisure and labour increase, while transport time becomes less important. Labour income is lower than in the initial equilibrium, while capital income is increased. With a fixed capital stock, a higher demand for capital services causes prices to increase. However, total household income is lower which results in a lower household demand for all goods. Therefore, on the household side the activity effect reinforces the intensity effect. The domestic production sector becomes more competitive, such that an opposite activity effect is observed there.

The welfare gain of the reduction in congestion level is mitigated by a change in the VOT. The most pronounced changes are observed for peak car transport and for bus, tram and metro transport. For peak car transport the VOT is reduced by 0.17%, while it is reduced by 0.33% for bus, tram and metro transport.

The downward pressure on the MCF from the congestion effect is strengthened by the effect on emissions. The reduction in emissions is mainly due to the reduction in transport emissions. The change in accident costs also reduces the MCF but is of smaller importance. It should be noted that for all tax instruments the final ranking of the policy instruments (i.e., on the basis of the total MCF) is the same whether MCF\textsuperscript{C} is taken into account or not.

Compared to peak road pricing the fuel tax is a less efficient instrument for tackling the congestion problem. Both peak and off-peak transport are discouraged by this instrument, which accounts for the fact that the ranking of the fuel tax and peak road pricing is reversed when incorporating the effect on the congestion level\textsuperscript{10}. The resulting reduction in congestion is offset partly by the feedback effect. Part of this feedback effect consists of the increase in transport in Belgium by foreign economic agents, since these are not subject to the increase in the fuel tax but can benefit from the higher speeds on Belgian roads. The impact on accident and air pollution costs is higher than in the case of peak road pricing, because transport is reduced more.

The balanced budget incidence analysis gives information on which revenue neutral policy reforms are welfare improving with respect to the initial equilibrium. Table 6 indicates that welfare can be improved by introducing peak road pricing or raising the fuel tax and by recycling the revenue through an increase in the poll transfer or a reduction in the labour income tax rates. It also suggests that the welfare improvement will be higher when the revenue is recycled through a decrease in the labour income tax rate rather than through the increase in the poll transfer. Indeed, the MCF of the lump sum tax is lower than that of the labour income tax. The next section elaborates on these findings by presenting a number of so-called differential incidence exercises.

\textsuperscript{10} One should note that the model does not yet take into account the possibility to switch to more fuel efficient vehicles. If this were possible, the fuel tax would be an even less efficient instrument to tackle congestion. Moreover, the tax on fuel should be set higher in order to finance the increase in separable government expenditures, which would exert an upward pressure on the MCF.
2. Differential Incidence Exercises

In the differential incidence analysis, one type of tax is replaced by another such that real government revenue is preserved at its original level. This is an important assumption, because otherwise the results would be a mixture of the effects of changes in tax system with those of changes in the overall size of the government. The change in the tax system will generally lead to different equilibrium prices. Therefore, assuming that the government receives the same amount of money as it did before the tax change is not satisfactory, since the goods that the government buys with that money will have changed in price. Shoven & Whalley (1977) discuss a number of ways to maintain revenue yield equality. In the present model, a utility function is formulated for the government and the corresponding expenditure function is used to calculate the government revenue required to achieve constant utility at any set of prices. The expenditure function gives the amount of money necessary to attain a given level of utility at a given set of prices. When simulating the effects of tax changes in the differential incidence simulations, we give the government enough revenue so that its utility remains constant at the level of the initial equilibrium.

Table 7 presents the welfare change of a small increase in the fuel tax and the introduction of peak road pricing for two different ways of revenue recycling: an increase in the poll transfer or a decrease in the labour income tax rate. The welfare change is measured by means of the equivalent gain ($EG$) which is split into three parts. $EG^g$ gives the equivalent gain at a constant level of emissions and accidents. $EG^p$ and $EG^c$ give the additional equivalent gain associated with the change in emissions and accidents respectively. The lower part of the table gives the equivalent gain as a percentage of the equivalent income in the reference equilibrium (EI$_{ref}$). It becomes clear from the table that the welfare gain is higher when the revenue is recycled through a change in the labour income tax rather than the transfer. This is due to the gross welfare costs (i.e. the welfare cost without taking into account the effect on the externalities), since the advantage of the labour income tax is somewhat offset by the higher level of congestion, emissions and accident costs in comparison with the lump sum transfer. Moreover, we know from the model without externalities that MCF is larger for the labour income tax than for the lump sum tax. The link can be made with the double dividend literature, which analyses revenue neutral environmental tax reforms which consist of increasing the tax on the externality generating good and of recycling the revenue obtained either by increasing the lump sum transfer or by reducing existing distortionary taxes. In the terminology of Goulder (1995), our results imply that a weak double dividend can be realized both for the fuel tax and for peak road pricing: by using the revenues of these taxes to finance a reduction in the labour income tax rate, one obtains a gross welfare gain relative to the case where the lump sum tax is used to return the revenue. The stronger versions of the double dividend hypothesis claim that the revenue neutral substitution of the externality tax for existing distortionary taxes leads to zero or negative gross welfare costs. From the first part of Table 6 we can conclude that a strong double dividend is present when the revenue from the increase in the fuel tax is recycled through

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11 For comparability, it is assumed that both instruments raise the same amount of real government revenue.
the labour income tax. The effect is not present for peak road pricing. Indeed, the MCF of the fuel tax is lower than that of the labour income tax, while the opposite is true in the case of peak road pricing.

IV. Conclusions and Extensions

The paper calculates the MCF of different policy instruments using an AGE model for Belgium. The model incorporates three types of externalities: congestion, which has a feedback effect on the behaviour of the economic agents, air pollution and accidents. The balanced budget incidence analysis shows that the ranking of the policy instruments in terms of their MCF changes significantly when the effect of the policy reform on the externalities is taken into account. The effects of the changes in congestion and air pollution are the most important. Secondly, it is shown that the welfare gain of an externality tax (such as a fuel tax or peak road pricing) is higher when the revenues from such a tax are devoted to reducing an existing distortionary tax (such as the labour income tax) rather than to increasing the poll transfer. This is explained by the difference in gross welfare costs between the lump sum tax and the labour income tax. A weak double dividend can be realized. The model shows that a strong double dividend could be realized by substituting the fuel tax for the labour income tax. Sensitivity analyses should shed more light on the results of the model. The main sensitivity analyses would involve the labour supply elasticities, the valuation of a reduction in the externalities and the elasticities of transport use.

The paper can be extended in several ways. The first extension consists of the inclusion of several household types, which would allow to study not only the efficiency impacts but also the distributional impacts of policy reforms. A second extension consists of the inclusion of non-separable rather than separable government expenditures which are to be financed by a change in the tax system. A natural candidate for this would be government spending on road capacity. Thirdly, the model assumes that there is no voluntary unemployment. We are in a Walrasian setting. Since the labour market determines the outcome of the model, it might be relevant to model it more realistically. The presence of involuntary unemployment also has an impact on the marginal value of time. The valuation of an additional unit of leisure is lower than the wage rate when there is involuntary unemployment, i.e. when the household is forced to work less than it wants to. As a consequence the value of a marginal time saving will be lower than if there is no restriction on the labour supply. This is important for the evaluation of the benefits of a policy reform. Finally, the assumption that air pollution and accidents enter the households’ preferences in a separable way, can be relaxed. This way, general equilibrium effects of the change in air pollution and accidents can be incorporated in the model.
Table 7: Differential Incidence Exercises: The Equivalent Gain with Different Ways of Revenue Recycling

<table>
<thead>
<tr>
<th>Revenue recycled by</th>
<th>EG</th>
<th>EG&lt;sup&gt;A&lt;/sup&gt;</th>
<th>EG&lt;sup&gt;B&lt;/sup&gt;</th>
<th>EG&lt;sup&gt;C&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change in transfer</td>
<td>Change in tax on labour income</td>
<td>Change in transfer</td>
<td>Change in tax on labour income</td>
</tr>
<tr>
<td>Policy instrument</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel tax</td>
<td>1462</td>
<td>1676</td>
<td>615</td>
<td>937</td>
</tr>
<tr>
<td>Peak road pricing</td>
<td>2080</td>
<td>2293</td>
<td>1548</td>
<td>1868</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenue recycled by</th>
<th>EG&lt;sup&gt;/EI&lt;sub&gt;ref&lt;/sub&gt;&lt;/sup&gt;</th>
<th>EG&lt;sup&gt;A/EI&lt;sub&gt;ref&lt;/sub&gt;&lt;/sup&gt;</th>
<th>EG&lt;sup&gt;B/EI&lt;sub&gt;ref&lt;/sub&gt;&lt;/sup&gt;</th>
<th>EG&lt;sup&gt;C/EI&lt;sub&gt;ref&lt;/sub&gt;&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change in transfer</td>
<td>Change in tax on labour income</td>
<td>Change in transfer</td>
<td>Change in tax on labour income</td>
</tr>
<tr>
<td>Policy instrument</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel tax</td>
<td>0.0041%</td>
<td>0.0047%</td>
<td>0.0017%</td>
<td>0.0026%</td>
</tr>
<tr>
<td>Peak road pricing</td>
<td>0.0058%</td>
<td>0.0064%</td>
<td>0.0043%</td>
<td>0.0052%</td>
</tr>
</tbody>
</table>
References


De Borger B., S. Ochelen, S. Proost, S. and D. Swysen (1997), Alternative Transport Pricing and


Mayeres, I. (1998b), The Applied General Equilibrium Model for Belgium: Model Implementation,
mimeo, C.E.S., K.U.Leuven.


Overall direct utility $U$

- **Current consumption of goods and time**
  - non-leisure goods and time
  - Leisure
  - Transport (see figure 1b)
  - Non-tp energy and other goods
    - Non-tp energy
    - Other goods
      - Electricity
      - Solid fuels
      - Petrol products
      - Gas

- **Future consumption**

**level**

- $w=0$ Overall direct utility is a Cobb-Douglas type function of present and future consumption
- $w=1$ Current consumption of goods and time is a MCES function of the non-leisure goods and time component and excess leisure
- $w=2$ The non-leisure goods and time utility component is a MCES function of the transport and the non-tp energy and other goods components
- $w=3$ The non-tp energy and other goods component is a MCES function of the excess quantities of other goods and the non-tp energy utility component
- $w=4$ The non-tp energy utility component is a MCES function of the excess quantities of electricity, solid fuels, petrol products and gas
Figure 1b: The Direct Utility Function (ctd)

Transport

Peak

Off-peak

Car

Bus, tram

metro

Rail

Non-motorized

w=3

The transport utility component is a MCES function of peak and off-peak transport

w=4

In each period, transport is a MCES function of transport by different modes

w=5

- Car transport is a MCES function of transport by different car types
  - The utility component of the other transport modes is a MCES function of the excess quantities of physical pkm and transport time

w=6

Car transport by the different vehicle types is a MCES function of committed and supplementary mileage

w=7

Committed and supplementary mileage are a MCES function of the excess quantities of physical pkm and transport time

w=8

Physical pkm is a Leontief function of vehicle services, fuel and maintenance in the case of committed mileage, and of fuel and maintenance in the case of supplementary mileage

level

Gasoline
car

Diesel
car

LPG
car

... committed
mileage

supplementary
mileage

veh. fuel maint.

fuel maint.
Figure 2a: The Production Structure of Type I and Type II Production Sectors (the upper part)

- Gross output is a MCES function of the capital, non-transport labour component, the transport component and the non-transport energy, other goods component
- The capital, non-transport labour component is a MCES function of capital and non-transport labour
- The non-tp energy, other goods component is a MCES function of the other goods component and the non-transport energy component
- The non-tp energy component is a MCES function of different non-transport energy inputs
Figure 2b: The Transport Component for Type I Production Sectors

Transport

Freight
- Freight transport is a MCES function of freight rail, inland navigation and road transport

Business
- Business transport is a MCES function of peak and off-peak transport

Freight rail

Road

Inland navigation

Peak
- Road freight transport is a MCES function of peak and off-peak transport
- In each period, business transport is a MCES function of car and rail transport

Off-peak

Peak

Off-peak

Car

Rail

Vehicle types

Vehicle types

Committed mileage

Supplementary mileage

Committed mileage

Supplementary mileage

veh. services

fuel

maint.

tp labour

fuel

maint.

tp labour

level

w=1 Transport is a MCES function of freight and business transport

w=2 - Freight transport is a MCES function of freight rail, inland navigation and road transport
- Business transport is a MCES function of peak and off-peak transport

w=3 - Road freight transport is a MCES function of peak and off-peak transport
- In each period, business transport is a MCES function of car and rail transport

w=4 - In each period, road freight transport is a MCES function of different vehicle types
- Car business transport is a MCES function of different vehicle types
- Rail business transport is a Leontief function of pkm and transport labour *

w=5 Both for freight and business transport, transport is a MCES function of committed and supplementary mileage

w=6 - Committed mileage is a Leontief function of vehicle services, fuel, maintenance and transport labour *
- Supplementary mileage is a Leontief function of fuel, maintenance and transport labour *

* The input-output coefficient for road transport labour depends on the congestion level
Figure 3: The Transport Component in Type II Production Sectors

Figure 3a: Peak Public Passenger Transport (goods 5a,6a)

Transport \( w=1 \)
\[ \text{Transport is a MCES function of different vehicle types} \]

\[ \text{vehicle types} \]

\[ \text{vehicle services} \]

\[ \text{fuel} \]

\[ \text{maint.} \]

\[ \text{tp} \]

\[ \text{labour} \]

Figure 3b: Freight Rail and Inland Navigation (goods 7, 8)

Transport \( w=1 \)
\[ \text{Transport is a MCES function of different vehicle types} \]

\[ \text{vehicle types} \]

\[ \text{committed mileage} \]

\[ \text{supplementary mileage} \]

Committed mileage \( w=2 \)
\[ \text{transport is a Leontief function of vehicle services, fuel, maintenance and transport labour (For good 5a, the input-output coefficient of transport labour depends on the congestion level)} \]

Supplementary mileage \( w=3 \)
\[ \text{fuel}, \text{maintenance and transport labour} \]

level

- 37 -
Figure 4: The Production of Export (goods 1, 2b, 2c, 3, 9)

- **Export**
  - **Domestically produced good**
    - Transport
      - **Freight rail**
      - **Road**
      - **Inland navigation**
        - **abroad**
        - **in Belgium**
      - **abroad**
      - **in Belgium**
    - **Committed mileage**
    - **Supplementary mileage**
    - **Peak**
    - **Off-peak**
      - **...**
    - **Committed mileage**
    - **Supplementary mileage**

- **w=0** The export of the domestically produced good is a Leontief function of the domestically produced good and transport.
- **w=1** Transport is a MCES function of freight rail, inland navigation and road transport.
- **w=2** Inland navigation and road transport are a MCES function of transport in Belgium and abroad.
- **w=3** - Road transport in Belgium is a MCES function of peak and off-peak transport.
  - Road transport abroad is a MCES function of committed and supplementary mileage.
- **w=4** - Peak and off-peak transport in Belgium are a MCES function of committed and supplementary mileage.
  - Committed and supplementary mileage are a Leontief function of their resp. inputs.
- **w=5** Committed and supplementary mileage are a Leontief function of their resp. inputs. The input-output coefficient for road transport labour depends on the level of congestion in Belgium.
Figure 5: The Production of Import (goods 1, 2b, 2c, 3, 9)

- Import is a Leontief function of the imported good and transport in Belgium
- Transport is a MCES function of freight rail, inland navigation and road transport
- Road transport is a MCES function of peak and off-peak transport
- In each period transport is a MCES function of committed and supplementary mileage
- Committed and supplementary mileage are a Leontief function of their resp. inputs. The input-output coefficient of road transport labour depends on the congestion level in Belgium.
Figure 6: Freight Transit Transport in Belgium

Freight transit transport in Belgium is a MCES function of freight rail, inland navigation and road transport.

Road transport is a MCES function of peak and off-peak transport.

Road transport in each period is a Leontief function of vehicle services, fuel, maintenance and transport labour. The input-output coefficient for road transport labour depends on the congestion level in Belgium.
APPENDIX 1: List of symbols

Indices (ordered alphabetically)

\(d\) Index of the time period \((d=\text{peak, off-peak})\)
\(en=1,\ldots,EN\) Index of non-transport energy goods
\(g\) Index of government instruments
\(j=1,\ldots,J\) Index of goods \((J=M+K)\)
\(k=1,\ldots,K\) Index of non-transport goods
\(K\) Capital good
\(m=1,\ldots,M\) Index of transport goods
\(n\) Index of accident types
\(po=1,\ldots,PO\) Index of air pollutants
\(r\) Can take two values: \(TP\) for transport goods and \(NTP\) for non-transport goods
\(v\) Corresponds with the index \(m\); however, \(v\) includes external objects as an extra element

Other symbols (ordered alphabetically)

\(A_{1,m}A_{2},A_{3},A_{4}\) The parameters of the time flow relationship.
\(ACC\) The vector of transport accidents
\(ACC_{m}^{n}\) The number of transport accidents of type \(n\) in which transport mode \(m\) is the victim
\(ACC_{m}^{ref,n}\) The number of transport accidents of type \(n\) in the initial equilibrium in which transport mode \(m\) is the victim
\(ar_{m,v}^{n}\) The probability that an accident of type \(n\) occurs between transport modes \(m\) and \(v\) in which \(m\) is the victim
\(c\) Endowment of capital services of each household
\(CAP\) Transport infrastructure capacity
\(EM\) Vector of emissions of air pollutants \(EM=(EM_{1},\ldots,EM_{po})\)
\(EM_{po}^{ref}\) Emissions of air pollutant \(po\) in the reference equilibrium
\(emen_{po,en}\) Emissions of pollutant \(po\) per unit of consumption of the non-transport energy good \(en\)
\(emtp_{po,m}\) Emissions of pollutant \(po\) per unit of consumption of the transport good \(m\)
\(ex_{j}\) The export demand for good \(j\)
\(ex_{j}\) Total world demand for good \(j\)
\(f_{ACC}\) Utility related to transport accidents
\(f_{EM}\) Utility related to emissions of air pollutants
\(f_{ui}\) Direct utility function
\(F\) Traffic flow
\(F^d\) The road traffic flow in period \(d\) in millions of passenger car units
\(I\) Number of identical households
\(INTTF\) Net international transfer by each household
\(LABEXP\) Time devoted by each household to labour abroad
\(lh\) Consumption of leisure by each household
\(mu_{ACC,n}\) The marginal utility to each household of a decrease in the number of accidents of type \(n\)
\(mu_{TP,po}\) The marginal utility to each household of a decrease in the emissions of pollutant \(po\)
\(P\) The poll transfer paid by the government to each household
\(ptt\) The price of transit transport in the country
\(pttw\) The price of transit transport abroad
\(pw_{j}\) The world price of good \(j\) (expressed in terms of the domestic currency)
\(px_{j}\) The export price of the domestic good \(j\)
\(q_{NTP,k}\) The consumer price of the non-transport good \(k\)
The consumer price of the transport good $m$

$q_{TP,m}$

The consumer price of capital services

$q_C$

Endowment of time of each household

$T$

The demand for transit transport in Belgium

$\Pi$

Total demand for international transport by foreign firms

$U$

Household utility

$V$

Indirect utility function

$wh$

The after tax wage rate

$xab_{TP,m}$

The input of the foreign transport good $m$ by the foreign production sector $j$ for transport of the import good $j$ in Belgium

$xh_{NTP}$

$K$ vector of each household’s consumption of non-transport goods

$xh_{NTP}=(xh_{NTP,1},...,xh_{NTP,M})$

$x_{TP}$

$M$ vector of each household’s consumption of transport goods $x_{TP}=(x_{TP,1},...,x_{TP,M})$

$xp_{NTP,\text{en}}$

The input of the non-transport energy good $en$ by the domestic production sector $j$

$xp_{TP,m}$

The input of the transport good $m$ by the domestic production sector $j$ for domestic delivery of good $j$

$x_{TP,m}$

The input of the transport good $m$ for transit transport in Belgium

$xx_{TP,m}$

The input of the transport good $m$ by the domestic production sector $j$ for transport of the exported good $j$ in Belgium

$X_{NTP,\text{en}}$

Total consumption in Belgium of the non-transport energy good $en$

$X_{TP,m}$

Total consumption in Belgium of the transport good $m$

$X_{TP}$

$M$ vector of total consumption in Belgium of transport goods

$Z$

The congestion level

$(\frac{\partial}{\partial TP,m})$

The marginal utility to each household of saving time in the consumption of transport good $m$

$0t$

Minus the elasticity of transit transport in Belgium w.r.t. the price of transit transport in Belgium

$0\chi_j$

Minus the price elasticity of export demand w.r.t. the export price of domestic goods

$2_{TP,m}$

The minimum time requirement for transport mode $m$ in period $d$

$2h_{TP}$

$M$ vector of time devoted by each household to the consumption of transport goods

$2h_{TP}=(2h_{TP,1},...,2h_{TP,M})$

$2h_{TP,m}^*$

The minimum time requirement for the consumption of transport good $m$

$8$

The marginal utility of income to each household

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List of abbreviations

AGE  
Applied general equilibrium

CO  
Carbon monoxide

CO$_2$  
Carbon dioxide

EG  
Equivalent gain

EI$_{ref}$  
Equivalent income in the initial equilibrium

HC  
Hydrocarbons

MCF  
Marginal cost of public funds

NO$_x$  
Nitrogen oxide

PCU  
Passenger car units

PM  
Particulate matter

SO$_2$  
Sulphur dioxide
APPENDIX 1: List of symbols

Indices (ordered alphabetically)

- $d$ Index of the time period ($d=$peak, off-peak)
- $en=1,...,EN$ Index of non-transport energy goods
- $g$ Index of government instruments
- $j=1,...,J$ Index of goods ($J=M+K$)
- $k=1,...,K$ Index of non-transport goods
- $K$ Capital good
- $m=1,...,M$ Index of transport goods
- $n$ Index of accident types
- $po=1,...,PO$ Index of air pollutants
- $r$ Can take two values: $TP$ for transport goods and $NTP$ for non-transport goods
- $v$ Corresponds with the index $m$; however, $v$ includes external objects as an extra element

Other symbols (ordered alphabetically)

- $A_{1,m},A_{2},A_{3},A_{4}$ The parameters of the time flow relationship.
- $ACC$ The vector of transport accidents
- $ACC^n_m$ The number of transport accidents of type $n$ in which transport mode $m$ is the victim
- $ACC^n_{ref,m}$ The number of transport accidents of type $n$ in the initial equilibrium in which transport mode $m$ is the victim
- $ar^n_{m,v}$ The probability that an accident of type $n$ occurs between transport modes $m$ and $v$ in which $m$ is the victim
- $c$ Endowment of capital services of each household
- $CAP$ Transport infrastructure capacity
- $EM$ Vector of emissions of air pollutants $EM=(EM_1,...,EM_{po})$
- $EM^n_{po}$ Emissions of air pollutant $po$ in the reference equilibrium
- $emen^n_{po,en}$ Emissions of pollutant $po$ per unit of consumption of the non-transport energy good $en$
- $emtp^n_{po,m}$ Emissions of pollutant $po$ per unit of consumption of the transport good $m$
- $ex_j$ The export demand for good $j$
- $ex^n_j$ Total world demand for good $j$
- $f_{ACC}$ Utility related to transport accidents
- $f_{EM}$ Utility related to emissions of air pollutants
- $f_U$ Direct utility function
- $F$ Traffic flow
- $F^d$ The road traffic flow in period $d$ in millions of passenger car units
- $I$ Number of identical households
- $INTTF$ Net international transfer by each household
- $LABEXP$ Time devoted by each household to labour abroad
- $lh$ Consumption of leisure by each household
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The consumer price of the transport good $m$
$q_{TP,m}$
The consumer price of capital services
$q_{C}$
Endowment of time of each household
$T$
The demand for transit transport in Belgium
$\pi$
Total demand for international transport by foreign firms
$U$
Household utility
$V$
Indirect utility function
$wh$
The after tax wage rate
$x_{ab,TP,m}^{j}$
The input of the foreign transport good $m$ by the foreign production sector $j$ for transport of the import good $j$ in Belgium
$xh_{NTP}$
$K$ vector of each household’s consumption of non-transport goods
$xh_{NTP}=(xh_{NTP,1},...,xh_{NTP,K})$
$xh_{TP}$
$M$ vector of each household’s consumption of transport goods $xh_{TP}=(xh_{TP,1},...,xh_{TP,M})$
$x_{NTP,en}^{j}$
The input of the non-transport energy good $en$ by the domestic production sector $j$
$x_{TP,m}^{j}$
The input of the transport good $m$ by the domestic production sector $j$ for domestic delivery of good $j$
$x_{TP,m}^{d}$
The input of the transport good $m$ for transit transport in Belgium
$x_{TP,m}$
The input of the transport good $m$ by the domestic production sector $j$ for transport of the exported good $j$ in Belgium
$X_{NTP,en}$
Total consumption in Belgium of the non-transport energy good $en$
$X_{TP,m}$
Total consumption in Belgium of the transport good $m$
$X_{TP}$
$M$ vector of total consumption in Belgium of transport goods
$Z$
The congestion level

$\ell_{TP,m}$
The marginal utility to each household of saving time in the consumption of transport good $m$
$0t$
Minus the elasticity of transit transport in Belgium w.r.t. the price of transit transport in Belgium
$0x_j$
Minus the price elasticity of export demand w.r.t. the export price of domestic goods
$z_{TP,m}^{d}$
The minimum time requirement for transport mode $m$ in period $d$
$2h_{TP}$
$M$ vector of time devoted by each household to the consumption of transport goods
$2h_{TP}=(2h_{TP,1},...,2h_{TP,M})$
$2h_{TP,m}^*$
The minimum time requirement for the consumption of transport good $m$
$\beta$
The marginal utility of income to each household

List of abbreviations

AGE Applied general equilibrium
CO Carbon monoxide
CO$_2$ Carbon dioxide
EG Equivalent gain
EI$_{ref}$ Equivalent income in the initial equilibrium
HC Hydrocarbons
MCF Marginal cost of public funds
NO$_x$ Nitrogen oxide
PCU Passenger car units
PM Particulate matter
SO$_2$ Sulphur dioxide