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A computable general equilibrium for Belgium with a special focus on transport policies

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Abstract – This paper seeks to extend the PLANET model to allow for an endogenous influence of transport sector outcomes on the economy. To this end, we embed the PLANET data on freight and household transport for 2003 into a static CGE model of the Belgian economy. Households use transport for commuting and leisure transport, while production sectors use freight as an input. We allow for important feedback effects on generalized transport costs through congestion. To illustrate the model, we contrast the effects of a kilometre charge on freight only and a charge that targets household transport as well.

Abstract – Le présent document vise à étendre le modèle PLANET afin d'endogénéiser l'impact du secteur des transports sur l'économie. A cette fin, les données issues du modèle PLANET, relatives au transport des marchandises et des ménages pour l'année 2003, sont incorporées dans un modèle d'équilibre général statique de l'économie belge. Les ménages utilisent les transports pour les trajets domicile-lieu de travail et pour leurs loisirs, tandis que les secteurs de production recourent au transport de marchandises comme input. Des effets de rétroaction importants sur les coûts de transport généralisés sont pris en compte via la congestion. Pour illustrer le modèle, les effets d'une taxe kilométrique appliquée exclusivement sur le transport de marchandises sont comparés à une taxe kilométrique appliquée également sur le transport des ménages.

Abstract – Deze paper heeft als doel het PLANET-model uit te breiden met endogene feedbackmechanismen van de transportsector naar de rest van de economie. Daartoe worden de PLANET-gegevens met betrekking tot vracht- en huishoudelijk transport voor 2003 ingevoerd in een statisch CGE-model van de Belgische economie. Gezinnen gebruiken transport voor woon-werkverkeer of ontspanning, terwijl productiesectoren vrachtvervoer gebruiken als input. Belangrijke terugkoppelingseffecten op gegeneraliseerde transportkosten door congestie worden mogelijk gemaakt. Om het model te illustreren, vergelijken we de gevolgen van een kilometerheffing op uitsluitend vrachtvervoer en een heffing die tevens betrekking heeft op het huishoudelijk transport.

Jel Classification - C68, D58, D62, R41

Keywords - Transport Economics, CGE models, Externalities

Executive summary

While the PLANET model is capable of delivering detailed long term projections of transport demand for Belgium and its regions, its results largely follow in a top down way, without a reverse link from transport outcomes to the economy. The model in this paper seeks to address this shortcoming.

We construct a static CGE model of the Belgian economy, calibrated for the year 2003, that makes use of many of the partial transport models that can be found in PLANET. The model consists of one representative household, 27 production sectors and the government.

The representative household maximizes its utility subject to a monetary and a time budget constraint, which yields demands for commodities and leisure. Labour supply is endogenous and depends on net wages and commuting costs (monetary as well as time costs). For leisure trips as well as for commuting journeys, they choose between different modes and two time periods – peak and off peak travel.

Firms minimize production costs, choosing the optimal mix of labour, capital and intermediate inputs. Among these inputs we discern between four modes (trucks, light duty vehicles, inland water ways and rail), of which the two road modes are again differentiated by time period. For households as well as firms, time costs are endogenous and depend on the total traffic flow.

The government is a passive actor, levying taxes, providing transfers and consuming goods according to mostly exogenous parameters and simple growth rules.

Three simulations are used for testing the model: a kilometer charge on trucks, on trucks and light duty vehicles and a comprehensive charge that include household transport. We find that, in terms of alleviating congestion, the comprehensive charge is able to achieve more compared to partial reform.

Synthèse

Bien que le modèle PLANET permette d'obtenir des projections à long terme détaillées sur la demande de transports en Belgique, aux niveaux national et régional, ses résultats sont majoritairement top-down, sans rétroaction entre les résultats de transport et l'économie. Le modèle présenté dans ce Working Paper a pour but de combler cette lacune.

Un modèle d'équilibre général statique de l'économie belge, calibrée pour l'année 2003 et utilisant les modèles d'équilibre partiels repris dans PLANET, a été élaboré. Dans son développement actuel, le modèle se base sur un ménage représentatif, 27 secteurs de production et le gouvernement.

Le ménage représentatif maximise son utilité sous contrainte budgétaire liée aux temps et à l'argent, ce qui entraîne une demande de produits de base et de loisirs. L'offre de travail est endogène et dépend des salaires nets et des coûts liés aux trajets domicile-lieu de travail (que ce soit en termes de temps ou d'argent). Pour les trajets liés aux loisirs et les navettes, les ménages choisissent entre différents modes et deux moments de la journée : les heures de pointe et les heures creuses.

Les entreprises minimisent leurs coûts de production en choisissant le meilleur rapport entre la main-d'œuvre, le capital et les inputs intermédiaires. Ces derniers ont été ventilés en quatre modes (camions, véhicules utilitaires légers, voies navigables et voies ferrées). Les deux modes de transport routier ont été à leur tour répartis selon le moment de la journée. Pour les ménages et les entreprises, les coûts liés au temps sont endogènes et tributaires de la circulation routière.

Le gouvernement est un acteur passif, qui perçoit des taxes, réalise des transferts et consomme des biens selon des paramètres essentiellement exogènes et des règles de croissance simples.

Le modèle est testé à l'aide de trois simulations: une taxe kilométrique sur les camions, une taxe sur les camions et les véhicules utilitaires légers et une taxe visant également les ménages. On constate que cette dernière permet de réduire davantage la congestion, comparée aux taxes kilométriques partielles (camions et véhicules utilitaires légers uniquement).

Synthese

Hoewel het PLANET-model in staat is gedetailleerde langetermijnprojecties te realiseren voor de transportvraag in België en zijn gewesten, zijn de resultaten ervan grotendeels top-down, zonder terugkoppeling van de transportresultaten naar de economie. Het model in deze paper probeert deze lancune te verhelpen. We bouwen een statisch algemeen evenwichtsmodel op voor de Belgische economie, geijkt voor het jaar 2003, dat gebruik maakt van verschillende van de partiële transportmodellen die deel uitmaken van PLANET. Het huidige model omvat een representatief gezin, 27 productiesectoren en de overheid.

Het representatief gezin maximaliseert zijn nut, rekening houdend met een monetaire en een tijdgebonden budgetbeperking, waaruit de vraag naar goederen en vrije tijd volgt. Het arbeidsaanbod is endogeen en afhankelijk van de nettolonen en de kosten voor woon-werkverkeer (monetaire en tijdkosten). Zowel voor vrijetijdsreizen als voor woon-werkverkeer kiest het gezin tussen verschillende vervoerswijzen en twee tijdspannes – spitsuur en daluur.

Ondernemingen minimaliseren hun productiekosten door te kiezen voor de optimale verhouding tussen arbeid, kapitaal en intermediaire inputs. Met betrekking tot die inputs onderscheiden we vier categorieën (vrachtwagens, lichte bedrijfsvoertuigen, binnenlandse waterwegen en spoorwegen). De twee categorieën van wegverkeer wordt opnieuw opgedeeld per tijdspanne. Zowel voor de gezinnen als voor de ondernemingen zijn de tijdkosten endogeen en afhankelijk van de totale verkeersstroom.

De overheid is een passieve actor die belastingen heft, transfers voorziet en goederen consumeert volgens voornamelijk exogene parameters en eenvoudige groeiregels.

Om het model te testen, worden drie simulaties gebruikt: een kilometerheffing op vrachtwagens, op vrachtwagens en lichte bedrijfsvoertuigen en een bredere heffing die ook de gezinnen omvat. Onze conclusie luidt dat, in termen van congestievermindering, meer bereikt kan worden door de bredere heffing dan door een gedeeltelijke hervorming.

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1. Introduction

With its long term transport model PLANET[1], the Federal Planning Bureau disposes of a powerful tool to make detailed projections of the transport sector for Belgium and its regions. However, the relationship between transport and the economy in the PLANET model is unilateral. Projections of main economic variables – GDP, employment – are exogenous, and results for the transport sector follow in a top down way. Moreover, welfare evaluation is done by using outside estimates of the marginal cost of public funds of different tax instruments, instead of being endogenously determined within the model.

In reality, the economy influences the transport outcome, but the evolution of transport also influences the economy. The model presented in this paper aims to take the mutual influence of transport and the economy into account. When performing policy analysis, such a two-way link yields additional interesting insights. One interesting channel is the influence of commuting time on labour supply. Parry and Bento (2001) analyse a labour supply model where the household choses the number of workdays and where daily commuting time has a negative influence on labour supply. In such a model, road pricing policies may have important consequences for employment and for the broader welfare evaluation of transport taxes. However, the labour market impact of transport costs need not go through the labour supply channel only. For example, Rupert, Stancanelli and Wasmer (2009), study how commuting time influences wage formation in labour markets with search-and-matching frictions, while De Borger (2009) studies optimal transport pricing when commuting costs influence wage negotiations. Of course, outcomes in the transport sector influence freight costs and production costs too. Calthrop, De Borger and Proost (2001) study optimal road freight taxes, when the downside of such congestion fighting taxes is that they raise the production costs of freight intensive goods.

This paper provides a first step towards the full endogenization of PLANET, by embedding the PLANET data on freight and passenger flows, time and monetary transport costs into a CGE model of the Belgian economy, using elements from the aforementioned literature.

In its present state the CGE model sacrifices some of the detail of the PLANET model. It is for now only a static model, contains no regional breakdown and has somewhat less detail in transport modes and car types. As such, PLANET and the CGE model may yet be viewed as complementary tools with different relative strengths. The CGE model should be more suited to study the welfare effects of different pricing policies for transport, while PLANET's relative strength lies in its ability to make detailed projections of transport demand in Belgium and to analyse the impact of transport policies on transport demand and on externalities such as pollution and congestion.

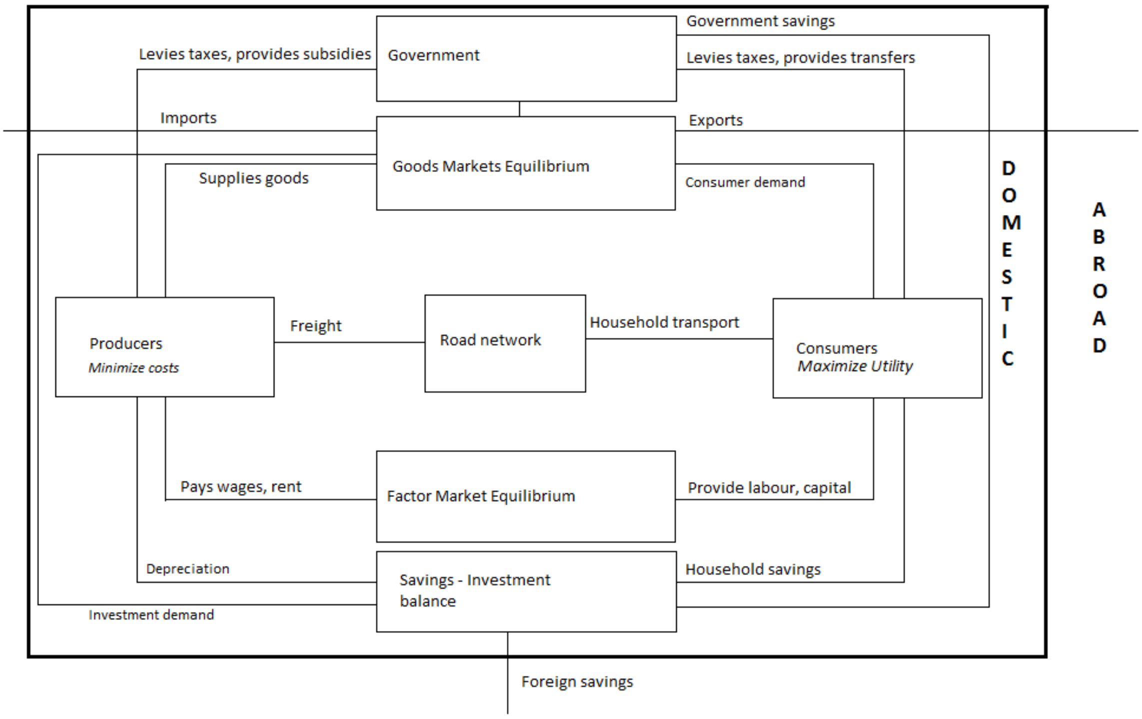
The structure of the paper is as follows: section 1 presents the theoretical structure, while section 2 extensively describes the dataset and the calibration of the model. To illustrate the properties of the model, illustrative policy analyses are given in section 3.

1 The PLANET model has been extensively described in Desmet, e.a. (2008).

2. Structure of the CGE model

Essentially, a CGE model describes the economy as a decentralized Walrasian equilibrium of a large number of simultaneously interrelated markets, where market clearing prices guarantee global equilibrium. It – mostly – formulates the supply and demand behaviour of the agents that interact on these markets as the result of an individual optimisation program. The major agents are consumers, firms, the government and the rest-of-the-world. A graphical summary of the CGE model presented in this paper is given in Figure 1.

Figure 1 Schematical representation of the model



Consumers own the capital stock of the economy and supply labour to firms. Their demand for commodities, among which transport demand, is derived from utility maximization, given income and prices. Producers minimize costs given input prices, among which freight, and factor prices, subject to a neo-classical constant-returns-to-scale production function. Households and firms alike use the transport network for commuting, leisure transport and freight.

The government is a passive actor, which levies taxes, pays transfers and subsidies and consumes goods according to fixed tax rates or simple growth rules.

The foreign sector supplies/demands goods to/from the domestic market according to fixed world market prices, and supplies foreign domestic investment to the domestic economy.

Foreign investment demand, household savings, government savings and replacement investment determine investment demand.

All prices of commodities and factor rewards, which influence the decisions of households and firms, are determined by equilibrium conditions on their respective markets. Important exceptions are transport prices faced by households and firms, which are partially determined by time costs. These time costs are determined through distance and the time spent on the road network, which is influenced by congestion.

The rest of this section describes in detail the different model components. The first three subsections discuss the modelling approach for households, domestic production sectors, international trade and the government. The last subsections treat the savings and investment decisions and the market equilibrium conditions.

Before we engage in a full description, however, it may help to summarize the notation of the model. Generally, variables are stated in upper case letters whereas parameters are in lower cases. In some cases, the initial values of the variables are taken explicitly as a parameter. In this case, the original name is preceded by the latter 'b' (from 'base year') and the name is written in lower cases.

Table 1 Subscripts associated with the different dimensions

	Subscript
Goods/sectors (SUT classification)	s
Consumption goods (Coicop classification)	c
Consumption good aggregates	c2
Tax types	t
Transport motive	mot
Time Period	p
Social mode of car transport	socc
Mode of road freight transport	m

A full listing of the sets, variables, parameters and equations of the CGE model is presented in Appendix A and Appendix B.

2.1. Households

2.1.1. The household's problem

Before describing the components of household utility in some detail, it is useful to state the household maximization problem schematically:

$$\max_{\text{C,QCleis,LeisTP}} U(C, QCleis, LeisTP) - \alpha_{LT} LT \cdot LeisTP - \alpha_{CT} CT \cdot LS$$

$$s.t. p_C C + p_{LTP} LeisTP = Ydisp$$

$$\bar{T} = LS + QCLeis$$

Households maximize utility, U, in consumption C (an aggregate of all other commodities, except for leisure transport), leisure $QCleis$ and leisure transport $LeisTP$ subject to the monetary constraint, which states that monetary expenditure on C and $LeisTP$ needs to equal disposable income $Ydisp$, and the time constraint, which says that labour supply LS and leisure have to exhaust the total time endowment $\bar{T}$.

It is important to note that we keep transport time out of the time constraint and have it appear as components of the utility function. α_{LT} and α_{CT} are parameters that translate transport time into disutility. LT and CT denote the unit time requirement of $LeisTP$ and labour supply,LS, (i.e. commuting time) respectively, which are in the model endogenous variables that depend on the total road flow, and therefore in turn on LS (which determines commuting) and $LeisTP$. However, in its maximization problem, the household treats LT and CT as given parameters. It ignores the contribution of an extra unit of labour supply or leisure transport on time costs, giving rise to a classical externality problem.

We kept transport time out of the time constraint that governs the labour-leisure choice, primarily because this is a representative agent model that seeks to capture the behaviour of the whole population in one problem. If we were to include leisure transport time in the same constraint as labour supply, such as in the following equation,

$$\bar{T} = (1 + CT) \cdot LS + QCLeis + LT \cdot LeisTP$$

any drop in leisure transport time would necessarily translate to a greater or lesser extent into higher labour supply as well, since the constraint must be met. It is doubtful whether we would see this behaviour in real life, even for employed persons. But since our representative agent model seeks to capture the behaviour of persons that do not participate on the labour market, like pensioners as well, we would expect a vast overstatement of labour supply reactions to commuting time by using the above time constraint.

Disposable monetary income $Ydisp$ is defined as follows. The household earns labour income and capital income, each net of taxes[2] τy and τky respectively, receive transfers TRF from the different governments and pay 'Lump Sum' taxes LST to the government. Monetary commuting costs CC are subtracted from the after tax wage $PL(1 - \tau y)$. Savings are defined according to a fixed savings rate mps.

$$Ydisp = \{LS \cdot [PL(1 - \tau y) - CC] + TOTCAPY(1 - \tau ky) + CPI \cdot TRF - CPI \cdot LST\} \cdot (1 - mps)$$

In this equation LS is labour supply and $TOTCAPY$ is total capital income. Both transfers and the lump sum tax are indexed to the consumer price index CPI.

Both time and monetary income constraints can be reduced to a single one, by plugging the time constraint in the monetary constraint:

$$p_C C + p_{LTP} LeisTP + QCLeis \cdot [PL(1 - \tau y) - CC] = Yext$$

Where the extended income $Yext$ includes both monetary and time budget, namely :

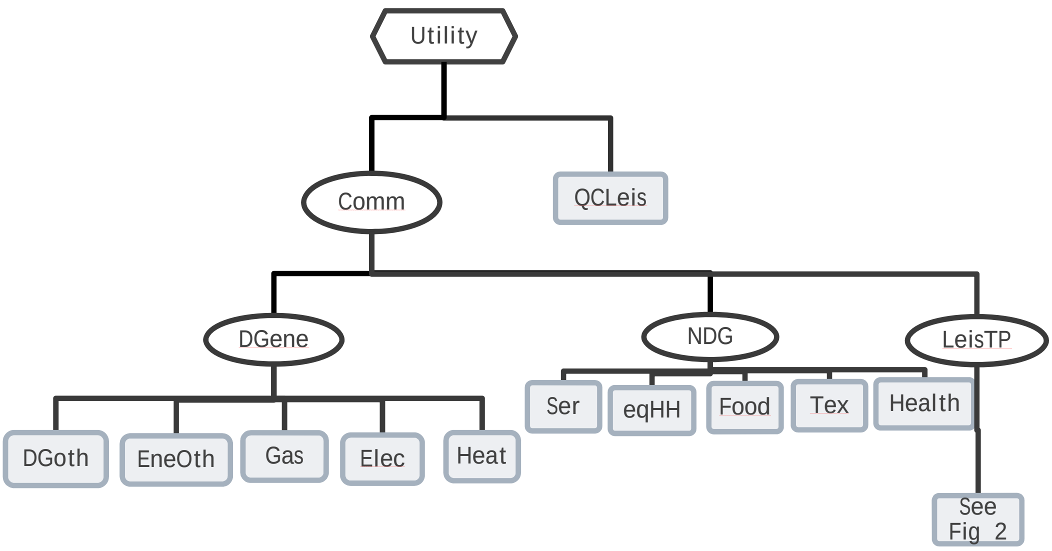
$$Yext = \{\bar{T} \cdot [PL(1 - \tau y) - CC] + TOTCAPY(1 - \tau ky) + CPI \cdot TRF - CPI \cdot LST\} \cdot (1 - mps)$$

[2] Labour income taxes τy include personal income taxes and all social security contributions.

Figure 2 describes the utility function $U(.)$ as it appears in the model. At the top level the first component of the utility function is a CES function of leisure time ($QCleis$) and a composite of the other goods and services (Comm). The composite commodity is a CES function of the composite of non-durable goods (NDG) and the composite of durable goods and energy (DGene) and Leisure transport. Leisure transport is a composite of trips by different modes and time periods. Its subutility function will be explained in a later paragraph (see figure 3). The non-durable goods composite is a CES function of five types of non-durable goods: health related goods and services (Hea), textile and shoes (Tex), food, drink and tobacco (Food), household equipment (eqHH) and education, communication, culture and others (Ser).

The durable goods and energy composite is a CES function of the consumption of 2 types of durable goods services (Major appliances (Heat) and Other durable goods (DGoth), comprising mainly housing) and of three energy goods (Gas, Electricity and Other energy).

Figure 2 The nesting structure of the household utility function



Solving the above system using the utility function in figure 2, yields the CES demand equations that are stated in full in appendix B.

In the model code, consumer prices PC_c are defined as tax inclusive:

$$PC_c = \sum_s Qmatrix_{s,c} P_s \left(1 + \sum_t \tau c_{c,t}\right)$$

where $Qmatrix_{s,c}$ is a mapping that translates prices by SUT category to prices by COICOP category. Households pay taxes $\tau c_{c,t}$, among which are VAT, excises, subsidies and other product related taxes[3].

[3] These include, for example, registration duties on the purchase of real estate.

The price of 'Leisure' transport equals the composite price of the leisure transport production function stated below.

Importantly, the price of leisure that results from the above maximization problem is:

$$PLEIS = [PL(1 - \tau y) - CC] - \alpha_{CT} CT/\mu$$

which implies that leisure demand (and therefore also labour supply) depends on the (daily) net wage, corrected for the (daily) time costs of commuting. These time costs are translated into monetary terms using the marginal utility of income, μ.

It should be noted that this labour market model, although it is quite common in the transport literature (see e.g. Parry and Bento (2001), Van Dender (2003)), is rather restrictive. Essentially, it imposes strict complementarity between daily commuting costs and the number of days worked and allows only for one behavioural margin, namely to change the number of working days in response to daily commuting costs. However, in reality people have more options at hand as a response to changes in commuting time. For example, they can choose to alter the start and finish of their working day or dispose of the option of teleworking.

Or, as stated by Gutierrez-i-Puigarnau and Van Ommeren (2010), workers may choose to change the total hours worked per day simultaneously with the number of days worked. In their empirical application, they found that employed workers actually increase the length of their working day due to commuting distance while cutting back in the number of days worked. Using German data, they find that the net effect on *total* hours worked (i.e. days x hours) would even be (slightly) positive.

However, such evidence does not necessarily refute the negative relationship between labour supply and commuting time that we impose here. For example, the participation decision – as opposed to the decision of how much to work – may be an influenced by commuting costs too. In this respect, the empirical results of Black, Kolesnikova and Taylor (2010) are interesting. They find a markedly high impact of commuting times on the labour participation rate of married women in the US. Moreover, their results suggest a higher probability to be retired earlier for men in cities with higher average commuter costs. This last point has also been made by Gonzales (2008).

2.1.2. Household Transport

In the current model, the household uses transport for two motives: commuting and 'leisure transport (LeisTP)'. For now, we depart from the PLANET model, which includes three motives: commuting, schooling and 'other' motives. In this version of the CGE model, we aggregated the last two motives and label them as 'LeisTP'.

Total demand for leisure trips, in person kilometres (pkm) just follows from utility maximisation, as outlined above. For work related travel, it is assumed that one unit of labour supply – measured in days worked – requires bcc[4] pkm of commuting transport:

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[4] The number of pkm required per trip is an exogenous parameter, so that we rule out that household use the option of moving as a response to transport costs. This is consistent with a short to medium run interpretation of the results.

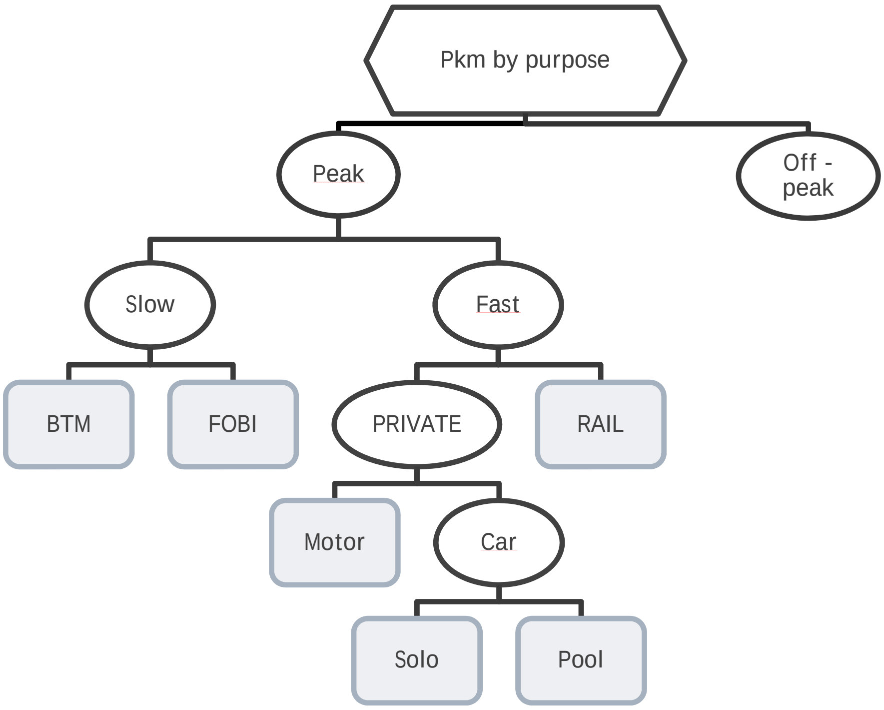
$$CHHTP\_0_{mot} = LeisTP \text{ if mot = 'LTP'}$$

$$CHHTP\_0_{mot} = bcc \cdot LS \text{ if mot = 'work'}$$

The household transport decision is determined per trip purpose. Given total demand for pkm, households are assumed to minimize their generalized transport costs subject to the household production technology for transport. The transport production function is a nested function as presented in Figure 3. The inputs of this production function are expressed in passenger km or vehicle km:

– by the different modes: car solo, car pool, motorcycle, rail, bus/tram/metro (BTM) and on foot/by bicycle (FOBI),
– per time period: peak and off-peak.

Figure 3 The production function for household transport (by trip purposes)



Lower level prices by mode (PHT) are a composite of time and monetary costs. For each mode and motive, we assume a unit time requirement (THT) and a unit requirement of transport inputs ($bmht$):

$$PHT = PMHT \cdot bmht + \frac{\alpha}{\mu} THT$$

Like upper level consumer prices, monetary prices in household transport ($PMHT$) are tax – inclusive. As usual we distinguish between VAT, excises, subsidies and other product related taxes. α is the disutility of time by motive, and μ is the marginal utility of income.

Note that only in the cases of car, motorcycle and BTM transport unit time requirements are endogenous (determined by the speed-flow relationship on the road).

2.2. Firms

The production side of the model considers 25 sectors, 8 of which are transport related. An overview is given in Table 2. The emphasis lies on industrial sectors, given their obvious link with freight transport, and transport service sectors.

Table 2 The LIMOBEL production sectors

	Non – transport sectors
AGR	Agriculture, forestry, fisheries
FUELS	Solid fuels
FUELL	Liquid fuels
MET	Ferrous and non – ferrous metals
RAW	Raw materials, building materials
CHE	Chemical products, pharmaceutics
OTHEN	Other energy intensive industries (paper, plastics, metal products)
ELEC	Electrical goods
CAR	Transport equipment
OTHEQ	Machinery
CONS	Consumer goods
FDT	Food, drinks and tobacco
CON	Construction
WAT	Water supply
FIN	Financial services
SERM	Market services
SERG	Government services
ELE	Electricity
GAS	Gas
	Transport sectors
ROADF	Road freight
MAR	Maritime transport
INNAV	Inland navigation
RAILG	Rail freight
RAILP	Rail passenger transport
BTM	Bus, tram, metro
OTHF	Other freight
OTHP	Other passenger transport

Firms, which operate in a perfectly competitive environment, minimize costs under the technological constraint which is represented by the nested CES function presented in Figure 4. Inputs are capital, labour, other intermediates and freight. At the upper nest producers decide between the value-added block KL and the materials-freight bundle MT. The MT bundle itself is a CES function of the intermediates composite (M), freight by rail, internal water ways and road freight by trucks and light duty vehicles, both by time period.

The freight inputs at the lowest level include both physical inputs (ton km) as time related inputs. The last category of inputs depends on the speed of the different modes. Only for road transport in the peak and the off-peak period speed is endogenous, which implies that traffic is not constrained by infrastructure for other modes than road transport.

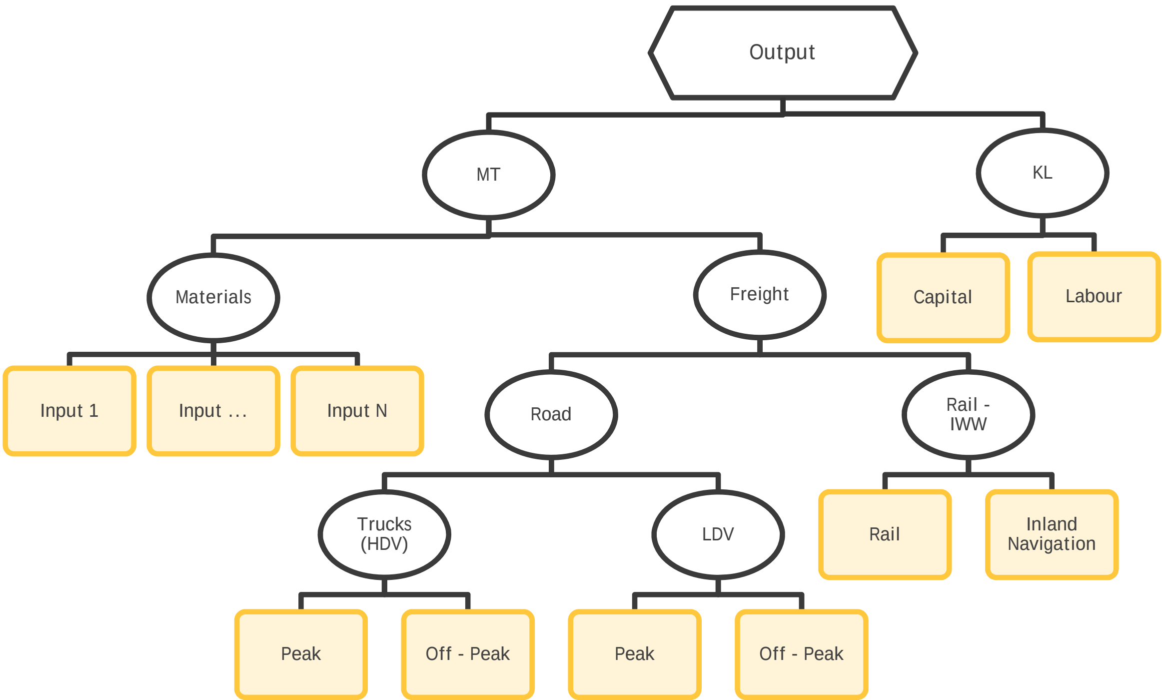
As in household transport, lower level prices of road freight PT are a combination of monetary and time costs. Monetary costs are the unit requirement of transport services per Vkm bmt which are modelled as purchases from the respective transport sectors, just like time costs TT.

$$PT = PMT \cdot bmt + PTT \cdot TT$$

Here, PTT is the market price of the good 'market services', while PMT is the price of transport services. This choice of modelling the time inputs of freight is not final at all. For example, one could link the use of time by freight to the wages of freight personnel, too.

We note that TT is a variable that depends on speed, which in turn depends on total road flow. However, firms treat TT as a given parameter in their cost minimization program, ignoring the contribution of a marginal increase in freight inputs on their own time costs.

Figure 4 The general nested production technology for all sectors



In equilibrium, firms do not earn any excess profits so that following restriction must hold:

$$PD_s\, XD_s(1 - \tau p_s + sp_s) = \sum_{ss} PPio_{ss,s}\, XPio_{ss,s} + PL \cdot XPlab_s + PPcap_s XPcap_s + PPfreight_s XPfreight_s$$

This equation says that the value of production $PD_s\, XD_s$, net of taxes τp_s and subsidies on tion sp_s, must be exhausted by the value of inputs. Note that here $XPfreight_s$ is the total demand of freight, so that its composite price $PPfreight_s$ includes time costs.

Implicitly, this equation determines the price of output, which is tantamount to assuming perfect competition in product markets. PD_s, which is normalized to 1, can be interpreted as an index of marginal costs. As before, input prices are tax – inclusive, with taxes on intermediate inputs falling mainly on energy products. The price of capital $PPcap_s$ equals the rate of return PK_s net of corporate income taxes τk_s plus the cost of replacement investment $\delta_s PINV$.

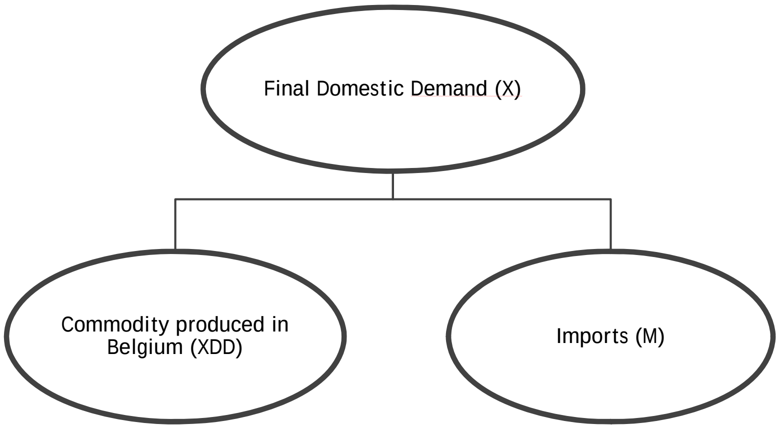
$$PPcap_s = PK_s(1 - \tau k_s) + \delta_s PINV$$

No taxes are assigned to labour on firm level. Note that in the zero profit constraint above $XPfreight_s$ is an aggregate of total freight inputs.

2.3. International trade

Demand for products by consumers, the government, producers (through intermediate demand) and investment demand, constitutes total domestic demand X_s. This total demand is allocated to domestically produced goods and imports by the ubiquitous Armington trade structure, shown in Figure 5. As is well known, Armington trade implies that consumers have CES preferences defined over the origin of goods. While as a theory of trade the Armington assumption has largely been rendered obsolete, it remains a popular assumption in applied large–scale models since it allows the modeller to reproduce real–life trade flows without having to resort to an explicit theory of trade.

Figure 5 The structure of foreign trade



Technically, it is assumed that imports and demand for domestic goods are the result of the following cost minimization program:

$$min_{XDD,M}\ COST = XDD_s PDD_s + M_s PM_s$$

$$s.t. X_s = ARM(XDD_s, M_s)$$

Where ARM is a CES function of XDD_s and M_s whose structure is depicted in figure 4.

The world market price of imports $bpwm_s$ is fixed. Correcting for the exchange rate ER, we arrive at the price of imports PM_s:

$$PM_s = bpwm_s ER$$

This problem yields demand function for M_s and XDD_s, in function of total demand, domestic production prices and import prices.

On the *export* side, we use a similar device to allocate domestic production over exports and domestic demand. Essentially, it is assumed that domestic firms are assumed to produce two differentiated goods, exports and domestic deliveries, using only domestic production as an input. The following cost minimization problem yields a supply system that has exports moving according to relative prices.

$$min_{XDD,M} \; COST = XDD_s PDD_s + E_s PE_s$$

$$s.t. XD_s = CET(XDD_s, E_s)$$

Here, CET is a 'constant elasticity of transformation' function, which is algebraically similar to a CES function. The small country assumption still holds, in the sense that a change in Belgian supply has no impact on the exogenous foreign price $bpwez_s$, so that the price of exports is:

$$PE_s = bpwez_s ER$$

2.4. Government

Government behaviour is largely exogenous, except for the allocation of government consumption across goods. Tax rates are treated as parameters, while transfers and deficits follow simple rules, mostly by indexing them to prices.

2.4.1. Tax income

Thanks to an extensive database, we are able to distinguish between a wide variety of indirect taxes, levied on different components of demand. More precisely we distinguish between VAT, excises, other taxes on products, import duties and subsidies. These indirect taxes can be distinguished as taxes on intermediate inputs, on final consumption, investment goods and government consumption.

Moreover, we have information on taxes and subsidies on production by sector, as well as labour and capital income taxes. Other revenue that has not been explicitly modelled, but which is needed to close the government constraint, is modelled as a 'Lump Sum' tax on households.

2.4.2. Government consumption

The basic constraint of the government is:

$$GOVBUDG = TAXREV + btrfEU \cdot GDPDEF - SG - TRF$$

which says that expenditure, in the form of government consumption $GOVBUDG$, transfers to households TRF, transfers paid to the European Union $btrfEU$ and public saving SG must equal tax revenue $TAXREV$.

This restriction necessitates us to choose one policy variable that serves to balance the goverment's books. In most cases, we will find it more interesting to vary a tax rate, such as the labour income tax, than to endogenize the government deficit or the government consumption budget. In the latter case government consumption will be kept constant in real terms:

$$bgovbudg \cdot PGINDEX = GOVBUDG$$

$PGINDEX$ is a Laspeyeres price index of government consumption:

$$PGINDEX = \frac{\sum_g P_g \left(1 + \sum_t \tau g_{g,t}\right) bcg_{\ g}}{\sum_g bp_g \left(1 + \sum_t \tau g_{g,t}\right) bcg_{\ g}}$$

Transfers to households include all kinds of social transfers and pensions, as well as interest payments on government debt. These are also kept constant in real terms.

Government consumption $GOVBUDG$ is in a standard way allocated across goods CG_s. The government maximizes a Cobb – Douglas utility function and keeps the value shares of goods α_s^G in its budget constant:

$$CG_s = \frac{GOVBUDG \cdot \alpha_s^G}{P_s\left(1+\sum_t \tau g_{s,t}\right)}$$

2.5. Saving and Investment

The model's saving – investment closure is 'neo–classical', i.e. investment is entirely determined by the amount of savings in the economy. Domestic saving S consists of savings by the household SH, government savings SG and depreciation.

$$S = SH + SG + \sum_s \delta_s PINV \cdot XPcap_s$$

To domestic savings we add the net inflow of capital from abroad SF to arrive at total investment:

$$INV = S + SF$$

Total investment demand is distributed across goods (I_s) by a Cobb – Douglas function according to fixed value shares α_s^I:

$$I_s = \frac{INV\alpha_s^I}{P_g\left(1+\sum_t \tau i_{s,t}\right)}$$

We also calculate the national rate of return ROR:

$$ROR = \frac{\sum_s PPcap_s XPcap_s}{\sum_s XPcap_s}$$

In this static model, the capital stock is fixed and immobile accross sectors.

2.6. Other equilibrium conditions

The model is closed by a number of equilibrium conditions.

By good/sector, domestic demand equals final demand by households, government consumption, investment demand and intermediate demand.

The foreign equilibrium condition says that exports and the net inflow of capital need to equal the value of imports and government transfers to the EU.

$$\sum_s X_s\, p_s^{abr} ER + SF = \sum_s M_s\, PM_s + btrfEU \cdot GDPDEF$$

Foreign closure is ensured by varying the net inflow of capital, which implies fixed exchange rates. In practical applications of the model, we drop the foreign equilibrium condition from the model, and use it ex-post to check the Law of Walras, which states that if in general equilibrium n -1 markets are in equilibrium, the n-th market will be in equilibrium as well.

The labour market is closed by:

$$LS = \sum_s XPlab_s$$

This equation, which says that labour supply equals labour demand, will determine a single gross wage rate PL accross sectors, implying perfect labour mobility across sectors.

3. Database and calibration

All flows between the major sectors of the economy (production sectors, households, governments, rest-of-the-world) are summarized in the social accounting matrix (SAM), which ensures consistency and equilibrium of revenues and expenditures. The model's SAM is shown schematically in figure 6. The dataset contained in the matrix has been largely based on the national accounts and the national supply and use tables for the year 2003.

Figure 6 The social accounting matrix

	Goods	Sectors	Households	Investment	Government	Foreign balance	TOTAL EXPENDITURE
Goods		Intermediate demand (Use table)	Consumption	Investment demand	Government consumption	Exports	Total demand
	Total domestic production						
Households		Labour and capital income			Transfers to households		
Investment		Depreciation	Savings		Suplus/deficit	Foreign investment	Total savings
Government	Taxes and subsidies on products	Taxes and subsidies on production Capital taxes	Income taxes				Government revenues
Foreign balance	Imports				Transfers to abroad		Total foreign expenditure
TOTAL RECEIPTS	Total supply in purchasers' prices	Total domestic production	Household expenditure	Total Investment	Government expenditure	Total foreign receipts	

Below, we will only briefly summarize the accounts of the government and households. We will pay more attention to transport data for households and firms, the calibration of their respective utility and production functions and the calibration of road flows.

3.1. Government accounts

In order to be able to model government behaviour, we need data on the different tax and spending instruments in our model. Ideally, we would like to model the following:

Table 3 Overview of data on the government

Revenues	Expenditure
Labour income taxes	Consumption (on 24 goods and services)
Capital income taxes	Transfers to other governments
Corporate income taxes	Transfers to households
Taxes on production	Transfers abroad
VAT	
Excise duties	Subsidies on products
Other consumption taxes[5]	Subsidies on production
Car registration taxes	

The Input-Output tables provide us with very detailed accounts of indirect taxes at the highest level of detail, for each cell in the use table. We therefore have been able to discern indirect taxes by intermediate use, household consumption, imports, investment goods and even government purchases. Other goverment data are mainly taken from the national accounts.

Table 4 and Table 5 give a complete overview of the government accounts as used in the model. The category 'Lump Sum Tax' captures all other revenue, expenditure and transfers and ensures that the deficits of the different governments correspond to those in the national accounts.

Table 4 Governments accounts – Receipts and expenditures
(2003)

	Receipts	Expenditure
LABTAX	73535.8	
CAPTAX	9637.8	
VAT	18730.4	
ACC	6263.6	
TP	2458.2	
CAR		
SUB	-1620.4	
LST	10492.6	
Consumption		63163.1
Transfers to HH		47049.7
Transfers abroad		2787.3
Deficit		-382

Source: National accounts (2003).

5 'Other taxes' include for example, registration duties on real estate sales.

3.2. Household Accounts

3.2.1. Data

In the Table 5, we present the household income and expenditure accounts by category for the year 2003. Gross income categories and total consumption are from the national accounts.

Table 5 Households account by category
(2003)

	Expenditure	Income
Expenditure		
Consumption	144034.6	
τ^K	1626.2	
τ^L	73526.8	
'Lump Sum' Tax	10492.6	
Income		
Gross Labour Y		142597.1
Gross Capital Y		56491.5
Transfers		47049.7
Savings		16449.2

Source: National accounts (2003).

From the PLANET database, we dispose of detailed information on commuting trips and school journeys by mode of transport and time period. These PLANET data are taken from the Socio–Economic Survey of 2001. Information on other trip purposes are taken from the MOBEL survey (Hubert and Toint, 2002).

Below, in Table 6, we present the total number of passenger kilometres (pkm) made by regional households per mode, time period and trip purpose.

Table 6 pkm by households
(mio. pkm, 2003)

		Commuting	Other
Bus, tram, metro	Off-Peak	698	2241
	Peak	1871	2376
Rail	Off-Peak	267	2961
	Peak	2489	1218
Car – solo	Off-Peak	6226	35706
	Peak	16369	3238
Car – pool	Off-Peak	820	31018
	Peak	1886	5805
Moto	Off-Peak	177	1101
	Peak	293	180
Foot and Bycicle	Off-Peak	155	889
	Peak	318	455

Source: Planet V1.0 and own calculations.

Estimates for monetary costs per Pkm are available in PLANET, but generally applying these unit costs yield very different expenditure on some categories when compared to expenditures derived by the national accounts. For example, while subsidies to rail are in the national accounts – from our point of view – correctly labeled as product related subsidies, this is not the case for BTM transport, where these are labelled as government consumption. We corrected the social accounting matrix so that these expenditures work as product related subsidies too.

Time costs are taken from the extensive PLANET database, which contains detailed information on average trip duration for work, other and school trips, by period and mode. The sources are the Social Economic Survey of 2001 and Bickel e.a. (2006).

Commuting time is valued at the daily net wage derived from the model. The value of time spent on other trips is set at 83% of that of commuting time, which is consistent with the treatment of time costs in the PLANET model.

For car transport, monetary expenses include only variable costs, namely fuel expenses (diesel as well as gasoline (which includes LPG)), VAT and excises. Table 7 summarizes, by mode and period, monetary costs, taxes and time costs per pkm.

Table 7 Costs per pkm, household transport
(euro, 2003)

		Producer prices	Taxes(*)	Time costs	Total
BTM	Off-Peak	0.075	-0.055	0.308	0.328
	Peak	0.075	-0.055	0.444	0.464
RAIL	Off-Peak	0.233	-0.159	0.176	0.249
	Peak	0.233	-0.159	0.224	0.299
CAR-SOLO	Off-Peak	0.018	0.008	0.173	0.213
	Peak	0.018	0.008	0.252	0.292
CAR-POOL	Off-Peak	0.007	0.021	0.237	0.251
	Peak	0.007	0.021	0.309	0.324
MOTO	Off-Peak	0.012	0.019	0.300	0.331
	Peak	0.012	0.019	0.365	0.396
FOBI	Off-Peak	0.139	0.026	1.129	1.295
	Peak	0.139	0.026	1.434	1.600

Source: Planet V1.0l and own calculations.
(*) Taxes include subsidies.

We chose to include only variable costs due to the short term, static nature of the model.

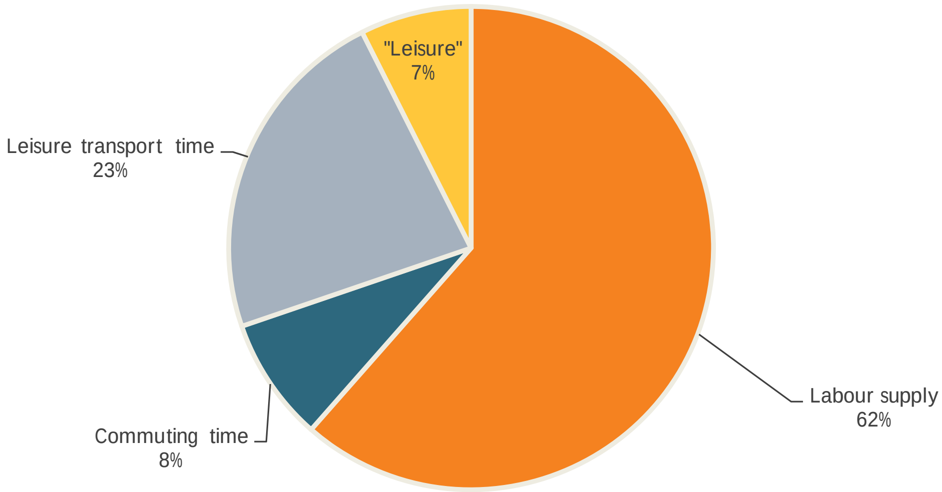
3.2.2. Calibration

As is common in CGE models, parameters are chosen to match elasticities that have been econometrically estimated by other studies, or which are otherwise common in the literature. Following Boeters and van Leeuwen (2009), we calibrate the income and wage elasticity of labour supply by appropriately choosing the household time endowment $\overline{T}$ and the top nest elasticity of substitution σ_U, respectively. The target income elasticity is -0.1, while the desired wage elasticity is 0.1.

The resulting total amount of 'leisure' is rather small compared to labour supply, commuting time and other transport time. (See Figure 7 compares labour supply and transport time, which are expressed in hours, based on data, and leisure, which is a fictive value.) We cannot choose a more realistic value of 'leisure', perhaps based on time budget studies, since this would imply too large income elasticities.

Given the presence of non – labour income in the household's budget, high income elasticities may lead to undesirably adverse effects of swings in e.g. capital income. For a discussion of leisure as a calibrated parameter: see Ballard (2000).

Figure 7 The representative household's time budget, with calibrated leisure



The small calibrated value of 'leisure time' is yet another reason why we decided to include time costs outside the time and monetary constraints and as an additive component of the utility function itself. If transport time is included in the time constraint, time gains need to translate into higher leisure and/or higher labour supply – above the gains one would expect from lower labour income taxes and a lower unit commuting cost. With such low values for leisure, these time gains would disproportionally go to labour supply.

The value of the parameter α_{ct} could be chosen to match an estimate of the elasticity of labour supply to commuting time. Our value, which has been set equal to the net money wage, implies an elasticity value of about -0.02. Note that this is well below the impact found for married women by Black, Kolesnikova and Taylor (2010), whose estimates implies value between -0.2 and -0.12 for women with a high school degree, and values between -0.09 and -0.05 for women with a college degree. We chose such a conservative value, to allow for the fact that labour supply of other subgroups may be far less sensitive to commuting costs.

As for the non-transport related goods, Table 8 gives the calibrated own price elasticities.

Table 8 Calibrated own price elasticities of goods

	Own Price Elasticity
Electricity	-1.678
Gasoline	-1.687
Other Energy	-1.692
Heating Appliances	-1.693
Other Durable Goods	-1.462
Health	-1.667
Textiles	-1.672
Food	-1.604
Household Equipment	-1.662
Services	-1.417

Source: National accounts (2003).

The elasticities of household transport with respect to generalized costs are reported in table 9.

Table 9 Generalized cost elasticities of households transport

Parameter			
BTM	Commuting	Peak	-1.71
		Off-Peak	-1.97
	Other	Peak	-1.87
		Off-Peak	-2.10
Rail	Commuting	Peak	-2.30
		Off-Peak	-2.43
	Other	Peak	-2.40
		Off-Peak	-2.45
Moto	Commuting	Peak	-1.24
		Off-Peak	-1.22
	Other	Peak	-1.50
		Off-Peak	-1.50
Car Solo	Commuting	Peak	-1.09
		Off-Peak	-0.82
	Other	Peak	-1.88
		Off-Peak	-2.04
Car Pool	Commuting	Peak	-1.44
		Off-Peak	-1.25
	Other	Peak	-1.71
		Off-Peak	-1.96

3.3. Freight and the production function

3.3.1. Data

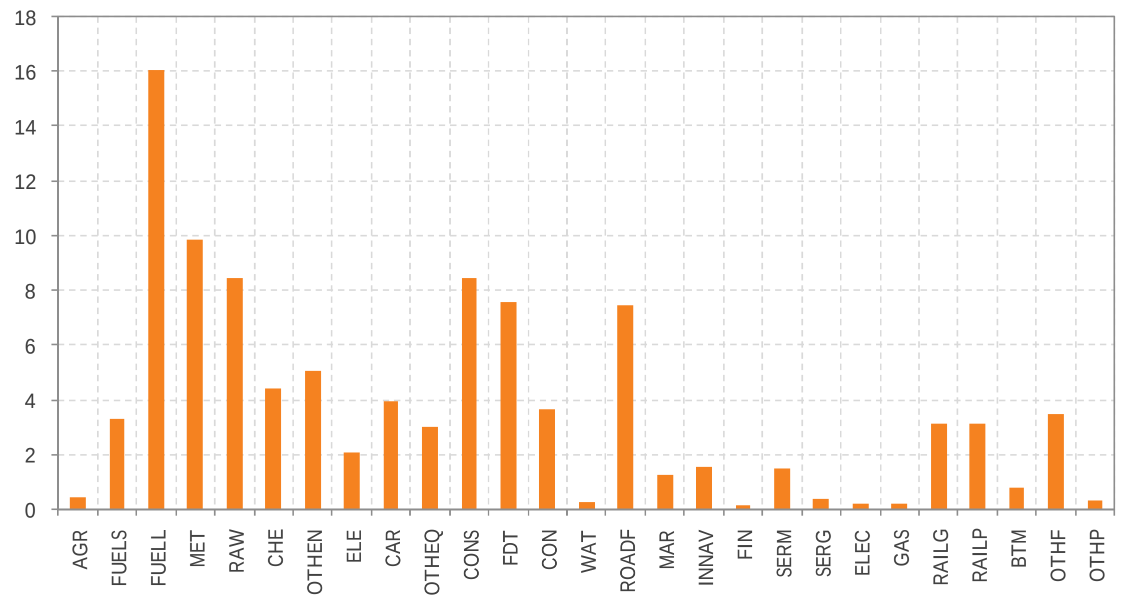
From the PLANET database, we have the number of ton/km driven in 2003 by NSTR good, as well as estimates of the unit time and monetary costs (before taxes) for different modes. Note that in this version we take as monetary costs only fuel costs. From these data we were able to calculate the amount of transport costs which are associated with transport taking place domestically for freight by rail, internal waterways (IWW), light duty vehicles (LDV) and trucks (HDV – or heavy duty vehicles), the last two by time period.

In this version of the model, we choose to assign all freight as inputs of the production sectors. To this end, we create six additional goods in the use table, corresponding to the new freight categories. The total time and monetary costs that we have obtained from the PLANET dataset are then assigned to the different sectors according to their share in total inputs of the original SUT goods 'internal waterways', 'rail freight' and 'road freight'. The total number of vkm driven is likewise assigned to different production sectors. The values of these new six goods are then subtracted from the value of the three original SUT goods.

All costs, monetary and time costs, are modelled as purchases from the relevant freight sectors. For road freight, we would like to introduce one more adjustment, to make sure that fuel taxes are directly assigned to the number of vehicle kilometres driven, rather than indirectly as taxes on the inputs of the road freight sector. The relevant amount of taxes (taken from PLANET) is then lifted from the road freight sector and re-assigned to the newly imputed road freight vkm per sector.

Figure 8 shows the resulting share of road freight in sectoral value added, while figure 9 does the same for rail and IWW freight.

Figure 8 Road freight expenditures as a % of Value Added, by sector



Figuur 9 Rail and IWW freight expenditures as a % of Value Added, by sector

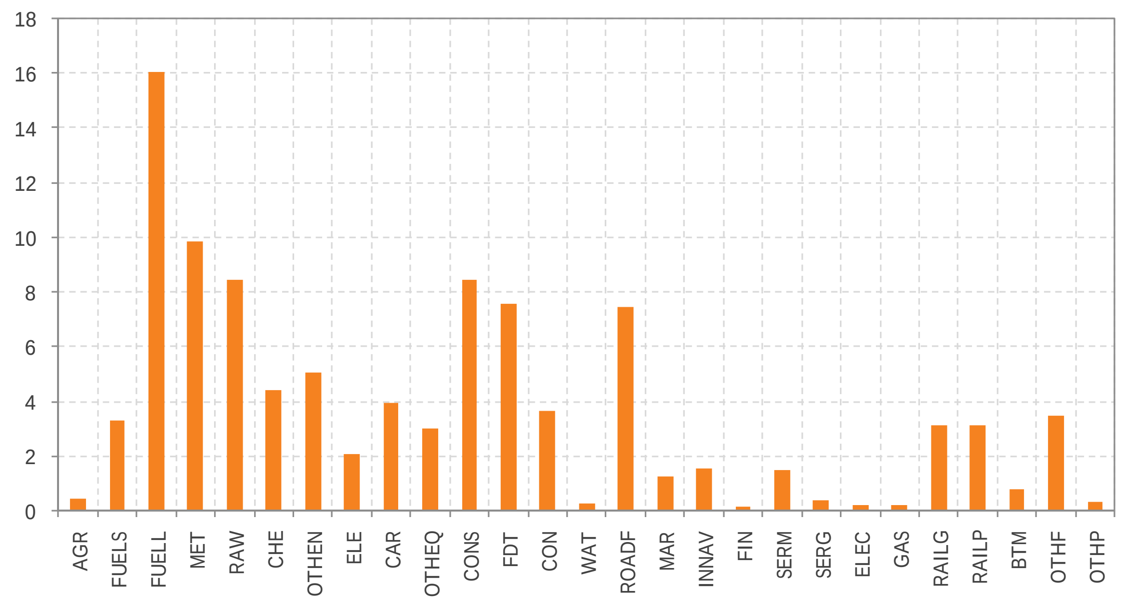


Table 10 shows the amount of vkm driven by time period and mode as well as the monetary and time costs per vkm.

Table 10 Calibrated own price elasticities of freight inputs

	Total number of Vkm	fuel costs per vkm	taxes per vkm	time costs per vkm
Heavy Duty – Peak	1283.8	0.122	0.108	0.816
Heavy Duty – Off-Peak	3471.9	0.122	0.108	0.464
Light Duty – Peak	2032.2	0.030	0.027	0.254
Light Duty – Off-Peak	5495.8	0.030	0.027	0.142

Source: Planet V1.0 and own calculations.

3.3.2. Calibration

For the calibration of the production function, some σ's have been 'guesstimated' such as the rather low value of the substitution elasticity between value added and material inputs. Others, such as the elasticity of substitution between HDV and LDV freight, and between peak and – off-peak freight are chosen so that generalized cost elasticities are situated as closely as possible to the values that are found in PLANET. The calibration results are shown in table 11.

Table 11 Generalized cost elasticities freight transport
(average over sectors)

Heavy Duty	Peak	-0.74
Heavy Duty	Off – Peak	-0.64
Light Duty	Peak	-0.59
Light Duty	Off – Peak	-0.61
Rail		-0.50
Inland Water Ways		-0.50

The values of σ_s^{KL} are chosen to yield labour demand elasticities from the HERMES model (see Bossier, 2000). Table 12 summarizes all elasticities of substitution of the production function.

Table 12 Elasticities of substitution of the production function

	between	
σ_s^{KLEMT}	Value added <-> Materials	0.2
σ_s^{MT}	Freight <-> Other materials	0.4
σ_s^{KL}	Capital <-> Labour	calibrated to match ε_w^L from HERMES
σ_s^{TR}	Road Freight <-> Rail/IWW	0.5
σ_s^{RIWW}	Rail <-> IWW	0.5
σ_s^{ROAD}	HDV <-> LDV	calibrated to match ε_{gc}^T from PLANET
σ_s^{HDV}	P <-> OP	calibrated to match ε_{gc}^T from PLANET
σ_s^{LDV}	P <-> OP	calibrated to match ε_{gc}^T from PLANET

3.4. The road network and congestion

In their respective maximization problems, households' demand for transport is measured in terms of passenger km (Pkm), while freight demand is in vehicle kilometres (Vkm). Household Pkm's are translated into Vkm's using following occupancy rates:

Table 13 Occupancy rates related to household transport

	Car solo	Car Pool	BTM	Moto
Commuting – Peak	1	2.3	37.0	1
Commuting – Off-peak	1	2.3	17.8	1
Leisure – Peak	1	2.8	37.0	1
Leisure – Off-Peak	1	2.8	17.8	1

Source: Planet V1.0.

To calculate each vehicle's effect on traffic congestion, the vkm's driven in the model are translated into passenger car units per hour (PCU/h), assuming the peak period lasts 3.57 hours in an average day of 24 hours, HDV's and busses/trams count for two cars while a LDV counts for 1.5 car. PCU/h's and the total road flow are shown in table 14 below. As expected: the lion's share of flows in each period is taken by cars. Commuters dominate peak hours, other purposes the rest of the day.

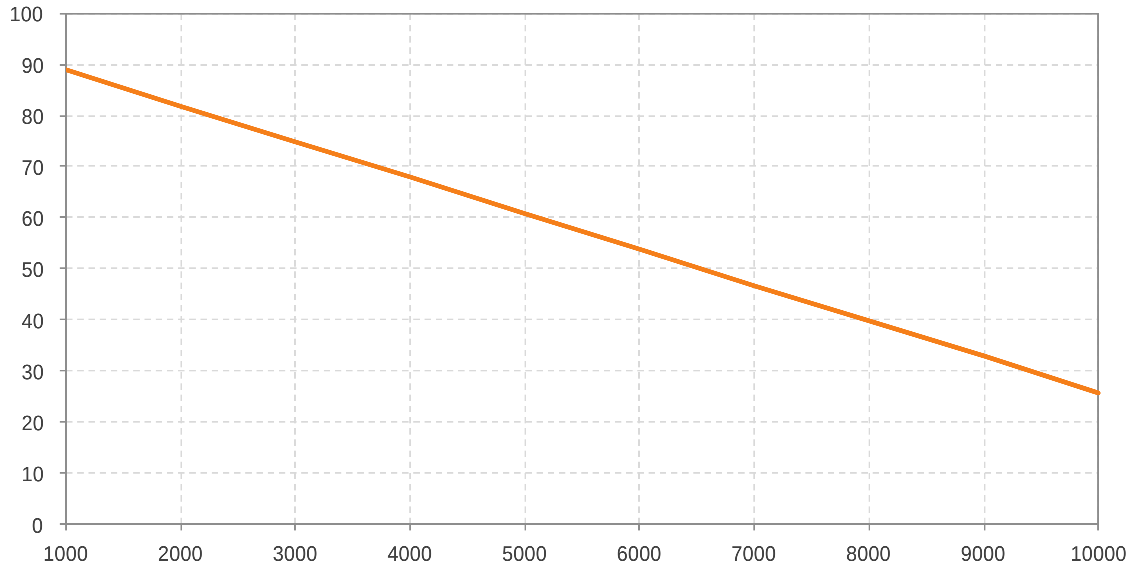
Table 14 PCU/h by mode and period

	Peak	Off - Peak
Heavy Duty Vehicles	719.2	339.9
Light Duty Vehicles	853.9	403.5
Car – commuting	4814.9	322.2
Car – leisure	1487.6	2289.9
Bus, Tram, Metro	64.3	16.1
Moto	132.2	62.6
Total Road Flow	8072.1	3434.3

Source: Planet V1.0 and own calculations

The calibrated speed per period is 40.5 km/h during peak hours, and 72.3 km/h during the rest if the day. As in PLANET, a linear function links speed to the road flow. The calibrated speed – flow relationship, shown in figure 10, implies a free flow speed of 96 km/h.

Figure 10 The speed-flow relationship
Road speed (km/h)



Using only those equations that are relevant for congestion and holding unit monetary time costs constant, one can easily calculate the loss in monetary terms of one extra vkm driven, or the marginal external congestion cost (MECC). Below we report the MECC implied by the current model, as well as the level of taxes per vkm.

Table 15 MECC and taxes
(euro/vkm)

	MECC	Taxes
Heavy Duty Vehicle – Peak	1.039	0.108
Heavy Duty Vehicle – Off Peak	0.172	0.108
Light Duty Vehicle – Peak	0.779	0.027
Light Duty Vehicle – Off Peak	0.129	0.027
Car – Peak	0.519	0.034
Car – Off Peak	0.086	0.034

4. Some technical simulations

In what follows we will introduce some technical simulations that serve to illustrate the properties of the model. Given the current debate on the introduction of a road tax for trucks in Belgium, we will examine how a fictious kilometre charge on trucks scores in terms of utility and economic effects compared to a more complete reform of transport taxation that targets other vehicles as well.

4.1. Description of the simulations

We introduce three basic scenarios that consist of introducing a levy on vehicle kilometres driven. Unless mentioned otherwise, the proceeds of that tax will be recycled back to households by lowering the labour income tax rate, which currently stands at 51.6% in the base year. The tax levels on vehicle kilometres driven are outlined in table 16.

Table 16 Vkm Tax level for different scenario's
(euro)

	Scenario I	Scenario II	Scenario III
Heavy Duty Vehicles – Peak	0.300	0.300	0.300
Heavy Duty Vehicles – Off Peak	0.070	0.070	0.070
Light Duty Vehicles – Peak		0.240	0.240
Light Duty Vehicles – Off Peak		0.060	0.060
Car – Peak			0.140
Car – Off Peak			0.020

4.2. Impact on the economy, public finances and on transport

The impacts of the three scenarios on the economy and on transport are presented in Table 17.

Table 17 Welfare, economic, traffic and public finance effects (% change compared to baseline)

	Scenario I	Scenario II	Scenario III
Impact on the economy			
Utility	0.04	0.26	1.15
GDP	0.01	0.04	0.06
Employment	0.05	0.13	0.30
Impact on transport			
Speed – Peak	0.73	3.00	22.73
Speed – Off Peak	-0.02	0.36	2.66
Commuting time	-0.44	-1.89	-9.89
Total Flow – Peak	-0.53	-2.19	-16.63
Total Flow – Off Peak	0.07	-1.12	-8.7
Flow HDV – Peak	-14.86	-10.69	-4.38
Flow HDV – Off Peak	-2.85	0.98	0.49
Flow LDV – Peak	3.79	-26.45	-23.96
Flow LDV – Off Peak	3.42	-12.83	-12.83
Flow Cars – Peak	0.49	1.89	-18.86
Flow Cars – Off Peak	-0.06	0.37	-9.17
Flow Other – Peak	0.82	3.34	42.18
Flow Other – Off Peak	-0.06	0.84	4.71

	Scenario I	Scenario II	Scenario III
Impact on Public Finance			
Labour tax revenue	-0.66	-1.50	-4.15
Capital tax revenue	-0.28	-0.56	-0.44
VAT revenue	0.16	0.39	0.06
Excise revenue	-0.29	-0.38	-2.33
Subsidies	0.00	-0.18	11.28
Other Product tax revenue	0.13	0.30	0.41
Taxes and subsidies on production	0.08	0.19	0.06
New labour income tax rate (old = 51.6%)	51.1%	50.9%	49.5%

Obviously, taxing trucks alone may not do much in terms of abating congestion. While results are positive, both in terms of utility as well as GDP and employment, the results are only a fraction of what can be achieved by taxing light duty vehicles and especially cars as well. This should not come as a surprise, since trucks make up only a small part of total traffic during peak hours, when congestion is more acute.

To understand what is going on in the model we will in turn discuss separately the major impacts of a road tax on freight, commuting and leisure transport.

In the case of *taxes on freight*, the first reaction of firms to a road tax will be to substitute away from road freight towards other modes of transport, other material inputs and ultimately towards labour and capital. However, because substitution possibilities are finite, production costs and therefore factory gate prices still have to rise. This cost push is stronger in freight intensive sectors than in others. Note that overall freight costs rise despite an improvement in road speed, which tends to lower the time costs of freight.

The amount of freight that ultimately disappears from the road will ultimately depend on indirect channels as well. Demand, comprising of all agents such as the consumers, firms, and the foreign sector will all tend to substitute away from freight intensive goods, reducing the amount of traffic even further. But as can be seen in table one, equilibrium GDP rises as well, so one can expect a slight countervailing rise in the demand for freight intensive goods as well. However, as is obvious in the results, the net effect on (taxed) freight traffic is clearly negative.

How much the *total* amount of traffic that will diminish in equilibrium, will depend on the reactions of households to changes on the road and indirectly, by changes in labour supply (for commuting) and income (for leisure transport). Falling freight levels will have small effects on speed lowers the costs of transport to households, while increased equilibrium employment and incomes tend to increase traffic demand as well. Both effects lead to partial crowding out of freight traffic by cars. This result is already evident in scenario I, but becomes even more pronounced in scenario II. Comparing the results for freight traffic for scenario II and III shows the opposite effect at work. For example, for HDV at peak periods, the total reduction in scenario III is half the amount in scenario II.

The broad supply shock that is caused by freight taxes ripples through the wider economy by a number of channels. First and most obviously, rising production costs cause domestic goods to lose ground to foreign goods. Domestic demand, via the Armington trade structure, substitutes away from expensive domestic produce towards imports, while demand for exports falls, too. The policy causes a terms-of-trade loss, which leads – other effects equal – to a fall in GDP and employment.

But there are potentially important effects on labour supply as well. In this respect, three main channels can be distinguished, one negative and two positive. As a direct effect, the freight tax – insofar it is passed down to consumers – causes the price of freight intensive goods to rise, rendering goods more expensive to the household relative to leisure so that labour supply tends to fall. Note that this tendency is exacerbated by the fact that prices rise more for some goods than for others. By distorting consumer choices, price hikes of freight intensive goods cause inflict greater costs to the consumer in terms of utility than a uniform price rise would do, eroding real wages even further. Not only does the tax interfere with the total amount of goods that can be consumed, but also with the preferred distribution among specific goods. This last effect, endemic to the classic labour supply model, is often referred to in the literature as the 'tax interaction effect' (see e.g., Bovenberg and De Mooij, 1994).

Recycling the proceeds of the tax back to households through a labour income tax reduction serves to counteract this negative effect. An income tax cut raises the price of leisure relative to goods, with positive effects on labour supply. Note, however, that an income tax reduction, because it is a broad based measure, does not compensate for the distortions caused by the price increases of specific goods.

Whatever the balance between both effects, in equilibrium employment – and ultimately production – still rise decisively through the feedback effect of higher road speed, which causes the third additional positive labour supply effect. Average commuting time drops (mostly at peak hours), so that the price of leisure rises even further. In the case of freight transport, there is also limited substitution in the production function towards labour, causing the labour demand curve to rises (slightly) as well.

This indirect effect through commuting time is the driving force behind this rare case of a (strong) double dividend, namely an improvement in economic parameters such as employment and GDP as well as a gain in broad utility due to a decrease in an externality, especially within the confines of a simple representative agent labour market model.

As for scenario III, the equilibrium amounts of car traffic are again the result of direct substitution effects, and subsequent income effects. For leisure transport as well as for commuting, households will substitute away from car traffic towards other modes, primarily public transportation (mainly captured by 'other'). Since equilibrium employment and incomes rise, demand for commuting and leisure transport will tend to rise.

Even more than in the case of freight taxes, which have broader implications for the economy, the tax on leisure transport works primarily through the same labour supply channels outlined above. The same forces are at work, the negative effect on the real wage, the tax recycling effect, and the important feedback effect through commuting time.

The strength of the tax recycling effect ultimately depends on how much of the proceeds the government will be able to give back to households. What happens to other sources of revenue is therefore important as well for the final result. In the case of additional household taxes, especially the shift towards subsidized public modes creates additional costs to the government in terms of additional subsidy payments, while the government also loses revenue from already existing fuel excises.

4.3. Sensitivity analysis

The results presented in section 4.2. are dependent upon the chosen parameters in the calibration and the specification of the model. In order to get an idea of the sensitivity of the results with respect to the specification of the model and the calibrated parameters, three sensitivity analyses are shown in this last subsection. The first one deals with the time externalities, the second one with the substitution elasticities and the last one with the instruments used by the government for tax recycling.

4.3.1. Sensitivity with respect to time externalities

In our case it is the time gain of travel that works to lower the cost of going to work as well as the cost of freight inputs. To gauge the relative strength of these different feedback effects, we show in table 21 the result of scen. III as a base case, a scenario where the same taxes are levied but without any time externality for households as well as firms (VIII), and two scenario's with externalities only for households (IX) or freight (X). Technically, feedback effects are suppressed by making time costs in the relevant price equations exogenous.

Table 18 Full versus partial externalities
(% change)

	Full time externalities (III)	No time externalities (VIII)	Households only (IX)	Freight Only (X)
GDP	0.06	-0.80	-0.24	-0.53
Employment	0.30	-0.15	0.28	-0.10

Scenarios VIII and X show clearly how important the feedback effects are for the positive results in GDP and employment. Without the feedback effect, not even recycling the tax by reducing the high labour income taxes is sufficient to combat the negative effects on employment and especially GDP described above. The fact that GDP falls by far more then employment, seems to suggest that the negative labour supply effects of the road taxes are far less important than the wider negative effects of increasing production costs of the freight tax, such as the terms-of-trade loss.

For additional insight, table 18 shows the sensitivity of the results to variations in some of the more crucial parameters. More precisely, we increase in turn the substitution elasticity of labour-leisure, the substitution elasticity between periods for both freight and households, and the substitution elasticity between car and rail transport.

Table 19 Sensitivity analysis with respect to elasticities used: gain in household utility
(% change with respect to results of scenario's I, II, III)

- % change with respect to results of scenario's I, II, III	standard elasticities	σ labour <-> leisure x 1.5	σ peak <-> off-peak freight x 2	σ peak <-> off-peak households x 2	σ car <-> rail households x 2
Scenario I	0.04	0.06	0.07	0.03	
Scenario II	0.26	0.31	0.31	0.23	
Scenario III	1.15	1.23	1.18	1.17	1.03

The labour-leisure elasticity determines both the wage elasticity of labour supply, and the strength of the feedback effect, namely the reaction of labour supply to commuting costs. A higher labour supply elasticity increases the benefit of reducing labour taxes on top of stronger effects of time gains, so that t is not surprising that utility gains reported in the second column are greater.

Higher cross – elasticities between peak and off-peak travel by households lead to more crowding out of road capacity by cars when trucks and LDVs leave the road at peak hours in the first two scenarios, reducing the effectiveness freight taxes even further. In the case of higher substitution for freight, there is potential for crowding out by trucks and LDVs in response to cars leaving the road, but that effect does not seem to translate to into lower utility in scenario III. Here, another effect may dominate, namely the fact that with higher substitution possibilities in the production function overall production costs do not need to rise as much.

In the case of car transport taxes, a higher cross-elasticity between car and rail transport yields slightly lower benefits, since the higher escape to rail transport exacerbates the negative public finance effects that are discussed above.

A different way to look at the problem of partial taxation is to ask what the gain in utility is from a tax on trucks in the case where other modes are already taxed more heavily as well. In the following table we show the gain in utility in the case where cars are taxed alone (scen. IV) and where cars are taxed alongside LDV's (scen. V). All tax rates are those of the above simulations.

Table 20 Effects of new HDV taxes given higher pre-existing taxes on car (IV) versus cars and LDV (V)
(% change)

	Cars alone (IV)	Cars and LDV (V)
Gain in Utility	0.81	1.02

The gain from a stand-alone car tax is less then the extra gain in utility when cars are taxed from a situation where freight is taxed already (i.e. the difference in utility from base scenario III and II is 0.91). Likewise, the gain from taxing trucks alone (scen. I) is far less then the gain in the hypothetical case where cars and LDV's would be taxed already (i.e. the difference in utility from scen. III and V is 0.08, double the gain in scen. I).

4.3.2. Sensitivity with respect to the recycling instruments

What would the results be if some different recycling instrument were chosen? We perform three alternative scenarios to scen. III, one where proceeds are recycled back to household as a transfer (Scenario VI, Transfer), and one where the government increases bus and rail subsidies by 5% while using what remains of the revenue from the kilometre charge to lower labour taxes (Scenario VII, Labour tax / public subsidies).

Table 21 Alternative uses to the government revenue following a road tax on trucks and cars
(% change w.r.t. baseline)

	Labour tax only (III)	Transfer (VI)	Labour tax / public subsidies (VII)
Utility	1.15	0.87	0.96
GDP	0.06	-0.34	0.00
Employment	0.30	-0.17	0.26

In case VI, the predictable negative employment effects of a transfer – which works on labour supply as unearned income – and in extensu on GDP are evident. Time gains keep the change in broad utility positive, albeit at a lower level then in case III. In case VII the utility and employment effects lie below the gain that can be achieved by full labour tax recycling. This is of course a logical result, since there is no reason to increase public transport subsidies if road taxes increase as well. If car transport is undertaxed and congestion is a problem, rail subsidies are justified – even when they are financed by labour income taxes. Raising car taxes to internalize external congestion costs takes away this efficiency rationale for public transport taxes.

5. Conclusion and further developments

In this paper, we have presented a CGE model that can be used as a basis to analyse the economic impact of pricing policies in the transport sector that can be enacted on a sufficiently large geographic scale. Households decide on travel for two motives, by six modes and two time periods. We follow an influential strand in the double-dividend literature that allows for important labour supply effects of congestion. Freight, differentiated by time period and four transport modes, is introduced as an input in production, whose price depends among others on endogenous time costs.

To study specific policy issues, some further refinements can in the future be easily introduced in the model. For example, a national model may not really capture the locality of the congestion problem. Since smart transport taxes will in practice not only differentiate between time periods but also between locations, one could introduce the choice between different road types (highways versus provincial roads and rural roads) as an extra choice in the utility- and production functions. Another possible refinement may be the differentiation of cars by fuel type, or even by size class.

The current focus of the model is on congestion externalities, which are important in the case of transport and yield interesting results from an economic point of view due to feedback effects on generalized transport prices. However, other sources of externalities, such as environmental effects, accidents or road wear-and-tear could later be introduced to provide a more complete analysis of costs and benefits.

If distributional issues are important, the introduction of different household categories, for example by education category or labour market status (i.e. unemployed versus employed) may be yet another option. Households may indeed differ in preferences for other modes, may be taxed differently – through access to company cars – and will therefore be affected differently by reforms in transport pricing. Also, different household categories would allow for a richer analysis of the transfers that are implied by recycling schemes for the proceeds of road taxes.

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7. APPENDIX A: Sets, Variables and parameters

SET	ELEMENTS
s,ss (sectors and goods, SUT)	
AGR	Agriculture, forestry, fisheries
FUELS	Solid fuels
FUELL	Liquid fuels
MET	Ferrous and non – ferrous metals
RAW	Raw materials, building materials
CHE	Chemical products, pharmaceutics
OTHEN	Other energy intensive industries (paper, plastics, metal products)
ELE	Electrical goods
CAR	Transport equipment
OTHEQ	Machinery
CONS	Consumer goods
FDT	Food, drinks and tobacco
CON	Construction
WAT	Water supply
ROADF	Road freight
LDV_P	Light Duty freight – peak
LDV_OP	Light Duty freight – off peak
HDV_P	Heavy Duty freight – peak
HDV_OP	Heavy Duty freight – off peak
MAR	Maritime transport
INNAV	Inland navigation
FIN	Financial services
SERM	Market services
SERG	Government services
ELEC	Electricity
GAS	Gas
RAILG	Rail freight
RAILP	Rail passenger transport
BTM	Bus, tram, metro
OTHF	Other freight
OTHP	Other passenger transport
Note: LDV_P, LDV_OP, HDV_P, HDV_OP appear as goods (inputs) only, supplied by the sector ROADF	
c (commodities – COICOP)	
GAS	Gas
ELEC	Electricity
ENEOTH	Other energy goods
HEALTH	Health expenditure
TEXT	Textiles
FOOD	Food, drinks, tobacco
EQHH	Household Equipment
SERV	Services

SET	ELEMENTS
HEAT	Heating
DGOTH	Other durables
BTM	Bus, tram and metro
RAIL	Rail
DIES	Diesel
GASO	Gasoline
FOBI	Foot and bike
c2 (aggregate commodities)	
DGene	Durables and energy
NDG	Non – durable goods
LTP	Other transport motives
t (indirect tax types)	
VAT	Value added tax
ACC	excises
TP	other product related taxes
SUB	product related subsidies
mot (transport motives)	
OTHE	other motives
WORK	commuting
p (periods)	
P	Peak
OP	Off-Peak
sf (aggregate transport modes)	
SLOW	
FAST	
s (slow transport modes)	
FOBI	Foot and bike
BTM	Bus, tram and metro
f (fast modes)	
RAIL	Rail transport
PRIV	Private fast modes
priv (private fast modes)	
CAR	Car by occupancy
MOTO	Motorcycle
socc (car by occupancy)	
POOL	Pooled
SOLO	Solo

VARIABLES	DESCRIPTION
Households: income	
Y	Monetary income
YE	Extended income
$CBUD$	Extended income minus savings
SH	Household savings
LS	Labour supply
PL	Gross wage rate
CC	Average monetary commuting costs
CT	Average commuting time
LT	Total leisure transport time
LC	Total monatary leisure transport costs
TRF	Government transfers to households
Households: consumption	
$UTILITY$	Total Utility
CU	CES subutility aggregator
PU	Price index associated with CES aggregator
$LAMBDA$	Marginal utility of income
$LEIS$	Leisure
$PLEIS$	Price of leisure
$CTOTAL$	Total consumption of commodities
$PTOTAL$	Price index of total consumption
$CGOODS_{c2}$	Total consumption of commodities by subcategory
$PGOODS_{c2}$	Total price of commodities by subcategory
C_c	Consumption of commodities
PC_c	Price of commodities
Households: transport	
$CHHTP5_{mot,p,sf,f,priv,socc}$	Demand of car transport, by occupancy type (pkm)
$CHHTP4_{mot,p,sf,f,priv}$	Demand of private fast transport (pkm)
$CHHTP3a_{mot,p,sf,f}$	Demand of fast transport(pkm)
$CHHTP3b_{mot,p,sf,s}$	Demand of slow transport (pkm)
$CHHTP2_{mot,p,sf}$	Demand of transport by subcategory (pkm)
$CHHTP1_{mot,p}$	Demand of transport by period (pkm)
$CHHTP0_{mot}$	Demand of transport by motive (pkm)
$PCHHTP6_{mot,p,sf,f,priv,socc,carinput}$	Monetary price of inputs for car transport
$PCHHTP5_{mot,p,sf,f,priv,socc}$	Monetary price of car transport, by occupancy type (pkm)
$PHHTP5_{mot,p,sf,f,priv,socc}$	Total price of car transport, by occupancy type (pkm)
$PCHHTP4_{mot,p,sf,f,priv}$	Monetary price of private fast transport (pkm)
$PHHTP4_{mot,p,sf,f,priv}$	Total price of private fast transport (pkm)
$PCHHTP3a_{mot,p,sf,f}$	Monetary price of fast transport(pkm)
$PHHTP3a_{mot,p,sf,f}$	Total price of fast transport(pkm)
$PCHHTP3b_{mot,p,sf,s}$	Monetary price of slow transport (pkm)
$PHHTP3b_{mot,p,sf,s}$	Total price of slow transport (pkm)
$PHHTP2_{mot,p,sf}$	Price index of transport by subcategory (pkm)
$PHHTP1_{mot,p}$	Price index of transport by period (pkm)
$PHHTP0_{mot}$	Price index of transport by motive (pkm)

VARIABLES	DESCRIPTION
Firms	
$XPio_{g,s}$	Non-transport intermediate inputs
$XPhdv_{s,p}$	Heavy duty freight inputs (by period)
$XPldv_{s,p}$	Light duty freight inputs (by period)
$XPhdva_s$	Total heavy duty freight inputs
$XPldva_s$	Total light duty freight inputs
$XPrail_s$	Total rail freight inputs
$XPiww_s$	Total internal water ways freight inputs
$XProad_s$	Total road freight inputs
$XPrailiww_s$	Total other freight inputs
$XPfreight_s$	Total freight inputs
$XPmat_s$	Total non-transport intermediate inputs
$XPmatt_s$	Total intermediate inputs
$XPlab_s$	Labour services
$XPcap_s$	Capital stock
$XPkl_s$	Capital-labour composite
XD_s	Total production
$PPio_{g,s}$	Tax inclusive price of non-transport intermediate inputs
$PPhdv_{s,p}$	Tax inclusive price of heavy duty freight inputs
$PPldv_{s,p}$	Tax inclusive price of light duty freight inputs
$PPhdva_s$	Composite price of heavy duty freight
$PPldva_s$	Composite price of light duty freight
$PPmat_s$	Composite price of non-freight intermediate inputs
$PPiww_s$	Tax inclusive price of internal waterway inputs
$PPrail_s$	Tax inclusive price of rail inputs
$PProad_s$	Composite price of road freight inputs
$PPrailiww_s$	Composite price of other freight inputs
$PPfreight_s$	Composite price of freight inputs
$PPmatt_s$	Composite price of intermediate inputs
$PPlab_s$	Price of labour services
$PPcap_s$	User cost of capital
PK_s	Rate of return to capital
$PPkl_s$	Composite price of value added
PD_s	Marginal production costs
XD_s	Total output
Government	
$GOVBUDG$	Total government consumption budget
CG_s	Government consumption
$TAXR$	Total tax revenue
$PGINDEX$	Laspeyeres index of government consumption
SG	Public savings
Trade	
E_s	Exports
XDD_s	Output delivered to domestic markets
PE_s	Price of exports
PDD_s	Price of output delivered to domestic markets
M_s	Imports

VARIABLES	DESCRIPTION
X_s	Total domestic demand
PM_s	Price of imports
P_s	Domestic prices
ER	Exchange rate
Saving-investment	
ER	
SF	Foreign capital inflow
S	Total savings
I_s	Investment demand
$PINV$	Price index of investment
Traffic	
$SPEED_p$	Average road speed
$ROADFLOW_p$	Total roadflow per hour
$PCUhdv_p$	Flow of heavy duty vehicles per hour (in PCU)
$PCUldv_p$	Flow of light duty vehicles per hour (in PCU)
$PCUpool_p$	Flow of cars per hour – pooled travel (in PCU)
$PCUsolo_p$	Flow of cars per hour – solo travel (in PCU)
$PCUbtm_p$	Flow of BTM per hour (in PCU)
$PCUmoto_p$	Flow of motorcycles per hour (in PCU)
$THTcar_{mot,socc,p}$	Time costs of car transport
$THTbtm_{mot,p}$	Time costs of btm transport
$THTmoto_{mot,p}$	Time costs of motorcycle transport
$TThdv_{s,p}$	Time costs of heavy duty freight
$TTldv_{s,p}$	Time costs of light duty freight
Other	
$PCINDEX$	Laspeyeres consumer price index
$GDPDEF$	Deflator of GDP
$GDPreal$	Real GDP

PARAMETERS	DESCRIPTION
Households: income	
mps	Marginal propensity to save
$\bar{T}$	Time endowment
$blst$	base year 'lump sum tax'
Households: consumption	
γc_c^{c2}	Share parameter commodities
σc^{c2}	Elasticity of substitution – lower nests
ac^{c2}	Scaling parameter – lower nests
γG_{c2}	Share parameter aggregate commodities
σG	Elasticity of substitution between aggregate commodities
aG	Scaling parameter total consumption nest
$\gamma TOTC$	Share paremeter total consumption
$\gamma LEIS$	Share paremeter leisure
σU	Top nest elasticity of substitution
aU	Top nest scaling parameter
α_{CT}	Marginal utility cost of commuting time

PARAMETERS	DESCRIPTION
α_T	Marginal utility cost of other transport time
$Qmatrix_{s,c}$	Matrix converting SUT tot COICOP commodities
Households: transport	
$\gamma ht^{5}_{mot,p,socc}$	Share parameter car transport modes
$\gamma ht^{4}_{mot,p,priv}$	Share paremeter private, fast transport modes
$\gamma ht^{3a}_{mot,p,fast}$	Share parameter fast transport modes
$\gamma ht^{3b}_{mot,p,slow}$	Share parameter slow transport modes
$\gamma ht^{2}_{mot,p,sf}$	Share parameter subcategories
$\gamma ht^{1}_{mot,p}$	Share parameter transport by period
$\sigma ht^{4}_{mot,p}$	Elasticity of substitution between occupancy types
$\sigma ht^{3}_{mot,p}$	Elasticity of substitution between car an motorcycle transport
$\sigma ht^{2}_{mot,p,sf}$	Elasticity of substitution between fast modes (slow modes)
$\sigma ht^{1}_{mot,p}$	Elasticity of substitution between slow and fast modes
σht^{0}_{mot}	Elasticity of substitution between periods
$aht^{4}_{mot,p}$	Scaling parameter car transport nest
$aht^{3}_{mot,p}$	Scaling parameter private, fast transport nest
$aht^{2}_{mot,p,sf}$	Scaling parameters slow and fast modes nest
$aht^{1}_{mot,p}$	Scaling parameter subtypes nest
aht^{0}_{mot}	Top nest scaling parameter
bcc	Unit transport requirement of labour supply
$bmht^{CAR}_{mot,p,socc,carinput}$	Unit monetary input requirement of car inputs
$bmht^{MOTO}_{mot,p}$	Unit monetary input requirement for motor transport
$bmht^{RAIL}_{mot,p}$	Unit monetary input requirement for rail transport
$bmht^{BTM}_{mot,p}$	Unit monetary input requirement for BTM transport
$bmht^{FOBI}_{mot,p}$	Unit monetary input requirement for FOBI transport
$btht^{RAIL}_{mot,p}$	Unit time requirement for RAIL transport
$btht^{FOBI}_{mot,p}$	Unit time requirement for FOBI transport
bcc	
Production	
$\gamma^{HDV}_{s,p}$	Share parameter periods – HDV freight
$\gamma^{LDV}_{s,p}$	Share parameter periods – LDV freight
γ^{HDVa}_{s}	Share parameter total HDV freight
γ^{LDVa}_{s}	Share parameter total LDV freight
γ^{ROAD}_{s}	Share parameter total road freight
γ^{RAIL}_{s}	Share parameter total rail freight
γ^{IWW}_{s}	Share parameter total iww freight
γ^{RIWW}_{s}	Share parameter total raill-iww freight
γ^{TR}_{s}	Share parameter total freight freight
$io_{g,s}$	io matrix
γ^{M}_{s}	share parameter total non-freight intermediate inputs
γ^{MT}_{s}	share parameter total intermediate inputs
γ^{K}_{s}	share parameter capital services
γ^{L}_{s}	share parameter labour services services
γ^{KL}_{s}	share parameter value added
σ^{HDV}_{s}	Elasticity of substitution between periods – HDV freight nest
σ^{LDV}_{s}	Elasticity of substitution between periods – LDV freight nest
σ^{ROAD}_{s}	Elasticity of substitution between HDV – LDV freight

PARAMETERS	DESCRIPTION
σ_s^{RIWW}	Elasticity of substitution between rail – iww freight
σ_s^{TR}	Elasticity of substitution between road – riww freight
σ_s^{MT}	Elasticity of substitution between freight – other inputs
σ_s^{KL}	Elasticity of substitution between capital – labour
σ_s^{KLMT}	Elasticity of substitution between VA – intermediate inputs
a_s^{HDV}	Scaling parameter HDV freight nest
a_s^{LDV}	Scaling parameter LDV freight nest
a_s^{ROAD}	Scaling parameter road freight nest
a_s^{RIWW}	Scaling parameter riww freight nest
a_s^{TR}	Scaling parameter total freight nest
a_s^{MT}	Scaling parameter total intermediate inputs nest
a_s^{KL}	Scaling parameter VA nest
a_s^{KLMT}	Top nest scaling parameter
δ_s	Depreciation rate
$bmtLDV_{s,p}$	Unit requirement of LDV freight services
$bmtHDV_{s,p}$	Unit requirement of HDV freight services
Government	
τp_s	Taxes on production
sp_s	Subsidies on production
τk_s	Taxes on capital – firm level
$\tau io_{g,s,t}$	Taxes on intermediate inputs
$\tau i_{s,t}$	Taxes on investment demand
$\tau g_{s,t}$	Taxes on government consumption
$\tau c_{c,t}$	Taxes on household consumption
τy	Labour income taxes
τky	Capital income taxes
bsg	Base year public deficit
α_s^G	Share parameter goverment consumption
$btfreu$	Base year transfers to the european union
Trade	
γ_s^T	Share parameter exports
σ_s^T	Elasticity of transformation exports – domestic demand
a_s^T	Scaling parameter
γ_s^A	Share parameter imports
σ_s^A	Elasticity of substitution imports – domestic demand
a_s^A	Scaling parameter Armington demand
$bpwez$	World market price exports (exogenous)
$bpwmz$	World market price import (exogenous)
Savings and investment	
α_s^I	Share parameter investment demand
aI	Scaling parameter investment demand
Traffic	
a_{speed}	Intercept speed-flow relationship
b_{speed}	Marginal change of speed wrt. road flow
$occrate_{mot,p}^{POOL}$	Occupancy rate
$occrate_{mot,p}^{BTM}$	Occupancy rate
$bday_p$	Length of a period, in hours

8. APPENDIX B: Equations

Households

Income and savings

$$Y = \sum_{s} PK_s XPcap_s (1 - \tau ky) + [PL(1 - \tau y) - CC]LS + TRF + LST$$

$$YE = \sum_{s} PK_s XPcap_s (1 - \tau ky) + PLEIS \cdot \bar{T} + TRF + LST + {}^{\alpha_T LT}/_{LAMBDA} - {}^{\alpha_{CT} CT \cdot LEIS}/_{LAMBDA}$$

$$CBUD = YE - SH$$

$$\bar{T} = LS + LEIS$$

$$SH = mps \cdot Y$$

Basic prices

$$PLEIS = [PL(1 - \tau y) - CC] - \alpha_{CT} CT / LAMBDA$$

$$PC_c = \left[\sum_{s} Qmatrix_{s,c} P_s\right]\left(1 + \sum_{t} \tau c_{c,t}\right)$$

Composite prices

$$CGOODS_{c2} PGOODS_{c2} = \sum_{c} C_c PC_c \ \ if\ c \in c2$$

$$PGOODS_{'ltp'} = PHHTP0_{'othe'}$$

$$CTOTAL \cdot PTOTAL = \sum_{c2} CGOODS_{c2} PGOODS_{c2}$$

$$CU \cdot PU = CTOTAL \cdot PTOTAL + PLEIS \cdot LEIS$$

$$LAMBDA = \frac{aU\gamma TOTC^{\frac{1}{\sigma U}} CTOTAL^{\frac{-1}{\sigma U}} \left[\gamma TOTC^{\frac{1}{\sigma U}} CTOTAL^{\frac{\sigma U - 1}{\sigma U}} + \gamma LEIS^{\frac{1}{\sigma U}} LEIS^{\frac{\sigma U - 1}{\sigma U}}\right]^{\frac{1}{\sigma U - 1}}}{PTOTAL}$$

Demand equations and utility

$$CU = \frac{CBUD}{PU}$$

$$UTILITY = CU - \alpha_T LT - \alpha_T CT \cdot LS$$

$$LEIS = CBUD\ \gamma LEIS(PLEIS)^{-\sigma U}(PU)^{\sigma U-1} aU^{\sigma U-1}$$

$$CTOTAL = CBUD\ \gamma TOTC(PTOTAL)^{-\sigma U}(PU)^{\sigma U-1} aU^{\sigma U-1}$$

$$CGOODS_{c2} = CTOTAL\gamma G_{c2}(PGOODS_{c2})^{-\sigma G}(PTOTAL)^{\sigma G-1} aG^{\sigma G-1}$$

$$C_c = CGOODS_{c2}\gamma c_c^{C2}(PC_c)^{-\sigma c^{C2}}(PGOODS_{c2})^{\sigma c^{C2}-1} ac^{C2^{\sigma c^{C2}-1}} if\ c \in c2$$

Household Transport

Basic prices

$$PCHHTP6_{mot,p,sf,f,priv,socc,'dies'} = \left[\sum_s Qmatrix_{s,'dies'}P_s\right]\left(1 + \sum_t \tau c_{'dies',t}\right)$$

$$PCHHTP6_{mot,p,sf,f,priv,socc,'gaso'} = \left[\sum_s Qmatrix_{s,'gaso'}P_s\right]\left(1 + \sum_t \tau c_{'gaso',t}\right)$$

$$PCHHTP4_{mot,p,sf,f,'moto'} = \left[\sum_s Qmatrix_{s,'moto'}P_s\right]\left(1 + \sum_t \tau c_{'moto',t}\right)$$

$$PCHHTP3a_{mot,p,sf,'rail'} = \left[\sum_s Qmatrix_{s,'rail'}P_s\right]\left(1 + \sum_t \tau c_{'rail',t}\right)$$

$$PCHHTP3b_{mot,p,sf,'btm'} = \left[\sum_s Qmatrix_{s,'btm'}P_s\right]\left(1 + \sum_t \tau c_{'btm',t}\right)$$

$$PCHHTP3b_{mot,p,sf,'fobi'} = \left[\sum_s Qmatrix_{s,'fobi'}P_s\right]\left(1 + \sum_t \tau c_{'fobi',t}\right)$$

Composite prices

$$PCHHTP5_{mot,p,sf,f,priv,socc} = \sum_{scarinput} PCHHTP6_{mot,p,sf,f,priv,socc,carinput} bmht_{mot,p,socc,carinput}^{CAR}$$

$$PHHTP5_{mot,p,sf,f,priv,socc} = PCHHTP5_{mot,p,sf,f,priv,socc} + {}^{\alpha_T}/_{LAMBDA}\, THTcar_{mot,socc,p}\ if\ mot{:}'othe'$$

$$PHHTP5_{mot,p,sf,f,priv,socc} = PCHHTP5_{mot,p,sf,f,priv,socc} + {}^{\alpha_{CT}}/_{LAMBDA}\, THTcar_{mot,socc,p}\ if\ mot{:}'work'$$

$$PHHTP4_{mot,p,sf,f,'moto'} = PCHHTP4_{mot,p,sf,f,'moto'} + {}^{\alpha_T}/_{LAMBDA}\, THTmoto_{mot,p}\ if\ mot{:}'othe'$$

$$PHHTP4_{mot,p,sf,f,'moto'} = PCHHTP4_{mot,p,sf,f,'moto'} + {}^{\alpha_{CT}}/_{LAMBDA}\, THTmoto_{mot,p}\ if\ mot{:}'work'$$

$$PHHTP4_{mot,p,sf,f,'car'} CHHTP4_{mot,p,sf,f,'car'} = \sum_{socc} PHHTP5_{mot,p,sf,f,priv,socc}\ CHHTP5_{mot,p,sf,f,priv,socc}$$

$$PHHTP3a_{mot,p,sf,'priv'}CHHTP3a_{mot,p,sf,'priv'} = \sum\nolimits_{priv} PHHTP4_{mot,p,sf,f,priv}CHHTP4_{mot,p,sf,f,priv}$$

$$PHHTP3a_{mot,p,sf,'rail'} = PCHHTP3a_{mot,p,sf,'rail'} + {}^{\alpha_T}/_{LAMBDA}\, THTrail_{mot,p}\ if\ mot{:}'othe'$$

$$PHHTP3a_{mot,p,sf,'rail'} = PCHHTP3a_{mot,p,sf,'rail'} + {}^{\alpha_{CT}}/_{LAMBDA}\, THTrail_{mot,p}\ if\ mot{:}'work'$$

$$PHHTP3b_{mot,p,sf,'btm'} = PCHHTP3b_{mot,p,sf,'btm'} + {}^{\alpha_T}/_{LAMBDA}\, THTbtm_{mot,p}\ if\ mot{:}'othe'$$

$$PHHTP3b_{mot,p,sf,'btm'} = PCHHTP3b_{mot,p,sf,'btm'} + {}^{\alpha_{CT}}/_{LAMBDA}\, THTbtm_{mot,p}\ if\ mot{:}'work'$$

$$PHHTP3b_{mot,p,sf,'fobi'} = PCHHTP3b_{mot,p,sf,'fobi'} + {}^{\alpha_T}/_{LAMBDA}\, THTfobi_{mot,p}\ if\ mot{:}'othe'$$

$$PHHTP3b_{mot,p,sf,'fobi'} = PCHHTP3b_{mot,p,sf,'fobi'} + {}^{\alpha_{CT}}/_{LAMBDA}\, THTfobi_{mot,p}\ if\ mot{:}'work'$$

$$PHHTP2_{mot,p,'s'}CHHTP2_{mot,p,'s'} = \sum\nolimits_{slow} PHHTP3b_{mot,p,sf,slow}CHHTP3b_{mot,p,sf,slow}$$

$$PHHTP2_{mot,p,'f'}CHHTP2_{mot,p,'f'} = \sum\nolimits_{fast} PHHTP3a_{mot,p,sf,fast}CHHTP3a_{mot,p,sf,fast}$$

$$PHHTP1_{mot,p}CHHTP1_{mot,p} = \sum\nolimits_{sf} PHHTP2_{mot,p,sf}CHHTP2_{mot,p,sf}$$

$$PHHTP0_{mot}CHHTP0_{mot} = \sum\nolimits_{p} PHHTP1_{mot,p}CHHTP1_{mot,p}$$

Demand equations

$$CHHTP5_{mot,p,sf,f,priv,socc} = CHHTP4_{mot,p,sf,f,'car'}\gamma ht^5_{mot,p,socc}\left(\frac{PHHTP4_{mot,p,sf,f,'car'}}{PHHTP5_{mot,p,sf,f,priv,socc}}\right)^{\sigma ht^4_{mot,p}} aht^4_{mot,p}{}^{(\sigma ht^4_{mot,p}-1)}$$

$$CHHTP4_{mot,p,sf,f,priv} = CHHTP3a_{mot,p,sf,'priv'}\gamma ht^4_{mot,p,priv}\left(\frac{PHHTP3a_{mot,p,sf,'priv'}}{PHHTP4_{mot,p,sf,f,priv}}\right)^{\sigma ht^3_{mot,p}} aht^3_{mot,p}{}^{(\sigma ht^3_{mot,p}-1)}$$

$$CHHTP3a_{mot,p,sf,fast} = CHHTP2_{mot,p,'f'}\gamma ht^{3a}_{mot,p,fast}\left(\frac{PHHTP2_{mot,p,'f'}}{PHHTP3a_{mot,p,sf,fast}}\right)^{\sigma ht^2_{mot,p,'f'}} aht^2_{mot,p,'f'}{}^{\left(\sigma ht^2_{mot,p,'f'}-1\right)}$$

$$CHHTP3b_{mot,p,sf,slow} = CHHTP2_{mot,p,'s'}\gamma ht^{3b}_{mot,p,slow}\left(\frac{PHHTP2_{mot,p,'s'}}{PHHTP3b_{mot,p,sf,slow}}\right)^{\sigma ht^2_{mot,p,'s'}} aht^2_{mot,p,'s'}{}^{(\sigma ht^2_{mot,p,'s'}-1)}$$

$$CHHTP2_{mot,p,sf} = CHHTP1_{mot,p}\gamma ht^2_{mot,p,sf}\left(\frac{PHHTP1_{mot,p}}{PHHTP2_{mot,p,sf}}\right)^{\sigma ht^1_{mot,p}} aht^1_{mot,p}{}^{(\sigma ht^1_{mot,p}-1)}$$

$$CHHTP1_{mot,p} = CHHTP0_{mot}\gamma ht^{1}_{mot,p}\left(\frac{PHHTP0_{mot}}{PHHTP1_{mot,p}}\right)^{\sigma ht^{0}_{mot}} aht^{0}_{mot}{}^{(\sigma ht^{0}_{mot}-1)}$$

$$CHHTP0_{mot} = bcc \cdot LS \ if \ mot = 'work'$$

$$CHHTP0_{mot} = CGOODS_{'ltp'} \ if \ mot = 'othe'$$

Definitions

$$\begin{aligned} LT = \Bigg(&\sum\nolimits_{mot,p,sf,f,priv,socc} THTcar_{mot,socc,p}CHHTP5_{mot,p,sf,f,priv,socc} \\ &+ \sum\nolimits_{mot,p,sf} THTbtm_{mot,p}CHHTP3b_{mot,p,sf,'btm'} \\ &+ \sum\nolimits_{mot,p,sf} THTfobi_{mot,p}CHHTP3b_{mot,p,sf,'fobi'} \\ &+ \sum\nolimits_{mot,p,sf} THTrail_{mot,p}CHHTP3a_{mot,p,sf,'rail'} \\ &+ \sum\nolimits_{mot,p,sf,f} THTmoto_{mot,p}CHHTP4_{mot,p,sf,f,'moto'}\Bigg) \ if \ mot = 'othe' \end{aligned}$$

$$\begin{aligned} LS \cdot CT = \Bigg(&\sum\nolimits_{mot,p,sf,f,priv,socc} THTcar_{mot,socc,p}CHHTP5_{mot,p,sf,f,priv,socc} \\ &+ \sum\nolimits_{mot,p,sf} THTbtm_{mot,p}CHHTP3b_{mot,p,sf,'btm'} \\ &+ \sum\nolimits_{mot,p,sf} THTfobi_{mot,p}CHHTP3b_{mot,p,sf,'fobi'} \\ &+ \sum\nolimits_{mot,p,sf} THTrail_{mot,p}CHHTP3a_{mot,p,sf,'rail'} \\ &+ \sum\nolimits_{mot,p,sf,f} THTmoto_{mot,p}CHHTP4_{mot,p,sf,f,'moto'}\Bigg) \ if \ mot = 'work' \end{aligned}$$

$$\begin{aligned} LS \cdot CC = \Bigg(&\sum\nolimits_{mot,p,sf,f,priv,socc} PCHHTP5_{mot,p,sf,f,priv,socc}CHHTP5_{mot,p,sf,f,priv,socc} \\ &+ \sum\nolimits_{mot,p,sf} PCHHTP3b_{mot,p,sf,'btm'}CHHTP3b_{mot,p,sf,'btm'} \\ &+ \sum\nolimits_{mot,p,sf} PCHHTP3b_{mot,p,sf,'fobi'}CHHTP3b_{mot,p,sf,'fobi'} \\ &+ \sum\nolimits_{mot,p,sf} PCHHTP3a_{mot,p,sf,'rail'}CHHTP3a_{mot,p,sf,'rail'} \\ &+ \sum\nolimits_{mot,p,sf,f} PCHHTP4_{mot,p,sf,f,'moto'}CHHTP4_{mot,p,sf,f,'moto'}\Bigg) \ if \ mot = 'work' \end{aligned}$$

Firms

Basic prices

$$PPio_{s,ss} = P_s\left(1 + \sum\nolimits_{t} \tau io_{s,ss,t}\right)$$

$$PPcap_s = PK_s(1 + \tau k_s) + \delta_s PINV$$

$$PPlab_s = PL$$

$$PPhdv_{s,p} = P_{'hdv'}\left(1 + \sum_t \tau io_{'hdv',s,t}\right) bmtHDV_{s,p} + TThdv_{s,p}$$

$$PPldv_{s,p} = P_{'ldv'}\left(1 + \sum_t \tau io_{'ldv',s,t}\right) bmtLDV_{s,p} + TTldv_{s,p}$$

$$PPiww_s = P_{'iww'}\left(1 + \sum_t \tau io_{'iww',s,t}\right)$$

$$PPrail_s = P_{'railg'}\left(1 + \sum_t \tau io_{'railg',s,t}\right)$$

Composite prices

$$PPmat_s XPmat_s = \sum_{ss} PPio_{ss,s} XPio_{ss,s}$$

$$PPhdva_s XPhdva_s = \sum_p PPhdv_{s,p} XPhdv_{s,p}$$

$$PPldva_s XPldva_s = \sum_p PPldv_{s,p} XPldv_{s,p}$$

$$PProad_s XProad_s = PPhdva_s XPhdva_s + PPldva_s XPldva_s$$

$$PPriww_s XPriww_s = PPrail_s XPrail_s + PPiww_s XPiww_s$$

$$PPfreight_s XPfreight_s = PPriww_s XPriww_s + PProad_s XProad_s$$

$$PPmatt_s XPmatt_s = PPfreight_s XPfreight_s + PPmat_s XPmat_s$$

$$PPkl_s XPkl_s = PPcap_s XPcap_s + PPlab_s XPlab_s$$

Zero profit condition

$$XD_s PD_s (1 - \tau p_s + sp_s) = PPcap_s XPcap_s + PPlab_s XPlab_s + \sum_{ss} PPio_{ss,s} XPio_{ss,s} + PPfreight_s XPfreight_s$$

Demand functions

$$XPio_{ss,s} = io_{ss,s} XPmat_s$$

$$XPlab_s = XPkl_s \gamma_s^L \left(\frac{PPkl_s}{PPlab_s}\right)^{\sigma_s^{KL}} a_s^{KL(\sigma_s^{KL}-1)}$$

$$XPkl_s = XD_s(1 - \tau p_s + sp_s)\gamma_s^{KL}\left(\frac{PD_s}{PPkl_s}\right)^{\sigma_s^{KLMT}} a_s^{KLMT(\sigma_s^{KLMT}-1)}$$

$$XPcap_s = XPkl_s\gamma_s^{k}\left(\frac{PPkl_s}{PPcap_s}\right)^{\sigma_s^{KL}} a_s^{KL(\sigma_s^{KL}-1)}$$

$$XPlab_s = XPkl_s\gamma_s^{L}\left(\frac{PPkl_s}{PPlab_s}\right)^{\sigma_s^{KL}} a_s^{KL(\sigma_s^{KL}-1)}$$

$$XPmatt_s = XD_s(1 - \tau p_s + sp_s)\gamma_s^{MT}\left(\frac{PD_s}{PPmatt_s}\right)^{\sigma_s^{KLMT}} a_s^{KLMT(\sigma_s^{KLMT}-1)}$$

$$XPmat_s = XPmatt_s\gamma_s^{M}\left(\frac{PPmatt_s}{PPmat_s}\right)^{\sigma_s^{MT}} a_s^{MT(\sigma_s^{MT}-1)}$$

$$XPio_{ss,s} = io_{ss,s}XPmat_s$$

$$XPfreight_s = XPmatt_s\gamma_s^{TR}\left(\frac{PPmatt_s}{PPfreight_s}\right)^{\sigma_s^{MT}} a_s^{MT(\sigma_s^{MT}-1)}$$

$$XProad_s = XPfreight_s\gamma_s^{ROAD}\left(\frac{PPfreight_s}{PProad_s}\right)^{\sigma_s^{TR}} a_s^{TR(\sigma_s^{TR}-1)}$$

$$XPhdva_s = XProad_s\gamma_s^{HDVa}\left(\frac{PProad_s}{PPhdva_s}\right)^{\sigma_s^{ROAD}} a_s^{ROAD(\sigma_s^{ROAD}-1)}$$

$$XPhdv_{s,per} = XPhdva_s\gamma_{s,per}^{HDV}\left(\frac{PPhdva_s}{PPhdv_{s,per}}\right)^{\sigma_s^{HDV}} a_s^{HDV(\sigma_s^{HDV}-1)}$$

$$XPldva_s = XProad_s\gamma_s^{LDVa}\left(\frac{PProad_s}{PPldva_s}\right)^{\sigma_s^{ROAD}} a_s^{ROAD(\sigma_s^{ROAD}-1)}$$

$$XPldv_{s,per} = XPldva_s\gamma_{s,per}^{LDV}\left(\frac{PPldva_s}{PPldv_{s,per}}\right)^{\sigma_s^{LDV}} a_s^{LDV(\sigma_s^{LDV}-1)}$$

$$XPriww_s = XPfreight_s\gamma_s^{RIWW}\left(\frac{PPfreight_s}{PPriww_s}\right)^{\sigma_s^{TR}} a_s^{TR(\sigma_s^{TR}-1)}$$

$$XPiww_s = XPriww_s\gamma_s^{IWW}\left(\frac{PPriww_s}{PPiww_s}\right)^{\sigma_s^{RIWW}} a_s^{RIWW(\sigma_s^{RIWW}-1)}$$

$$XPrail_s = XPriww_s\gamma_s^{RAIL}\left(\frac{PPriww_s}{PPv_s}\right)^{\sigma_s^{RIWW}} a_s^{RIWW(\sigma_s^{RIWW}-1)}$$

Savings and investment

Total savings

$$S = SH + SG - SF \cdot ER + \sum\nolimits_s \delta_s XPcap_s PINV$$

Investment demand

$$I_s P_s \left(1 + \sum\nolimits_t \tau i_{s,t}\right) = \alpha_s^I S$$

Price of index of investment

$$PINV = \frac{\prod_s \frac{\left(P_s\left(1 + \sum_t \tau i_{s,t}\right)\right)^{\alpha_s^I}}{\alpha_s^I}}{aI}$$

Government

Balanced budget condition

$$GOVBUDG = TAXR - TRF - btrfeu \cdot ER - SG$$

Government consumption demand

$$P_s \left(1 + \sum\nolimits_t \tau g_{s,t}\right) CG_s = \alpha_s^G GOVBUDG$$

Price index of government consumption

$$PGINDEX = \frac{\sum_s P_s \, bcg_s}{\sum_s pb_s bcg_s}$$

Tax revenue

$$
\begin{aligned}
&TAXREV \\
&= PL \cdot LS \cdot \tau y + \sum\nolimits_{s} PK_s XPcap_s\, \tau ky + \sum\nolimits_{c,t} \left[\sum\nolimits_{s} Qmatrix_{s,c} P_s\right] C_c \tau c_{c,t} + \sum_{s,t} \tau i_{s,t} I_s P_s \\
&+ \sum_{s,t} \tau g_{s,t} CG_s P_s + \sum_{s,ss,t} \tau io_{s,ss,t} XPio_s P_s + LST + \sum\nolimits_{s} XD_s PD_s (\tau p_s - sp_s) + \sum\nolimits_{s} PK_s \tau k_s XPcap_s \\
&+ \sum_{s,p} P_{'hdv'} \sum\nolimits_{t} \tau io_{'hdv',ss,t}\, bmtHDV_{s,p} XPhdv_{s,p} + \sum_{s,p} P_{'ldv'} \sum\nolimits_{t} \tau io_{'ldv',ss,t}\, bmtLDV_{s,p} XPldv_{s,p} \\
&+ \sum_{mot,p,sf,f,priv,socc} CHHTP5_{mot,p,sf,f,priv,socc} bmht^{CAR}_{mot,p,socc,'dies'} \left[\sum\nolimits_{s} Qmatrix_{s,'dies'} P_s\right] \sum\nolimits_{t} \tau c_{'dies',t} \\
&+ \sum_{mot,p,sf,f,priv,socc} CHHTP5_{mot,p,sf,f,priv,socc} bmht^{CAR}_{mot,p,socc,'gaso'} \left[\sum\nolimits_{s} Qmatrix_{s,'gaso'} P_s\right] \sum\nolimits_{t} \tau c_{'gaso',t} \\
&+ \sum_{mot,p,sf,f} CHHTP4_{mot,p,sf,f,'moto'} bmht^{MOTO}_{mot,p} \left[\sum\nolimits_{s} Qmatrix_{s,'moto'} P_s\right] \sum\nolimits_{t} \tau c_{'moto',t} \\
&+ \sum_{mot,p,sf} CHHTP3a_{mot,p,sf,'rail'} bmht^{RAIL}_{mot,p} \left[\sum\nolimits_{s} Qmatrix_{s,'rail'} P_s\right] \sum\nolimits_{t} \tau c_{'rail',t} \\
&+ \sum_{mot,p,sf} CHHTP3b_{mot,p,sf,'btm'} bmht^{BTM}_{mot,p} \left[\sum\nolimits_{s} Qmatrix_{s,'btm'} P_s\right] \sum\nolimits_{t} \tau c_{'btm',t} \\
&+ \sum_{mot,p,sf} CHHTP3b_{mot,p,sf,'fobi'} bmht^{FOBI}_{mot,p} \left[\sum\nolimits_{s} Qmatrix_{s,'fobi'} P_s\right] \sum\nolimits_{t} \tau c_{'fobi',t}
\end{aligned}
$$

Trade

Exports: Supply equations

$$E_s = \left(\frac{XD_s}{aT_s}\right)\left(\frac{\gamma^T_s}{PE_s}\right)^{\sigma^T_s} \left[{\gamma^T_s}^{\sigma^T_s} {PE_s}^{(1-\sigma^T_s)} + \left(1-\gamma^T_s\right)^{\sigma^T_s} {PDD_s}^{(1-\sigma^T_s)}\right]^{\frac{\sigma^T_s}{(1-\sigma^T_s)}}$$

$$XDD_s = \left(\frac{XD_s}{aT_s}\right)\left(\frac{\gamma^T_s}{PDD_s}\right)^{\sigma^T_s} \left[{\gamma^T_s}^{\sigma^T_s} {PE_s}^{(1-\sigma^T_s)} + \left(1-\gamma^T_s\right)^{\sigma^T_s} {PDD_s}^{(1-\sigma^T_s)}\right]^{\frac{\sigma^T_s}{(1-\sigma^T_s)}}$$

Exports: Market clearing

$$XD_s PD_s = PDD_s XDD_s + PE_s E_s$$

Imports: Armington demand equation

$$M_s = \left(\frac{X_s}{aA_s}\right)\left(\frac{\gamma^A_s}{PM_s}\right)^{\sigma^A_s} \left[{\gamma^A_s}^{\sigma^A_s} {PM_s}^{(1-\sigma^A_s)} + \left(1-\gamma^A_s\right)^{\sigma^A_s} {PDD_s}^{(1-\sigma^A_s)}\right]^{\frac{\sigma^A_s}{(1-\sigma^A_s)}}$$

$$XDD_s = \left(\frac{X_s}{aA_s}\right)\left(\frac{\gamma_s^A}{PDD_s}\right)^{\sigma_s^A} \left[\gamma_s^{A^{\sigma_s^A}} PE_s^{(1-\sigma_s^A)} + \left(1-\gamma_s^A\right)^{\sigma_s^A} PDD_s^{(1-\sigma_s^A)}\right]^{\frac{\sigma_s^A}{(1-\sigma_s^A)}}$$

Imports: Balanced budget condition

$$X_s P_s = PDD_s XDD_s + PM_s M_s$$

Foreign trade: prices

$$PM_s = ER \cdot bpwm_s$$

$$PE_s = ER \cdot bpwe_s$$

Traffic

$$SPEED_p = a_{speed} + b_{speed} ROADFLOW_p$$

$$ROADFLOW_p = \sum\nolimits_{mot} \left(PCUpool_{mot,p} + PCUsolo_{mot,p} + PCUmoto_{mot,p} + PCUbtm_{mot,p}\right) + PCUhdv_p + PCUldv_p$$

$$PCUpool_{mot,p} = \frac{CHHTP5_{mot,p,sf,f,priv,'pool'}}{occrate_{mot,p}^{POOL} bday_p}$$

$$PCUsolo_{mot,p} = \frac{CHHTP5_{mot,p,sf,f,priv,'solo'}}{bday_p}$$

$$PCUbtm_{mot,p} = \frac{CHHTP3b_{mot,p,sf,'btm'}}{occrate_{mot,p}^{BTM} bday_p} \cdot 2$$

$$PCUmoto_{mot,p} = \frac{CHHTP4_{mot,p,sf,f,'moto'}}{bday_p}$$

$$PCUhdv_p = \frac{\sum_s XPhdv_{s,p}}{bday_p} \cdot 2$$

$$PCUldv_p = \frac{\sum_s XPldv_{s,p}}{bday_p} \cdot 1.5$$

$$THTcar_{mot,socc,p} = \frac{bthtcar_{mot,socc,p}}{SPEED_p}$$

$$THTbtm_{mot,socc,p} = \frac{bthtbtm_{mot,p}}{SPEED_p}$$

$$THTmoto_{mot,socc,p} = \frac{bthtmoto_{mot,p}}{SPEED_p}$$

$$TThdv_{s,p} = \frac{btthdv_{s,p}}{SPEED_p}$$

$$TTldv_{s,p} = \frac{bttldv_{s,p}}{SPEED_p}$$

Other market clearing conditions

Labour market equilibrium

$$\sum_s XPlab_s = LS$$

Foreign equilibrium condition

$$\sum_s M_s PM_s + TRFEU \cdot ER + SF = \sum_s PE_s E_s$$

Goods market equilibrium

$$
\begin{aligned}
X_s = {} & \sum_c Qmatrix_{s,c}\, C_c + CG_s + I_s + \sum_{ss} XPio_{s,ss} + indic_s^{RAIL} \sum_{ss,p} XPrail_{ss,p} \\
& + indic_s^{IWW} \sum_{ss,p} XPiww_{ss,p} \\
& + indic_s^{ROADF} \left(\sum_{ss,p} XPhdv_{ss,p} \left(bmtHDV_{ss,p} + TThdv_{ss,p} \right) \right. \\
& \left. + \sum_{ss,p} XPldv_{ss,p} \left(bmtLDV_{ss,p} + TTldv_{ss,p} \right) \right) \\
& + Qmatrix_{s,'btm'} \sum_{mot,p,sf} CHHTP3b_{mot,p,sf,'btm'} bmht_{mot,p}^{BTM} \\
& + Qmatrix_{s,'fobi'} \sum_{mot,p,sf} CHHTP3b_{mot,p,sf,'fobi'} bmht_{mot,p}^{FOBI} \\
& + Qmatrix_{s,'rail'} \sum_{mot,p,sf} CHHTP3a_{mot,p,sf,'rail'} bmht_{mot,p}^{RAIL} \\
& + Qmatrix_{s,'moto'} \sum_{mot,p,sf,f} CHHTP4_{mot,p,sf,f,'moto'} bmht_{mot,p}^{MOTO} \\
& + Qmatrix_{s,'dies'} \sum_{mot,p,sf,f,priv,socc} CHHTP5_{mot,p,sf,f,priv,socc} bmht_{mot,p,socc,'dies'}^{CAR} \\
& + Qmatrix_{s,'gaso'} \sum_{mot,p,sf,f,priv,socc} CHHTP5_{mot,p,sf,f,priv,socc} bmht_{mot,p,socc,'gaso'}^{CAR}
\end{aligned}
$$