The Distributional Impacts of Policies for the Control of Transport Externalities
An Applied General Equilibrium Model[1]

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Technical abstract

The paper uses an applied general equilibrium model, calibrated to the situation in Belgium in 1990, to evaluate the welfare effects of small policy changes in the presence of transport 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. The model is used to perform balanced budget incidence simulations in which the marginal cost of public funds is calculated for four alternative policy instruments: a lump sum tax, the labour income tax, the fuel taxes and peak road pricing. For each of these instruments the marginal cost of public funds is calculated. The results of the model are compared with those of a model in which congestion, air pollution and accidents are assumed to remain constant at their initial level.

The model contributes to the literature in two ways. First of all, it includes non-identical individuals which allows to analyse the equity effects of the policy reforms. The second contribution is related to the way in which the externalities are modelled: the feedback effect of congestion is explicitly taken into account and the value of a marginal time saving is determined endogenously in the model.

The simulations show that the ranking of the instruments in terms of their marginal cost of public funds changes significantly when the effect of the reform on the externalities is taken into account. Secondly, regardless of the way in which the tax revenue is recycled, the welfare gain of peak road pricing is higher than that of the fuel tax. When the externality tax revenue is recycled through the lump sum tax the welfare gains are higher for the poorer than for the richer quintiles. On the other hand, the main beneficiary of revenue recycling through the labour income tax is the richest quintile. Consequently, when the social welfare function gives a higher weight to the welfare of individuals belonging to the poorer quintiles, the distributional impacts of the policy reforms cause the welfare gain to be higher when the revenue is recycled through an increase in the lump sum transfer rather than through a lower labour income tax rate.

The link is made with the double dividend literature. A weak double dividend can be realised only when all individuals are given the same welfare weight. However, the inclusion of distributional considerations offers the possibility of realising a strong double dividend for low degrees of inequality aversion.

Non-technical abstract

The paper uses an applied general equilibrium model, calibrated to the situation in Belgium in 1990, to evaluate the welfare effects of small policy changes in the presence of transport 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. The model is used to perform balanced budget incidence simulations in which the marginal cost of public funds is calculated for four alternative policy instruments: a lump sum tax, the labour income tax, the fuel taxes and peak road pricing. For each of these instruments the marginal cost of public funds (MCF) is calculated. The results of the model are compared with those of a model in which congestion, air pollution and accidents are assumed to remain constant at their initial level.

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 MCF of the instrument used to finance it, in order to make a correct comparison with its benefits. 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, 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).

The paper contributes to the literature in two ways. First of all, it includes non-identical individuals. Therefore, the evaluation of the policy instruments takes into account the equity effects of the policy reforms. The second contribution is related to the way in which the externalities are modelled: the feedback effect of congestion is explicitly taken into account and the value of a marginal time saving is determined endogenously in the model.

The structure of the paper is as follows. After the introduction, we first describe the general characteristics and the specification of the applied general equilibrium model, with a particular attention to the modelling of the externalities. It is followed by a brief description of the initial equilibrium, which corresponds with the situation in Belgium in 1990. Next, we discuss the results of the balanced budget incidence simulations. The final section concludes and describes some extensions to the model.

The simulations show that the ranking of the instruments in terms of their marginal cost of public funds changes significantly when the effect of the reform on the externalities is taken into account. Secondly, regardless of the way in which the tax revenue is recycled, the welfare gain of peak road pricing is higher than that of the fuel tax. When the externality tax revenue is recycled through the lump sum tax the welfare gains are higher for the poorer than for the richer quintiles. On the other hand, the main beneficiary of revenue recycling through the labour income tax is the richest quintile. Consequently, when the social welfare function gives a higher weight to the welfare of individuals belonging to the poorer quintiles, the distributional impacts of the policy reforms cause the welfare gain to be higher when the revenue is recycled through an increase in the lump sum transfer rather than through a lower labour income tax rate.

The link is made 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 welfare gain that can be obtained by using the externality tax revenue to reduce existing distortionary taxes. A weak double dividend is said to be realized if one can obtain a higher gross welfare gain by using the revenues from the externality taxes to cut existing distortionary taxes rather than by returning the revenues in a lump sum way. The strong double dividend hypothesis states that a revenue-neutral tax reform which consists of the substitution of the externality tax for distortionary taxes results in zero or negative gross welfare costs. Our simulations show that a weak double dividend can be realised only when all individuals are given the same welfare weight. However, the inclusion of distributional considerations offers the possibility of realising a strong double dividend for low degrees of inequality aversion.

I. Introduction

The paper uses an applied general equilibrium (AGE) model, calibrated to the situation in Belgium in 1990, to evaluate the equity 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 balanced budget incidence simulations. These 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 tax and peak road pricing. For each of these instruments the 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 *MCF* of the instrument used to finance it, 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[2], 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).

A comparison is made of 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 welfare gain that can be obtained by using the externality tax revenue to

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[2] The optimal taxation in the presence of externalities is treated in, e.g., 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.

reduce existing distortionary taxes. A weak double dividend is said to be realized if one can obtain a higher gross welfare gain by using the revenues from the externality taxes to cut existing distortionary taxes rather than by returning the revenues in a lump sum way. The strong double dividend hypothesis states that a revenue-neutral tax reform which consists of the substitution of the externality tax 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 analysis 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]. It allows to take into account the interaction between those policies and public finance. This is especially relevant since the externality taxes serve the dual purpose of, on the one hand, internalising the transport externalities and, on the other hand, financing the public sector.

The paper is closely related to Ballard & Medema (1993), Bovenberg & Goulder (1997) and Brendemoen & Vennemo (1996). It contributes to this literature first of all because it evaluates the equity effects of the policy reforms. The AGE model includes non-identical individuals and allows to analyse the distributional impacts of the policy changes. A second difference, compared to Bovenberg & Goulder (1997) 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), Proost & Van Regemorter (1995) and Capros *et al.* (1997a). The present paper relaxes the separability assumption in the case of the congestion externality: the consumers' allocation of expenditure over the different goods is affected by the level of congestion. In the literature a limited number of AGE models can be found in which the separability assumption is relaxed. Examples are Beaumais & Schubert (1994), Espinosa & Smith (1995), Pireddu (1996) and Mayeres & Proost (1997)[4].

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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.

[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

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 consumer 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 the balanced budget 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 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

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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.

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 (including global warming) and accidents. Four types of economic agents are considered: the consumers, the production sectors, the government and the foreign sector. The next section discusses first in general terms the modelling of the behaviour of the economic agents. 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 ($j=1, . . . ,J$). A distinction is made between transport and non-transport goods ($r=TP,NTP$). There are M transport goods ($r=TP; m=1, . . . ,M$) and K non-transport goods ($r=NTP; k=1, . . . ,K$) with $M+K=J$. The Kth non-transport good is taken to be the capital good[5].

a. The Consumers

There are I consumer groups, each consisting of a^i ($i=1,...,I$) identical individuals. Two individuals belonging to a different consumer group differ in terms of two characteristics: their productivity, which is captured by the efficiency parameter of labour hours supplied (e^i) and their tastes. Individuals belonging to the same consumer group are however assumed to be identical in terms of their needs. Each individual has a fixed endowment of capital goods, which provides a fixed supply of capital services (c^i). It is also endowed with a fixed amount of time (T). The utility of each individual belonging to consumer group i is given by:

$$U^i = f_U^i\,(xh_{TP}^i, xh_{NTP}^i, \theta h_{TP}^i, lh^i) + f_{EM}^i(EM) + f_{ACC}^i(ACC) \qquad (i=1,...,I) \qquad (1)$$

Utility U^i is determined by three components. The first component is direct utility $f_U^{\,i}$ 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 $f_{EM}^{\,i}(EM)$. 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 $f_{ACC}^{\,i}(ACC)$. ACC is a vector of accidents occurring to the different transport modes. The exact form of $f_{EM}^{\,i}(EM)$ and $f_{ACC}^{\,i}(ACC)$ is discussed in a later section. It is assumed that the individual'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 individuals negatively ($MU^i/MEM<0$, $MU^i/MACC<0$). In its behaviour each individual is assumed to ignore his own impact on EM and ACC. He considers himself 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). Here we adapt the exposition of DeSerpa (1971) and Bruzelius (1979). The function $f_U^{\,i}$ is defined as a function not only of goods but also of time allocated to the consumption of goods and to leisure. It is

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[5] Appendix 1 provides a list of symbols.

assumed to be quasi-concave in its arguments, continuous and twice differentiable. xh_{NTP}^{i} is a K vector of non-transport goods consumed by each individual belonging to consumer group i. The individual's consumption of the non-transport good k is denoted by $xh_{NTP,k}^{i}$ ($xh_{NTP,k}^{i} \geq 0$). 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}^{i} is an M vector of transport goods consumed by each individual belonging to group i ($xh_{TP}^{i}=(xh_{TP,1}^{i},...,xh_{TP,M}^{i})$ with $xh_{TP,m}^{i} \geq 0$). Total leisure consumed by the individual is denoted by lh^{i} ($lh^{i} \geq 0$). Total time allocated to transport good m is denoted by $\theta h_{TP,m}^{i}$. It is assumed for each individual 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 of each individual belonging to group i is given by expression (2).

$$\sum_{m=1}^{M} qh_{TP,m}\ xh_{TP,m}^{i} + \sum_{k=1}^{K} qh_{NTP,k}\ xh_{NTP,k}^{i} + wh^{i}\left(\sum_{m=1}^{M} \theta h_{TP,m}^{i} + lh^{i}\right) - P^{i}$$
$$- qh_{C}\ c^{i} - wh^{i}\left(T - \overline{LABEXP^{i}}\right) - wabh^{i}\ \overline{LABEXP^{i}} - \overline{INTTF^{i}} \leq 0 \qquad (i=1,...,I) \tag{2}$$

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 $qh_{NTP,k}$ and $qh_{TP,m}$ respectively. The net domestic wage rate received by an individual belonging to group i is denoted by wh^{i}. It equals the product of the gross domestic wage rate per efficiency unit and the number of efficiency units per hour of labour supplied e^{i}, from which the labour income tax is subtracted. Full income consists of non-labour income ($P^{i}+qh_{C}c^{i}$) and wage income which would have been obtained if the individual devoted all his time to labour ($wh^{i}\ (T-\overline{LABEXP^{i}})+wabh^{i}\ \overline{LABEXP^{i}}$) minus net international transfers ($\overline{INTTF^{i}}$) which are assumed to be constant. P^{i} is the poll transfer received from the government. c^{i} gives the capital services rendered by the capital stock owned by the individual. The capital services are sold at a price qh_{C}. It is assumed that c^{i} is a constant. T is the total time available to each individual and is also constant. It is assumed that each individual devotes a fixed amount of time ($\overline{LABEXP^{i}}$) to labour abroad for which he receives a net wage rate $wabh^{i}$. This equals the gross wage rate per efficiency unit paid to exported labour multiplied by the number of efficiency units e^{i}, from which the labour income tax is substracted.

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.

$$\theta h_{TP,m}^{*}(Z)\ xh_{TP,m}^{i} - \theta h_{TP,m}^{i} \leq 0 \qquad (i=1,...,I;\ m=1,...,M) \tag{3}$$

The minimum time requirement is defined as the product of the total consumption of the transport good by the individual (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 individual considers the minimum time requirement to be given exogenously, and therefore does not take into account the effect of his own transport decisions on this minimum requirement.

From the first order conditions of the individual'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:

$$\frac{\partial U^i/\partial lh^i}{\lambda^i} = wh^i \qquad (i=1,...,I) \tag{4}$$

8^i 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.

$$\frac{\gamma^i_{TP,m}}{\lambda^i} = wh^i - \frac{\partial U^i/\partial \theta h^i_{TP,m}}{\lambda^i} = \frac{\partial U^i/\partial lh^i}{\lambda^i} - \frac{\partial U^i/\partial \theta h^i_{TP,m}}{\lambda^i} \qquad (i=1,...,I;\ m=1,...,M) \tag{5}$$

$(_{TP,m}^{i}$ 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 individuals 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 individuals, 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 individual's welfare, while this assumption is dropped for congestion. For each individual belonging to consumer group *i* we have:

$$xh^i_{r,n} = xh^i_{r,n}\,(qh, qh_C, wh^i, wabh^i, P^i, Z) \qquad (n=1,...,M \text{ for } r=TP;\ n=1,...,K \text{ for } r=NTP) \tag{6}$$

$$\theta h^{i}_{TP,m} = \theta h^{*}_{TP,m}\ xh^{i}_{TP,m} \qquad m=1,\ldots,M \tag{7}$$

$$lh^{i} = lh^{i}\ (\ qh\ ,\ qh_{C}\ ,\ wh^{i}\ ,\ wabh^{i}\ ,\ P^{i}\ ,\ Z\ ) \tag{8}$$

The indirect utility function of an individual belonging to consumer group i can be defined as:

$$V^{i} = V^{i}\ (qh\ , qh_{C}\ , wh^{i}\ , wabh^{i}\ , P^{i}\ , Z\ , EM\ , ACC) \tag{9}$$

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 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 ex_j for each good j:

$$ex_j = \overline{ex_j} \left(\overline{pw_j} / px_j \right)^{\eta x_j} \tag{10}$$

$\overline{pw_j}$ 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 px_j. ηx_j equals minus the price elasticity of export demand. $\overline{ex_j}$ is a positive constant representing total world demand for good j. A change in 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 it 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:

$$tt = \overline{tt} \left(\overline{pttw} / ptt \right)^{\eta t} \tag{11}$$

where $\overline{pttw}$ is the price of transit transport abroad, which is assumed to be constant, ptt is the price of transit transport in the country, $\overline{tt}$ is a constant representing total demand for international transport by foreign firms. ηt equals minus the elasticity of transit transport in the country with respect to 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 consumers, 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 consumers 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 consumers. Secondly, it can levy excises on the input of transport and non-transport goods by the domestic production sectors and the consumers and indirect taxes on the consumers' 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.

$$Z = Z(F, CAP) \qquad \text{with } \frac{\partial Z}{\partial F} > 0, \ \frac{\partial Z}{\partial CAP} < 0 \tag{12}$$

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

$$X_{TP,m} = \sum_{i=1}^{I} a^i \, xh^i_{TP,m} + \sum_{j=1}^{J} \left(xp^j_{TP,m} + xx^j_{TP,m} + xab^j_{TP,m} \right) + xt_{TP,m} \qquad (m=1,...,M) \tag{13}$$

It equals the sum of the total use of the transport good *m* by the consumers ($\sum_i a^i\, xh_{TP,m}{}^i$), by the domestic production sectors for the transport of domestically demanded goods ($\sum_j xp_{TP,m}{}^j$) , by the domestic production sectors for export related transport in Belgium ($\sum_j xx_{TP,m}{}^j$), by the foreign sectors for import related transport in Belgium ($\sum_j xab_{TP,m}{}^j$) and by transit transport in Belgium ($xt_{TP,m}$). 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:

$$F = F\left(X_{TP} \right) \tag{14}$$

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 and non-transport energy goods. We define the total consumption of the non-transport energy good *en* as

$$X_{NTP,en} = \sum_{i=1}^{I} a^i \, xh^i_{NTP,en} + \sum_{j=1}^{J} xp^j_{NTP,en} \qquad en=1,...,EN \tag{15}$$

It equals the sum of the consumption of the good by the consumers ($\sum_i a^i\, xh_{NTP,en}{}^i$) and by the domestic production sectors ($\sum_j xp_{NTP,en}{}^j$). The level of emission of air pollutant *po* is defined as

$$EM_{po} = \sum_{m=1}^{M} emtp_{po,m} \, X_{TP,m} + \sum_{en=1}^{EN} emen_{po,en} \, X_{NTP,en} \qquad po=1,...,PO \tag{16}$$

$emtp_{po,m}$ 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 $f_{EM}{}^i$ in (1) is defined as:

$$f^i_{EM} = \sum_{po=1}^{PO} mu^i_{AP,po} \; (EM^{ref}_{po} - EM_{po}) \qquad (i=1,...,I) \tag{17}$$

$mu_{AP,po}{}^{i}$ is the marginal utility to each individual of consumer group *i* 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

$$ACC^n_m = \sum_v ar^n_{m,v} \; X_{TP,m} \tag{18}$$

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 $f_{ACC}{}^i$ is defined as follows:

$$f^i_{ACC} = \sum_n mu^i_{ACC,n} \sum_m (ACC^{ref,n}_m - ACC^n_m) \qquad (i=1,...,I) \tag{19}$$

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* ($mu_{ACC,n}{}^i$) 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 to the domestic market by the consumers and by the rest of the world should equal the sum of total labour demanded by the domestic production sectors.

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

(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) should equal the domestic demand for the domestic variety of the good and the export demand.

(iv) on the other goods markets: the supply of the good by the domestic production sectors should equal the sum of the domestic demand for the domestic variety and the export demand.

(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 consumers. The inflow of funds equals the sum of the value of exports, the value of exported labour and 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 consumers such that the balance of payments is in equilibrium. This good is considered by them as a perfect substitute for physical capital. In the simulations it is assumed that the deficit remains constant at the level of the initial equilibrium.

g. Investment

Although the model is static, we have to take into account the investment that takes place during the period which is considered. The value of total physical investment in the economy is defined as the sum of consumer savings and government investment minus the government deficit and the surplus on the balance of payments (which is observed in the initial equilibrium and which is assumed to be offset by the sale of capital services by the rest of the world to the domestic economy; cf. supra).

2. The Model Specification

This section discusses in more detail the specification of the model presented in the previous sections. Table 1 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. We limit the discussion here to the specification of the consumers' utility function and the congestion function. A discussion of the specification for the domestic production sectors, the government and the foreign sector is presented in Mayeres (1998a).

a. The Consumers

The direct utility function f_U^i of each individual belonging to consumer group *i* 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 individuals 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. 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

Table 1: Classification of the domestic production sectors

no.	Type I	no.	Type II	no.	Type III	no.	Type IV
1	Capital goods	5a	Peak bus tram metro		*Electricity*		*Transport vehicle services*
2a	Electricity	5b	Off peak bus tram metro	2a1	El. electricity sector	3a	Gasoline car
2b	Solid fuels	6a	Peak passenger rail	2a2	El. production sectors	3b	Diesel car
2c	Petrol products	6b	Off-peak passenger rail	2a3	El. households	3c	LPG car
2d	Gas	7	Freight rail		*Solid fuels*	3d	Gasoline van
3	Transport vehicle services	8	Inland navigation	2b1	Solids electricity sector	3e	Diesel van
4	Transport maintenance			2b2	Solids production sectors	3f	Truck
9	Other goods and services			2b3	Solids households	3g	Bus, tram, metro
					Petrol products	3h	Passenger train
				2c1	Gasoline	3i	Freight train
				2c2a	Diesel road transport	3j	River vessel
				2c2b	Diesel non-road tp		
				2c3	LPG		
				2c4a	Other petr. prod. electricity sector		
				2c4b	Other petr. prod. production sectors		
				2c4c	Other petr. prod. households		
					Gas		
				2d1	Gas electricity sector		
				2d2	Gas production sectors		
				2d3	Gas households		

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 individual 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 pkm and transport time. At $w=8$, committed mileage is a Leontief-type function of vehicle km (vkm), fuel and maintenance. In the case of supplementary mileage pkm is a Leontief function of fuel and maintenance only.

b. 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:

$$\theta^{d}_{TP,m} = A_{1,m} \left[A_2(CAP) + A_3(CAP) * \exp\left(A_4(CAP) * F^{d} \right) \right] \tag{20}$$

$\theta_{TP,m}{}^{d}$ 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 and 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 average uncompensated labour supply elasticity equals 0.55 in the benchmark equilibrium, while the average 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.

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[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.

This evidence is corroborated by later work of the same authors [Hansson & Stuart (1993)]. Fitting a 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 average uncompensated own-price and income elasticities of a number of consumer goods in the initial equilibrium are presented in Table 2. On the producer side, the elasticities of substitution are based on Capros et al. (1997b). The elasticities of substitution for freight transport are chosen on the basis of the elasticity estimates presented in Oum, Waters & Yong (1992).

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

	Average own price elasticity		Average income elasticity
	Peak	Off-peak	
Car mileage (gasoline car)			
Committed mileage	-0.16	-0.43	0.7
Supplementary mileage	-0.43	-0.36	1.53
Public transport pkm			
Bus, tram, metro	-0.19	-0.28	0.6
Rail	-0.37	-0.43	0.84
Non-transport energy			
Electricity	-0.77		1.53
Solid fuels	-0.40		0.69
Petrol products	-0.39		0.69
Gas	-0.39		0.69
Capital goods	-0.69		0.99
Other goods and services	-0.74		1.08

The valuation of the externalities is based on the following sources. For the consumers, 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 [ECU/h][8]

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Peak car	2.414	2.720	3.747	4.884	7.244
Off-peak car	2.147	2.419	3.332	4.344	6.442
Peak bus, tram, metro	1.898	2.277	2.733	3.834	5.685
Off-peak bus, tram, metro	1.546	1.855	2.226	3.123	4.631

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

Table 4 gives the elasticity of the VOT w.r.t. its determinants in the initial equilibrium for persons belonging to the third quintile. The VOT is related positively to the wage rate and to the minimum time requirement. For car transport, the VOT is a negative function of the money price, while the opposite is true for bus, tram and metro transport.

Table 4: The Elasticity of the VOT with respect to its Main Determinants in the Initial Equilibrium (Quintile 3)

	The elasticity of the VOT w.r.t.		
	Wage rate	Money price of the transport good	Minimum time requirement
Peak car	1.144	-0.134	0.715
Off-peak car	1.278	-0.259	0.277
Peak bus, tram, metro	1.429	0.028	2.407
Off-peak bus, tram, metro	1.767	0.134	2.123

The calibration of $mu_{AP,po}{}^{i}$ and $mu_{ACC,n}{}^{i}$ is based on the value for the marginal external air pollution and accident costs. Table 5 summarizes the marginal external air pollution costs in the initial equilibrium. The model includes the following air pollutants: NO_x, SO_2, HC, CO, CO_2 and particulate matter with a diameter smaller than 10 and 2.5 microns (PM_{10} and $PM_{2.5}$ 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.

[8] In the paper all monetary values are expressed in prices of 1990.

Table 5: The Marginal External Costs of Air Pollution in the Initial Equilibrium

NOTE: all values are expressed in 10^{-3} ECU/g per 1000 000 persons; the values for CO and CO_2 are expressed in 10^{-3} ECU/kg per 1000 000 persons

	Marginal external air pollution costs		Marginal external air pollution costs
NO_x	0.196	CO_2	1.235
SO_2	0.561	$PM_{2.5}$	21.815
HC	0.024	PM_{10}	2.069
CO	0.217		

The methodology for calculating the marginal external accident costs is similar to that presented in Mayeres, Ochelen & Proost (1996). Per 1000 000 persons these costs equal 2.3 10^{-3} ECU/vkm for cars in the initial equilibrium, 9.097 10^{-3} ECU/vkm for buses, 0.013 10^{-3} ECU/vkm for trams, 1.307 10^{-3} ECU/vkm for trucks and 17.661 10^{-3} ECU/pkm for nonmotorized transport. The high costs for non-motorized transport are explained by the relatively high accident risks of this mode.

Table 6: The Marginal External Costs of Road Transport in the Initial Equilibrium

	Marginal External Costs (ECU/vkm)		Taxes as Percentage of Marginal External Costs	
	Peak	Off-peak	Peak	Off-peak
Passenger transport				
Non-business car vkm				
Gasoline car	0.221	0.073	35%	104%
Diesel car	0.264	0.116	18%	42%
LPG car	0.216	0.068	17%	53%
Business car vkm				
Gasoline car	0.221	0.073	14%	42%
Diesel car	0.264	0.116	7%	16%
LPG car	0.216	0.068	5%	17%
Bus, tram, metro vkm				
Electric vehicles	0.367	0.071	0%	0%
Diesel vehicles	0.900	0.603	11%	17%
Road freight transport				
Gasoline van	0.218	0.071	20%	63%
Diesel van	0.271	0.123	9%	21%
Truck	0.692	0.396	14%	25%

On the basis of these values we can calculate the marginal external costs of the different transport modes in the initial equilibrium. Table 6 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.

III. The Balanced Budget Incidence 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. The revised case simulations are of the balanced budget incidence type. 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 social welfare of raising an additional unit of government revenue by means of instrument g. It is defined as the negative ratio of the monetary value of the change in social welfare (dSW_g) and the change in government revenue ($dREV_g$) brought about by instrument g.

$$MCF_g = -\frac{dSW_g}{dREV_g} \tag{21}$$

As regards the denominator of (21) it is assumed that each instrument generates an equal yield for reasons of comparability. This is important because otherwise the differences between the scenarios would be a mixture of the effects of differences in the tax system with those of differences in the size of the government. There are several possible definitions of equal yield [see, Shoven & Whalley (1977)]. The policy reforms generally lead to differences in equilibrium prices across the different scenarios. Therefore, assuming that the government receives the same amount of money in each scenario is not satisfactory, since the goods that it buys with that money have a different price in each of them. Based on Shoven & Whalley (1977) the present model formulates a utility function for the government which it is assumed to maximize subject to its budget constraint. The corresponding expenditure function is used to calculate the government revenue required to achieve the same level of utility at any set of prices. When simulating the effects of tax changes in the balanced budget incidence simulations, we give the government enough revenue so that its utility is the same across all revised-case simulations. Finally, since the prices are different between the initial and the revised-case equilibrium, we cannot simply compare the revenues in both equilibria. Instead of using a Laspeyres price index or some other index to correct for relative price changes, we use the expenditure function in order to obtain the real change in government revenue.

In order to calculate the monetary value of the change in social welfare (dSW_g), we first define the social welfare function as:

$$W = \sum_{i=1}^{5} a^i \frac{(EI^i)^{1-\varepsilon}}{1-\varepsilon} \tag{22}$$

g is the degree of inequality aversion. The exercise is repeated for different degrees of inequality aversion in order to test the sensitivity of the results to this parameter. A value of $g = 0$ means that the social welfare function gives an equal weight to the welfare of individuals belonging to different consumer groups. As the value of g increases, society has a higher degree of inequality aversion. The welfare of an individual belonging to consumer group i is measured by means of his equivalent income EI^i. It 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 new price vector and level of congestion, emissions and accidents. To obtain a monetary measure of the social value of the policy reforms, we use the concept of the social equivalent gain, denoted by SG_g. It is defined as the increase in each individual's original equivalent income which would produce a social welfare level equal to the one obtained in the post-reform equilibrium [King (1983)].

$$\sum_{i=1}^{5} a^i \frac{(EI^{i,ref} + SG_g)^{1-\varepsilon}}{1-\varepsilon} = \sum_{i=1}^{5} a^i \frac{(EI_g^i)^{1-\varepsilon}}{1-\varepsilon} \qquad (23)$$

The marginal cost of public funds of instrument g is then defined as:

$$MCF = -\frac{\sum_{i=1}^{5} a^i SG_g}{dREV_g} \qquad (24)$$

Note that the *MCF* 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 social 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 an ECU of social value per ECU 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 consumers. 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. The revenue generated by one instrument is assumed to be returned through the second instrument.

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.

$$MCF_g = MCF_g^A + MCF_g^B + MCF_g^C \qquad (25)$$

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.

The findings for the model with externalities are contrasted with the *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 speed since these are assumed to be constant. The *MCF* calculated by the model without externalities is referred to by the symbol MCF^* in the rest of the paper.

The AGE model is used to compute the *MCF* and its components for four alternative instruments. These instruments are used to finance a real increase in separable government expenditures of approximately 0.2%. Table 7 provides an overview of the simulations. A distinction is made between the model without externalities and the model with externalities.

Table 7: The Balanced Budget Incidence Simulations

	Initial equilibrium	AGE model without externalities	AGE model with externalities
Real government spending	65.11 10^3 ECU/day	+0.1960%	
Real lump sum transfer			
Quintile 1	17 ECU/day/person	all quintiles: -0.1475%	all quintiles: -0.1473%
Quintile 2	14 ECU/day/person		
Quintile 3	10 ECU/day/person		
Quintile 4	8 ECU/day/person		
Quintile 5	6 ECU/day/person		
Labour income tax rate			
Quintile 1	7%	all quintiles: +0.1078%	all quintiles: +0.1077%
Quintile 2	18.18%		
Quintile 3	29.28%		
Quintile 4	39.80%		
Quintile 5	54.37%		
Real peak road pricing	0 ECU/vkm	+0.0024 ECU/vkm	+0.0023 ECU/vkm
Excise on fuel for road transport	(as % of producer price)		
Gasoline	125.634%	all fuels: +2.951 percentage points	all fuels: +2.910 percentage points
Diesel	85.237%		
LPG	0.000%		

We consider the following instruments[9]:

1. *a lump sum tax*: this instrument consists of a reduction in the lump sum transfer received by the individuals. The share of the lump sum transfer in generalized income ranges from 34.7% for the poorest quintile to 5.8% for the richest quintile in the initial equilibrium. The percentage

[9] As regards the other policy instruments, the following assumptions are made. Unless the instruments are changed as described for the different balanced budget exercises, it is assumed that:
- the VAT rate, the indirect tax rate, the labour income tax rate and the capital income tax rate remain constant at the level of the initial equilibrium;
- the lump sum transfer, the total government subsidies, the international government transfers and the government deficit are constant in real terms (measured by the consumer price Laspeyres index).

reduction in the real lump sum transfer is assumed to be the same for all quintiles.

2. *an increase in the tax rate on labour income*: the income tax rate is increased by the same rate for all quintiles.

In addition to these two more conventional revenue generating tax instruments we consider two instruments aimed specifically at the transport sector:

3. *an increase in the fuel tax*: in this revised-case simulation the excise on the fuels used by road transport is raised. When expressed as percentage of the producer price, the excise is increased by the same number of percentage points for all fuel types. The fact that the excise, rather than the VAT rate, rises, makes that the use of fuel for road transport both by the consumers and the domestic producers is taxed. Foreign road transport users are not subject to this tax. The tax on fuel used by rail transport and inland navigation is assumed to remain a constant percentage of the producer prices.

4. *peak road pricing*: this instrument consists of the introduction of a tax per vkm driven by motorized peak road transport. All vehicle types driving on Belgian roads during the peak period are subject to this tax, regardless of their country of origin.

1. The AGE Model without Externalities

Table 8 summarizes the results of the balanced budget incidence exercises for the model without externalities. In the case of a utilitarian social welfare function ($g = 0$), the MCF^* of all policy instruments is larger than one. The MCF^* of the lump sum tax is higher than 1 and it is also higher than the MCF^* of the fuel tax. This can be explained as follows. First of all, the reduction in the lump sum transfer reduces the consumption of taxed goods by the consumers, which reduces the tax revenues from this source. Secondly, there is a reduction in the tax income from the labour income tax. The total labour supply increases. However, the effect of this on tax revenue is offset by the decrease in the wage rate, but also by the shift from heavily taxed labour (supplied by the highest quintiles) to less heavily taxed labour (supplied by the lower quintiles). The proportionate increase in the labour supply is the highest for the poorer quintiles. Since the share of the lump sum transfer in generalized income is higher for these quintiles than for the richer quintiles, their generalized income is reduced by a larger percentage. Moreover, their income elasticity of labour supply is higher. There is a decrease in the real wage rate, which offsets the effect of a lower lump sum transfer on labour supply in the case of the richest quintile, but not for the other quintiles. The labour supply of the richest quintile decreases slightly. The shift from heavily to less heavily taxed labour explains the relatively high MCF^* of the lump sum tax.

The increase in the labour income tax leads to an increase in the total labour supply. This is due to the higher labour supply of the first three quintiles, while that of the two richest quintiles falls. The smaller share of highly productive and heavily taxed labour and the larger share of the less productive and less heavily taxed labour explains the high MCF^* of the labour income tax when $g = 0$.

The MCF^* of peak road pricing and the fuel tax are lower than that of the labour income tax, despite the fact that these taxes have a relatively narrow tax base. For the fuel tax the MCF^* is even lower than that of the lump sum tax. This is because both measures increase labour supply even though at the same time more time is spent in leisure. This is made possible by the fact that less time is devoted to transport. Moreover, there is a shift from relatively lowly taxed labour (supplied by the first two quintiles) to relatively highly taxed labour. The MCF^* is higher for peak road pricing than for the fuel tax because the former instrument has a narrower tax base than the latter.

For $g = 0$ the MCF^* is the lowest for the fuel tax, followed by the lump sum tax, peak road pricing and the labour income tax. This ranking changes for higher degrees of inequality aversion. A higher degree of inequality aversion leads to a higher MCF^* in the case of the lump sum tax and to a lower value of the MCF^* in the case of the other instruments. The reason for this becomes clear when we look at the value of the equivalent gain per 1000 persons for each of the quintiles (EG^*). In the case of the lump sum transfer the welfare loss per 1000 persons is the highest for the lower quintiles, while the opposite is the case for the other policy instruments. A higher degree of inequality aversion implies that more weight is given to the welfare impacts on the lower quintiles. Therefore, e.g., for a high inequality aversion ($g = 1.5$) the labour income tax has the lowest MCF^*, followed by the fuel tax, peak road pricing and the lump sum tax.

In order to measure the impact of the policy reforms on the inequality, we use a scalar measure of inequality defined over the distribution of equivalent incomes. Based on Kolm (1969) and Atkinson (1970) we first define the equally distributed equivalent level of equivalent income (EI_E) as that level of equivalent income which, if shared equally by all individuals, would produce the same level of social welfare as that generated by the actual distribution of equivalent income:

$$\sum_{i=1}^{5} a^i \frac{(EI_E)^{1-\varepsilon}}{1-\varepsilon} = \sum_{i=1}^{5} a^i \frac{(EI^i)^{1-\varepsilon}}{1-\varepsilon} \tag{26}$$

The Atkinson-Kolm index of inequality is then defined as:

$$INEQ = 1 - \frac{EI_E}{\overline{EI}} \tag{27}$$

where $\overline{EI}$ is the mean level of equivalent income. $INEQ$ lies between zero and one. When $INEQ$ equals 0 there is complete equality. A higher value of $INEQ$ means a higher degree of inequality. Table 8 gives the inequality index in the reference equilibrium ($INEQ^{*,ref}$) and the percentage change in the index with respect to $INEQ^{*,ref}$ for each of the instruments and for different degrees of inequality aversion. The lump sum transfer increases inequality and more so for higher degrees of inequality aversion. The three other instruments reduce inequality, the labour income tax having the largest impact. The impact also rises with the degree of inequality aversion.

2. The AGE Model with Externalities

The ranking of the policy instruments in terms of their *MCF* changes significantly when the effect on the externalities is accounted for. Table 9 presents the *MCF* results for this case. Peak road pricing now has the lowest *MCF*, followed by the excise on fuel for road transport. In these two cases

Table 8: Balanced Budget Incidence Simulations: The AGE Model without Externalities

	Lump sum tax		Labour income tax		Peak road pricing		Fuel tax	
MCF*								
ε = 0	1.150		1.178		1.164		1.141	
ε = 0.25	1.174		1.141		1.143		1.122	
ε = 0.5	1.198		1.105		1.122		1.103	
ε = 1.5	1.298		0.974		1.037		1.026	
Ranking from low to high MCF*								
ε = 0	[2]		[4]		[3]		[1]	
ε = 0.25	[4]		[3]		[2]		[1]	
ε = 0.5	[4]		[2]		[3]		[1]	
ε = 1.5	[4]		[1]		[3]		[2]	
EG* a								
Quintile 1	-24.5	(-0.0495%)	-8.1	(-0.0165%)	-7.1	(-0.0143%)	-7.6	(-0.0153%)
Quintile 2	-20.2	(-0.0327%)	-8.0	(-0.0129%)	-11.5	(-0.0186%)	-11.5	(-0.0187%)
Quintile 3	-14.8	(-0.0203%)	-9.0	(-0.0123%)	-13.7	(-0.0187%)	-13.3	(-0.0182%)
Quintile 4	-11.7	(-0.0139%)	-13.3	(-0.0159%)	-16.0	(-0.0191%)	-15.5	(-0.0185%)
Quintile 5	-10.3	(-0.0094%)	-28.2	(-0.0258%)	-20.1	(-0.0184%)	-19.5	(-0.0178%)
Percentage change in INEQ* w.r.t. INEQ*,ref								
ε = 0.25	0.0843%		-0.0366%		-0.0045%		-0.0018%	
ε = 0.5	0.0854%		-0.0358%		-0.0048%		-0.0020%	
ε = 1.5	0.0893%		-0.0323%		-0.0058%		-0.0027%	

[a] The values are expressed in 10^{-3} ECU/1000 persons/ day. The figures within brackets give the EG^* as % of EI^{ref}

the value of the *MCF* is below one for all degrees of inequality aversion. E.g., for $g = 0$ the *MCF* of peak road pricing equals 0.681. This means that the increase in government spending financed with this instrument would still be welfare improving with a social benefit of only 69% of non-tax costs. The *MCF* of the lump sum tax and the labour income tax is higher than one in most cases. Though the degree of inequality aversion affects the value of the *MCF*, it changes the ranking only for the labour income tax and the lump sum tax. The ranking of the instruments according to the value of the *MCF* is determined completely by the MCF^A. This is the case for all values of g considered in the study. Including the effects on air pollution and accidents leaves the ranking unaltered.

Table 9: Balanced Budget Incidence Exercises: The MCF in the AGE Model with Externalities

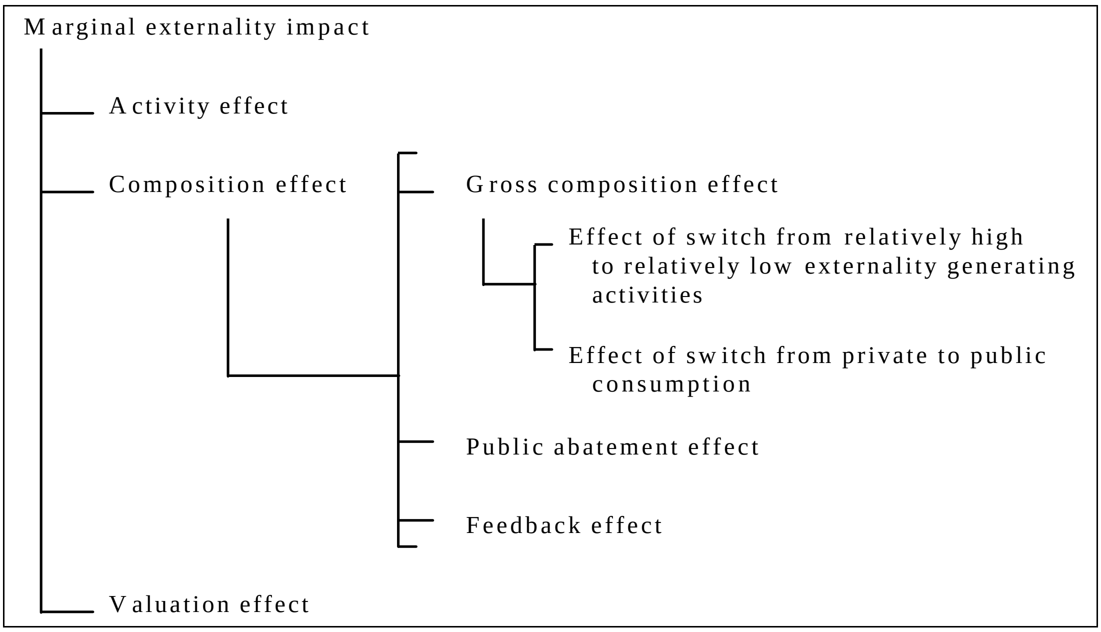
	Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
MCF				
ε = 0	1.130	1.138	0.681	0.798
ε = 0.25	1.154	1.102	0.669	0.783
ε = 0.5	1.178	1.067	0.657	0.768
ε = 1.5	1.280	0.937	0.606	0.707
MCF^A				
ε = 0	1.137	1.158	0.775	0.948
ε = 0.25	1.160	1.121	0.763	0.933
ε = 0.5	1.185	1.086	0.751	0.918
ε = 1.5	1.286	0.956	0.700	0.856
MCF^B				
all values of ε	-0.002	-0.015	-0.075	-0.118
MCF^C				
all values of ε	-0.005	-0.004	-0.020	-0.031
Ranking from lowest to highest MCF				
ε = 0	[3]	[4]	[1]	[2]
ε = 0.25	[4]	[3]	[1]	[2]
ε = 0.5	[4]	[3]	[1]	[2]
ε = 1.5	[4]	[3]	[1]	[2]

For all policy instruments the *MCF* is lower than the MCF^*. The reason for this is that they have an impact on the level of the externalities. In order to explain the welfare impact of the changed level of the externalities, it is useful to decompose the marginal externality impact into three components. They are summarized in Figure 1. The first two components are the activity and the composition effect [see, e.g., Bovenberg and van der Ploeg (1994)]. The *activity effect* consists of the impact on the level of economic activity by the different economic agents. 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 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 reduces 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 consumers' 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, e.g., Bovenberg & van der Ploeg (1994).

The final component of the marginal externality impact is related to the impact of the policy change on the marginal utility of a change in the different externalities. We term this the *valuation effect*. In the model the marginal utility of a time saving in transport is affected by the policy changes and therefore influences the value of the *MCF*. This effect is not present in the case of air pollution and accidents, since the model assumes that the marginal utility of a change in emissions and accidents remains constant in all simulations.

Figure 1: The Components of the Marginal Externality Impact



The next section discusses the results for the lump sum tax and the labour income tax. First, we discuss the determinants of the different components of the *MCF*. Then we turn to the distributional impacts of the two policies. Afterwards, the results for the two other instruments are presented.

a. The Lump Sum Tax and the Labour Income Tax

(1) MCF^A

The MCF^A of the lump sum tax and the labour income tax is lower than the MCF^* for all degrees of inequality aversion considered in the model. This is because the instruments have an impact on the level of congestion. Tables 10 and 11 summarize the effect of the four policy instruments on freight and passenger transport in Belgium for the model with externalities. Table 12 presents the resulting changes in the road traffic flow and car speed in the peak and off-peak period.

The activity effect is the main reason for the reduced congestion level caused by the labour income tax and the lump sum tax. 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 real generalised income for all quintiles. This lowers the consumer demand for all goods, except nonmotorized transport. Since the percentage reduction in the real wage rate is the highest for the richer quintiles, the proportional reduction in real generalized income and therefore in consumption is the highest for them. The activity effect is also present at the production side of the economy. The fall in consumer demand leads to lower production levels and to a reduction in the total number of tkm transported in Belgium by the domestic production sectors. Moreover, higher production prices of the domestic production sectors increase (due to the increase in the wage rate), increase the share of imports in the Armington composite and reduce the demand for exports. Both effects strengthen the negative impact on the demand for domestic products. The other components of the marginal externality impact are less important. As regards the composition effect, the switch from private to public consumption lowers the congestion level, since public consumption generates no externalities. This effect acts in the same direction for all policy instruments. At the consumer's side there is a small shift from car to non-car transport, which also results in a lower congestion level. However, the feedback effect mitigates to some extent the previous effects. The increase in speed causes the consumers to reduce their consumption of road transport by less than if speed had remained constant. The same phenomenon is present at the production side of the economy. In the domestic production sectors, the increase in speed of road freight transport causes the share of this mode in the total number of tkm to rise at the expense of rail and inland navigation. The share of road freight transport of imports and transit transport increases because of the same reason. Moreover, for business transport there is a switch from the rail to the car mode. Still, the activity effect being dominant, the overall impact is that the congestion level is lower than in the initial equilibrium. This results in higher speeds both in the peak and in the off-peak period.

Note that the increase in speeds allows to finance the increase in real government spending by

Table 10: Freight transport in Belgium - The AGE Model with Externalities

	Initial equilibrium (tkm)	% change w.r.t. initial equilibrium			
		Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
Freight transport in Belgium by domestic production sectors					
Road	87311	0.013%	0.001%	-0.005%	-0.117%
Peak	16257	0.014%	0.002%	-0.055%	-0.102%
Off-peak	71054	0.013%	0.001%	0.006%	-0.120%
Inland navigation	8069	0.005%	-0.002%	0.015%	0.307%
Freight rail	16036	-0.007%	-0.039%	0.007%	0.149%
Total	111416	0.009%	-0.005%	-0.002%	-0.048%
Import related freight transport in Belgium					
Road	13784	0.007%	0.017%	-0.016%	0.060%
Peak	2566	0.007%	0.017%	-0.072%	0.068%
Off-peak	11217	0.007%	0.016%	-0.003%	0.058%
Inland navigation	5614	0.018%	0.006%	0.055%	0.028%
Freight rail	4792	0.006%	-0.037%	0.051%	-0.186%
Total	24189	0.009%	0.004%	0.014%	0.004%
Transit freight transport in Belgium					
Road	9044	0.003%	0.000%	-0.047%	0.017%
Peak	1684	0.003%	0.001%	-0.099%	0.025%
Off-peak	7360	0.003%	0.000%	-0.035%	0.015%
Inland navigation	1141	0.010%	-0.002%	-0.012%	0.012%
Freight rail	2060	0.003%	-0.025%	-0.021%	-0.100%
Total	12245	0.003%	-0.004%	-0.039%	-0.003%
Total freight transport in Belgium					
Road	110138	0.011%	0.003%	-0.010%	-0.084%
Peak	20508	0.012%	0.004%	-0.061%	-0.071%
Off-peak	89631	0.011%	0.003%	0.002%	-0.087%
Inland navigation	14824	0.010%	0.001%	0.028%	0.179%
Freight rail	22888	-0.004%	-0.037%	0.014%	0.057%
Total	147850	0.009%	-0.003%	-0.003%	-0.036%

Table 11: Passenger transport in Belgium - The AGE Model without Externalities

	Initial equilibrium (pkm)	% change w.r.t. initial equilibrium			
		Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
Non-Business					
Car					
Peak	69433	-0.015%	-0.015%	-0.475%	-0.137%
Off-peak	122823	-0.028%	-0.032%	0.012%	-0.245%
Bus, tram, metro					
Peak	11614	-0.002%	-0.005%	0.297%	0.089%
Off-peak	11827	-0.001%	-0.013%	0.025%	0.046%
Rail					
Peak	7702	-0.012%	-0.033%	0.076%	0.039%
Off-peak	9261	-0.012%	-0.031%	0.022%	0.067%
Non-motorized					
Peak	8949	0.000%	0.008%	0.165%	0.077%
Off-peak	12937	0.004%	0.014%	0.042%	0.124%
Business					
Car					
Peak	10863	0.017%	0.001%	-0.043%	-0.040%
Off-peak	19131	0.016%	0.000%	0.001%	-0.051%
Rail					
Peak	477	0.017%	-0.005%	0.049%	-0.026%
Off-peak	885	0.017%	-0.004%	0.030%	-0.022%

Table 12: Road Traffic Flow and Speed - The AGE Model with Externalities

	Initial equilibrium	% change w.r.t. initial equilibrium			
		Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
Road traffic flow (mio PCU/h)					
Peak	15.25	-0.008%	-0.011%	-0.373%	-0.113%
Off-peak	9.00	-0.013%	-0.021%	0.010%	-0.184%
Car speed (km/h)					
Peak	51.77	0.010%	0.014%	0.474%	0.143%
Off-peak	77.44	0.006%	0.009%	-0.004%	0.077%

Table 13: The Marginal Utility of a Time Saving in Transport

	% change w.r.t. initial equilibrium			
	Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
Car				
Peak				
Quintile 1	-0.026%	-0.003%	0.018%	-0.018%
Quintile 2	-0.023%	-0.014%	-0.200%	-0.102%
Quintile 3	-0.022%	-0.026%	-0.231%	-0.108%
Quintile 4	-0.021%	-0.037%	-0.173%	-0.085%
Quintile 5	-0.019%	-0.059%	-0.115%	-0.062%
Off-peak				
Quintile 1	-0.025%	-0.003%	-0.050%	-0.041%
Quintile 2	-0.027%	-0.016%	-0.071%	-0.162%
Quintile 3	-0.026%	-0.030%	-0.064%	-0.167%
Quintile 4	-0.025%	-0.044%	-0.055%	-0.133%
Quintile 5	-0.022%	-0.069%	-0.046%	-0.098%
Bus, tram, metro				
Peak				
Quintile 1	-0.024%	-0.002%	-0.121%	-0.073%
Quintile 2	-0.020%	-0.014%	-0.362%	-0.162%
Quintile 3	-0.022%	-0.031%	-0.514%	-0.212%
Quintile 4	-0.023%	-0.043%	-0.358%	-0.152%
Quintile 5	-0.023%	-0.068%	-0.268%	-0.117%
Off-peak				
Quintile 1	-0.021%	0.002%	-0.080%	-0.134%
Quintile 2	-0.022%	-0.011%	-0.109%	-0.243%
Quintile 3	-0.028%	-0.033%	-0.114%	-0.294%
Quintile 4	-0.029%	-0.051%	-0.089%	-0.222%
Quintile 5	-0.029%	-0.083%	-0.070%	-0.175%

a smaller rise in the labour income tax rate than in the model without externalities [see Table 7]. This is a second reason why the MCF^A is lower than the MCF^*. It is explained by the feedback effect which causes highly taxed road transport to be discouraged less than if speed had not changed. Moreover, the feedback effect causes the domestic production to fall less than in the absence of this effect. Given that the capital stock is fixed, the price of capital services provided by the stock falls less and the tax revenue from this source is reduced by less. The need for lower tax increases when the feedback effect is modelled, is also observed for the other policy instruments, as becomes clear from Table 7.

The lump sum tax affects the level of congestion less, which accounts for a smaller difference between the MCF^A and the MCF^* for this instrument. Here also, the activity effect is the main determinant of this result. The lower lump sum transfer reduces generalized income, an effect which is reinforced by the lower real after-tax wage rate. On average, real generalized income falls less than in the case of the labour income tax. However, the distribution over the quintiles is different: since the lump sum transfer accounts for a larger share of generalized income of the poorer quintiles, the percentage reduction of generalized income is larger for them. The reduction in generalized income lowers consumer demand for all goods, except nonmotorized transport, and reduces the congestion level. Consumption of the poorer quintiles is reduced proportionally more than that of the richer quintiles. However, the activity effect at the consumer side is partly offset by an opposite activity effect at the domestic production side. The lower wage rate and the increase in speed allow domestic production sectors to produce more cheaply. As a result, domestic demand for domestically produced goods increases at the expense of imports and exports rise. The demand for all inputs, including transport, increases which causes a rise in the level of congestion. The total activity effect leads to a lower level of congestion and higher speeds for road transport. The composition effect is similar to that of the labour income tax.

For both instruments the valuation effect reduces the welfare impact of the higher speeds. Table 13 shows that the lump sum tax and the labour income tax cause the marginal utility of a time saving (mu_T^i) in transport to be slightly lower in the new equilibrium. As a result, the welfare gain of the lower congestion levels is lower than if the mu_T^i had remained constant. However, the valuation effect is relatively small. For peak car transport, the reduction in the mu_T^i ranges from -0.019% to -0.026% in the case of the lump sum tax and -0.003% to -0.059% in the case of the labour income tax. For the last instrument the mu_T^i is reduced proportionally less for the lower than for the higher quintiles. This pattern is observed for all transport modes and is closely related to the change in the after-tax wage rate. The same is true for the lump sum tax, where the proportionate change in the mu_T^i is of the same order of magnitude for all quintiles, as is the proportionate change in the after-tax wage rate.

(2) MCF^B and MCF^C

The first of the two other components of the *MCF* is the MCF^B, which reflects the additional welfare gain associated with the change in emissions. Table 14 presents the percentage change in the emission levels caused by the four policy instruments. The lump sum tax and the labour income tax both lead to lower air pollutant emissions. 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 residential (consumer) and the production sectors. Table 15 summarizes the change in non-transport energy use w.r.t. the initial equilibrium. The activity effect is the main determinant of the change in non-transport energy in the case of the lump sum tax and the labour income tax and explains why the former reduces emissions more than the latter. The composition effect is relatively less important. The switch from private to public consumption reduces emissions since public consumption does not cause air pollution. On the consumer side the share of solid fuels rises. Since these are associated with higher air pollution costs in the residential sector, this increases air pollution costs. On the producer side the opposite phenomenon is observed: the input of solid fuels is reduced more than that of other fuels. Note that the feedback effect and the valuation effect are absent.

Table 14: The Effects of the Policy Reforms on the Emissions of Air Pollutants

Emissions	Initial equilibrium (ton/day)	% change w.r.t. the initial equilibrium			
		Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
Transport					
NO_x	613	-0.006%	-0.014%	-0.074%	-0.128%
SO_x	45	-0.001%	-0.009%	-0.083%	-0.118%
HC	430	-0.016%	-0.022%	-0.110%	-0.163%
CO	1747	-0.018%	-0.024%	-0.119%	-0.170%
CO_2	55976	-0.008%	-0.015%	-0.098%	-0.140%
$PM_{2.5}$	42	-0.000%	-0.008%	-0.080%	-0.121%
Non-transport					
NO_x	380	0.000%	-0.011%	0.001%	-0.007%
SO_x	869	0.000%	-0.010%	-0.006%	-0.017%
HC	29	-0.008%	-0.014%	-0.002%	-0.012%
CO	2	0.014%	0.002%	0.017%	0.011%
CO_2	230890	-0.002%	-0.011%	-0.001%	-0.008%
$PM_{2.5}$	1	0.014%	0.002%	0.017%	0.011%
PM_{10}	12	-0.001%	-0.014%	0.005%	0.000%
Total emissions					
NO_x	992	-0.004%	-0.013%	-0.045%	-0.082%
SO_x	914	0.000%	-0.010%	-0.010%	-0.022%
HC	459	-0.015%	-0.022%	-0.103%	-0.154%
CO	1749	-0.018%	-0.024%	-0.119%	-0.170%
CO_2	286866	-0.003%	-0.012%	-0.020%	-0.034%
$PM_{2.5}$	43	0.000%	-0.008%	-0.079%	-0.119%
PM_{10}	12	-0.001%	-0.014%	0.005%	0.000%

The MCF^C reflects the change in the external transport accident costs. The activity effect of the labour income tax reduces the number of transport km and hence the total accident costs. The switch from private to public consumption strengthens this effect. But at the consumers' side there is a shift from car to non-car transport and especially to non-motorized transport which has relatively high external accident costs. Moreover, at the producer side the share of road transport increases, which also leads to higher accident costs. The overall impact of the activity and the composition effect is a reduction in the accident costs. Note that the composition effect does not include a feedback effect in the case of accidents. In the case of the lump sum tax, the composition effect acts in the same direction as for the labour income tax. However, the activity effect reduces transport demand by the consumers but increases the input of transport in the production sectors.

Table 15: The Effect of the Policy Reforms on the Domestic Demand for Non-Transport Energy

	Initial equilibrium	% change w.r.t. the initial equilibrium			
		Lump sum tax	Labour income tax	Peak road pricing	Fuel tax
Consumer demand					
Electricity (MWh/day)	41	-0.042%	-0.058%	-0.021%	-0.018%
Solid fuels (t/day)	2	-0.022%	-0.023%	-0.010%	-0.024%
Petrol products (t/day)	9	-0.024%	-0.026%	-0.019%	-0.022%
Gas (toe/day)	7	-0.026%	-0.025%	-0.019%	-0.017%
Input by the domestic production sectors					
Electricity (MWh/day)	486	-0.015%	-0.008%	-0.015%	-0.009%
Solid fuels (t/day)	58	0.002%	-0.012%	0.008%	-0.002%
Petrol products (t/day)	98	0.001%	-0.002%	-0.007%	-0.014%
Gas (toe/day)	21	0.009%	-0.003%	0.013%	0.007%

(3) The Distributional Impacts of the Lump sum Tax and the Labour Income Tax

Table 16 gives more information on the distributional impacts of the policies. They can be compared with the results for the model without externalities, which were presented in Table 8. It is clear that including the externalities in the analysis does not greatly affect the instruments' distributional impacts. The lump sum tax continues to affect mainly the lower quintiles, while the labour income tax mainly affects the higher quintiles. As a result, the *MCF* of the lump sum transfer increases with the degree of inequality aversion, while the opposite is true for the labour income tax [see Table 9]. The value of the MCF^B and the MCF^C is not affected by the degree of inequality aversion. This is because the marginal willingness to pay for a reduction in emissions and accidents is assumed to be identical for all individuals (across the quintiles).

Table 17 presents the impact of the four policy measures on the inequality index. *INEQ* incorporates the welfare effects of the change in all externalities, while $INEQ^A$ includes only the effect on congestion. The effect of the lump sum tax and the labour income tax on the inequality indices is similar to the effect in the model without externalities. The lump sum tax increases inequality, while the opposite is true for the labour income tax. When account is taken only of the impact on the congestion level, inequality is increased more (by the lump sum tax) or reduced less (by the labour income tax) than in the model without externalities. The opposite is observed when the effect on the other externalities is included as well. This indicates that the reduced congestion leads to a higher relative increase in welfare for the individuals belonging to the higher quintiles, while the reverse is true for air pollution and accidents.

b. Peak Road Pricing and the Fuel Tax

(1) MCF^A

The fact that peak road pricing is a very effective instrument to tackle the congestion problem is reflected in the large difference between the MCF^A and the MCF^* for this instrument [see Tables 10 and 11]. It is because of this characteristic that peak road pricing becomes the best instrument to finance the increase in government expenditures when externalities are taken into account. This is the case not only when only efficiency aspects are considered (i.e., for $g = 0$) but also for higher degrees of inequality aversion. The gross composition effect is the main explanation for the substantial difference between the MCF^A and the MCF^*. Table 11 shows that the imposition of a tax on peak road transport induces the consumers and the domestic production sectors to switch from peak car to off-peak car transport, and to the other transport modes. At the consumer side, the percentage changes are larger for the poorer than for the richer quintiles. This is because the price elasticities are higher for the poorer quintiles. The proportional changes are smaller for business than for non-business transport, due to the lower price sensitivity of the former category. As regards freight transport, Table 10 shows that there is a switch from peak to off-peak road freight transport and from road freight transport to inland navigation and rail. The effect on transit transport is larger than that on domestic and import related transport given the higher price sensitivity of this type of transport. The gross composition effect is offset to some extent by the feedback effect. E.g., because of the higher speeds the consumer demand for peak car pkm is reduced by 0.48% compared to 0.64% in the model without externalities (which assumes constant speed).

The activity effect is of relatively small importance. On the consumer side it reinforces the composition effect. The real after tax wage falls 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 lowers the productivity of the other inputs in the production process. Part of the burden will be borne by labour. The lower real after tax wage rate leads to a reduction in real generalized income. The proportional reduction is higher for the richest quintiles, because time income accounts for a larger share of their generalized income compared to the poorer quintiles. Consumer demand for all goods is reduced, and the proportional decrease is higher for the richer quintiles. However, the domestic production sector becomes more competitive, thanks to the lower wage rate and the increase in transport speed, such that an opposite activity effect is observed on the production side.

The welfare gain of the reduction in the congestion level is mitigated by a change in the marginal utility of a time saving (mu_T^i) [see Table 13]. The impact is larger than for the lump sum tax and the labour income tax. The most pronounced changes are observed for peak car and peak bus, tram and metro transport which are affected the most by the policy reform. The percentage change in mu_T^i for peak car transport ranges from -0.115% (for quintile 5) to -0.231% (for quintile 3)(quintile 1 has a small positive change), while for peak bus, tram and metro transport it ranges from -0.12% (for quintile 5) to -0.514% (for quintile 3). For individuals belonging to the second to fifth quintile the mu_T^i for peak car transport is related negatively to its consumer price, its speed and the individuals' demand for the good. It is related positively to the wage rate. The mu_T^i of the poorer quintiles is more sensitive to

Table 16: Balanced Budget Incidence Exercises: The Distribution of the Welfare Impact among the Quintiles - The AGE Model with Externalities[a]

	Lump sum tax		Labour income tax		Peak road pricing		Fuel tax	
EG								
Quintile 1	-24.3	(-0.0491%)	-7.8	(-0.0157%)	-3.2	(-0.0066%)	-4.3	(-0.0087%)
Quintile 2	-20.0	(-0.0324%)	-7.5	(-0.0123%)	-6.6	(-0.0107%)	-7.8	(-0.0126%)
Quintile 3	-14.6	(-0.0200%)	-8.6	(-0.0117%)	-8.9	(-0.0121%)	-9.6	(-0.0131%)
Quintile 4	-11.4	(-0.0136%)	-12.8	(-0.0153%)	-9.9	(-0.0118%)	-11.2	(-0.0133%)
Quintile 5	-9.9	(-0.0091%)	-27.6	(-0.0252%)	-11.1	(-0.0101%)	-13.8	(-0.0126%)
EG^A								
Quintile 1	-24.4	(-0.0493%)	-8.0	(-0.0162%)	-4.5	(-0.0090%)	-6.2	(-0.0125%)
Quintile 2	-20.1	(-0.0325%)	-7.8	(-0.0126%)	-7.9	(-0.0127%)	-9.7	(-0.0157%)
Quintile 3	-14.7	(-0.0201%)	-8.8	(-0.0120%)	-10.1	(-0.0138%)	-11.5	(-0.0157%)
Quintile 4	-11.5	(-0.0137%)	-13.1	(-0.0156%)	-11.1	(-0.0132%)	-13.1	(-0.0156%)
Quintile 5	-10.0	(-0.0091%)	-27.8	(-0.0254%)	-12.3	(-0.0112%)	-15.7	(-0.0143%)
EG^B								
Quintile 1	0.02	(0.00005%)	0.20	(0.0004%)	0.96	(0.0019%)	1.52	(0.0031%)
Quintile 2	0.02	(0.00004%)	0.20	(0.0003%)	0.96	(0.0016%)	1.52	(0.0025%)
Quintile 3	0.02	(0.00003%)	0.20	(0.0003%)	0.96	(0.0013%)	1.52	(0.0021%)
Quintile 4	0.02	(0.00003%)	0.20	(0.0002%)	0.96	(0.0011%)	1.52	(0.0018%)
Quintile 5	0.02	(0.00002%)	0.20	(0.0002%)	0.96	(0.0009%)	1.52	(0.0014%)
EG^C								
Quintile 1	0.06	(0.00012%)	0.05	(0.00010%)	0.25	(0.0005%)	0.40	(0.0008%)
Quintile 2	0.06	(0.00010%)	0.05	(0.00008%)	0.25	(0.0004%)	0.40	(0.0007%)
Quintile 3	0.06	(0.00008%)	0.05	(0.00007%)	0.25	(0.0004%)	0.40	(0.0006%)
Quintile 4	0.06	(0.00007%)	0.05	(0.00006%)	0.25	(0.0003%)	0.40	(0.0005%)
Quintile 5	0.06	(0.00005%)	0.05	(0.00004%)	0.25	(0.0002%)	0.40	(0.0004%)

[a] All values are expressed in 10^{-3} ECU/1000 persons/day. The figures within brackets give the EG as % of EI^{ref}

Table 17: The Effect of the Policy Measures on the Inequality Index - The AGE Model with Externalities

	ε = 0.25	ε = 0.5	ε = 1.5
Percentage change of INEQ w.r.t. $INEQ^{ref}$			
Lump sum transfer	0.0842%	0.0853%	0.0892%
Labour income tax	-0.0369%	-0.0361%	-0.0327%
Peak road pricing	-0.0021%	-0.0024%	-0.0039%
Fuel tax	-0.0043%	-0.0045%	-0.0056%
Percentage change of $INEQ^{A}$ w.r.t. $INEQ^{A,ref}$			
Lump sum transfer	0.0844%	0.0855%	0.0894%
Labour income tax	-0.0363%	-0.0355%	-0.0320%
Peak road pricing	0.0010%	0.0006%	-0.0008%
Fuel tax	0.0005%	0.0003%	-0.0007%

changes in the wage rate and the consumer price than that of the higher quintiles. This explains why the change in the mu_T^i for peak car transport is smaller for the richer quintiles. For the first quintile its value increases. This is because for this quintile mu_T^i is positively related to the consumer price. The mu_T^i for bus, tram and metro transport is related positively to the wage rate and the consumer price, and negatively to speed and the individual's consumption of the good. The different magnitude of the effect on the mu_T^i for peak bus, tram and metro transport for the different quintiles is mainly explained by differences in the sensitivity of this variable to changes in the wage rate and the consumer price across the quintiles.

The fuel tax performs worse than peak road pricing in tackling the congestion problem. This explains why its ranking in terms of the *MCF* changes from the first place in the modl without externalities to the second place when the externalities are taken into account. The composition effect is to blame for this. Table 11 shows that the fuel tax lowers total car pkm more than peak road pricing. However, this reduction takes place both in the peak and in the off-peak period. Moreover, the percentage reduction is larger in the latter period, even though the congestion problem is much less stringent in this period. In Table 10 a similar impact is observed for freight transport by the domestic production sectors. Note that the share of the road mode increases for import related and transit transport, since these are assumed not to be subject to the fuel tax but can benefit from the higher speeds on Belgian roads.

Also for the fuel tax the welfare impact of the lower traffic levels is mitigated by the reduction in the mu_T^i marginal utility of a time saving (see Table 13). The reduction is slightly larger in the off-peak period. For car transport this is due to the fact that off-peak transport is more sensitive to changes in the consumer price and wage rate than peak transport. For transport by bus, tram and metro, the sensitivity to changes in the wage rate, speed and the consumption of the good is much higher in the off-peak period.

(2) MCF^B and MCF^C

The downward pressure on the *MCF* from the congestion effect of peak road pricing and the fuel tax is strengthened by the effect on emissions, which is much larger than for the two other instruments.

The fall in emissions is mainly due to lower transport emissions. The change in accident costs also reduces the *MCF* but is of smaller importance, though it is also larger than in the case of the lump sum tax and the labour income tax. The impact of the fuel tax on accident and air pollution costs is higher than for peak road pricing, because transport is reduced more.

(3) The Distributional Impacts of Peak Road Pricing and the Fuel Tax

Table 16 shows that for both instruments the equivalent loss per 1000 persons is higher for individuals belonging to the richer quintiles. As a consequence the value of the *MCF* decreases for higher degrees of inequality aversion (see Table 9). If we express the equivalent loss as a percentage of the equivalent income in the initial equilibrium, the proportional welfare loss is the highest for individuals belonging to quintiles 2, 3 and 4.

As in the model without externalities, the fuel tax and peak road pricing reduce inequality. However, the proportional reduction in *INEQ* is lower than for $INEQ^*$. This is because the relative welfare impact of the reduction in congestion is high for quintiles 2, 3 and 4. Indeed, when account is taken only of the impact of the policy measures on congestion, the evolution of $INEQ^A$ actually indicates a higher inequality for $g = 0.25$ and $g = 0.5$. Inequality is reduced only when the degree of inequality aversion is sufficiently high or when the welfare impact of the change in air pollution and accidents is included. Of the two instruments the fuel tax is associated with the highest proportional reduction in inequality. This contrast with the results of the model without externalities and can be explained by the larger impact of the fuel tax on air pollution and accidents.

c. Revenue Neutral Welfare Improving Tax Reforms and the Link with the Double Dividend Literature

The results of the balanced budget incidence experiments can be used to decide which revenue neutral policy reforms are welfare improving with respect to the initial equilibrium. When taking into account the externalities and for $g = 0$, the *MCF* is the lowest for peak road pricing, followed by the fuel tax, the lump sum tax and the labour income tax. Table 9 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 lump sum transfer or a reduction in the labour income tax. It also suggests that the welfare gain will be higher for peak road pricing than for the fuel tax and that for both instruments the welfare gain is higher when the revenue is recycled through a change in the labour income tax rather than the transfer. Indeed the *MCF* of the lump sum tax is lower than that of the labour income tax. This is due to the difference in the gross welfare costs of the two instruments, since the advantage of a lower labour income tax is somewhat offset by the higher level of congestion, air pollution and accidents in comparison with the lump sum transfer. Moreover, we know from the model without externalities that the MCF^* is larger for the labour income tax than for the lump sum tax when $g = 0$.

From Table 16 we can derive that the revenue neutral substitution of peak road pricing or the fuel tax for the lump sum tax leads to higher welfare gains for the poorer than for the richer quintiles. E.g., the combination of peak road pricing and a higher lump sum transfer leads to a welfare gain of 21.1 10^{-3} ECU (=24.3 10^{-3} ECU-13.2 10^{-3} ECU) per day per 1000 persons belonging to quintile 1 compared to -1.2

10^{-3} ECU (=9.9 10^{-3} ECU-11.1 10^{-3} ECU) for quintile 5. When the revenue is recycled through a lower labour income tax, the main beneficiaries are the two richest quintiles and the first quintile.

For higher degrees of income aversion, it is still welfare improving to introduce peak road pricing or raise the fuel tax and to return the revenue via a lump sum transfer or a lower labour income tax rate. However, because of the distributional impacts of the policy reforms the welfare gain is now higher when the revenue is returned through an increase in the lump sum transfer rather than a lower income tax rate.

Table 17 shows that the policy reforms involving revenue recycling through the lump sum transfer reduce inequality, while the reverse is observed when the labour income tax is reduced instead. E.g., peak road pricing with lump sum replacement reduces *INEQ* by -0.0862% (=-0.0021%-0.0842%) compared to the increase in *INEQ* by 0.0348% (=-0.0021%+0.0369%) when the labour income tax rate is lowered.

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), a weak double dividend is realised when, by using the revenues of the externality taxes to finance a reduction in a distortionary tax, one obtains a gross welfare gain relative to the case where the lump sum tax is used to return the revenues. One can examine the presence of a weak double dividend by comparing the gross welfare costs of the labour income tax and the lump sum transfer. Table 8 shows that a weak double dividend is present only for $g = 0$, since only in that case the MCF^* of the labour income tax is larger than that of the lump sum tax. For higher degrees of inequality aversion no weak double dividend can be realised. 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. Table 8 shows that for $g = 0$ a gross welfare gain can be realised when using the revenues of peak road pricing or the fuel tax to finance a reduction in the labour income tax. The MCF^* of the two tax instruments is lower than that of the labour income tax. For $g = 0.25$ and $g = 0.5$ a strong double dividend can be realised only for the fuel tax. For higher degrees of inequality aversion there are no more possibilities for a strong double dividend.

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, air pollution (including global warming) and accidents. It includes non-identical individuals which allows to study the distributional impacts of the policy reforms. Firstly, 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, a higher degree of inequality does not have a large impact on the ranking of the instruments except for the lump sum tax and the labour income tax whose place in the ranking is reversed. Thirdly, regardless of the way in which the tax revenue is recycled, the welfare gain of peak road pricing is shown to be higher than that of the fuel tax, because peak road pricing tackles the congestion problem in the period in which it is the most stringent and it is applicable to all peak road transport no matter what is their country of origin.

Fourthly, when the externality tax revenue is recycled through the lump sum tax the welfare gains are higher for the poorer than for the richer quintiles. On the other hand the main beneficiaries of revenue recycling through the labour income tax are the two richest and the poorest quintile. As a consequence, when the social welfare function gives a higher weight to the welfare of individuals belonging to the poorer quintiles, the distributional impacts of the policy reforms cause the welfare gain to be higher when the revenue is recycled through an increase in the lump sum transfer rather than through a lower labour income tax rate. In the former case the level of inequality is reduced, while the reverse is oberved in the latter case.

Finally, a weak double dividend is realised only when all individuals are given the same welfare weight. In the other cases the use of the revenues of the externality taxes to finance a reduction in the labour income tax leads to a gross welfare cost relative to the case where the lump sum tax is used to return the revenues. However, the inclusion of distributional considerations offers the possibility of realising a strong double dividend for low degrees of inequality aversion.

The analysis can be extended in several ways. A first 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 transport capacity. Secondly, 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 if there is involuntary unemployment, i.e., when the individual 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 consumer’s 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.

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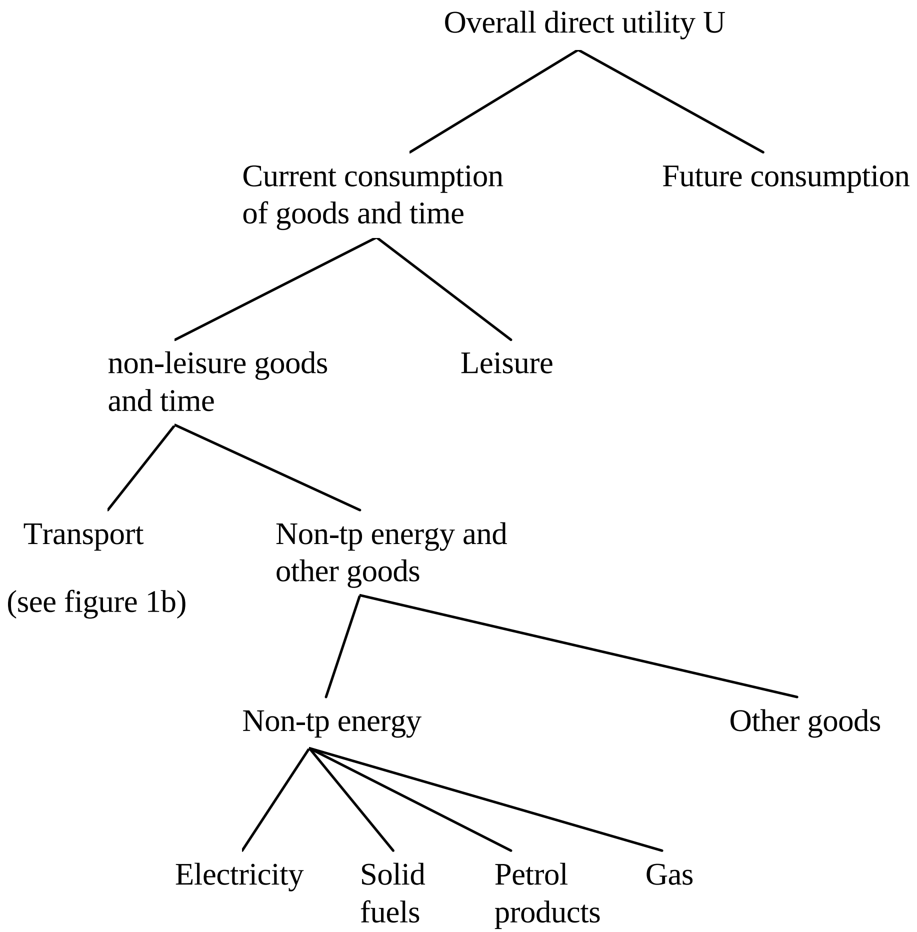
Figure 1a: The Direct Utility Function



level

w=0 Overall direct utility is a Cobb-Douglas type function of present and future consumption

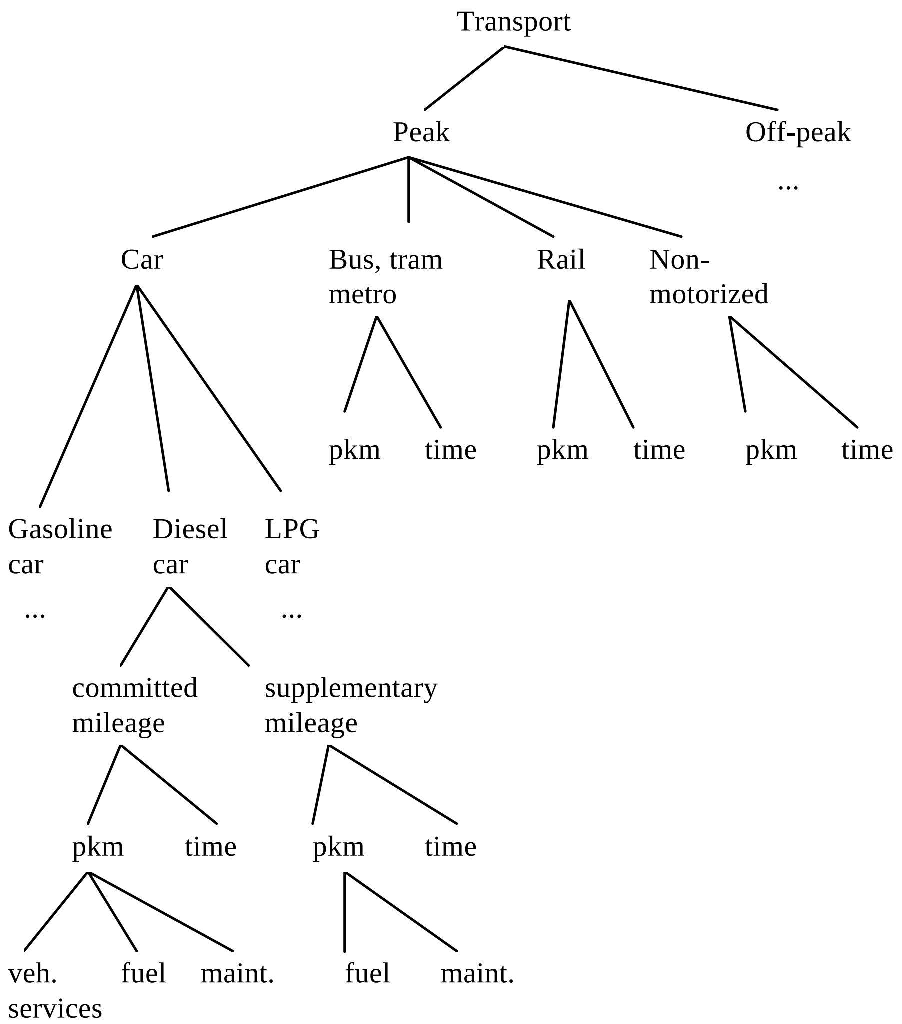
w=1 Current consumption of goods and time is a MCES function of the non-leisure goods and time component and excess leisure

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)



level

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

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
$i=1,...,I$	Index of consumer groups
$j=1,...,J$	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^i	Number of consumers belonging to consumer group i
$A_{1,m},A_2,A_3, A_4$	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^i	Endowment of capital services of a consumer belonging to consumer group i
CAP	Transport infrastructure capacity
$dREV_g$	Change in separable government spending financed by instrument g
dSW_g	Monetary value of the change in social welfare caused by instrument g
e^i	Efficiency parameter
EM	Vector of emissions of air pollutants $EM=(EM_1,...,EM_{PO})$
EM_{po}	Emissions of air pollutant po
$emen_{po,en}$	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
$\overline{ex}_j$	Total world demand for good j
$f_{ACC}^{\ i}$	Utility related to transport accidents
$f_{EM}^{\ i}$	Utility related to emissions of air pollutants
$f_U^{\ i}$	Direct utility function
F	Traffic flow
F^d	The road traffic flow in period d in millions of passenger car units
$\overline{INTTF}^{\,i}$	Net international transfer by a consumer belonging to consumer group i
$\overline{LABEXP}^{\,i}$	Time devoted to labour abroad by a consumer belonging to consumer group i
lh^i	Consumption of leisure by a consumer belonging to consumer group i
$mu_{ACC,n}^{\ \ i}$	The marginal utility of a decrease in the number of accidents of type n
$mu_{AP,po}^{\ \ i}$	The marginal utility of a decrease in the emissions of pollutant po
$mu_T^{\ i}$	The marginal utility of a time saving in transport
P^i	The poll transfer paid by the government to a consumer belonging to consumer group i
ptt	The price of transit transport in the country
$\overline{pttw}$	The price of transit transport abroad
$\overline{pw}_j$	The world price of good j (expressed in terms of the domestic currency)
px_j	The export price of the domestic good j

$qh_{NTP,k}$	The consumer price of the non-transport good *k*
$qh_{TP,m}$	The consumer price of the transport good *m*
qh_C	The consumer price of capital services
T	Endowment of time of each consumer
tt	The demand for transit transport in Belgium
$\overline{tt}$	Total demand for international transport by foreign firms
U^i	Utility of a consumer belonging to consumer group *i*
V^i	Indirect utility function
$wabh^i$	The after tax foreign wage rate
wh^i	The after tax wage rate
$xab_{TP,m}^j$	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}^i	*K* vector of each household's consumption of non-transport goods $xh_{NTP}^i=(xh_{NTP,1}^i,...,xh_{NTP,K}^i)$
xh_{TP}^i	*M* vector of each household's consumption of transport goods $xh_{TP}^i=(xh_{TP,1}^i,...,xh_{TP,M}^i)$
$xp_{NTP,en}^j$	The input of the non-transport energy good *en* by the domestic production sector *j*
$xp_{TP,m}^j$	The input of the transport good *m* by the domestic production sector *j* for domestic delivery of good *j*
$xt_{TP,m}$	The input of the transport good *m* for transit transport in Belgium
$xx_{TP,m}^j$	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
W	Social welfare
Z	The congestion level
$(_{TP,m}^i$	The marginal utility to a consumer of saving time in the consumption of transport good *m*
g	Degree of inequality aversion
$0t$	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
$2_{TP,m}^d$	The minimum time requirement for transport mode m in period *d*
$2h_{TP}^i$	*M* vector of time devoted by a consumer to the consumption of transport goods $2h_{TP}^i=(2h_{TP,1}^i,...,2h_{TP,M}^i)$
$2h_{TP,m}^*$	The minimum time requirement for the consumption of transport good *m*
8^i	The marginal utility of income to a consumer belonging to consumer group *i*

List of abbreviations

AGE	Applied general equilibrium
CO	Carbon monoxide
CO_2	Carbon dioxide
EG^i	Equivalent gain of a consumer belonging to group *i*
EI^i	Equivalent income of a consumer belonging to group *i*
EI_E	Equally distributed equivalent level of equivalent income
HC	Hydrocarbons
INEQ	Inequality index
MCF	Marginal cost of public funds
NO_x	Nitrogen oxide
PCU	Passenger car units
pkm	passenger kilometre
PM	Particulate matter
SG	Social equivalent gain
SO_2	Sulphur dioxide
tkm	Tonne kilometre
vkm	Vehicle kilometre
VOT	Value of a marginal time saving