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EUCARS: A partial equilibrium model of EUropean CAR emissions (Version 3.0)

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1. INTRODUCTION

This paper presents the EUCARS 3 model: a EUropean partial equilibrium CAR emissions Simulation model. This model was originally developed to study CO_2 emission limitation policies in passenger transport (Koopman, 1995). It was subsequently expanded to extend its applicability to a variety of transport policy questions. The model has, for example, been used to study the cost-effectiveness of various measures aimed at limiting conventional emissions from cars as part of the preparatory work of the Commission services for the Auto-Oil 1 Programme[1] (EC, 1995a and 1995b). The differences between the previous versions and EUCARS 3 are summarised in Annex 1.

The essential characteristic of the model is its partial equilibrium nature: all relevant transport markets are modelled and cleared through prices. Both consumers and producers are modelled as optimising agents who maximise utility and profits under a variety of constraints (e.g. budget and time constraints). This structure allows an assessment of the welfare effects of various policy measures, unlike other simulation models that track the effects of transport policies on emissions and fuel use, but can not assess the welfare costs of such measures (Samaras and Zierock, 1992; Acutt and Dodgson, 1993). The welfare effects comprise the "full" costs and benefits of any policy measure and the costs of both technological and behavioural change. The welfare effects of changes in emission levels are, however, not modelled.[2] Overall, this model permits comparison of quite different policy measures and is well suited for cost-effectiveness analyses of policies to reduce air emissions.

The structure of this paper as follows: first, a relatively informal presentation of the general organisation of EUCARS is provided in Chapter 2. Chapter 3 then presents a detailed technical description of the functions and equations used. The reader who is not interested in technical aspects of the model can skip this chapter without loss of continuity, as the essential concepts have been explained in Chapter 2. Following these conceptual chapters, Chapter 4 presents the main data sources of the model, and the key elasticities used. More detailed information on these matters as well as on the model's calibration and operation can be found in a separate technical note (Denis, 1998). Chapter 5 briefly reports on a number of simulation experiments with the model to give the reader an idea of its simulation properties. Finally, Chapter 6 sums up some important findings and reports on possible future extensions.

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1 Programme jointly launched by the European Commission, the automobile and fuel industries to study the reduction of noxious emissions from road vehicles.

2 The TRENEN system of models is another example of models based on the welfare cost concept. The valuation of changes in external costs is included in a broader welfare cost function (De Borger *et al.*, 1996; De Borger *et al.*, 1997).

2. General Organisation and Description of the Model

2.1. General structure and overview

The EUCARS model describes European passenger transport by car and public transport. The focus of the model is on car transport, where a significant disaggregation of the vehicle fleet is provided. Demand for public transport, vehicle ownership and usage is modelled as the outcome of decisions by consumers and producers on various interrelated markets. This implies that the key transport variables (e.g. car mileage of various categories, travel times etc.) are endogenous and are implicitly determined by exogenous price components (e.g. fuel prices, taxes), infrastructure capacity and income. Vehicle emissions and congestion are determined simultaneously and in function of these transport variables. All markets are cleared by prices. This feature explains the equilibrium nature of the approach that has been chosen. It is a partial approach, however, as only the transport markets are analysed, and feedback on, for example, the labour market is ignored. These, in turn, could have an effect on transport, but this is outside of the scope of EUCARS. With this *caveat* in mind, it can be said that the model allows an integrated evaluation of policy measures on the demand for passenger transport, a variety of transport externalities (i.e. air emissions, congestion) and welfare.

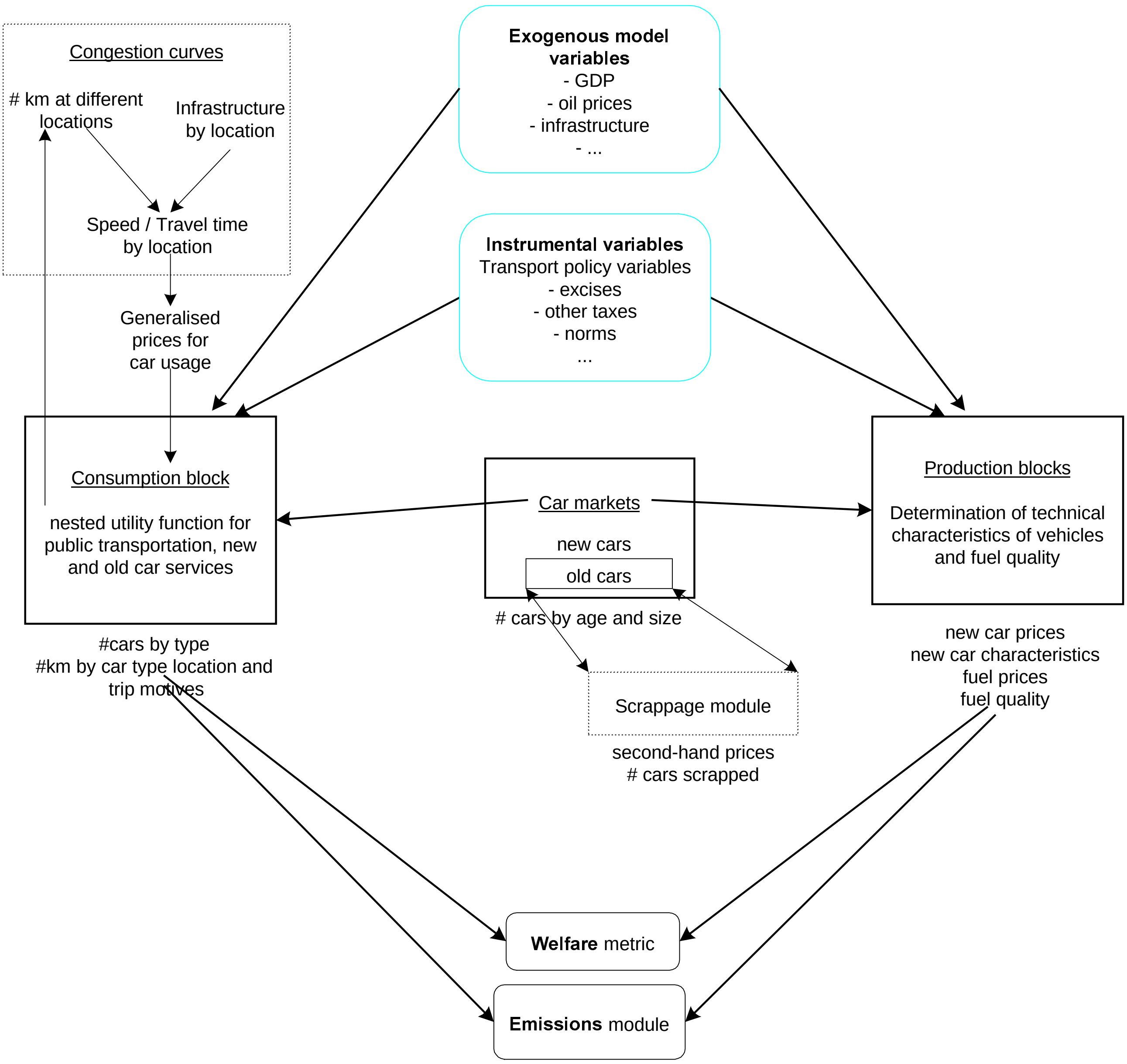
The overall structure of EUCARS is depicted in Figure 1 below. A number of exogenous factors – for example, disposable income, infrastructure capacity and oil prices, together with the system of transport taxation set by the government – are the main input variables in producers' and consumers' decisions. The behaviour of consumers and producers is described in individual blocks, which are interdependent.

Consumers make numerous choices when allocating disposable income to various consumption categories. These choices are determined by the relative prices of the various categories and by travel times, as consumers are also faced with a time budget. Specific account is taken of public and private transport, various car types, and vehicle age, as well as travel motives and location. The consumer choice procedure is described in more detail in Section 2.2.

The demand for mobility is constrained by available infrastructure on the network (disaggregated into urban roads at peak and off-peak time, rural roads and highways) through generalised speed flow curves. This determines subsequent travel speeds, which affect, in turn, the time costs of driving, the *real* fuel consumption and transport emissions, and also, through the impact on transport costs, demand for travel.

In the production block of the model, the technical characteristics (fuel consumption, emission factors etc.) of new vehicles and fuels are determined. Producers are assumed to develop vehicles to specifications that minimise consumers’ expectations of lifetime costs. The assumptions and mechanisms of the production blocks are presented and discussed in Section 2.3.

Figure 1. General structure of the model.



New car prices are determined by producers and are independent of the level of production[3]. Given the prevailing new car prices, demand from the consumption block equals the number of new cars sold during each period. For old vehicles (i.e. those that are not produced during the current period) the second hand market price clears the market as both the available stock and demand are price sensitive. The sensitivity of demand results from the fact that car purchase prices affect car ownership costs, which are among the determinants of demand (e.g. through depreciation). Supply is influenced by prices through scrappage, which is partly endogenous. Higher second hand market prices imply that repair following breakdown becomes relatively more

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3 Economies of scale are less relevant in an aggregate model such as EUCARS than in models which forecast sales by brand

attractive and less cars are therefore scrapped. This subject is discussed in paragraph 2.4.

EUCARS has been designed to analyse the cost-effectiveness of various transport policy measures in the context of air emission policy objectives. In order to assess the costs, use is made of a welfare metric that expresses the (technical and behavioural) cost of policy measures to society as a whole. This welfare metric, and possible extensions, as well as the computation of car emissions (CO_2 and conventional emissions) are discussed in Section 2.5.

The EUCARS model is dynamic and calculates equilibrium outcomes on the transport markets for five year periods, from 1990/1995 to 2010/2015[4]. Hence, these results only take account of medium and long term policy effects and do not encompass short-term fluctuations. The car fleet consists of vintages (by five year period). The stock of old vehicles, which is handed over from one period to the next, links the different periods. Consumers expectations of future costs are static (i.e. identical to current costs). Moreover, when choosing new cars, consumers are assumed to be short-sighted, i.e. they underestimate the future fuel savings they could make by buying more fuel efficient cars. Therefore, the model is not time consistent (in the sense that consumers do not have perfect foresight), and the equilibrium outcome is calculated on a period by period basis.

The numerical results of the model simulation are, to a large extent, illustrative since the model has not been estimated econometrically, but was calibrated on an incomplete data set, representing EU-12 aggregates during the period 1985/1990. Where possible, use has been made of the FOREMOVE database (Zachariadis, 1992) and the underlying CORINAIR data to obtain information on the reference situation. This applies in particular to the distribution of vehicle ownership and mileage across vehicle categories, age groups, vehicle speeds and driving conditions. The relations for fuel efficiency and emissions are also taken from COPERT/CORINAIR (Eggleston *et al*, 1991), while prices come from various sources, in particular the results of a survey on car costs in different countries (SEO, 1992). The costs of different vehicle technologies were obtained during the Auto Oil programme (Touche Ross, 1995). The calibration of the model is further described in Denis (1998).

2.2. The consumption block

Consumer choices are described in the model by a decision tree. The idea underlying the consumption block is that, in allocating their income, consumers first decide how much to spend on large aggregates of goods and services (e.g. transport) and subsequently on how these budgets are further subdivided into smaller aggregates (e.g. private transport). This process continues until one arrives at the level of individual goods and services (e.g. mileage of small cars purchased in 1990 driven on highways for professional purposes). Hence, decision making is described as a series of separable choices, which can be visualised as a nesting structure (decision tree) and is presented in Figure 2.

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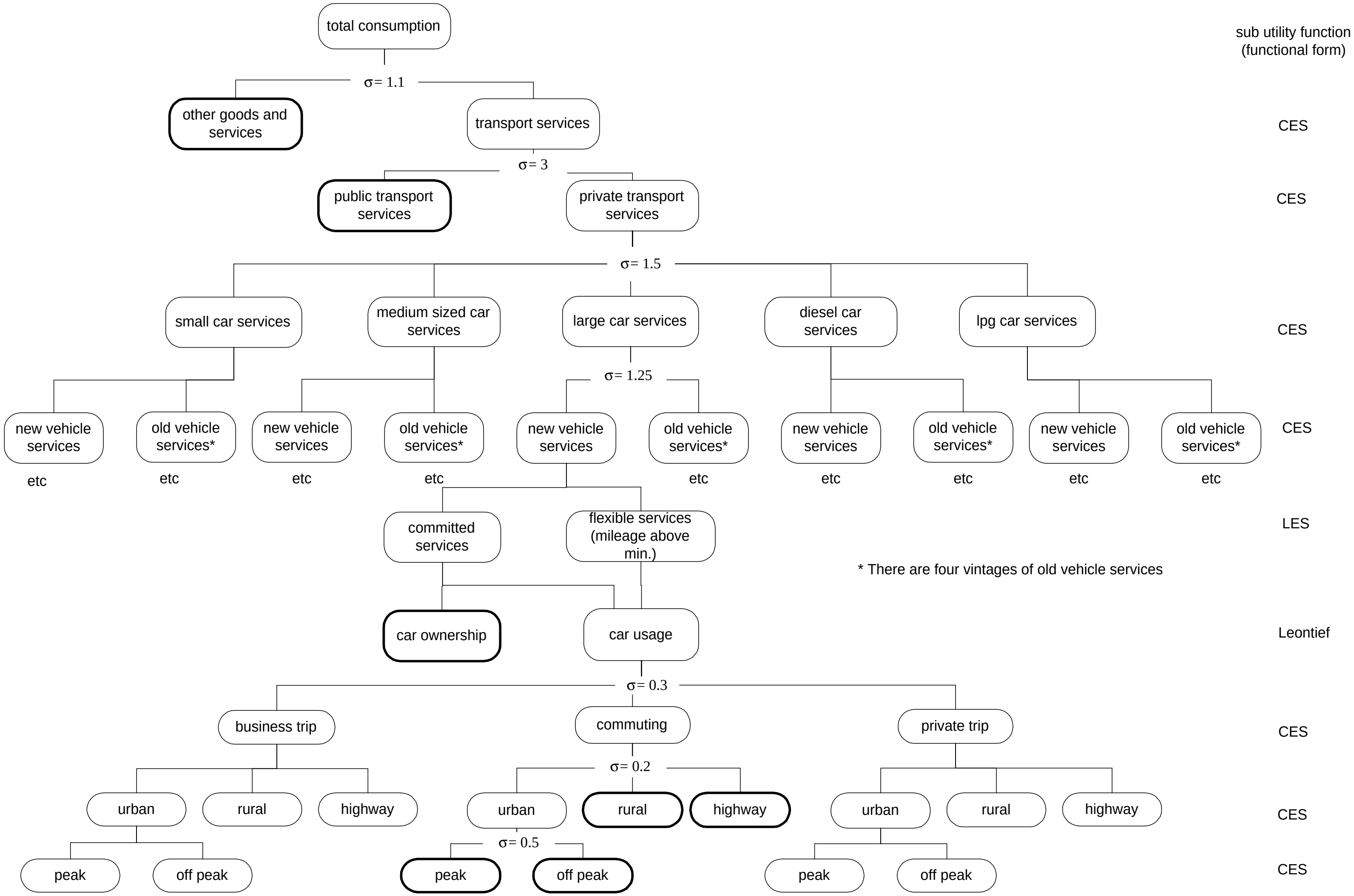
4 The first period serves as the reference for calibration.

All budget allocations are based on utility maximisation given income levels and relative prices. The model has only one representative consumer who optimises his/her welfare and is considered to be representative of all consumers in the economy. Figure 2 therefore also represents the nested utility function of the representative consumer (Section 3.1.2 describes the functional forms chosen, which are indicated in the margin in Figure 2).

Figure 2. The consumption module in EUCARS



The impact of various measures on the distribution of income cannot be studied in models with only one representative consumer. However, some insights about the distributive effects of policy measures can be found by analysing the impact of measures on the composition of the fleet (effects on small versus large, and new versus old, cars). Both the nesting structure and the representative consumer are common characteristics of models of this type, although their use in transport models has hitherto been limited. Another example of this approach is the TRENEN system of transport models.

Income allocated in EUCARS is *full* income, i.e. monetary income (salary, wages etc.) plus the value of available time. The idea behind the latter concept is that time is scarce and, therefore, represents a value. This feature is of major importance for transport choices, since transport always implies time "costs". As is shown in the next chapter, this feature can be captured in the model by using the concept of full income and prices that consist of both monetary components and time costs.

The decision tree comprises nine levels, each of which represents a choice between substitutable services. The only exception is the complementarity between a minimum level of car usage and car ownership, which is modelled at the fifth and sixth level of the tree. The functional forms that have been selected for the various nodes of the decision tree (indicated in the margin of Figure 2) and the relevant parameters to which the model has been calibrated are discussed in Chapters 3 and 4, respectively.

Consumption expenditure is given outside the model. The first decision, therefore, concerns the allocation of total consumption of *non-transport* goods and services, on the one hand, and *(total) transport* services on the other, while the second choice is between the consumption of *public* transport services and of *private* vehicle services. Note that total transport services only refer to passenger transport. Public transport services are not further sub-divided, and modal substitution therefore only occurs at the (aggregated) second level, as the focus is on passenger transport by car in the remaining part of the decision tree.

The two succeeding levels refer to the type of car. At the third level, spending on private vehicle services is allocated to five vehicle *categories* or *“size” classes*. More information on these classes is provided in Table 1.

Table 1. Vehicle categories in EUCARS

Category	Number of vehicles in 1990 (millions)
Small (gasoline, motor content ≤ 1400cc)	65.2
Medium (gasoline, 2000cc≥ motor content>1400cc)	37.7
Large (gasoline, motor content > 2000cc)	7.3
Diesel	15.8
LPG	1.8
Total	127.8

Subsequently, at the fourth level, spending on these size classes is subdivided into spending on vehicles of five age groups: cars produced during the current period (new cars, average age 2.5 years), cars produced in the previous period (average age 7.5 years), cars produced two periods ago (average age 12.5 years), cars produced three periods ago (average age 17.5

years) and cars that are older than 20 years. The distinction of various age groups - per size category - is important as the emission profiles differ strongly across old(er) and new(er) cars due to the progressive tightening of vehicle emission standards[5]. Table 2 presents the age structure of the vehicle fleet in 1990.

Table 2. The age structure of the vehicle fleet

Category	Number of vehicles in 1990 (millions)
New	54.8
Aged 5-10	48.2
Aged 10-15	22.8
aged 15-20	1.9
Aged more than 20	0.1
Total	127.8

Up to this point in the model, spending on the various vehicle categories has been formulated as spending on both car ownership and usage. The shares of "ownership" and "usage" cost in this total are not fixed as annual mileage can be varied. However, demand for ownership and usage is also strongly interlinked at the level of the individual consumer. Optimising consumers take joint decisions on ownership and usage: people buy cars to use them (De Jong (1989, 1991)). Therefore, at the aggregate level, fuel costs not only affect mileage, but also ownership (people with low annual mileage who are given an incentive to reduce mileage further are, to some extent, also dissuaded from owning a car). Conversely, fixed costs not only affect the number of cars purchased, but also the total mileage driven by the fleet (less cars also implies less kilometres driven).

At the fifth and sixth levels of the decision tree, this strong relationship between the demand for car ownership and car usage is modelled. At the fifth level it is assumed that ownership of a private vehicle automatically implies a minimum usage of that vehicle which is set at 35% of the average annual mileage (the choice of an exact value for this parameter is related to the model properties, see Chapter 4). Hence, consumers allocate their spending between, on the one hand, car ownership (and the associated minimum usage of the vehicle) and, on the other hand, the free or supplementary usage of those vehicles. These two "services" are labelled *com(mitted)* and *suppl(ementary)* car services, respectively. Gross complementarity has been assumed here, i.e. an increase in the price of one category not only entails a drop in demand for this category, but also for the other category[6]. At the sixth level, the *committed* part of car services is split into *ownership* and committed mileage. As the minimum mileage “bought with the car” has been fixed, no substitution possibilities have been modelled at

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5 The phasing in of the various emission standards over time does not correspond perfectly to the age categories distinguished in EUCARS, implying that some vehicles meeting a certain emission standard belong to different age groups. In order to allow a relatively precise calculation of the emissions, a transition matrix between age groups and vehicle technologies has been constructed (see Denis, 1998).

6 This formulation implies that when fixed costs increase, total mileage decreases. It is implicitly assumed that the decrease in kilometres associated with the reduction in car ownership (a process occurring at the micro level) outweighs the increase in “free” kilometrage of vehicles that remain in the vehicle fleet.

this level. Subsequently, the committed mileage is combined with the free (*supplementary*) mileage to obtain the total *usage.*

At this level, fleet composition and annual mileage per vehicle are fixed. Further subdivisions concern the allocation of mileage among various trip motives, locations and time of day. At the seventh level, mileage is distributed across three trip types that correspond to travel motives: commuting, professional usage and other (private use). This distinction is important as the value of time differs strongly across these activities according to available studies. Moreover, the price sensitivity of these trips also varies: professional and commuting trips have lower price elasticities than private trips.[7]

Finally, at the eighth and ninth levels, mileage for the different trip types is allocated to four types of driving conditions (peak urban, off peak urban, rural roads and highways). These proportions are nearly fixed (low elasticity of substitution between locations), except for the substitution between peak and offpeak periods which is considered easier. Information for rural roads and highways on further differentiation according to the period of the day is difficult to obtain and less relevant. The average driving speeds resulting from traffic are different in these four situations, which affect the time costs of driving and, consequently, demand.

The order in which the different choices are organised can be discussed; in particular the question arises whether the different trip motives and location alternatives should not come earlier in the decision tree. However in that case, emphasis would be on “trips” and it would consequently be more difficult to model the composition of the fleet and of mileage. Also less emphasis would be given to modelling vehicle characteristics which are of considerable importance to fleet emissions, and so better considered at an upper level (although there are some obvious interactions between trip characteristics and car type). Consequently, greater accuracy can be expected from evaluating fiscal, regulatory and other policies impacting the vehicle fleet rather than modelling policies that affect local driving conditions. Another question is whether further disaggregation should be included, for example a distinction could be made on the basis of car occupancy rates, which would allow the impact of policies on car-pooling to be taken into account. As mentioned before, the public transport bundle could also be further disaggregated.

2.3. The production block

Cars can be made more fuel-efficient and less polluting at a cost. By changing the technology (e.g. improved catalytic converters) and materials used, vehicle emissions can be reduced. According to the available literature, fuel economy and conventional emissions (e.g. NOx, CO) are practically unrelated and a reduction in emissions does not always increase fuel consumption (as was the case following the introduction of the catalytic converter). Moreover, reductions in emissions are often obtained after the combustion process (catalytic converters), which also separates the two problems physically[8]. The

7 This distinction also opens up the possibility (not exploited in the current model version) of taking differences in the fiscal treatment of these trips into account (e.g. tax deductibility of the costs of commuting).

8 Personal communications by Ashley Fergusson and UBA

model therefore has two separate modules for vehicle technology: one for fuel efficiency and one for emission reduction technologies. In addition, a separate module deals with fuel quality. At present, no interactions between fuel quality and vehicle technology are included in the model, but this could in principle be easily remedied.

The main feature underlying both modules is that producers select technical characteristics of the various vehicle categories so that the models they put on the market correspond to consumers' preferences, given prevailing taxes, interest rates, fuel prices, other cost components, mileage and emission standards (if relevant). Such an outcome would prevail given sufficient competition amongst vehicle manufacturers. It is also assumed that for each technology average costs are independent of the scale of production, a reasonable assumption in a model of this nature. This also implies that any cost increases (taxation or technological add-ons) are fully passed to consumers. As a result, producers will specify their product to match consumers expectations of financial savings, and vehicle producers effectively compare the cost of producing a cost-saving device (e.g. of lighter materials leading to lower fuel use per kilometre) with the cost savings that are perceived by the consumer as a result.

A critical assumption in this respect is that consumers are somewhat myopic. This hypothesis concerns the perception consumers have of lifelong cost savings from switching to technologies that save costs over time: they are assumed to be short-sighted, i.e. they do not take real lifetime costs or benefits into account. Their choice is therefore suboptimal when compared to the fuel economy that would be chosen under rational expectations about future costs (Train, 1985) and, due to the above assumption, the production outcome (set of emission factors and related costs) is also suboptimal, which in turn implies the existence of no-regret measures that would correct for this market failure.[9]

Consumers and producers base their decisions regarding fuel economy on fuel prices inclusive of taxes. The fuel tax wedge should, in principle, lead to distortions in levels of fuel economy from the point of view of society as a whole. Efficient levels of fuel economy should be based on the resource (and environmental) costs of fuel. Due to high fuel tax levels, decisions by consumers and producers with perfect foresight would result in an "overprovision" of fuel economy. However, consumer myopia works in the other direction, i.e. consumers and producers are less price sensitive on account of this phenomenon. In EUCARS 3, consumer myopia is so strong that, with respect to the existing high fuel taxes, there is an "underprovision" of fuel economy in the base case. Although this might seem counter-intuitive, it is borne out by the available evidence on the marginal costs of improvements in fuel economy presented in Section 3.4.

For each of the five size categories, average costs and technical characteristics of new vintages are determined in the production block, according to these two important assumptions. Finally, different combinations of diesel and petrol fuel quality are distinguished in the fuel quality module of EUCARS. Subject to possible standards, the least cost combination is selected by refineries. Differential taxation based on fuel characteristics can be simulated. Through consumer choice, this affects the different diesel/petrol combinations produced over a certain period.

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9 See for instance Eriksson (1993) for an application to road traffic.

Fuel economy of the various size classes can be adjusted over a relatively wide range, in small steps. It is consequently modelled as a continuous cost-minimisation problem. Reducing conventional emissions is modelled as a discrete cost-minimisation problem. In view of the limited number of distinct technologies available, the selection process consists of a discrete choice by size class. The same holds for the selection of fuel quality. In all cases, emission standards can be introduced and imply an upper emission limit on eligible technologies.

A more detailed discussion of the modules is provided in Chapter 3.

2.4. Price formation, car markets, endogenous scrappage and model dynamics

As prices balance supply and demand on all markets, the price formation process is crucial to the simulation properties of the model. Prices for usage are determined at the bottom end of the decision tree discussed in Section 2.2 above. Ownership prices are determined at level six of the same decision tree. They are subsequently aggregated to prices at higher levels in the decision tree in a manner that is consistent with the underlying demand structures at each level (see Section 3.1.3).

Usage costs

The usage prices depend essentially on monetary cost components on the one hand, and time costs on the other. The time costs are a simple function of travel speeds (determined by the speed flow curves) and value of time (which are exogenous to the model).

The monetary cost components firstly comprise exogenous factors like maintenance, oil use etc, which vary across size and age categories. Secondly, they consist of fuel costs, which depend on fuel prices (tax included) and fuel efficiency. Fuel efficiency varies with the technical characteristics of the vehicle and driving conditions.

Ownership costs

Ownership costs are modelled as the sum of running expenses (to the extent that these are independent of mileage) and capital costs, as the full costs of owning a vehicle during the period under consideration.

The model distinguishes four individual components: exogenous ownership costs (e.g. vehicle insurance), ownership taxes (annual road tax or “circulation tax”), depreciation and capital costs (net of depreciation). For a new car, the last term covers both interest foregone on car ownership and capital gains/losses (i.e. differences between the book value (purchase price minus depreciation) of a car and second hand prices). Clearly, annual taxes have a direct impact on ownership costs, whereas purchase taxes affect ownership costs indirectly through depreciation. Depreciation is linear and depends uniquely on the age of the car (i.e. not on mileage). The latter simplifying assumption seems reasonable in an aggregate model of this kind where, due to the gross complementarity between ownership and usage, annual mileage is relatively stable in simulations.

The car markets

The car markets are cleared through car prices, which are different to the ownership costs outlined above. Price determination is different for new and for second-hand cars. New car prices are set by producers operating at constant average cost, implying that supply is perfectly elastic. Hence, new car ownership is essentially dependent on demand[10].

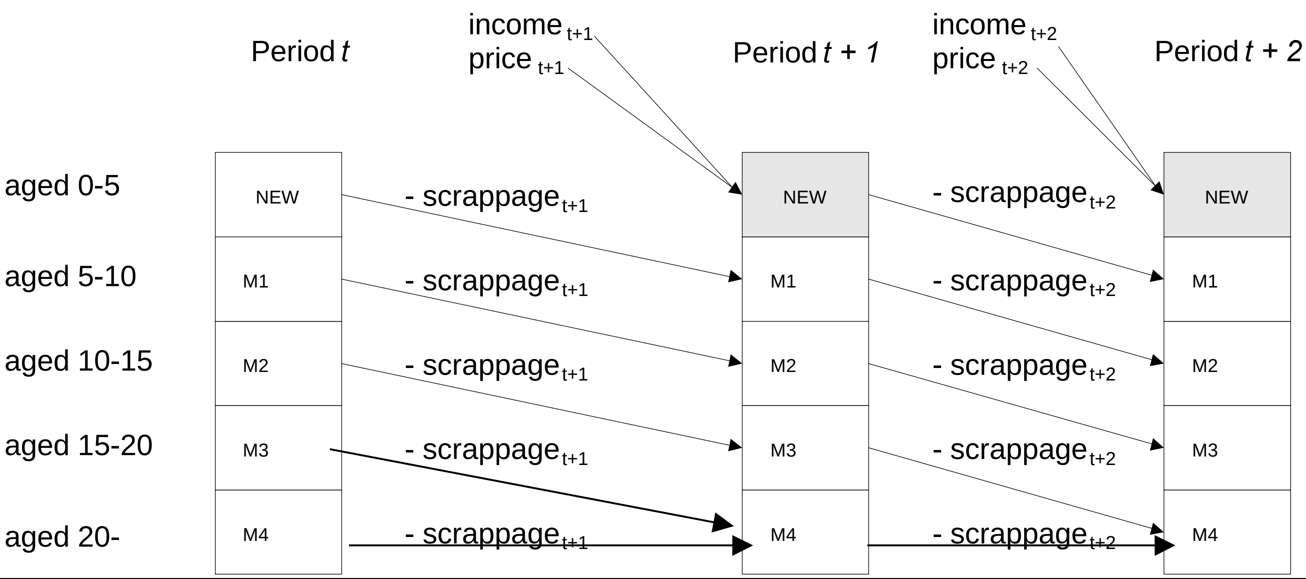
Box 1. A DYNAMIC MODEL

* Periods of five years

* One model run by period

* Periods linked via vintages and expectations

Car stock broken down by vintages



For car ownership of old vehicles (those not produced during the current period), supply depends on the stock of the previous period and scrappage. Scrappage itself is partly endogenous. The exogenous part represents "total losses" which are assumed equivalent to one third of total scrappage in the base year. Exogenous scrappage occurs at an increasing rate with the age of the car. Endogenous scrappage is important as measures that directly affect car prices, such as purchase and/or circulation taxes, are known to have a significant impact on the average age of the fleet. A good example is Denmark where relatively very high purchase taxes have led to high car prices across the board and an average vehicle age that is more than one year above the European average.

10 Strictly speaking in a simultaneous model like EUCARS all relations are interdependent and one should, therefore, qualify all statements as to uni-causal relations (x determines y). Here, for example, demand levels influence driving and congestion, this affects prices and demand.

Box 1 above visualises the scrappage process and indicates that scrappage decisions have long-lasting effects on the composition of the vehicle fleet. The – partly endogenous – turnover of the vehicle fleet implies that the model is dynamic.

Model dynamics

The model describes medium term (five year) equilibria of passenger transport markets. However, as vehicles have an average lifetime of some 11 years, expectations play an important role in determining the results of the model. In all cases, it has been assumed that consumers and producers have static expectations, i.e. that prices and average traffic volumes in future periods will correspond to those in the current period. This assumption greatly simplifies the computation of results as the model can be solved on a period by period basis. However, this feature also implies that the model is not "time consistent" in the sense that consumers do not have forward looking expectations and are not capable of taking future *equilibria* into account when making decisions. Theoretically, the use of static expectations in the context of optimising models is not correct. However, it should be noted that, as time periods represent five year intervals, feedback from future to current periods (which in themselves are second order effects) are, in a quantitative sense, probably not so important, especially given the myopic assumption adopted to describe consumer “investment” behaviour. Furthermore, the authors are not aware of any disaggregated dynamic transport model, with optimising consumers and producers, into which perfect foresight has been incorporated.

2.5. Evaluation of policy scenarios with EUCARS

EUCARS is used in simulation exercises where policy scenarios are evaluated by comparison to a baseline scenario. The baseline scenario builds upon the reference situation (EU-12 in 1990) to which the model is calibrated, and is then established by fixing income and infrastructure growth for the future periods, leaving standards and fiscal instruments unchanged.[11] Once the baseline scenario is obtained, evaluations of simulations are made on the basis of welfare costs. The welfare “yardstick” integrates all the major social costs components described below: consumer welfare, producer welfare and government revenues, excluding the effects the measures can have on environmental, noise and accident externalities.

Consumer welfare obviously depends on the levels of consumption, and changes in welfare are measured through the nested utility function depicted in Figure 2, which relates utility to the consumption levels of the two largest consumption categories in the model: transport services and non-transport goods and services. These aggregated consumption levels are related to lower level consumption through sub-utility functions. The structure of the utility function is such that a doubling of the consumption levels of both categories leads to a doubling of welfare. On the other hand, if at the prevailing prices the quantities of both consumption categories are altered while respecting the budget constraint, then utility obviously falls (for more information see Section 3.8).

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[11] Information on baseline specifications and outcome is to be found in the technical document. For the versions used in the Auto-Oil programme, FOREMOVE projections of the fleet evolution were taken as the baseline reference scenario to be approached.

The prices that determine the consumption levels at the top level of the decision tree are aggregates of prices at lower levels. Expenditure shares, updated between periods, are used as weights in the aggregation process (see Chapter 3 for more detail). This means that if substitution possibilities at low levels of the decision tree are significant, the impact of price increases on welfare will be limited, as greater shares of categories in which prices do not increase imply that price increases at the highest level of aggregation are mitigated. It should be noted that changes in travel times due to modifications in traffic volumes also affect prices through modified time costs.

Losses in consumer welfare can be calculated in each period by analysing the so-called equivalent variation, i.e. the increase in income (at baseline prices) that would be needed to keep utility at baseline levels following a policy change.

Given the assumptions made in the production block, producer welfare would not change in the simulations as prices equal costs and profits are not affected.

Social welfare, excluding the effects of measures on environmental and accident externalities, can therefore be calculated as the sum of the change in consumer welfare and the change in tax revenues (if any). It is assumed that changes in tax revenues from the no-policy case are returned to the economy in a lump-sum way, which implies that their contribution to welfare is one ECU for one ECU of revenue[12] Obviously, if the money were used to cut highly distortionary taxes then its "welfare contribution" would be higher. Conversely, if the money were spent on projects that have a low social benefit, the contribution of the tax revenues to societal welfare would be smaller. In the absence of additional information on the use of additional tax revenues, it is standard to assume lump sum recycling. Sensitivity analyses can easily be performed by varying the value for the contribution to welfare of revenues collected (Marginal Cost of Public Funds, or MCPF). Only changes in tax revenues from the transport sector are taken into account.

These changes in societal welfare can, for presentational purposes, be expressed as a percentage of baseline spending on transport for each period. Alternatively, they can be discounted over the full simulation period to obtain the cumulated welfare change.

When policy simulations are run with the model, these welfare changes can be used to carry out a cost-effectiveness study. In such a study, an (environmental) objective is fixed and a variety of policy scenarios are run to determine the least cost policy instrument. In such exercises, the welfare metric is used to determine the costs. For example, in European Commission (1995c) a set of simulations is reported, which aim at reducing CO_2 emissions from passenger transport by 10% from baseline. The results reported suggest that the least cost way of obtaining this result is the imposition of a CO_2 tax.

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12 This is obviously a rough approximation since transport taxes affect the price of consumption goods and thereby distort the labour-leisure choice as a result of which welfare losses occur outside of the transport system. This means that part of the recycling is required to offset these welfare losses and that therefore, the total welfare effects are somewhat more negative than the welfare effects measured in EUCARS.

3. DETAILED DESCRIPTION OF THE MODEL

This chapter gives a detailed discussion of the structure of individual blocks of the model, the main equations and their derivations. Equations are given in a somewhat simplified form; i.e. not all indices/subscripts are explicitly written as the main emphasis is on describing the principles. A complete list of equations is to be found in Annex 3 (model listing), while the list of all symbols used in the model appears in Annex 2.

3.1. Consumption block

3.1.1. Generalised costs and full income

The consumption block describes the allocation of available income by a representative consumer over consumption categories by means of a nested choice process. As transport activities take time and time is scarce, decisions as to the structure of consumption also imply an allocation of available "consumption" time (i.e. time that is not used for working, resting etc.). Hence, time "costs", together with monetary costs enter directly into the decision process. Utility is maximised by selecting the "optimal" mix of goods and (transport) services, respecting the budget and time constraints.

This can be analysed by considering the following setting for the utility optimisation:

$$Max\ U\left(X_1, TX_1, X_2, TX_2, ...\right)$$

s.t.

$$P_1X_1 + P_2X_2 + ... \leq Y \qquad \text{(budget constraint; associated Lagrangian multiplier: } \lambda\text{)}$$
$$t_1X_1 + t_2X_2 + ... \leq T \qquad \text{(time constraint; associated Lagrangian multiplier: } \mu\text{)}$$
$$TX_i = t_iX_i$$

in which:

X_i	passenger mileage with mode *i*
TX_i	travel time with mode *i*
P_i	monetary costs per unit (e.g. kilometre) of mode *i*
t_i	travel time per unit (e.g. kilometre) of mode *i*
Y	monetary budget
T	available "consumption" time

The first order conditions that follow from maximising the associated Lagrangian are:

$$\frac{\delta U}{\delta X_i} = \left(\mu - \frac{\delta U}{\delta TX_i}\right) * t_i + \lambda * P_i$$

Dividing both sides by λ gives:

$$\left(\frac{\delta U}{\delta X_i}\right)\frac{1}{\lambda} = CX_i = \left(\frac{\mu}{\lambda} - \left(\frac{\delta U}{\delta X_i}\right)\frac{1}{\lambda}\right) * t_i + P_i$$

This expression has an interesting interpretation as the left-hand side clearly represents the monetary value of an additional unit of X_i (recall that λ stands for the marginal utility of income) i.e. the marginal benefit. The right-hand side can be understood as the sum of monetary costs (P_i) and time costs expressed in monetary-equivalents (μ/λ equals the marginal money value of time and that the second term between brackets represents a mode specific utility cost expressed in monetary terms) and, thus, represents the generalised cost of travel (CX_i). In the optimum the marginal benefits of and additional unit of X_i equal the marginal cost.

One can subsequently reformulate the optimisation procedure by using the concept of generalised costs as defined above, as well as the associated concept of Full Income (*FI*). Full Income represents the monetary income *Y* plus the monetary equivalent of the endowment in consumption time (determined by multiplying the various TX_i by the respective value of time). This leads to the following optimisation problem:

$$Max\, U(X_1, X_2, \ldots)$$

s.t.

$$CX_1X_1 + CX_2X_2 \leq FI$$

It can easily be demonstrated that the first order conditions of this problem are identical to those of the former optimisation problem. In EUCARS the latter, reduced, approach is followed. Thus, income is full income and prices contain both a purely monetary component as well as a component reflecting the value of time. The various demand systems are derived by maximising the sub-utility functions, given full income and generalised prices. An important consequence of the use of generalised prices including time costs is that congestion costs are included in the welfare metric.

3.1.2. Sub-utility functions

As indicated by Figure 2 the consumption block consists of a nested structure of sub-utility functions with nine levels. The nested structure, by assuming separable choices, allows one to limit the number of cross price elasticities to be estimated. When choices occur between substitutable services, the functional form is CES (constant elasticity of substitution) and the substitution elasticity is indicated on the decision tree; other functional forms are used to model joint demand of car ownership and usage.

CES demand systems

Of the nine levels, the first four are modelled by a CES function. The CES function is also used at level seven eight and nine (distribution of mileage over trip motives, locations and periods of the day).

The expression for the CES utility function for the case of five consumption categories (which occurs at levels 3 and 4 in the model) is written as follows:

$$u = \left[\sum_{i=1}^{5} \alpha_i^{\frac{1}{\sigma}} q_i^{1-\frac{1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

in which σ represents the elasticity of substitution and α is a share parameter.[13] Utility maximisation under the restriction of the budget equation

$$\sum_{i=1}^{5} p_i q_i = \mathrm{I}$$

results in the following demand equation:

$$q_1 = \frac{\mathrm{I}}{p_1\left[1+\left(\frac{p_1}{p_2}\right)^{\sigma-1}\frac{\alpha_2}{\alpha_1}+\left(\frac{p_1}{p_3}\right)^{\sigma-1}\frac{\alpha_3}{\alpha_1}+\left(\frac{p_1}{p_4}\right)^{\sigma-1}\frac{\alpha_4}{\alpha_1}+\left(\frac{p_1}{p_5}\right)^{\sigma-1}\frac{\alpha_5}{\alpha_1}\right]}$$

Or more generally:

$$\boxed{\begin{aligned} q_i &= \frac{\mathrm{I}}{p_i\left[\left(\frac{p_i}{p_1}\right)^{\sigma-1}\frac{\alpha_1}{\alpha_i}+\left(\frac{p_i}{p_2}\right)^{\sigma-1}\frac{\alpha_2}{\alpha_i}+\left(\frac{p_i}{p_3}\right)^{\sigma-1}\frac{\alpha_3}{\alpha_i}+\left(\frac{p_i}{p_4}\right)^{\sigma-1}\frac{\alpha_4}{\alpha_i}+\left(\frac{p_i}{p_5}\right)^{\sigma-1}\frac{\alpha_5}{\alpha_1}\right]} \\ &= \frac{\alpha_i \mathrm{I}}{p_i^{\sigma}\gamma} \quad avec \quad \gamma = \sum_j \alpha_j p_j^{1-\sigma} \end{aligned}}$$

The expression for the (own) price elasticity parameters is:

$E_{ii} = -\sigma - \alpha_i (1-\sigma) p_i^{1-\sigma}\gamma^{-1}$ with $\gamma = \sum_j \alpha_j p_j^{1-\sigma}$. They can also be written like

$E_{ii} = \sigma (w_i - 1) - w_i$ with $w_i = p_i q_i / \mathrm{I}$ (budget share)

(The compensated price elasticity parameter is equal to $-\sigma\left(-\alpha_i p_i^{1-\sigma}\gamma^{-1}+1\right)$, or $\sigma(w_i - 1)$, since the income elasticity of demand is equal to 1.)

The cross price elasticities are given by:

$$E_{ij} = -w_i\left[(1-\sigma)\left(\frac{p_i}{p_j}\right)^{\sigma-1}\left(\frac{\alpha_j}{\alpha_i}\right)\right] = w_j(\sigma-1)$$

Therefore, the cross price elasticities are positive for the first four levels in the model tree (substitutable services), while they are negative for the bottom levels (7, 8, 9) with very low substitution possibilities ($\sigma \le 0.5$; $\sigma = 0$ would correspond to the Leontief function with

13 The traditional presentation scales the utility function by imposing $\sum_i \alpha_i^{\frac{1}{\sigma}} = 1$ (see for instance Shoven and Whalley, 1992). We do not use the same scaling factor here.

fixed shares of each component). At level 7, the distinction between trip motives is to be understood as decomposition into services with a different value and with varying composition. Obviously at the individual level, there is no or very little direct substitution between the three alternatives when market conditions change[14]. However the differentiated increase or decrease in mileage according to trip motives can change the eventual proportions.

For level 8, it is easily understandable that the substitution possibilities between rural, highway and urban locations are limited: on balance, as trips often consist of using various stretches of the different networks, there is a strong complementarity between these three services.

Clearly, CES is in itself a fairly restrictive demand system for studying consumption behaviour as it implies unitary income elasticities and a constant elasticity of substitution that determines the own and cross price elasticities at individual levels of the consumption block.[15] This substitution elasticity is the only parameter whose value is "free" and can be determined in the calibration process. However, it should be noted that the overall implicit price elasticities of individual consumption categories (at the lowest level of disaggregation) depend on the parameters at *all* levels of the consumption block, which allows for a much higher degree of flexibility in the overall modelling process (see Section 4.1).

Aggregate prices are determined using a CES price aggregator (see below).

LES demand systems

The joint demand for car ownership and usage is modelled in levels 5 and 6 of the decision tree. The fifth level – the distinction between committed services purchased with the car and free or supplementary usage - has been modelled by means of a *LES (Linear Expenditure System)* function. This utility function, which allows for the existence of gross complementarity between the components, is written as follows for the case of two dependent variables:

$$u = (q_1 - \beta_1)^{\alpha_1} (q_2 - \beta_2)^{\alpha_2}$$

with q_1, q_2 the quantities consumed of the two goods,

u utility

α_i, $\beta_i > 0$ (i = 1,2) , and $\alpha_1 + \alpha_2 = 1$.

Utility maximisation leads to the following demand equations, for the case of two variables and more than two variables, respectively:

$$q_1 = \beta_1 + \alpha_1 (y - p_1\beta_1 - p_2\beta_2)/p_1$$

---

14 It is difficult to imagine a scenario where the price of the alternatives would not move together, even if not in proportion.

15 Keller (1976) proposed to use "modified CES" functions in comparable decision tree. "Modified CES" functions impose minimal quantities and are more flexible than the classic CES functional form.

$$q_i = \beta_i + \alpha_i \, (y - \Sigma_k p_k \beta_k) \, / \, p_i$$

Income elasticity is equal to $E_i = \alpha_i \, . \, y/p_1 . q_1$. Its value has been fixed at 1.2 for supplementary mileage, and approximately 0.85 for committed services (ownership and minimum mileage). This latter elasticity diminishes with the age of the car. For (own) price elasticity, the equation is $E_{ii} = \beta_i \, (1-\alpha_i) \, -q_i \, / \, q_i$. Values are close to –1 because of parameter specification. Cross price elasticities (general formula is: $E_{ij} = - \, \alpha_i \, \beta_j \, p_j \, / \, p_i \, . \, q_i$) are close to zero.

Leontief demand systems

At level 6 demand depends in fixed proportions on demand at the previous level, i.e. car usage consists 100% of supplementary mileage, plus the (compulsory) mileage associated with ownership. The Leontief function implies substitution elasticity equal to zero. There is therefore no change in the relative proportion of the two goods/services following a change in relative prices.

It is the combination of the LES function (complementarity) with the association of minimum mileage to car ownership, as modelled by the Leontief function, that ensures the strong complementarity between ownership and mileage (see Chapter 4 and 5 for an indication of model properties in this respect).

3.1.3. Price aggregation in the consumption block

In EUCARS, prices of car transport services are determined at the lowest levels of aggregation of the consumption block (i.e. levels nine and six). Variable costs per km (*PCTSGATR*, i.e. **P**rice to the **C**onsumer, at a specific period of **T**ime, for a particular **S**ize, **G**eneration and **A**spect of car services for a specific **T**ravel motive on a specific **R**oad class) are aggregated from level nine, then they are combined with fixed cost ($PCTSGA_{\text{ownership}}$) at level 5. These prices are the generalised costs defined above and their composition is described in further detail in the next section.

The aggregates at the higher level cannot be interpreted as total costs but rather as price indices. For instance, the aggregation of prices in the CES demand systems uses the price index for a CES function:

$\underline{P} = \left[\sum_i \alpha_i P_i^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ where the α's and the σ's are the same coefficients and elasticities of substitution as in the demand equations.

For the LES function a geometrical average has been used:

$\underline{P} = \prod_k p_k^{w_k}$ with w_k, share of k in the budget.

The price aggregation for the Leontief demand systems uses simple weighed averages.

3.2. Generalised costs and car markets

The generalised cost of car traffic services consists of a monetary component and a time cost component. The latter component is determined endogenously as the product of the value of time (*VaOT*: exogenous) and the travel time (*Time*: endogenous) under the different driving conditions. The costs of car ownership depend largely on the market prices for new and (four age categories of) old cars through depreciation and the use of capacity costs.

Generalised costs of car usage

The generalised cost of car usage or variable cost consists of three components:

$$PCTSGATR_{\text{usage}} = VCE + FEFF * (PFUEL + VCP) * (1 + VATF) + VaOT * Time.$$

Where - *VCE* is the exogenous component of variable costs (reflecting oil use, mileage dependent insurance etc.)[16],

- *FEFF* is the (endogenous) fuel use per kilometre,
- *PFUEL* is the price net of taxes for a specific fuel type,
- *VCP* are the fuel excises, and *VATF* is the VAT rate (%),
- *VATF* is the value added tax

This equation is replicated 300 times (five vehicle categories; five age groups, three trip motives and four driving conditions) in the model as some of the components differ for the individual vehicle categories, trip motives and driving conditions. Table 3 presents the value of the components in the reference situation for selected trips. The relatively high costs of urban peak commuting should be noted, largely the result of a relatively high value of time for commuting and low travel speeds during the peak hour.

Table 3. Examples of usage costs in the reference situation.

Type of car	Type of trip	VCE value (Ecu/100km)	Fuel use (Ecu/100km)	Time costs (Ecu/100km)	Total cost
Small gasoline New	Rural private	3.24	3.71	5.18	12.13
Small gasoline 10-15 y old	Urban offpeak private	4.75	7.52	12.26	24.53
Large gasoline more than 20 y	Highway Business	11.22	6.40	12.58	34.20
Diesel New	Rural Private	6.98	2.05	5.26	14.30
Diesel New	Urban peak Commuting	6.98	5.03	21.92	33.93

16 Parking costs are not explicitly modelled in EUCARS, but can easily be incorporated in the model framework. This could significantly affect the analysis of policies targeting urban traffic (see Van Dender *et al.*, 1997).

Costs of car ownership

Ownership costs vary with the type and age of the car. All the equations should therefore be indexed with the car type (*s* subscript, see Table 1), while differentiation due to vintage is explained in the text. Ownership costs follow a capital cost approach and comprise two exogenous parameters together with two endogenous variables:

$$PCTSGA_{\text{ownership}} = FCE + FCP + DEPR + CAPC.$$

Where: - *FCE* is the exogenous component in the fixed cost of cars,

- *FCP* is the annual road tax ("circulation" tax),

- *DEPR* and *CAPC* are the depreciation and capacity costs (see equations below).

For new cars, it is assumed that the total depreciation of a new car over a five-year period amounts to 60% of its original value:

$$DEPR = 0.6\ NCPC$$

where *NCPC* is the purchase price (tax incl.) of the new car.

For old cars, it is assumed that the average five-year-old car still has six years of economic "life" at the beginning of each period:

$$DEPR_{m1} = 5 * (OCMP_{m1} / 6)$$

where $OCMP_{m1}$ stands for the second-hand price of this type of car. In view of the average 11 year lifetime of cars, this hypothesis is a reasonable approximation in period t for vehicles purchased in period t-1. For cars belonging to older generations (i.e. 10 years and older) it is assumed that the expected lifetime at the beginning of the period is shorter than five years. Consequently they are fully depreciated during the period ($DEPR_{mi} = OCMP_{mi}$ for i=2,3,4).

The capacity cost is calculated as the opportunity cost of capital. The opportunity cost of capital equals the interest rate (*i*), times the "book value" of the car. The latter variable decreases over time, due to depreciation (which is assumed linear). Therefore, the capacity cost for one period is equal to[17]:

$$CAPC = i * (5\ OCMP - 2\ DEPR)$$

---

[17] Starting from the second-hand car price, the *annual* capacity cost can be calculated as ($CAPC_y$):

$$\begin{aligned}
CAPC_y &= i * OCMP \\
CAPC_{y+1} &= i * (OCMP - DEPR_y) \\
CAPC_{y+2} &= i * (OCMP - 2\ DEPR_y) \\
CAPC_{y+3} &= i * (OCMP - 3\ DEPR_y) \\
CAPC_{y+4} &= i * (OCMP - 4\ DEPR_y)
\end{aligned}$$

where *y* is the year and $DEPR_y$ the annual depreciation (i.e. one fifth of *DEPR*, the total depreciation per period). The costs for the five years are summed in order to arrive at the total capacity cost per period. To simplify the relations no intra-period discounting has been applied.

Applying it to the different vintages we obtain $CAPC_{m1} = i * 20/6\ OCMP_{m1}$ for vehicles belonging to the vintage of cars introduced in the previous period, and

$$CAPC = i * (5\ OCMP - 2\ DEPR) = \mathrm{i} * 3\ OCMP$$

for all other old vehicles. When calculating the capacity costs for new cars, the result is:

$$CAPC = i * 3.8\ NCPC + (0.4\ NCPC - OCMP_{m1})$$

given that the relevant price is the new car price (*NCPC* instead of *OCMP*), and that the annual depreciation is equal to 0.6/5 *NCPC*. The final term records the difference between the residual "book value" of the car at the end of the period (0.4 *NCPC*) and the price of the same vehicle on the second-hand car market, as this latter price is the relevant indicator of the value of the asset at the beginning of the next period[18].

However, this equation uses current second-hand prices instead of the prices that will be set by the second-hand market in the next period. This is in general not very important and may be considered to be consistent with consumer myopia. Nevertheless in the particular case of technology changes, this assumption would be equivalent to base expectations on pre-existing technologies rather than on new technologies. It has therefore been assumed that the relative price increase for second-hand cars, following the adoption of new technology, would equal the relative increase new cars incur for the same reason. In other words, the resell value at the end of the period incorporates the (depreciated) value of the technological add-ons. The modified equation is:

$$CAPC = i * 3.8\ NCPC + (0.4\ NCPC - OCMP_{m1} * (1+kti))$$

where $(1+kti)$ is the ratio of new car prices with and without the new technology:[19]

$$(1+kti) = (NCPP_t / NCPP_{t-1}).$$

Car markets

Producer *new* car prices (*NCPP)* are set in the production block following a minimisation by car manufacturers of the lifetime costs assumed by consumers for a given vehicle category. Consumer prices (*NCPC*) differ from producer prices as VAT and purchase taxes (*OCP)* are generally due upon registration of vehicles by consumers. The purchase tax is modelled as an ad-valorem tax (i.e. proportional to the value of the car), a system that is found in some Member States (e.g. NL) and one that seems a reasonable approximation of the different tax equations applied by Member States with purchase taxes. An implicit consequence of this is that the purchase tax also taxes technological add-ons and increase car prices.

$$NCPC = NCPP * (1+VATCAR+OCP)$$

---

18 Note that no adjustment is made for (expected) capital gains/losses of applying a linear depreciation scheme in the case of old cars. This can be justified by the lower book values of old vintages, implying that the share of capacity costs in total ownership costs are of less importance than for new cars.

19 This ratio is measured by comparing prices in two subsequent periods. As autonomous technical progress is included in the model, one should always applied this modified equation (including for the baseline runs) or alternatively, correct for it.

Car prices on second hand markets equate the demand and available stock of "old" vehicles. Second-hand car markets are therefore cleared, with endogenous scrappage and second-hand prices as the crucial variables.

3.3. Fleet turnover

The age structure of the fleet is an important characteristic, as the emission profiles differ very significantly across vintages. The relative (cost-)effectiveness of various policy instruments to limit emissions is therefore strongly dependent on this characteristic. This aspect is for instance especially relevant each time the relative prices of old and new cars change. The age structure depends on:

- the stock of old cars transferred from period to period (which depends on the scrappage of existing old cars),

- the number of new cars added to the fleet in each period.

The available number of old cars (($VCTSG_o$) is reduced over time following scrappage during successive periods. Beginning with the number of cars (at the moment of purchase) of each vintage (*VINT*, by size and generation), and keeping track of successive scrappage in previous periods (*CSCRAP*), the available number of old cars by size and vintage in each period can be calculated:

$$\begin{aligned} VCTSGC_o &= VINT_o - CSCRAP - ESCRAP \\ &= Stock_o - ESCRAP \end{aligned}$$

ESCRAP is the scrappage occurring during the period. It is partly dependent on market conditions and partly fixed exogenously.

The parameters of cumulated scrappage (*CSCRAP*) and of the initial size of the vintage (*VINT*) are indexed to period and vintage (*o = m1,m2,m3,m4*, i.e. cars aged 1, 2, 3, 4 or more periods). These parameters are transferred and updated between periods, making the model dynamic (refer to box1 for a visualisation of the process):

$VINT_{t+1,M1} = VCTSGA_{t,NEW}$ with $VCTSGA_{t,NEW}$, the number of new cars,

$$VINT_{t+1,M2} = VINT_{t,M1}$$

$$VINT_{t+1,M3} = VINT_{t,M2}$$

For the oldest vintage (cars aged 20 or more), this equation is modified:

$$VINT_{t+1,M4} = VINT_{t,M3} + VINT_{t,M4}$$

as some cars of the oldest vintage remain (are not scrapped).

The same pattern is followed for the transcription of cumulated scrappage in previous periods (*CSCRAP).* The cumulated scrappage $CSCRAP_{t+1,M}$ in one period is equal to the sum of cumulated scrappage $CSCRAP_t$ at the beginning of the pervious period and the number of scrapped cars in the previous period.

$$CSCRAP_{t+1,M1} = 0$$
$$CSCRAP_{t+1,M2} = 0 + ESCRAP_{t,M1}$$
$$CSCRAP_{t+1,M3} = CSCRAP_{t,M2} + ESCRAP_{t,M2}$$
$$CSCRAP_{t+1,M4} = CSCRAP_{t,M3} + ESCRAP_{t,M3} + (CSCRAP_{t,M4} + ESCRAP_{t,M4})$$

The cumulated scrappage, hence, refers to the cumulated scrappage at the *beginning* of the simulation period. In the model, it is assumed that no scrappage has yet taken place for vehicles that were introduced into the vehicle fleet in the previous period (i.e. no scrappage for 'new' cars). Available statistical evidence suggests that this is a reasonable approximation as only a small fraction of new cars are scrapped in the first five years.

Endogenous scrappage

The idea behind endogenous scrappage in EUCARS is that the scrappage decision is based on a comparison of likely repair expenditures and current vehicle market prices (vintage dependent). The expected repair expenditures are assumed to follow a normal distribution. Furthermore, homogeneity is assumed, i.e. subsequent to repair a vehicle becomes indistinguishable again from other vehicles of its size-vintage class (i.e. all vehicles belonging to a size-vintage class are homogenous). Non-repaired vehicles cannot be used and have a market value of zero. A fixed proportion of exogenous scrappage represents cars that can no longer be repaired ("total losses").

As consumers are assumed to optimise utility, they will repair the vehicle if the expected repair expenditures are below the second hand market price of the size-vintage class. Given the homogeneity assumption, it is always better to repair a vehicle if the associated costs are less than the second hand market price. Vehicles with repair costs above the second hand market price are scrapped[20].

The number of vehicles per size-vintage class that are scrapped in a certain period (*ESCRAP*), is thus expressed as follows:

$$ESCRAP = \left\{\left[1 - CUMNPF\left(\frac{OCMP - RC\mu}{RC\sigma}\right)\right] + EXSCRAP\right\} * Stock$$

where $RC\mu$ is the mean of the required repair costs following breakdown (size and vintage dependent),
$RC\sigma$ is the standard deviation of the repair costs ($RC\mu = 3\ RC\sigma$),
OCMP is the second hand market price,
EXSCRAP is the proportion of the stock scrapped in any event (exogenous scrappage forms about one third of total scrappage), and
Stock is the vehicle stock by size and vintage at the beginning of the period,

and in which *CUMNPF(x)* is the integral of the standard normal distribution from -∞ to x.

20 If governments were to introduce policies to stimulate scrappage, this would affect the choice a consumer has to make. In the set-up chosen in this model a modest scrappage subsidy would have similar effects to an increase in repair costs, but would, in addition, also have budgetary implications. Hence, "modest" scrappage schemes can be evaluated in EUCARS by increasing the repair costs, and, in addition, increasing the available income by the amount of subsidies given.

$$VCTSGC_{'OLD'} = VINT - CSCRAP - ESCRAP = Stock - ESCRAP$$

The "supply" of old cars in a specific period is now completely specified, with its dependence on stock previously accumulated, and on second-hand market conditions. Demand is a function of relative prices on these and other related markets.

3.4. Production blocks: specific fuel consumption, emissions and fuel quality

The specific fuel consumption and conventional emission profiles of new vehicles depend on technology choices made by car manufacturers, which are modelled explicitly in EUCARS. The approach chosen assumes a perfectly competitive car market with consumer short-sightedness: i.e. manufacturers will produce vehicles with characteristics such as to arrive at the lowest life cycle cost possible for consumers given their assumed high discount rate (50%), subject, of course, to prevailing regulations (e.g. emission standards). The same applies to fuel manufacturers who decide on the types of petrol and diesel fuel on offer. Subject to rules on fuel quality, a least-cost combination of diesel and petrol fuel qualities is chosen. Whereas vehicle technologies are fixed once produced, fuel quality can be changed every five-year period. Car manufacturers minimise discounted costs of the average lifetime of a vehicle (11 years in EUCARS), whereas fuel manufacturers can change specifications after five years. Short-sightedness is therefore not an issue for fuel quality.

Decisions on specific fuel consumption, conventional emission profiles and fuel quality are independent in EUCARS. This reflects the fact that, according to available evidence, changes in specific fuel consumption are unrelated to specific conventional emissions per kilometre and vice versa. Changes in fuel quality have proportional effects on emissions, independent of vehicle technologies chosen, e.g. a 2% reduction in NO_x emissions across gasoline vehicles, independent of their pollution abatement equipment. Whereas this assumption does not hold under all circumstances, it seems a reasonable approximation, which is also followed in other transport emission models. Moreover, to the extent that interaction effects are important, they can be imposed on the model. This might be particularly relevant in cases where anti-pollution equipment on vehicles requires certain fuel specifications (e.g. low sulphur fuel for De-NOx catalytic converters on diesel cars). The production block of the model, in its current state, consists of three distinct modules describing specific fuel consumption (3.4.1), conventional emissions (3.4.2) and fuel quality (3.4.3).

3.4.1. Specific fuel consumption

Different measures of fuel efficiency are used in EUCARS for the production block and the main module (the transport module). We describe here the determination of the “technical fuel consumption” used in the production block. The “technical fuel consumption” referred to is the labelled fuel consumption (EuroMix[21] values are used to calibrate the production block). The “on-road fuel consumption”, and the link with technical fuel consumption are presented in Section 3.7.

[21] Labelling standard for fuel consumption.

The fuel consumption module of the production block determines the characteristics (fuel economy and price) of newly produced cars. Two possible effects are considered: technical progress, and changes in price affecting consumers' preferences (mainly fuel price changes, but also the effects of (other) fiscal instruments such as the introduction of a specific purchase tax based on fuel economy, also called the gas-guzzler tax (*Ggtax*)). Technical progress is supposed to reduce the costs of achieving a given fuel consumption over time. A time factor (*Tf*) is introduced in the equations to describe this effect. Technical cost curves are used to relate improvements in fuel efficiency and car price increases due to these improvements.

The technical cost curves are based on OECD information (Michaelis, 1996), and on the situation in the current car market.[22] An exponential function was chosen to describe the technical relationships:

$$NCPP = \Omega * Tf * exp(\alpha / (FC\text{-}\lambda))$$

Where $NCPP$ is the pre-tax price of the new car,

FC is the technical fuel consumption of this new car,

Tf is the technical progress parameter (time factor) whose value is 0.97 in the first 5-year period, and decreases by 0.03 for each subsequent new period,

α, Ω and λ are technical parameters. The λ value can be interpreted as the maximum technically feasible (the minimum reachable fuel consumption).

For the fuel price effects, consumers are assumed to be short-sighted, i.e. to over-discount expected mileage and fuel efficiency gains. They equalise marginal cost and marginal benefit based on their expected mileage (*Km*), along a technical cost curve. Their assumed discount rate is 50%, which corresponds to an undiscounted payback period of three years[23]. For small cars, the (expected future discounted) mileage taken into account is 33 300 km, while it would be 86 600 km if a more rational discount rate of 7% was used. The expected mileage is to be multiplied by current fuel prices including taxes (*Pfuelt*). [24]

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22 Minimum and maximum curves are given; they relate percentage increases in car prices and percentage reductions in fuel consumption. These were applied to the current situation on the different markets (small, medium, large, diesel, LPG cars) to obtain five different sets of curves, in absolute terms. As relative changes are converted into absolute changes the reference situation plays an important role. See the technical document for further detail.

23 Based on oral communication from car industry representative.

24 The assumption used here is that myopic consumers take only 38% of the total fuel costs (including tax) into account, and therefore choose sub-optimal specific fuel consumption. However, as the taxes amount to 66% of the fuel price, the selected fuel consumption might be close to an optimum calculated on the basis of resource prices (exclusive of tax).

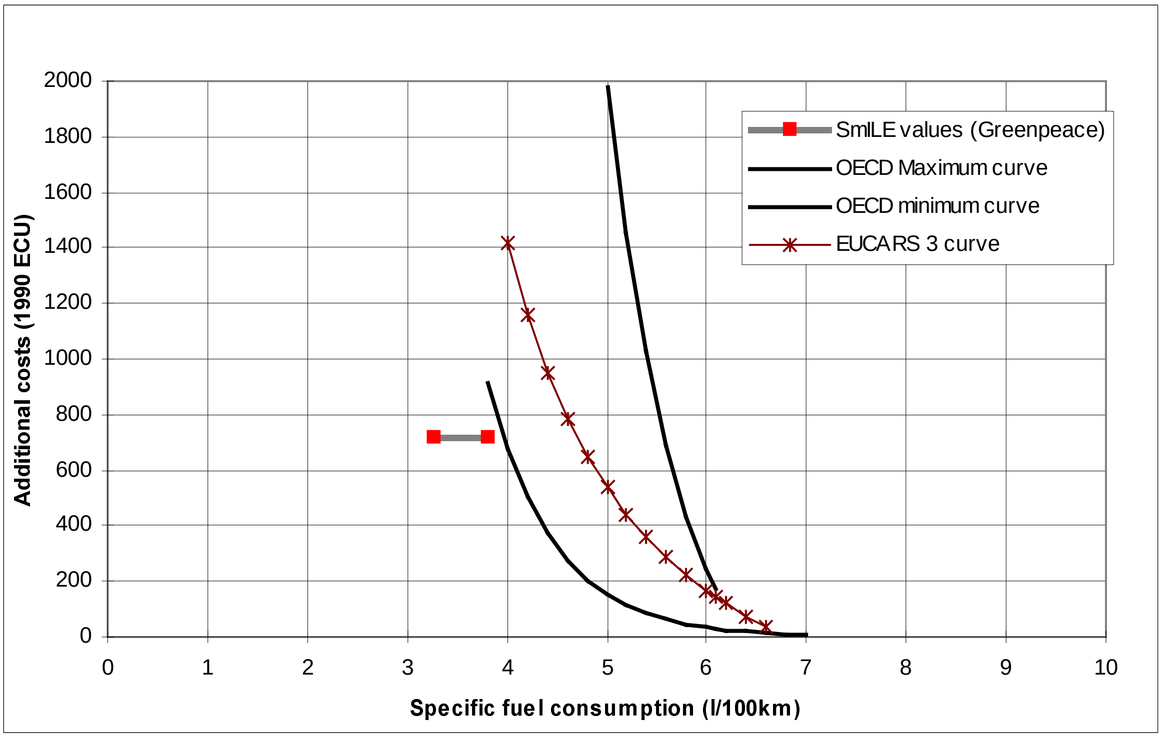
The selected fuel consumption for a particular car type is therefore given by:

$$FC = \sqrt{\frac{(1+tax)Pcar*\alpha*t}{Km*Pfuel-Ggtax(1+tax)}}+\lambda$$
$$= \sqrt{\frac{(1+OCP+VATCAR)NCPP\alpha\,Tf}{Km*Pfuelt-Ggtax*(1+OCP+VATCAR)}}+\lambda$$

since the relevant price for consumers includes taxes: *NCPC = NCPP*(1+OCP+VATCAR)*.

The **Error! Reference source not found.** below shows the cost curve for small cars, compared to the OECD reference data, and to the Greenpeace Twingo SmILE[25]. The cost curve indicates that small improvements in fuel efficiency (of up to 15%) can be achieved at very low production costs. This is, of course, fully consistent with the assumed high discount rates used by consumers in evaluating future fuel savings: indeed without this assumption the existence of such low marginal cost would be hard to explain.

Figure 3. Cost curve: fuel economy for small gasoline cars: comparison of OECD, Greenpeace and EUCARS data



[25] Greenpeace literature simply states that the "(Twingo SmILE) will not be significantly more expensive than the respective original model. The final price naturally depends in the final analysis upon mass production". The costs figure (12% increase compared to the original cost of the model) used here was taken from the press (for instance TIME International Magazine, October 14, 1996, **146** (16)). The achieved fuel economy ranges from 3.26 l/100km (stated fuel consumption) to 3.8 l/100 km (Swiss road test).

3.4.2. Specific emissions of conventional pollutants

For each type of car, costs to consumers related to conventional emissions (CO, VOC, NO_x, and PM10) are minimised over the whole life of the vehicle. These costs comprise, on the one hand, emissions control costs (i.e. production costs – passed on by manufacturers to consumers – and higher maintenance costs) and, on the other hand, possible emission costs linked to "taxes on emissions" which can be introduced in EUCARS. For example, an annual road tax based on average emission factors and/or on mileage driven can be introduced. The average emission factors depend on the control technology chosen when manufacturing the vehicle, and on the maintenance of the car[26]. Here also the consumer is expected to be short-sighted, i.e. expenses over the whole life are discounted with the same very high discount rate (50%).

This leads to the following discrete optimisation problem:

$$\forall s, \quad \min \sum_i \sum_j x_{ijs} c_{ijs} + \sum_{pol} emiss_{s,pol} * tax_{pol}$$

s.t.

$$\sum_i x_{ijs} \leq 1 \quad \forall j \ \forall s$$

$$c_{ijs} = cost_{ijs}\left(1 + OCP_s + VATCar_s\right) + lifecost_{ij}\ \frac{(1+Int)^{VIE} - 1}{Int\left(1+Int\right)^{VIE-1}} \qquad \forall i \ \forall j \ \forall s$$

$$emiss_{s,pl} = evapoemiss_{s,pl}\ \frac{\left(1+Int\right)^{VIE} - 1}{Int\left(1+Int\right)^{VIE} - 1} \sum_i x_{i,evap,s}\left(1 - RED_{i,s}\right) + \sum_{year=1}^{VIE} \frac{km_{year,s}\, avgexhaust_{s,pl} \prod \sum x_{ijs}\, factor_{year,i,j,s,pl}}{\left(1+Int\right)^{year-1}} \qquad \forall s \ \forall pol$$

With: s: type of car
small (gasoline), *medium* (gasoline), *large* (gasoline), *diesel*

j: instrument
car (technology), *IM* (inspection and maintenance), *evapo* (control of evaporation emissions)

i: intensity of instrument j
0 (no measure), ... *n* The number of intensities per instrument depends on the instrument.

pol: primary pollutant
NOx, *CO*, *VOC*, *PM* (particulate matter)

x_{ijs} : 0/1 variable. $x_{ijs} = 1$ if the i^{th} intensity of the instrument j is chosen for new type s cars. Number of available instruments and intensities vary with car type: evaporative

26 The choice of a maintenance scheme is partially determined at purchase, because some inspection and maintenance cases require installation of "On Board Diagnostics".

emissions are a problem for gasoline cars only, inspection and maintenance schemes vary for diesel and gasoline cars, etc.

c_{ijs}: additional cost for a type s car if the instrument j is chosen with the intensity *i.* $c_{ijs} = 0 \quad \forall i = 0$ [ECU/car]

$cost_{i,j,s}$: additional cost to the car manufacturer (including increase in margin to be paid by consumer) for a type s car if the instrument j is chosen at the intensity i[ECU/car]

$OCP_s, VATCar_s$: purchase tax and VAT [%]

$lifecost_{i,j}$: average annual cost of the chosen instrument to the consumer (nonzero only for IM schemes) [ECU/car/year]

Int : interest rate (50%)

VIE : expected lifetime of a new car (11) years

tax_{pol}: tax on emissions ECU/g pol

$emiss_{s,pol}$: expected emissions of a type s vehicle during its whole life (discounted) [g pol/car]

$evapoemiss_{s,pol}$:average evaporative emissions per car. $evapoemiss_{s,pol} = 0$ $\forall pol \neq VOC$ [g/car/year]

$km_{year,s}$: expected mileage per year [km/car/year]

$avgexhaust_{s,pol}$:average exhaust emission factor of a new car type s (if no control technology is chosen) [g pol/km]

$factor_{year,i,j,s,pol}$: emission reduction factor, depending on the instruments chosen. This factor applies to emissions of pollutant pol.

Relevant data is presented in Denis (1998) and follows the conclusions of the study undertaken for the Auto-Oil Programme (Touche Ross, 1995), which can be updated should new information become available. The cost-minimisation problem is solved depending on the exact emission tax setting (see Chapter 5 for examples of use). Clearly, emission standards and other regulatory policies can be simulated by selecting specific control technologies.

3.4.3. Fuel Quality

In EUCARS, the choice of fuel quality is also based on cost-minimisation. Two elements determine this process: the costs of producing ’cleaner’ fuels, and the possible costs to consumers (in function of fuel taxation) of more polluting fuels. A change in fuel composition would affect emissions instantaneously, but it can be reverted without major difficulties in the next period. For these reasons, optimisation is carried out on a period by period basis (implying that there is no need for discounting over the entire lifetime of the vehicle fleet).

Because there are technical links between production of petrol and diesel fuels (not all combinations are possible in a refinery, precise allocation of costs is difficult) and because a change of fuel would affect emissions of all cars, the optimisation must be done for the refinery sector as a whole. The fuel quality model gives the fuel quality of diesel and petrol, plus the associated consumer prices, which influence consumer behaviour in the rest of the model.

$$\boxed{\min \sum_i x_i c_i + \sum_s \sum_g \sum_{pol} n_{s,g} emissions_{s,g,pol} tax_{pol}}$$

s.t. $\sum_i x_i = 1$

$$emissions_{s,g,pol} = km_{s,g} avgemis_{s,g,pol} \sum_i x_i (1 - RED_{i,s,pol})$$

Sets:

s: type of car
small (gasoline), *medium* (gasoline), *large* (gasoline), *diesel*

g: vintage of car
new (aged 0-5), *m1* (aged 5-10), *m2* (aged 10-15), *m3* (aged 15-20), *m4* (aged 20 and over)

i: fuel package (= definition of gasoline and diesel fuels)
0 (no change), ... *23.* Numbering of the options follows Touche Ross, 1995.

pol: primary pollutant
NOx, *CO*, *VOC*, *PM* (particulate matter)

Decision variable:

x_i:0/1variables. $x_i = 1$ if the i^{th} fuel package is chosen for the entire fleet. Only one fuel package (combination of diesel and petrol) is chosen as the result of the optimisation:.

Control costs:

c_i : Total cost of the i^{th} package, inclusive of VAT [ECU]

Technical costs of the packages are estimated at the refineries level: they therefore represent costs of fuel(s) reformulating for the whole of the EU.

Emission costs:

$n_{s\,g}$:	number of cars of type s and vintage g for the period	[cars]
tax_{pol} :	tax on emissions	[ECU/g pol]
$emissions_{s,g,pol}$	average car emissions over a period	[g pol/car]

$\sum_s \sum_g n_{s,g} emissions_{s,g,pol}$ is a technical formula that is equivalent to 'fleet average emission factors' multiplied by the 'number of cars'.

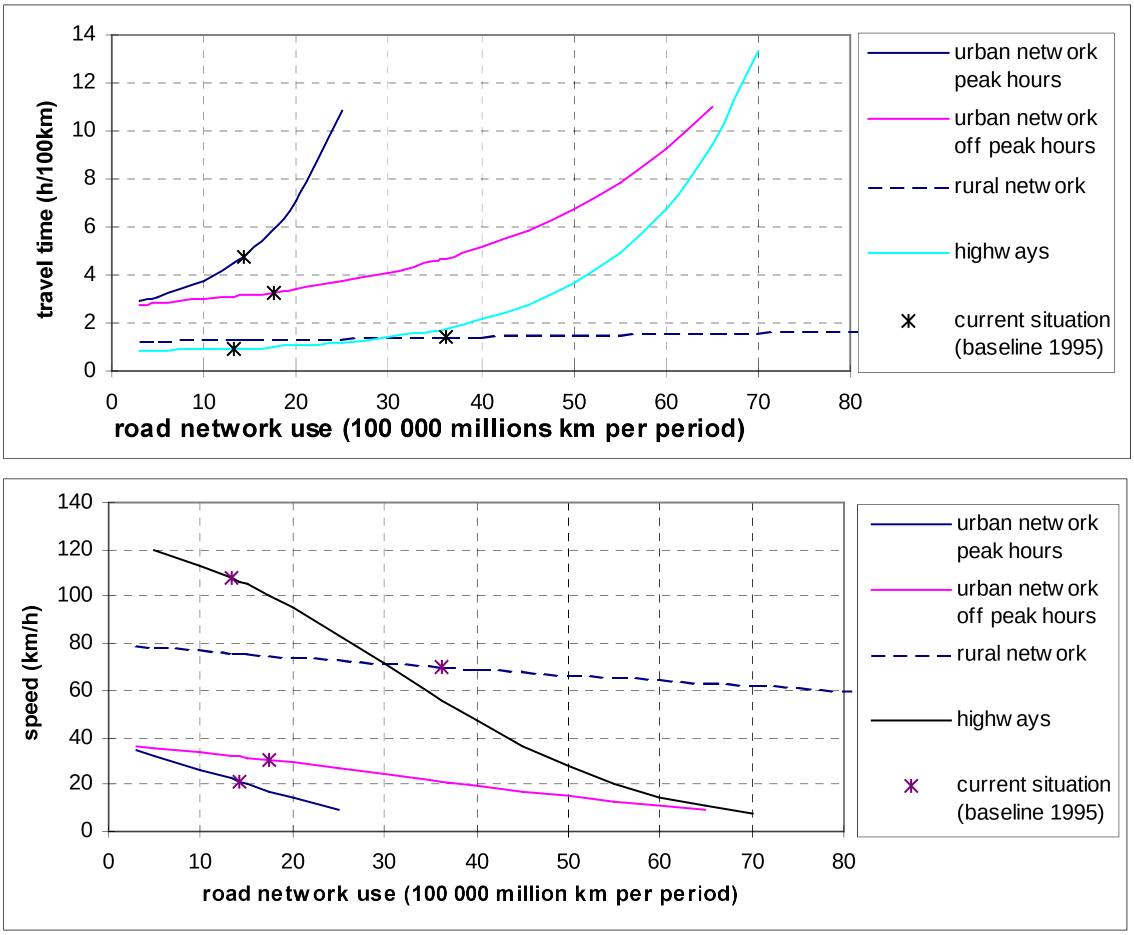
$\sum_s \sum_g \sum_{pol} n_{s,g} emissions_{s,g,pol} tax_{pol}$ therefore represents the costs for the entire fleet of the chosen option due to the presence of an emission tax. [ECU]

Emission costs are calculated for the entire fleet, based on a theoretical tax rate depending on average emission factors. In practice however (and in EUCARS main module) two different excise rates are applied on fuels (one excise rate for petrol and one for diesel).

3.5. Congestion and determination of average speeds

The congestion module depicts the interrelation of traffic volume and available infrastructure to determine average speed. The assumption is that every additional km has an impact on other users of the same network by reducing speed. This is modelled through aggregate speed-flow curves, one per network (rural, urban peak, urban off-peak, highway)[27] with the assumption that the driving style is homogenous on the network. An illustration of the curves used in EUCARS 3 is given below.

Figure 3. Speed-flow curves used in the model.



The aggregate travel time curves are exponential in capacity utilisation, which, according to available studies (Kirwan *et al*, 1994), is a reasonable approximation of the relation between travel speeds and traffic flows in transport networks. The link between average travel time (*Time* = 1/*Speed*) and total number of kilometres (*km*) driven is formulated in the following way:

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27 For reasons of simplicity, two different networks are used for urban peak and urban off-peak.

$$Time = Z * \exp(traffic) + \alpha \quad Time_{network} = Z * exp(traffic_{network}) + \alpha$$

where Z and α are parameters specific to the individual networks and where *traffic* represents the capacity utilisation of the infrastructure:

$$traffic = \sum_{size} \sum_{generation} \sum_{triptype} km \Big/ (INFRA / \beta) \quad traffic = \sum_{size} \sum_{generation} \sum_{triptype} km \Big/ (INFRA / \beta)$$

The level of infrastructure by location (*INFRA*) is determined exogenously. $Z, and\ \alpha\ \beta$ is used, for the urban infrastructure, to indicate the ratio between peak and offpeak hours. The default value is one. It is three for the urban peak network to approximate the ratio between the two periods (on average 5 to 6 hours in the peak period, for 15 to 20 hours off-peak).

The average travel times per car category are then determined by modifying the average travel time on a specific network to account for the differences in engine size.

$$Times_{size} = factor_{size} * Time$$

Speeds (and travel times) are generally affected by the infrastructure utilisation level, but could also be modified by rigorously enforced speed limits (for example see European Commission, 1995a).

The travel time of public transport is partly a function of road congestion as buses and trams are (partly) affected by road congestion. Clearly, public transport by metro or train is independent of road traffic volumes. The average travel time per km of public transport can thus be written as:

$$Time_{publ\ c\ transport} = \lambda k + (1 - \lambda)\delta \sum_{locat\ on} \varpi_l Time_{network,l}$$

in which:

λ represents the share of mileage by means of public transport that is "insensitive" to road congestion,
k is the average fixed travel time for public transport insensitive to "road" congestion,
δ represents the ratio between travel time by "road congestion sensitive" public transport and by cars (assumed fixed) and
ϖ is the share of public transport on rural, urban (peak and offpeak) and highway areas.

The inclusion of congestion implies that reducing mileage has a positive effect on welfare, especially when urban peak mileage is reduced.

3.6. Conventional emissions

EUCARS contains a block comprising equations that describe total emissions of NOx, CO, HC, PM and NO_2, by size, class and vintage (in addition, emissions from public transport are modelled). These equations are for the most part taken from the Copert II methodology adopted in the CORINAIR working group (Eggleston H.S. *et al*, 1991). They are generally technology specific. The same methodology is the basis for the FOREMOVE emission computer (Zachariadis, 1992).

Basic methodology

Emissions are made of various components. Exhaust and evaporative emissions are first computed separately. Extra emissions due to cold start are then added to basic emissions (occurring with hot engines), while degradation factors depending on maintenance and mileage driven modify the basic emission factors.

Emission factors for the different pollutants are technology specific and speed dependent. They vary with road classes and average speeds (urban peak/off-peak, rural, highway). Extra cold start emissions are taken into account by modifying the hot emissions for urban driving (i.e. all cold start emissions are allocated to urban driving). An outline of the basis methodology is given in Box 2.

BOX 2. Basic Copert methodology for calculating the emissions from road transport

♦ Exhaust emissions from hot engines by size, class and vintage [in grams]

$$= \sum_{drivingmode} emissionfactor(speed_{drivingmode}) * vehicles * annualmileage * share_{drivingmode}$$

$$= \sum_{\text{road class}} \text{emission factor}_{\text{road class}}[\text{g / km}] * \text{vehicles} * \text{annual mileage}[\text{km / vehicle}] * \text{share}_{\text{roadclass}}$$

♦ Cold start correction factor

$= 1 + \beta * totalmileage * \frac{e_{cold}}{e_{hot}} = 1 + \beta * \text{total mileage} * \frac{\text{e}_{\text{cold}}}{\text{e}_{\text{hot}}}$ with $\beta = \text{fraction}$ of mileage driven with cold engines

♦ Total exhaust emissions by size and vintage (in grams)

$$= exhaust\ emissions\ from\ hot\ engines * cold\ start\ correction\ factor$$

$$= exhaust\ emissions\ from\ hot\ engines\ [\text{in grammes / by size, class and vintage}] * cold\ start\ correction\ factor$$

♦ Evaporative emissions from gasoline cars include diurnal and hot soak emissions in addition to running losses. These emissions depend on climatic conditions, fuel and car characteristics and driving pattern.

Evaporative emissions [in grams]

$$= 365 * \text{vehicles} * \text{emission factor} + \text{k} * \text{mileage}$$

♦ Total emissions = exhaust emissions + evaporative emissions

Emission factors for catalyst cars deteriorate following a linear trend. The slope of the degradation depends on the type of inspection and maintenance scheme adopted. Emission factors for conventional cars assume a certain degree of inspection and maintenance and correspond to a lifelong average. Further inspection would reduce these emission factors.

Two main determinants influence total emissions. First, technical emission factors, which can be improved through new technologies, inspection and maintenance, modifications of the fleet structure (scrappage scheme, fiscal incentives) and possibly through speed modifications. The second determinant is 'traffic volume' (i.e. mileage or number of cars), broken down to be coherent with technical emission factors. This determinant will vary with price changes (of fuel, new cars, taxes etc.), traffic regulations, and congestion levels. The reader interested in the calculation details and the functions relating emission factors and speed is referred to the Copert methodology, or Denis (1998) for its application to EUCARS.

Emissions and the production block

The conventional emission characteristics of new vehicles sold during the 1990-2010 simulation period follow from the minimisation of lifetime vehicle costs by car manufacturers. This is carried out in the production block of EUCARS. Obviously, emissions standards imply that manufacturers can only choose from vehicle technologies with emissions per kilometre below the standard.

Introduction of new techniques is modelled through percentage reductions in the current emission factors. Once the emission reduction percentage is determined in the production block, it is applied to the emissions output calculated as a function of speed by the model.

Emissions and the technical characteristics of fuels

Emission formulae presented above are given for reference petrol and diesel fuels. For the 23 packages of reformulated fuels investigated in the AD Little study, reduction factors for the emission of the main pollutants are used (see 3.4.3).

3.7. On road fuel use and CO_2 Emissions

3.7.1. Fuel efficiency in the transport module (in-use fuel consumption)

The technical fuel economy of new cars is fixed in the production block. However, like emissions, the real fuel consumption of a car is affected by many other factors, including the average network speed (highway or congested city).

Calculation of on-road fuel consumption follows the same calculation method described above for emissions, based on the Copert formulae. The model contains formulae linking fuel consumption to speed that are different for different types of car (vintage, size and fuel types). Average speeds are endogenous in EUCARS, and therefore, the fuel consumption for the same trip with the same car can change for different policy scenarios[28]. Extra consumption for cold starts is added and allocated exclusively to urban driving (this is also the rule in the Copert reference manual).

According to this methodology, average consumption of the whole fleet in the 1991-1995 is roughly equal to 8.25 l/100 km, while average consumption of new cars in the same period

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[28] Average speed and allocation to different location are taken here as a proxy for driving styles, as is the case in FOREMOVE.

is equal to 8.19 l/100 km[29] (this is to be compared with average fuel consumption in the production block of 7.77 l/100 km).

3.7.2. Link between technical fuel economy (production block) and on-road fuel economy

Improvements in technical fuel efficiency are based on technical improvement over time, as well as the possible effect of tax incentives. They are incorporated in the production module (see above §3.4.1.), and transmitted proportionally to the TRANPORT module. For example, if, due to calculations in the production block, fuel consumption appears to be reduced by 10% in period t when compared to period t-1, then the speed formula for the new cars is multiplied by 0.9 in the TRANPORT module:

$$RATIOf_t = \frac{FC_t}{FC_{t-1}} \quad \text{and} \quad ORFC_t = RATIOf_t * f(Speed)$$

with *ORFC*, the on-road fuel consumption.

We therefore ensure that both the speed and technology effects can modify the on-road fuel consumption.

3.7.3. CO_2 emissions

Fuel consumption figures are the basis for calculating CO_2 emissions. Given the fixed relationship between fuel types and CO_2 emissions, the calculation of car emissions can be carried out directly based on total fuel use and specific emission coefficients (*EM*). CO_2 emissions per unit of public transport use are fixed (*CO2TP*) and consequently possible improvements in fuel economy, possible fuel switches, and possible alternative uses of available capacity are ignored.

$$\begin{aligned} CO2 &= VCTP * CO2TP \\ &+ \sum_{type} \left[EM_{type} \sum_{generation} FEFF_{type,generation,drivingmode} * VCTSGAR_{type,generation,drivingmode} \right] \end{aligned}$$

where *VCTP* is the volume of public transport (endogenous),

FEFF is the “on-road fuel efficiency” (endogenous),

and *VCTSGAR* is the mileage by car size, vintage and driving mode (endogenous).$CO2 = VCTP \ * CO2TP + \sum_{size} \left[EM_{size} \sum_{gen} FEFF_{size,gen} VCTSGA_{size,gen,'usage'} \right]$

CO_2 is a global pollutant, and therefore emissions are not attributed to location.

[29] Introduction of catalytic converters during the period explains why there is so little difference between the consumption of old and new cars.

3.8. Appraisal parameters

For the purpose of scenario evaluation, aggregate emissions from transport (CO_2 and conventional) are computed in the emission modules (3.6 and 3.7.3), and compared with the total costs of introducing policy measures (i.e. welfare costs).

Total costs include congestion as the model uses the concept of full income and prices including a time component (§3.1). Contrary to congestion, air emissions do not directly affect economic welfare, as EUCARS does not contain any information on damage costs from emissions. They are however calculated to enable scenario evaluation. Other external costs (noise, accidents) are not reported, and are not included in the model.

Welfare: private welfare and government revenues

Consumer welfare is determined at the highest level of the consumption block where a choice is made between transport services and other goods and services. This is modelled by a simple CES demand system which, due to the fact that it is linear homogeneous, allows welfare changes induced by policy measures to be directly translated into equivalent variations:

$$EV = - \{(U_{new} - U_{old})/U_{old}\} * Y$$

in which U_{new} and U_{old} denote utility levels in the policy simulation case and the baseline respectively. Y stands for total expenditures on consumption.

If we add to this expression the change in government revenues, the total welfare cost (negative welfare change), denoted *WELFCOST,* can be computed[30]. The revenues change can be negative: diminution of the tax basis, subsidy, or positive: new taxes or increase in existing taxes. It is standard practice to weight the welfare contribution of tax revenue as equal to one (see section 2.5). Other assumptions (revenues used to reduce highly distorting taxes, …) modify the marginal cost of public funds (*MCPF*):

$$WELFCOST(V) = - \{(U_{new} - U_{old})/U_{old}\} * Y - MCPF * (REV_{new} - REV_{old})$$

REV, total net government revenues, is the sum of revenue from all taxes in the road transport sector: the purchase tax and VAT on new cars (*OCP*, *VATCar*), the fuel taxes (*VCP*, *VATF*), the annual road tax on ownership (*FCP*) and the eventual gas-guzzler or emission-based tax levied on new cars depending on their characteristics (*Ggtax* and *tax*). Revenues of a possible road-pricing scheme are also added, and possible subsidies (scrappage incentives, further subsidy to public transport[31]) are subtracted.

The welfare metric calculated in EUCARS does not contain the welfare effects of environmental damage. This implies that the current version of the model can only be used

30 No changes in producers' surplus given the assumptions taken.

31 For reasons of simplicity changes in public transport levels do not affect government welfare in the current version of EUCARS (i.e. subsidies remain constant). Changes in the subsidy level (cheaper fares) are the only changes acknowledged.

for a cost-effectiveness analysis, where, for fixed environmental or other objectives, policy instruments can be evaluated by inspecting the associated welfare costs. Clearly, if more information on damage costs is available, then the welfare concept could be expanded to comprise a broader welfare definition, including environmental costs. This would technically be relatively simple, but would require good estimates of damage cost relations. Such a formulation would allow the model to be used for carrying out cost-benefit analysis of policies.

4. MAIN ELASTICITIES AND DATA SOURCES

This chapter briefly describes the key parameters and main data sources that have been used to quantify EUCARS. A more detailed listing of data information is available in the technical note.

4.1. Elasticities

It is useful to make a distinction between explicit and implicit elasticities. The former refers to parameters of the model and, hence, to elasticities that can actually be found in the programme codes (i.e. the structural coefficients). Generally, these elasticities occur in equations describing interactions between a limited number of variables. Implicit elasticities refer to the sensitivity of a variable to some exogenous shock, taking account of *all* the interactions that occur in the model. These elasticities can, hence, only be deduced from a particular simulation. The elasticities found in the literature (see, for example, Goodwin (1992) and Oum et al. (1992)) are often based on reduced form equations, in which case they have to be interpreted as "implicit" elasticities.

The explicit elasticities in EUCARS are found at relatively disaggregated levels in the model. For example, at all levels of the consumption block, individual substitution elasticities are needed. They condition the price and income elasticities at this specific level. For instance, while the price elasticity of fuel consumption has been the subject of research and publication, the different mechanisms involved (fleet reduction, fleet downsizing, technical improvements in fuel economy, changes in annual mileage) can only be influenced in EUCARS through very specific, technical parameters. For other domains, relatively little information is available, or information on elasticities at a low level of aggregation is often not in a format that allows direct transposition to the neo-classical demand structures used in EUCARS.

This implies that the parameterisation (i.e. setting of the explicit elasticities) has been guided by a number of the entire model’s resulting key implicit elasticities, as these could be verified by referring to the literature. This process, together with data input for the reference situation, was carried out during the calibration phase. Obviously, as in any model of this nature, there are only a limited number of degrees of freedom in selecting implicit and explicit price elasticities, resulting from the functional forms chosen.

Two very important "benchmark" explicit elasticities, subject to extensive research, have been used during calibration together with other information. They are the price elasticity of total mileage with respect to fuel prices, and the price elasticity of total fuel consumption with respect to fuel prices. The model has been calibrated so as to obtain a long run value of -0.2 for the price elasticity of total mileage with respect to fuel prices and a value close to

-0.5 for the price elasticity of total fuel consumption. The benchmark taken is Goodwin (1992), which is considered the most extensive survey on this issue:

> "for a sustained real 10 percent increase in fuel price, the response in the longer run consists of a reduction in traffic of 3 to 5 percent (with reduction in car ownership accounting for the half of it), while the total fuel consumption diminishes by about 7 percent through downsizing, better fuel economy and behavioural changes (adaptation of the driving mode)".

As this later behavioural response is missing in EUCARS, the benchmark taken is a total reduction in fuel consumption of –4.5 percent for a 10 percent increase in fuel prices. Half of the response should then come from reduced mileage (of which half from reduced fleet size and half from reduction in average annual driving) and half from fuel economy (adaptation in fleet composition and technical changes). The main explicit elasticities and structural coefficients determining the fuel consumption response in the model are:

- the substitution elasticity at the first level (transport vs. other goods and services),

- the SHAREMIN parameter (i.e. part of the compulsory mileage "bought with" the ownership of a car). The smaller its value, the more the mileage component responds to the fuel price signal. On the other hand, very small values would damage necessary the complementarity between ownership and usage.

- the coefficients and functional form of the efficiency module of the production block, conditioning the technical response. The cost curves used and the short-sighted component fit reasonably well with the results published by Goodwin.

Admittedly, the chosen elasticities are a bit on the low side. However they result from a detailed model describing different behavioural patterns, and are not simple parameter(s) plugged into a reduced form equation. Moreover the structure of the response to a shock in fuel is in keeping with the literature. Finally, previous work on CO_2 emission limitation has been published (Koopman, 1995) using a set of generally accepted elasticities close to the present set.

Regarding the choice between public and private transport, there is also a significant amount of empirical work available. Most studies conclude that, at the aggregate level, the cross-price elasticity of car use with respect to public transport prices and travel times is relatively small. Conversely, demand for public transport is strongly sensitive to car prices and travel times (for an extensive discussion, see Gwilliam *et al*. (1991)). Clearly, this is largely determined by the fact that the public transport share in total mobility is quite small (approx. 16% of mileage and 8% of total transport expenses). In EUCARS, the substitution elasticity between private and public transport is set at three, implying cross-price elasticities with respect to generalised costs of 1.6 for public transport and 0.4 for car

Table 4. Long run (after 15 years) implicit elasticities of EUCARS 3.[32]

Effects of: / on:	car usage	car ownership	use of public transport	average travel time in urban congested / non congested areas	Total tax revenues from car ownership and use	technical fuel consumption (litre/km) (medium gasoline cars)
1% increase in fuel prices	- 0.20 %	- 0.09 %	+ 0.20 %	- 0.19 % / - 0.07 %	+ 0.52 %[33]	- 0.27 %
1% increase in new car prices	- 0.17 %	- 0.35 %	+ 0.26 %	- 0.17 % / - 0.06 %	- 0.02 %[34]	-
1% reduction in public transport prices	- 0.07 %	-0.06 %	+ 0.95 %	- 0.07 % / - 0.02 %	- 0.07 %	-
1% reduction in travel time by public transport	- 0.14 %	- 0.13 %	+ 1.96 %	- 0.14 % / - 0.05 %	- 0.14 %	-
1% reduction in travel time by car	+ 0.81 %	+ 0.42 %	- 2.61 %	- 0.15% / -0.70 %[35]	+ 0.63 %	-
1% increase in infrastructure capacity (roads)	+ 0.33 %	+ 0.13 %	+ 0.11 %	- 0.65 % / - 0.24 %	+ 0.23 %	-

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[32] Version of 01/10/97

[33] The fuel price increase is realised through an increase in taxation

[34] New car prices (net of taxes) are 1% above baseline. Car purchase taxes are proportional to the car price; the increase in consumer prices, and in car taxes is therefore also equal to 1%.

[35] Secondary effects nearly outweigh the initial shock in urban area rush hours

usage[36]. Obviously, the elasticities with respect to individual components of the generalised costs (i.e. petrol prices) are much smaller. These values are close to averages reported for aggregate cases in the above-mentioned survey by Goodwin (1992) and accord well with some of the evidence presented in Koopman (1992).

The magnitude of price sensitivity between old and new cars, as well as between different car categories, is more uncertain. Various studies report differing findings which seem to depend strongly on the definition of car categories. However, especially where substitution between various car types is concerned, it seems that cross-price elasticities are relatively large in a number of cases (see e.g. Bordley (1993) and De Pelsmacker (1990)). Given the functional specification used at levels three and four (CES) in EUCARS, the price sensitivity can only be affected by means of the elasticity of substitution of the CES function which subsequently determines all the cross price elasticities. A value of 1.25 has been used, implying cross-price elasticities up to 0.15 for (the various categories of) old and new cars, whilst the elasticity of substitution is fixed at 1.5 for substitution between individual car types.

At the fifth level, for the choice between committed (COM) services and supplementary (SUPPL) mileage, the parameters of the LES function determine the cross effect of price changes. Changes in SUPPL price have little effect on the volume of COM services. This was chosen in view of the fact that SUPPL price elements are already contained in COM. Conversely, there is a small negative effect on the volume of SUPPL services from a price increase in COM services. The resulting implicit cross-price elasticities of car ownership and usage (see Table 4) square reasonably well with results reported by De Jong (1989, 1991) for the Netherlands.

While the cross price elasticities are positive for the first four levels in the model tree (substitutable services), they are negative for the bottom levels (seven to nine) with very low substitution possibilities ($\sigma \leq 0.5$). These latter levels are characterised by gross complementarity in view of the different links that exist between the different services at each level.

The congestion curves also have an important impact on the properties of the model, especially since, through the use of generalised prices, any reduction in mileage can potentially have a positive welfare effect by reducing travel times. Speed-flow curves are calibrated on the basis of German data (Bundesministerium für Verkehr, 1993) and other information (Kirwan *et al.*, 1994), as well as projections for specific cities (presented in Van Dender *et al.,* 1997)). The values of time for different trip types are also very important parameters. Their values were taken from a benchmark study by the Hague Consulting Group (1992). The average value of time in urban driving is between five and six ECU per hour.

Table 4 presents a number of important implicit long run elasticities of EUCARS that have been used to calibrate the model. These values are close to comparable long run elasticities presented in Goodwin (1992), Gwilliam et al. (1991), de Jong (1989, 1991), Koopman (1992) and Oum et al. (1992). Important characteristics are the complementarity between

36 This is a relatively high substitution elasticity, chosen after comments received on previous versions of EUCARS.

car usage and car ownership, as well as the induced increase in traffic volume following an increase in infrastructure (last row). Time effects are far from negligible, for example to increase public transport attractiveness.

It should be noted that the possibility of obtaining accurate estimates of the elasticities presented in Table 4 for the European Union as a whole is limited. In the absence of a comprehensive data set for Europe, the necessary econometric work cannot be carried out and use must be made of "mean elasticities" (based on a wide variety of country studies) reported in the literature. However, since there is a reasonable degree of convergence across a number of main studies, the rough orders of magnitude are known for most of the key (implicit) elasticities (for an informal and highly useful description, see in particular Gwilliam et al. (1991)).

4.2. Main data sources

All data on the size and composition of the car fleet (by vintage and technology) have been taken from the FOREMOVE database, which in turn is based on CORINAIR. Moreover, this database also provided the average speeds at various locations, the average annual mileage (by location, vintage and technology), and the key relationships between emissions and fuel use per kilometre on the one hand and vehicle speeds on the other. Furthermore, whereas scrappage has been endogenised in EUCARS, the scrappage equations have been calibrated to be consistent with the survival curves used in FOREMOVE. The strong reliance on FOREMOVE has two related explanations. The first is that the underlying database is one of the most complete available. Secondly, FOREMOVE was chosen to model road transport emissions for the AUTO/OIL I programme, in which EUCARS was used as one of the tools for assessing the cost-effectiveness of various policy measures to limit emissions.

Data on individual cost components come from a variety of sources. Fuel prices are taken from data compiled by DG XVII. Information on purchase and circulation tax levels is from a compendium drawn up by ACEA (1993). Information on other car cost components is largely based on SEO (1992) which contains detailed cost statistics by vehicle category for the Netherlands, the United Kingdom, Luxembourg, Denmark, France and Italy. These data have been weighted and additional calculations were undertaken in order to ensure compatibility with the underlying structure of EUCARS (see Denis (1998) for more detail). Data from the EUROSTAT (1996) budget survey were used to verify the resulting budget shares for transport (as well as for public and private transport individually). Data from a variety of sources on modal split (reported in Koopman (1992)) were used to determine the annual mileage by public transport.

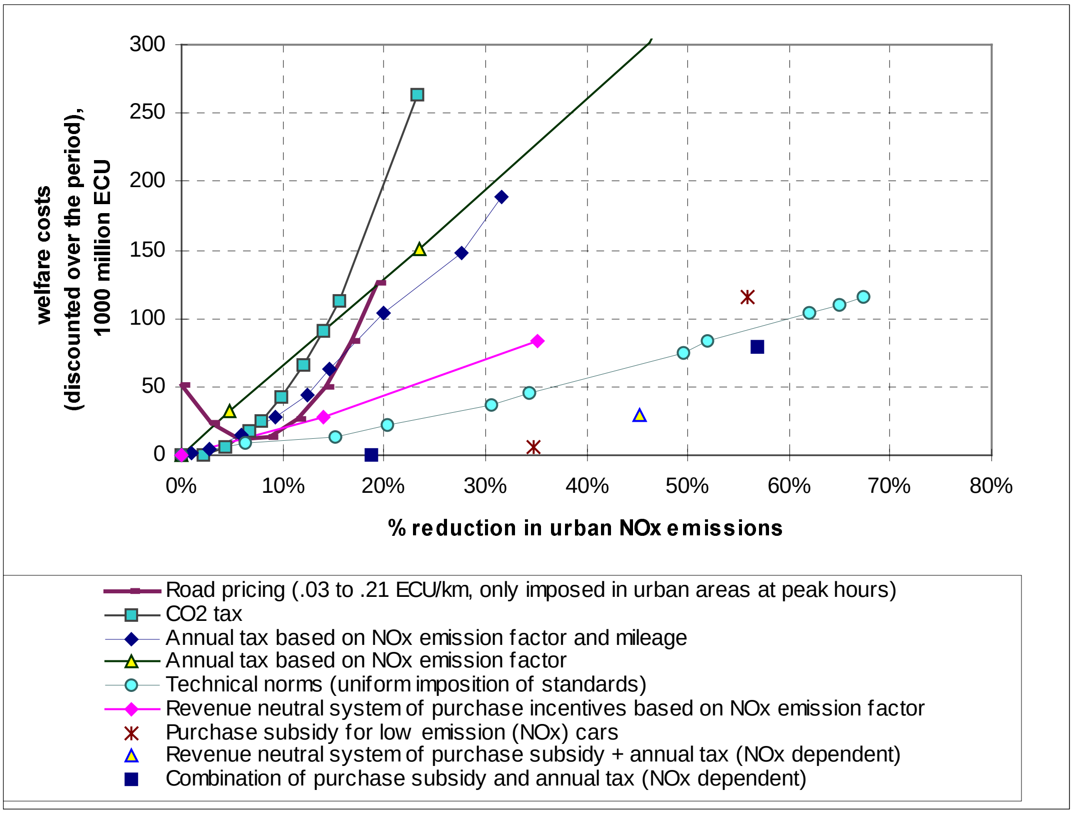
In the production block, the average values by fuel and vehicle size are taken from the DRI database on new cars (1993). These values are used to calibrate the production block for the 1991-1996 period. Benchmark cost curves come from the OECD (Michaelis, 1996) study as already mentioned. The main source for engine and fuel emission technologies is Touche Ross (1995).

5. SIMULATION PROPERTIES AND RESULTS

EUCARS 3.0 has been used to carry out a cost-effectiveness analysis of policies to reduce NO_X and CO_2 emissions. This chapter briefly presents some of the results to illustrate the simulation properties of the model; for a full overview, the reader is referred to Jansen and Denis (1998).

Figure 4 gives an overview of the discounted welfare costs of a series of policy measures and their effect on urban NO_X emissions. These simulations have been carried out assuming that the Marginal Cost of Public Funds equals 1.0. This assumes that tax revenues from transport are returned in a lump sum manner to consumers and are not used to cut highly distortionary taxes elsewhere in the economy. The somewhat irregular form of some curves can be explained by the fact that the different emission reducing technologies are not continuous. For technical changes imposed by uniform standards, another reason is that costs increase quite differently across vehicle categories as standards are tightened.

Figure 4. Welfare cost assessment of various policy instruments to reduce urban NOx emissions (MCPF = 1)



The results illustrate that, for small emission reductions (of the order of 5%), the costs of various instruments are comparable. At these levels of emission reductions, policies that directly target vehicle emissions (e.g. emission standards and emission-related vehicle taxes) do not outperform measures that cut emissions by reducing vehicle mileage (e.g. road pricing, fuel (CO_2) taxation). This is because the latter policies reduce congestion; the benefits of which largely offset the welfare costs of reduced vehicle mileage.

However, the analysis also shows that significant emission reductions can only be achieved through policies that directly affect vehicle emission technology. The costs of measures that mainly curb mobility rise exponentially as the congestion-reducing benefits taper off and are outweighed by the exponentially increasing dead-weight burden of taxation.

Interestingly, vehicle emission standards are also more cost-effective than annual taxes related to vehicle emissions, even when the latter are based on mileage and emissions per kilometre. The reason for this counter-intuitive result is the high degree of myopism assumed, which implies that the annual tax has to be very significant to give consumers and manufacturers incentives to switch to clean technologies. As a result, the welfare losses on account of reductions in mileage are larger than the efficiency advantages of emission taxes over standards (i.e. the equalisation of the marginal costs across different vehicle categories).

This result can be changed by the introduction of fiscal purchase incentives dependent on car emissions. These purchase incentives directly target the consumer purchase decision and can be considered as a tool for correcting consumers' insufficient accounting of future costs (myopism). Purchase incentives can be implemented as pure subsidy or in a revenue neutral manner, implying net taxes on high emission technologies, the revenues of which are recycled to subsidise low emission technologies. As such, the instrument is analogous to a gas-guzzler tax/sipper rebate. The policy appears to be cost-effective when subsidy levels are significant so that the additional costs due to technological changes are (more than) fully offset by subsidies.[37]

When the purchase instrument is introduced in combination with emission-based annual taxes, the direct targeting of the purchase decision turns out to be highly cost-effective. The results show that this combination can achieve emission reductions at about half the cost of standards, depending on the precise formulation of the scheme (particularly the mix between annual taxes, purchase incentives and the impact on government spending).

The ranking of policy instruments changes significantly when the marginal costs of public funds are evaluated at 1.25 instead of 1.0. Since this assumes that tax revenues from transport are put to good use elsewhere in the economy, instruments that raise revenues become more attractive, as Emission-related taxes and road pricing now become negative cost policy instruments for achieving emission reductions of up to 20%. The V-shaped forms of the cost curves for these instruments can be explained by the fact that as charges increase, the associated benefits from government revenues increase in a linear manner, whereas the distortionary effects cause exponentially rising costs. Most purchase incentive and combined emission tax/purchase incentive schemes simulated are revenue neutral and therefore not affected by the pricing of public funds. However, it is still possible to design a (revenue-raising) scheme that is cost-effective for emissions reductions. Since evaluation of the welfare costs of direct regulations hardly changes compared to the previous case, this implies that economic instruments and, in particular, road pricing (reductions up to 20%) and combined emission tax/purchase incentive schemes (further reductions) are the most efficient policy instruments available.

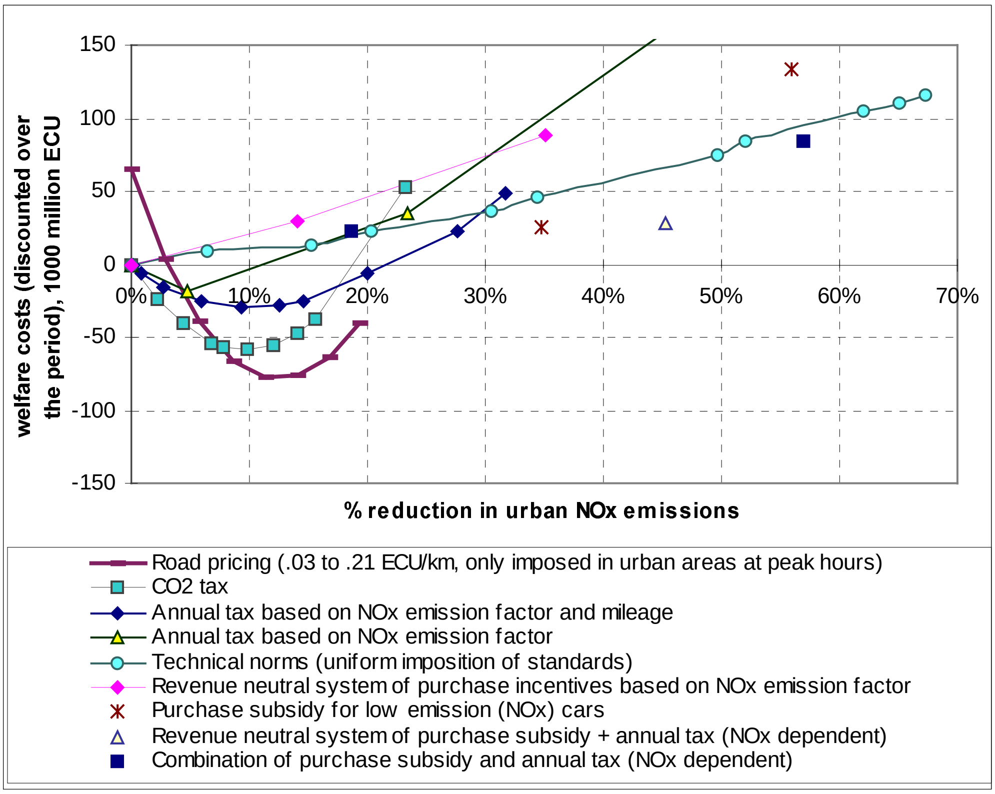
Figure 5 shows. Conversely, subsidies (or instruments that lead to revenue losses for the government) become more costly.

Emission-related taxes and road pricing now become negative cost policy instruments for achieving emission reductions of up to 20%. The V-shaped forms of the cost curves for these instruments can be explained by the fact that as charges increase, the associated benefits from

[37] Note, however, that this conclusion is only valid for a low marginal cost of public funds (MCPF=1).

government revenues increase in a linear manner, whereas the distortionary effects cause exponentially rising costs. Most purchase incentive and combined emission tax/purchase incentive schemes simulated are revenue neutral and therefore not affected by the pricing of public funds. However, it is still possible to design a (revenue-raising) scheme that is cost-effective for emissions reductions. Since evaluation of the welfare costs of direct regulations hardly changes compared to the previous case, this implies that economic instruments and, in particular, road pricing (reductions up to 20%) and combined emission tax/purchase incentive schemes (further reductions) are the most efficient policy instruments available.

Figure 5. Welfare cost assessment of various policy instruments to reduce urban NOx emissions (MCPF = 1.25)



Most adjustments occur in the first two periods (ten years) after introduction of a new policy. This is illustrated by Table 5, which presents the results for the example of a combined tax/purchase incentive tool where taxation revenues are recycled to stimulate the introduction of low emission technologies.

As can be seen from this table, emission taxes lead to the introduction of different clean technology packages in the various vehicle categories. They also cause a non-negligible scrapping of old vehicles in the first period: old vehicles have high emissions per kilometre and the new emission tax therefore implies that their use becomes relatively expensive: as demand drops, second hand prices fall, implying that, for more cases than in the baseline, investments in maintenance and repair are no longer economically justified. Higher scrappage results. Obviously, as new vehicle purchases lead to a "cleaner" fleet, this effect gradually disappears over time. However, as the purchase incentive is maintained throughout the simulation period, more new cars are bought, and leading to additional scrappage. Once the fleet is renewed (90%

after 15 years (three periods)) a new equilibrium is reached, with more car ownership and less car use.

Table 5. Simulation results of the combined imposition of an annual road tax based on mileage and NOx emission factors (0.005 ECU/gNOx), in addition to a system of purchase subsidy for low emission cars (3 ECU per gNOx/km above/under 0.4g/km).

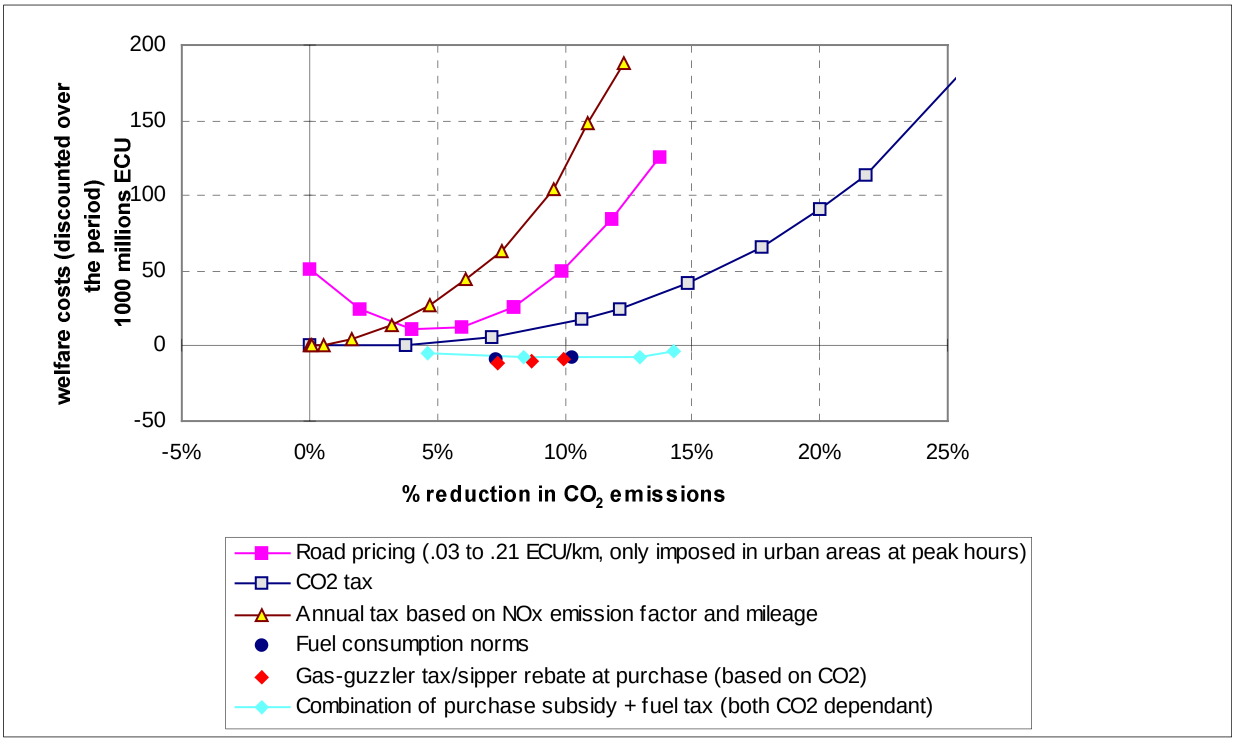
Key variables	First 5-year period	Second 5-year period	Third 5-year period
1. Technology effect	diesel cars: package 1 gasoline cars: small: package 2 / medium and large: package 3		
2. Volume effect Fleet size Total mileage	 +0.72% -1.68%	 +0.76% -1.41%	 +0.98% -1.11%
Ownership / usage costs (average)	*-1.37%/+4.35%*	*-1.38%/+3.35%*	*-1.49%/+2.70%*
3. Speed change Urban peak hour Highways	 +1.23% +0.46%	 +1.12% +0.42%	 +0.93% +0.37%
4. Age effect Average fleet age New cars purchase Scrappage	 -0.86% +2.35% +0.90%	 -0.69% +1.73% +1.83%	 -0.7% +2.1% +1.8%
Ownership/usage costs *- new cars* *- old cars*	 *-2.73%/+1.42%* *-0.30%/+6.98%*	 *-2.14%/+1.45%* *-0.81%/+5.03%*	 *-2.46%/+1.45%* *-0.66%/+3.83%*
Second-hand prices of cars	*-0.43%*	*-1.12%*	*-0.92%*
5. Composition effect Small gasoline cars Medium gasoline Large gasoline cars Diesel cars	 +1.76% +0.55% -0.54% -0.65%	 +1.83% +0.67% -0.47% -0.71%	 +2.07% +0.96% -0.19% -0.71%
Purchase price (new) *small gasoline* *medium gasoline* *large gasoline* *diesel*	 *-4.53%* *-2.27%* *-0.54%* *+0.65%*	 *-4.70%* *-2.36%* *-0.57%* *+0.68%*	 *-4.87%* *-2.44%* *-0.59%* *+0.72%*
Second-hand prices *small gasoline* *medium gasoline* *large gasoline* *diesel*	 *-0.34%* *-0.46%* *-0.58%* *-0.23%*	 *-2.35%* *-1.11%* *-0.25%* *+0.37%*	 *-1.83%* *-0.90%* *-0.25%* *+0.27%*
6. Public transport change	+0.89%	0.92%	+0.69%

A. Emission effects			
Urban NOx	-18.31%	-36.23%	-45.24%
Urban PM	-9.61%	-17.16%	-20.74%
CO_2 emissions	-1.54%	-1.28%	-1.01%
B. Change in government revenues from transport	+1.57%	0.0%	- 0.93%
of which			
purchase tax/subsidy	-4.92%	-5.06%	-5.11%
annual emission tax	+7.37%	+5.77%	+4.71%
fuel related taxes	-0.88%	-0.71%	-0.53%
C. Net welfare costs			
Pure welfare costs	44.22 bn ECUs	47.39 bn ECUs	38.09 bn ECUs
Time costs	-31.88 bn ECUs	-31.08 bn ECUs	-28.44 bn ECUs
Rev. losses(+)/gains(-)	-11.41 bn ECUs	0.04 bn ECUs	7.99 bn ECUs
TOTAL	0.93 bn ECUs	16.34 bn ECUs	17.64 bn ECUs
TOTAL (%baseline spending on transport services)	-0.02%	-0.25%	-0.26%

The welfare effects change significantly over time because the costs of new technology investments increase over time, in line with the penetration of clean vehicle technologies in the vehicle fleet. This is hard to see from Table 5 because the “pure welfare costs” in the table decrease in line with reductions in annual emission taxes (due to erosion of the tax base). However, if this effect (which is welfare neutral as it implies consumer gains and roughly equivalent losses for the government due to only limited impact on consumer behaviour) is discounted, it is clear that welfare losses related to more expensive vehicle technology increase over time (the welfare effects of reduced congestion are stable). In contrast with the present simulation, it should be noted that policies that do not affect the level and composition of the vehicle fleet are characterised by a near full attainment of the new equilibrium in the first period.

Some characteristics of the NO_X emissions simulations are also found in simulations that aim to reduce CO_2 emissions, presented in Figure 7. These results demonstrate that a CO_2 tax can achieve significant emission reductions at low cost: apart from its effect on vehicle fuel economy (both at the technical level and at the fleet composition level) it also reduced mileage, which at low levels has a positive welfare effect because it reduces congestion. As expected, fuel taxes are much more efficient than road pricing or other mileage-related taxes that do not give an incentive to improve fuel economy.

Figure 7. Welfare cost assessment of various policy instruments to reduce CO_2 emissions (MCPF = 1)



However, given the significant degree of assumed consumer myopism, a gas guzzler tax/sipper rebate is the most cost-effective policy instrument available (see also Koopman, 1995). This revenue neutral tool adequately corrects for high consumer discount rates, which distort the private purchase decision. The degree of myopism assumed in EUCARS and the fuel economy cost curves used imply that CO_2 emissions from passenger cars can be cut by some 15% at zero cost. This result depends critically on the shape of the cost curves: as indicated in Section 3.4, available evidence suggests that small improvements (up to 15%) could be produced at very low cost. This, in turn, would also imply that some forms of direct regulation of fuel economy could be low cost. This counter-intuitive result in a situation where some 60% of fuel prices consist of excise duties and where improved fuel efficiency leads to increased congestion hinges crucially on the very low costs of marginal improvements in fuel economy. [38]

Efficient measures for large CO_2 emission reductions require technical change, as is the case with NOx emissions. Emission-lowering technology differs for CO_2 and NOx, so measures to lower CO_2 do not, in general, cut NOx emissions as well. However, synergy effects do exist for small emission reductions through behaviour change (mileage reduction).

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38 Obviously, one could question the relatively very high implicit CO_2 taxes on transport compared to other sectors of the economy. Whilst these may be justified by other policy objectives, they do not seem to be efficient from a global CO_2 perspective. However, these deliberations relate to the global cost-effectiveness of CO_2 emission reduction policies. Within the partial context of EUCARS and given relatively high fuel prices, consumer myopism leads to a no-regret potential.

6. CONCLUSIONS AND OUTLOOK

The EUCARS model permits a detailed cost-effectiveness evaluation of various fiscal and non-fiscal policy tools used to limit air emissions and curb congestion. It was originally designed and is particularly well suited for analysis of various fiscal instruments, owing to its detailed representation of the tax system. But it is also suitable for analysis of other instruments targeting the car fleet (new standards, scrappage incentives), as well as instruments influencing car usage (road pricing and, albeit to a smaller extent, traffic management policies). As the cost concept used in EUCARS comprises the costs of behavioural adjustments and time spent in transport, it provides a common yardstick for evaluating very different policy instruments. By comparison, traditional analyses of air quality policies are limited to comparison of the technical costs of different emission standards, therefore ignoring behavioural reactions, as well as the potential contribution of changing other determinants of emissions (car usage, fleet structure, ...). Whilst air quality policies might indirectly affect a wide range of transport decisions that policy makers may not target intentionally, other transport policies might contribute to reducing road transport air emissions. Ideally, these interactions should be fully taken into account in developing air quality measures as well as transport policies.

The simulations reported in Chapter 5, as well as in Koopman (1995), European Commission (1995) and Jansen and Denis (1998), demonstrate that ignoring all these elements could potentially prejudice policy choices, so that serious consideration should be given to policy tools other than standard setting. In addition, by incorporating consumer myopism in an optimising context, EUCARS reflects a crucial characteristic of vehicle purchase decisions. Large reductions in air emissions can only be achieved at low cost through changes in emission abatement technology. Given consumer myopism, cost-effective policy tools must, therefore, target purchase decisions. Incentive taxes and subsidies prove to be highly cost-effective and allow cost differences across vehicle categories to be equalised. Single emission standards do not have this characteristic and are, thus, less cost-effective.

Given these results, and the properties outlined before, the model provides a useful tool for establishing rough orders of magnitude of the costs of policy instruments to cut emissions. Moreover, evaluation of the model's results allows policy analysts to evaluate the different mechanisms that affect a policy scenario's outcome. As EUCARS describes a much larger number of mechanisms than are common in transport/air quality models, this feature is of general value, even when particular cases are numerically significantly different from the transport market described in EUCARS.

However, and despite its disaggregated nature, there is still a considerable degree of averaging in EUCARS, which can significantly affect the results. There is one representative household, implying that differences across household categories cannot be studied. Since some policy instruments have significant effects on the composition of the vehicle fleet, and car ownership of different vintages varies across household categories, this could potentially bias the comparison of policy measures. The determination of travel speeds is, of course, highly simplified and provides only a very crude description of real life. Similarly, the cost and vehicle composition data represent European averages and hide very significant variations across Member States. This obviously implies that the results can only be applied to concrete situations after careful analysis. This can however be overcome easily, provided the necessary data are available: it only requires a different calibration, not affecting the model structure in itself. Finally, the determination of new car supply and vehicle technology choices takes place at a very aggregate level, preventing an analysis of the impact on different vehicle manufacturers in the European market.

These model features and the stylistic description of passenger transport, mean that the model results should be interpreted with great care. Moreover, they are also likely to imply a certain bias against differentiated economic instruments, which derive their cost-effectiveness from allowing the flattening of cost differences across emission reduction "sources". Moreover, the dynamic effects of economic instruments on R&D and the development of clean technology are also not taken into account. With these caveats in mind, however, we reiterate that this model is invaluable for comparing policy options and understanding the work of various interlinked mechanisms governing transport markets.

Furthermore, various possibilities exist for extending the model to add to its usefulness for policy evaluation purposes.

First, the current model does not consider road freight transport. Whilst, commercial road transport only represents approximately 14% of mileage, its share in various emissions (notably NOx and particulate matter) is very high and increasing due to above average growth rates. However, road freight transport is an intermediate input and its inclusion in the current model architecture would therefore require very significant changes. Since the determinants of demand differ significantly across passenger and freight transport, it is likely to be more attractive to develop a separate freight transport model and link it with EUCARS through a combined road network module.

Secondly, further differentiation of important mechanisms within the current model could also be attractive, although care has to be taken not to expand the model too much for computational reasons. However, a more detailed description of the supply side of the car market and the inclusion of various manufacturers would represent an important improvement and could add to the insights derivable from the model. The current behavioural assumption (average cost pricing) is very simplistic and could bias the results.

Thirdly, the inclusion of various household categories would allow distributional effects to be studied. Such an extension would require significant changes to the model structure, as different types of consumers would have to be modelled. However, once the calibration data is available, this merely duplicates (or replicates, depending on how many consumer classes are included) the equations of the model, through the inclusion of an additional index. This approach is, for example, followed in TRENEN (De Borger *et al.*, 1997).

Finally, the model currently excludes important transport externalities such as accidents and noise emissions that have significant welfare effects. Inclusion of these transport characteristics would expand the scope of EUCARS to encompass all major transport externalities. Incorporating noise and accidents other than through fixed relationships with mileage would necessitate incorporating new model modules. This could, however, be done without significantly modifying the current model architecture.

The current model has been used to carry out cost-effectiveness analyses given fixed emission-reduction targets. In its current form it cannot, however, be utilised to optimise social welfare (i.e. including the welfare effects of reducing air emissions). This would require formulation of a different objective function (a social welfare function) which could be maximised subject to various constraints. In such an approach, the various policy instruments would be endogenous variables that result from the optimisation process. The basic structure of the model need not be modified to carry out such evaluations, although an appropriate objective function would have to be formulated and monetary valuations put on the various external costs. Whilst air quality policies are currently formulated so as to meet emission reduction targets derived from air quality standards (necessitating a cost-effectiveness approach), a social welfare approach would be an interesting complementary analysis allowing a further evaluation of the air quality targets.

Finally, EUCARS cannot be used for a spatial evaluation of air quality problems, as it has no geographical dimension. Whilst this could be built into the model to some extent through further differentiation of the road networks, a spatial differentiation of the vehicle fleet composition and behavioural responses is not possible within the current model architecture. These latter features are, however, important characteristics of air quality problems in Europe. Rather than attempting to develop the model further, which would require a major extension of its size, it is probably more attractive to calibrate EUCARS for different regional situations, run independent simulations of promising policy tools per geographical area and feed these results into a spatial optimisation model (see, for example, Degraeve and Koopman, 1998, and Denis and Jansen, 1998). This is the favoured approach for the current Auto-Oil II programme.

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TABLE OF ANNEXES

ANNEX 1 REVIEW OF THE DIFFERENT VERSIONS

EUCARS 3.0 represents the final stage of a modelling development. This annex describes the major characteristics of previous model versions. The original model (referred to as EUCARS 1) was developed in 1994 to study CO2 emission limitation policies in passenger transport. Results of that model are discussed in Koopman, 1995.

In 1995, the model was expanded to include other externalities: congestion and conventional emissions. Time costs, emission calculation and technologies to control pollution were therefore explicitly included in EUCARS 2. EUCARS 2 was intensively used in the context of the first Auto-Oil programme[1], to compare different policy options and to calculate the associated welfare effects. Simulation results are reported in two European Commission reports (1995a and 1995b). Another version of EUCARS 2 was also used to support the analysis on "CO_2 from cars" (European Commission, 1996). In this context particular emphasis was given to myopic decisions regarding fuel economy (resulting in insufficient investment in fuel saving equipment because the lifelong saving potential is underestimated) and on no-regret policies that would correct this market failure.

The new version prepared in 1997, EUCARS 3, integrates and improves the previous versions to enable a comprehensive_analysis of the problem of car emissions (Jansen and Denis, 1998). The baseline version now incorporates myopic behaviour. Modules for fuel economy and congestion were adjusted on the basis of updated data, and a peak/offpeak differentiation was introduced along with other minor changes. Assessment of policy measures is therefore refined but also more complex because of the impact of any single measure on a series of model mechanisms.

The main differences between the different versions of EUCARS are described in more detail below, following the structure of the main text. The aim is to summarize the changes introduced in the model, thereby presenting a comprehensive reference to the different versions used for the various reports. Only differences with respect to EUCARS 3 are presented below. For all the other features, which are therefore shared with EUCARS 3 version, the reader is refered to the detailed and comprehensive presentation of the main text.

A1.1 General changes in structure

The basic model structure is the same in all versions of EUCARS. However additional modules were introduced over time, as can be seen by comparing figure A1, depicting the general structure in EUCARS 1, with Figure 1 of the main text, which sketches the structure of EUCARS 3.

Time costs and generalised prices including time costs were introduced in EUCARS 2. Speed determination via speed-flow curves and congestion problems were thus not dealt with in EUCARS 1. With EUCARS 3 a distinction between peak and off-peak was introduced for the urban network. This further disaggregation allows for better differentiation of congestion effects and instruments.

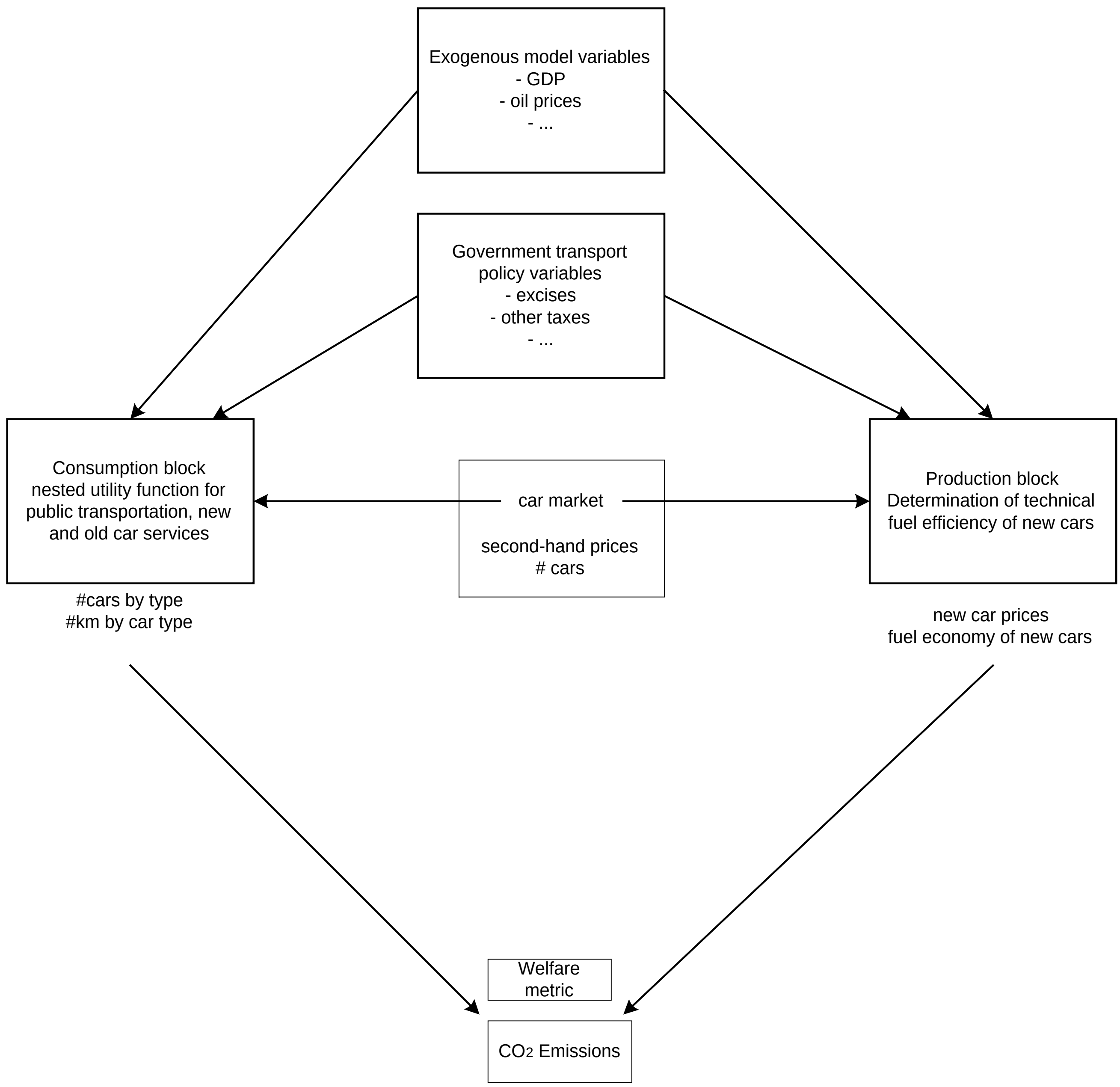
In EUCARS 1, the focus was on CO_2 and the module calculating the emissions of conventional pollutants was only introduced from EUCARS 2 onwards. This module replicates the CORINAIR-Copert equations, which are speed-dependant. On-road fuel consumption was then also calculated following the same methodology. As a consequence, a discrepancy was introduced between the fuel consumption defined in the production block and the real on-road fuel consumption. Other

[1] Programme jointly launched by the European Commission, the automobile and fuel industries to study the reduction of noxious emissions from cars.

production modules were added to determine the car technology and the fuel type that would be chosen in response to economic incentives to reduce conventional emissions.

The endogenous scrappage feature was introduced in EUCARS 2 (EUCARS 1 used fixed scrappage rates). The dynamic of the model is the same in all versions and is based on vintage differentiation, which was not however fully apparent in EUCARS 1.

Figure A1. General structure of the model EUCARS 1.



A1.2 Consumption module

The decision tree was expanded in EUCARS 2 and EUCARS 3. Levels 7 and 8, and the split of the binary choice at level 4 (OLD and NEW) into five vintage categories (NEW, MOINS1, MOINS2, MOINS3 and MOINS4) were added to EUCARS 2 (compare Figure A2 and A3 with Figure 2 in the main text). The functional form of this level was also changed, from an Indirect Addilog Demand System (IADS) to a CES function. Key parameters of the functions used in the consumption module were also slightly modified.

The decision tree has been further expanded in EUCARS 3, with the introduction of a ninth nest. Key parameters were again modified to keep implicit elasticities at levels consistant with the literature, after the introduction of the short-sightedness assumption and the other changes in the fuel economy and speed modules, which requested significant adjustments.

Functional forms used in the consumption module

The functional form of level 4 (choice between new or second-hand car services) was modelled through IADS (Indirect Addilog Demand System) in EUCARS 1.

The budget share expression of an IADS function in the case of two independent variables is written as follows:

$$w_1 = \frac{\beta_1 \left[\frac{p_1}{y}\right]^{1-\sigma_1}}{\beta_1 \left[\frac{p_1}{y}\right]^{1-\sigma_1} + \beta_2 \left[\frac{p_2}{y}\right]^{1-\sigma_2}}$$

$$w_2 = \frac{\beta_2 \left[\frac{p_2}{y}\right]^{1-\sigma_2}}{\beta_1 \left[\frac{p_1}{y}\right]^{1-\sigma_1} + \beta_2 \left[\frac{p_2}{y}\right]^{1-\sigma_2}}$$

The following expressions for the demand equation and the different price and income elasticities can subsequently be derived.

For the demand equation

$$q_i = \beta_i \, (p_1 /y)^{1-\sigma_i} \quad / \quad \Sigma_k \, \beta_k \, (p_k/y)^{1-\sigma_k} \,.\, y/p_i$$

For the income elasticity:

$$E_i = 1+\sigma_i - \Sigma_k \, w_k \,.\, \sigma_k$$

For the (own) price elasticity

$$E_{ii} = -\, w_i \, (1-\sigma_i) - \sigma_i$$

For the cross price elasticity

$$E_{ij} = -\, w_j \, (1-\sigma_j)$$

In EUCARS 1, the aggregation of prices at this level was done by means of a geometric average, as for the LES function (level 5).

$$\underline{\mathrm{P}} = \prod_k p_k^{w_k} \text{ with } w_k \text{ share of } k \text{ in the budget}$$

Figure A2. Consumption module EUCARS 1.

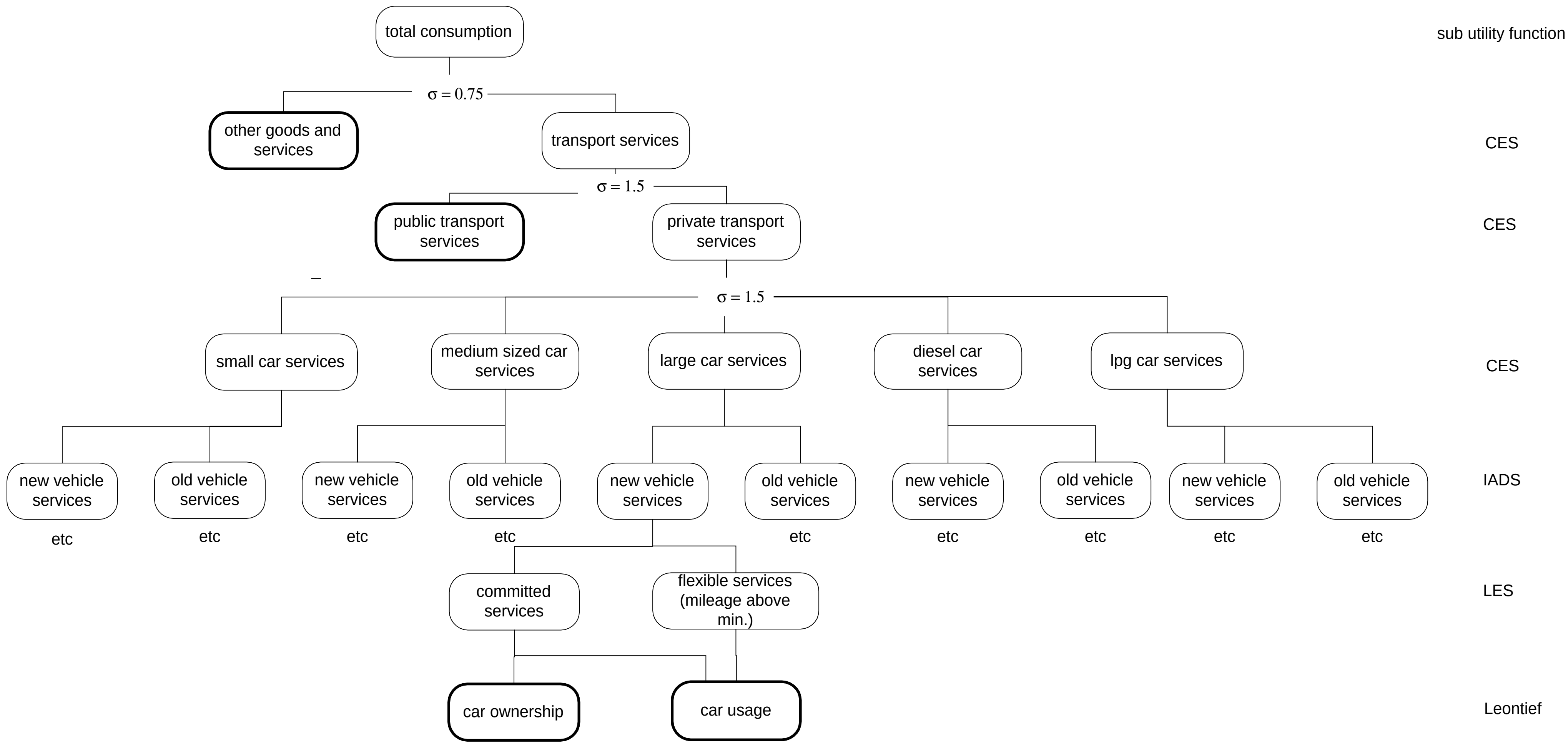
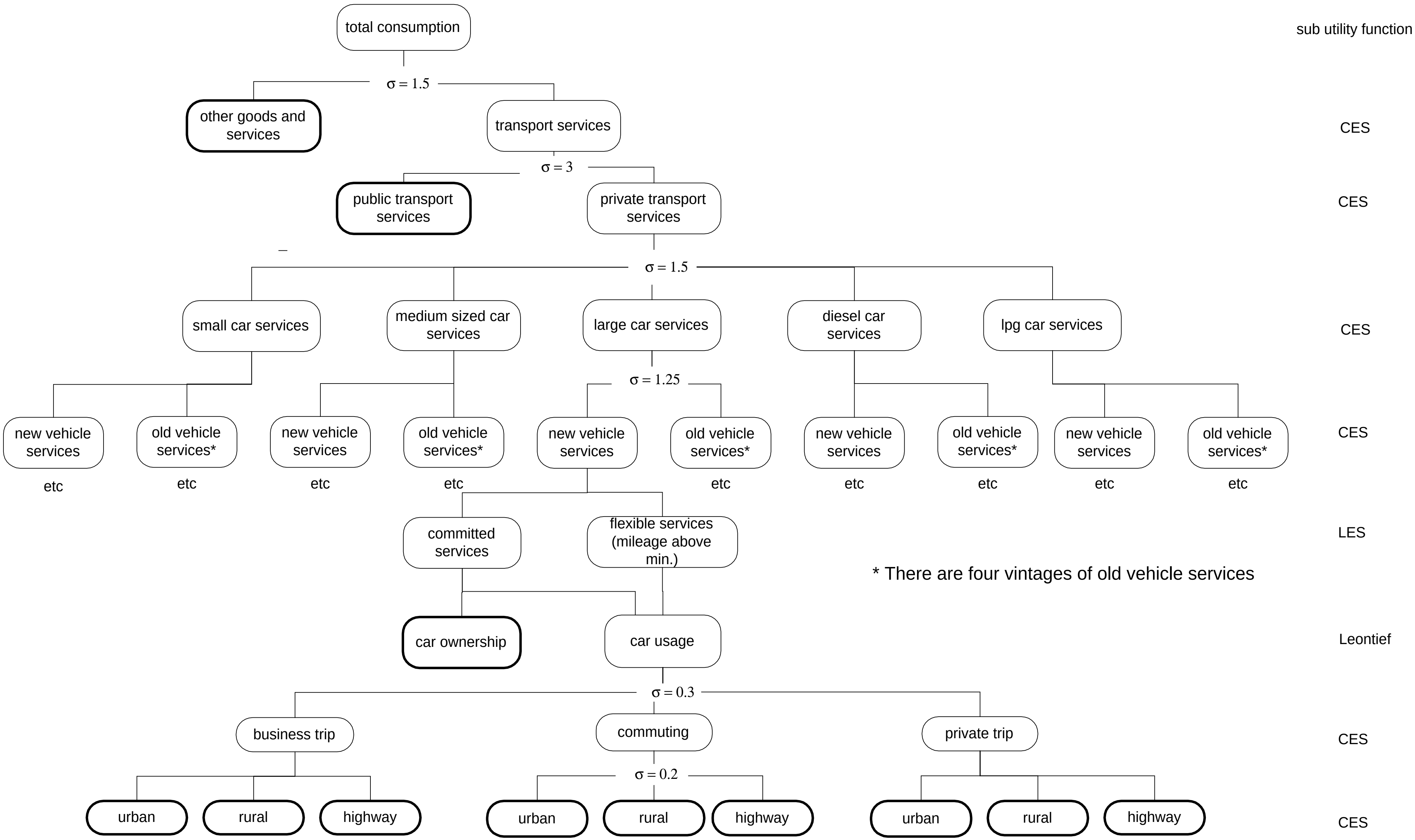


Figure A3. Consumption module EUCARS 2.



A1.3 Price formation, car market, endogenous scrappage, model dynamics

Generalised costs

As explained above, time constraint and transport time costs were not considered in EUCARS 1. The full income concept and the generalised costs were thus not relevant for EUCARS 1. Consequently, in EUCARS 1 the prices referred only to the monetary costs.

Costs and prices on car markets

In addition to the inclusion of time costs, fiscal instruments were not as detailed in EUCARS 1 as they are in EUCARS 3 (VAT rates were included in the taxation of cars and fuels but not distinguished from other taxes in EUCARS 1).

In EUCARS 1, the cost of car usage was modelled as:

$$PCTSGA_{usage} = VCE + FEFF * PFUEL\ (1+VCP),$$

with:

- VCE, exogenous component for the variable costs
(reflecting oil use, mileage dependent insurance etc.),
- FEFF, fuel use per kilometre
- PFUEL, the price net of taxes for a specific fuel type,
- VCP, ratio of fuel taxation (excises and VAT) over fuel price.

Ownership costs are based on a capital cost approach and comprise two exogenous parameters together with two endogenous variables (capital costs and depreciation). The equation is unchanged, but the construction of these endogenous variables has been slightly modified. In EUCARS 1 it was assumed that the average old car had a remaining economic "life" of five years:

$$DEPR = 5 * (OCMP/5)$$

where OCMP stands for the second-hand price of this type of car. The capacity costs were thus equal to:

$$CAPCF = INT/100\ (5\ OCMP - 10\ DEPR_t) = INT/100 * 3\ OCMP$$

Purchase prices of new cars include taxation in the following way:

$$NCPC = NCPP * (1+OCP) + TAX(FEFF - TFEFF)$$

with:

- NCPC, consumer price of a new car,
- NCPP, producer price of a new car,
- TAX, the gas-guzzler tax (alternatively sipper rebate) per l/100km above (respectively under) the "target" fuel use,
- FEFF, fuel use per kilometre

- TFEFF, "target" fuel use per kilometre
- OCP, ratio of car taxation (purchase tax and VAT) over car price.

EUCARS 2 equations are similar to EUCARS 3 equations given in the main text.

Age, scrappage and vintages

The distinction between separate vintages in the consumption block was only made in EUCARS 2. In comparison EUCARS 1 only had one homogenous category for old cars, and only one second-hand market – and thus one price – per vehicle category. However, the composition of the "old" vehicle fleet was explicitly based on detailed information on vintages.

The scrappage rates of old cars in every vintage were therefore fixed in EUCARS 1, so as to give an approximation of the "average" life cycle of cars:

$$VCTSGC_{old} = 0.90 \text{ MOINS1} + 0.45 \text{ MOINS2} + 0.05 \text{ MOINS3} + 0.00 \text{ MOINS4}$$

with $VCTSGC_{old}$, the total volume of old cars, and MOINS1 to MOINS4 the number of new cars in period T-1 to T-4. This meant that:

- after one period, 90% of the cars originally sold remain on the market,

- after 2 periods, 45% of the cars originally sold remain on the market,

- after 3 periods, 5% of the cars originally sold remain on the market,

- no cars remain on the market after 4 periods.

This structure is a reasonable approximation of the average FOREMOVE survival curves, and parameters of the endogenous scrappage equation in EUCARS 2 and 3 were calibrated to keep the same profile.

The endogenous scrappage module was slightly modified between version 2 and version 3 to introduce emission based taxes. The EUCARS 2 equation for endogenous scrappage included one additional β parameter whose value varied between 0.2 and 0.8 according to car age. This "breakdown rate" indicated the "breakdown" frequency and thereby the number of occasions when the car owner would compare repair costs and second-hand prices:

$$\text{ESCRAP} = \left\{ \left[1 - CUMNPF\left(\frac{\text{OCMP} - \text{RC}\mu}{\text{RC}\sigma}\right) \right] * \beta + \text{EXSCRAP} \right\} * \text{Stock}$$

This equation was simplified in EUCARS 3 by putting β at 1.0.

Transition matrices between car technology and car vintage entered the model in EUCARS 2 only.

A1.4 Production blocks

The endogenous determination of the emission characteristics of cars and fuels (§ 3.4.2 and § 3.4.3) was added in EUCARS 2. The production block of EUCARS 1 only determined the optimal fuel efficiency of new cars, on the basis of assumed perfect rationality of economic agents.

The main change introduced in EUCARS 3 is the short-sightedness assumption. In previous versions economic agents were assumed to take into account the full (discounted) benefit of the fuel saving devices that could be installed in new cars; these benefits were discounted over the life of the car with a rational discount rate of 7% (the rate used for capital costs). As explained in the main text, this assumption is now replaced by an overdiscounting assumption (a 50% rate is used) which seems to better fit observed behaviour. The shift from a rational to a short-sighted assumption does not change the principle nor the equations; it alters only the Z quantity, which is the expected future mileage taken into account when purchasing a new car.

However, the cost curves used in the production block were also changed, in line with new data. The fuel efficiency module of EUCARS 1 and EUCARS 2 is presented in box A1.

Given the database and the functional forms chosen, the imposition of myopic behaviour led to a different model, in that key parameters and elasticities changed with respect to the rational version. This implied that the baseline also changed and that, therefore, one can not directly compare simulation results with the two models since they are expressed as differences with respect to the baseline.

BOX A1. Specific fuel consumption as modelled in EUCARS 1 and EUCARS 2

Vehicle producers select technical characteristics of the vehicle so that the models they put on the market have the lowest obtainable lifetime costs per kilometre given prevailing taxes, interest rates, fuel prices, other cost components, and actual mileage. Hence, vehicle producers effectively compare the cost of producing a cost-saving device (e.g. of lighter materials leading to lower fuel use per kilometre) with the lifetime cost savings that accrue to the consumer as a result. Such an outcome would prevail if consumers based their vehicle purchase decisions on lifetime costs.

The specific fuel consumption of new cars is obtained by equalising the marginal benefit of fuel efficiency to consumers (i.e. reductions in discounted fuel bills) and the marginal costs of improving fuel efficiency. The starting relation is the following:

$$dRF/d(1/FEFF) = dNCPC/d(1/FEFF)$$

in which FEFF is the fuel consumption, NCPC represents consumer vehicle prices and RF stands for the discounted vehicle lifetime fuel costs. RF can be written explicitly as:

$$RF = FEFF*(PFUEL+VCP)*Z$$

where Z is the discounted value of lifetime mileage, PFUEL the fuel price and VCP the fuel taxes.

Producer and consumer prices of vehicles are then determined by:

NCPP = Ω exp [α 1/FEFF TIME]
NCPC = (1+ OCP) * (NCPP + TAX (FEFF - TFEFF))

in which:

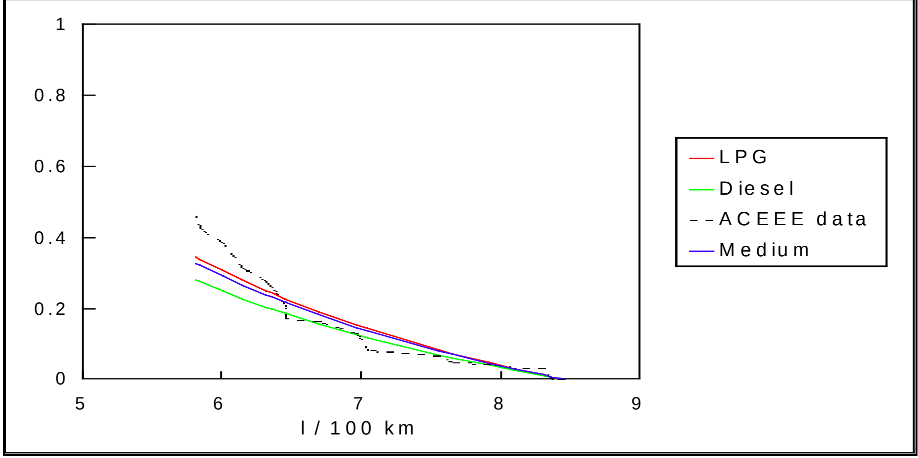
Ω, α are vehicle type specific constants,
NCPP, NCPC are, respectively, the producer and consumer price of new cars,
OCP is the *ad-valorum* purchase tax (expressed as a percentage)
TIME is a fixed shift parameter of autonomous technical progress

Costs of improving fuel efficiency increase exponentially. As purchase taxes are *ad-valorem* in the model, increases in producer prices following improved fuel efficiency are translated proportionally into consumer prices. These equations can be re-written to arrive at the following expression for optimal fuel efficiency:

$$\frac{1}{FEFF} = \sqrt{\frac{(1+OCP)NCPP\alpha TIME}{(PFUEL+VCP)Z}}$$

Figure A4 presents the resulting cost curve of reducing fuel use for medium gasoline, diesel and LPG vehicle respectively, compared with a US study (ACEEE (1992)) based on a detailed bottom-up engineering study.

Figure A3. Cost curves for fuel economy, used in EUCARS 1 and EUCARS 2.



A1.5 Fuel use and conventional emissions

The fuel efficiency used in the consumption module of EUCARS 1 was identical to the fuel efficiency computed in the production block. Calibration was based on apparent fuel consumption and estimates of the relative fuel efficiency of small/medium/large cars and new/old cars. This also meant that fuel use in EUCARS 1 was not dependent on speed (which was not modelled in EUCARS 1). EUCARS 2 and EUCARS 3 use Copert relationships for on-road fuel consumption. Cold start extra consumption was however only introduced in EUCARS 3.

The air emissions of conventional pollutants were not computed in EUCARS 1.

A1.6 Congestion curves and speed determination/travel times

Not relevant for EUCARS 1.

Speed-flow curves were changed in EUCARS 3 when the peak/offpeak differentiation was introduced.

For reference, information on speed-flow curves in EUCARS 2 is given in box A2.

BOX A2. Speed-flow curves as modelled in EUCARS 2

EUCARS 2 contains an aggregate speed-flow curve per network (rural, urban, highway). These curves link average travel time (1/speed) and total number of kilometres performed on each network in the following way:

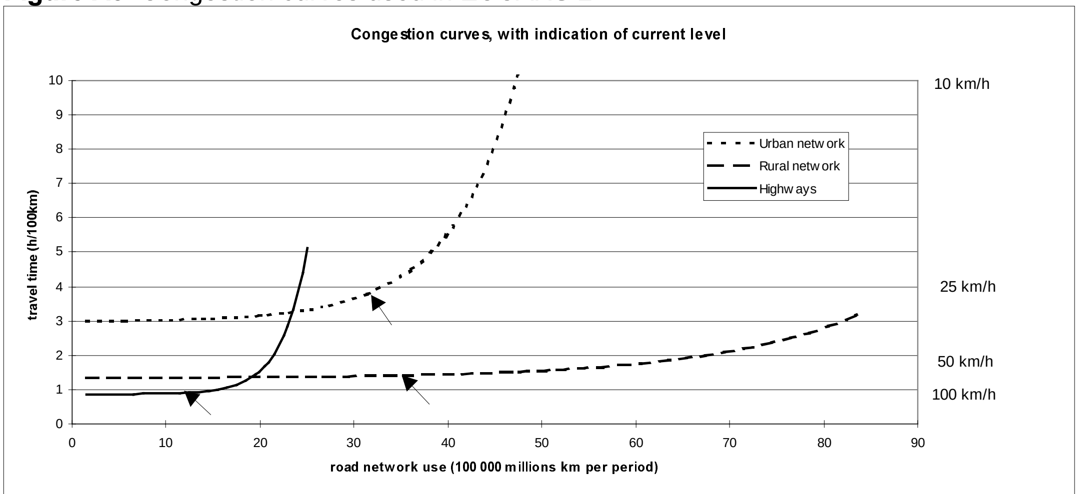
$$\text{Time}_{\text{network}} = Z * \mathit{exp(}\text{traffic}_{\text{network}} / \alpha_1 \mathit{)}^{\beta} + \alpha_2$$

where **traffic** represents the capacity utilisation of the infrastructure (the level of infrastructure by location is determined exogenously):

$$\text{traffic}_{\text{network}} = \sum_{\text{size}} \sum_{\text{generation}} \sum_{\text{triptype}} \text{km} \Big/ \text{INFRA}$$

and where $Z, \alpha_1, \alpha_2, \beta$ are parameters specific to the individual locations. The parameters of the functions have been chosen to express the relative absorption capacity and maximum speed of each network. Figure A5 presents the three congestion curves.

Figure A5. Congestion curves used in EUCARS 2.



A1.7 Elasticity

The addition of the time dimension in EUCARS 2 modified relative prices. The structure of the decision tree was also altered. It was thus necessary to modify some explicit elasticities and parameters of EUCARS 1 in order to keep the same order of magnitude for the implicit key elasticities in both versions. Values of some implicit elasticities for EUCARS 1 are given in KOOPMAN (1995).

Implicit elasticities in two different versions of EUCARS 2 are summarised below. The first version is the one used to obtain the results described in the interim report on the cost-effectiveness of measures to reduce conventional emissions (EC, 1995a). The model was then finalised, and slightly modified to account for the comments received, before the final report was written (EC, 1995b). A major change between the two versions is the completion of the production blocks for fuel and car emission technologies, broadening the range of policy instruments that could be assessed, while the modification most noticeable in the tables concerns the doubling of the substitution elasticity between public and private passenger transport following external advice.

Table A1. Implicit elasticities of EUCARS 2.0
(Version used for EC, 1995a)

Effects of on:	car ownership	car usage	average travel time by cars in urban area	use of public transport	government tax revenues
increase of 1% of fuel prices	- 0.13 %	- 0.18 %	-0.15 %	+ 0.09 %	+ 0.30 %[2]
increase of 1% of new car prices	- 0.44 %	- 0.21 %	- 0.17 %	+ 0.16 %	- 0.02 %[3]
diminution of 1% of public transport price	- 0.02 %	-0.02 %	- 0.02 %	+ 0.50 %	- 0.02 %
diminution of 1% of travel time via public transport	- 0.04 %	- 0.05 %	- 0.04 %	+ 0.95 %	- 0.05 %
increase of 1% of infrastructure (roads)	+ 0.08 %	+ 0.23 %	- 0.62 %	+ 0.17 %	+ 0.12 %

Table A2. Implicit elasticities of EUCARS 2.3
(Version used for EC, 1995b and EC, 1996)

Effects of on:	car ownership	car usage	average travel time by cars in urban area	use of public transport	government tax revenues
increase of 1% of fuel prices	- 0.14 %	- 0.15 %	-0.12 %	+ 0.22 %	+ 0.02 %[2]
increase of 1% of new car prices	- 0.51 %	- 0.32 %	- 0.25 %	+ 0.61 %	- 0.02 %[3]

[2] Excises on fuel are also increased by 1%.

[3]The increase in new car prices is not realised through taxation.

diminution of 1% of public transport price	- 0.11 %	-0.11 %	- 0.11 %	+ 0.95 %	- 0.01 %
diminution of 1% of travel time via public transport	- 0.21 %	- 0.22 %	- 0.17 %	+ 1.82 %	- 0.025 %
increase of 1% of infrastructure (roads)	+ 0.10 %	+ 0.20 %	- 0.62 %	+ 0.17 %	+ 0.01 %

A1.8 Data sources

There are no major changes in data sources for the common variables, except, as already mentioned before, as far as the fuel economy cost curves and speed-flow relationships are concerned.

ANNEX 2. SETS, PARAMETERS AND VARIABLES ACRONYMS.

A2.1 Sets

A	Aspect
ABC	position in FEFFrel
ACT	Activity
C	Characteristic
G	Generation vintaGe
H	Aliased with G
I	Intensity of a technology instrument
II	fuel package
IM	I and M scheme intensity
J	instrument
L	Location
LL	Aliased with L
N	Network
NEWTEC	new technologies (after catalyst intro)
O	age of Old vehicles
OLDTEC	old (conventional) technologies
P	Petrol car size
PK	Period
POL	POLlutants
PPK	Aliased with PK
R	Aliased with S
S	vehicle Size
SIZETEC	correspondance between size and technologies
T	simulation period
TEC	TEChnology
TT	Trip Types
TX	origin of tax revenues
U	Aliased with TT
V	possible periods
Y	*Years in the life of a car as an old car*
YEAR	*YEARs in the life of a car*

A2.2 Parameters

A1RC	alpha first level rest consumption	
A1TR	alpha first level transport	
A2PR	alpha second level private transport services	
A2PU	alpha second level public transport services	
A3	alpha CES function	third level
A4	alpha CES function	fourth level
A5	alpha coefficient	fifth level
A7	alpha coefficient	seventh level
A8	alpha coefficient	eighth level
A9	alpha coefficient	ninth level
ACOLD	affix for ratiocold relationship	
ACOLDF	affix for ratiocold relationship fuel consumption	
ADDSCRAP	additional scrappage	10000 ECU p car p year
AGE	average age of a vintage	
ALPH	speed curve parameter	
ALPHAF	alpha coefficient in cost curves	mult in Exp
AVGAGE	average age of the car stock	
AVGAGES	average age of the car stock by S	
AVGEM	computed average of CO2 emission	tCO2 per l
AVGEMG	emissions by G POL	g per km
AVGEMI	emissions by S G L POL	g per km
AVGEMISF	average emission factor	g per km
AVGEML	emissions by L POL	g per km
AVGEMS	emissions by S POL	g per km
AVGEMSG	emissions by S G POL	g per km
AVGEMT	emissions by S TEC L POL	g per km
AVGEXHAUST	baseline exhaust emiss factor	kg p km
AVGFEFF	computed average FEFF	l per 100 km
AVGFTECH	average technical FEFF	l per 100 km
AVGKM	mean annual mileage	100 000 km
AVGSPEED	average speed in km per hour	
AVGSPEEDL	time by S and Location	
B5	beta coeffecient	fifth level
BAVGEMSG	baseline emissions by S G POL	g per km
BCOLD	coefficient for ratiocold relationship	

```
BCOLDF      coefficient for ratiocold relationship fuel consumption
BETA        infrastructure parameter
BETACOLD    share of cold mileage
BUDG0       budget total consumption including value of time
BVCTSGA     baseline volume by size generation and aspect       Mio cars
CC          total cost to the producer of the IIth package      10**6 ECU
CO2         total CO2 emissions               Mio tCO2 per 5 years
CO2PU       tCO2 per unit of public transport services
COEFE       coefficients in emissions formula
COEFF       coefficients in FEFF CORINAIR relationships
CORR        correcting factor for the differences in consumption
COST        additional cost to the producer     10000 ECU p car
COSTPL      cost per litre of the chosen package II             ECU p 1000 l
CSCRAP      cumulated previous to 1990 scrappages               Mio cars
DEGR        degradation due to the current period
DEGRA       degradation factor exhaust emissions
DISCWELF    discounted welfare                10 Mrd ECUs
DPRIVWELF   change in private welfare
E           emissions by S TEC L PK POL       1000 t  per year
ECOLD       additional cold start emissions   g per km
ELA         elasticity of speed wrt traffic
ELA1CRC     cross price elasticity of rest of consumption           1st level
ELA1CTR     cross price elasticity of transport services            1st level
ELA1ORC     own price elasticity of rest of consumption             1st level
ELA1OTR     own price elasticity of transport services              1st level
ELA2CPR     cross price elasticity of private transport services    2nd level
ELA2CPU     cross price elasticity of public transport services     2nd level
ELA2OPR     own price elasticity of private transport services      2nd level
ELA2OPU     own price elasticity of public transport services       2nd level
ELA3        own and cross price elasticities        third level
ELA4        own and cross price elasticities        fourth level
ELA7        own and cross price elasticities        seventh level
ELA8        own and cross price elasticities        eighth level
ELA9        own and cross price elasticities        ninth level
ELACROSS    cross price elasticities by S G volumeC   5th level
ELAINC      income elasticities by S G C  fifth level
ELAPRICE    price elasticities by S G C   fifth level
EM          CO2 emission by fuel              tonne CO2 per litre
EMISG       emissions by G POL                1000 t  per year
EMISL       emissions by L POL                1000 t  per year
EMISS       emissions by S POL                1000 t  per year
EMISSG      emissions by S G POL              1000 t  per year
EMISSIONS   emissions by S G L POL            1000 t  per year
EMISSIONT   emissions by S TEC POL            1000 t  per year
EMPU        t pollutant per unit of public transport services
EMPUBTRP    emissions from public transport                     1000 t per 5 y
ETA         elasticity (technical fuel use wrt fuel prices)
EVAPEMIS    baseline evapo emiss factor       kg p car p year
EVAPO       evapo emission factor per P and TEC                 kg per car per period
EVAPOG      evapo emissions                                     t per period
EVAPOGF     evapo emissions                   t per period
EVAPOGG     evapo emissions                   t per period
EVAPOS      evapo emissions                   t per period
EVAPOT      evapo emissions                   t per period
EXSCRAP     exogenous scrappage rate
FCE         exogenous part of fixed costs     5 years 10 000 ECU
FCEPCT90    1990 percentage of maintenance +ins costs in fixed costs
FCP         taxes affecting fixed cost components              10000 ECU
FEFFF       fuel use factor                   l per 10 km
FEFFTECH    technical fuel use i.e. for the production block    l per 10 km
FRED        emissions reduction factor
FREDEVAP    reduction factor for evaporative emissions
FREDEVAPV   reduction factor for evap related to chosen fuel quality
FREDV       reduction factor due to the choice of the fuel package
INDIC       indicator of the type of a polynomial CORINAIR relation
INDIC2      indicates old -i.e. before the base year-  technologies
INDIC3      indicates pre2000 technologies
INDICIM     indicates IeM 2
INDTIMERC   h per day per individual for rest consumption
INFRA       indice of infrastructure level
INT         interest rate
INVTTYPE    determination matrix  from locations to trip types
IRATE       discount rate applicable in the production block
K           degradation factor
K80000      emission degradation after 80 000 km  function of IM POL
K80000V     emissions after 80 000 km  for the period V
KDEGRA      degradation factor according to the IM scheme chosen
KF          emiss factor for car technologies
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KFV	reduction factor due to choice of better car technology	
KK		
KMAX	maximal degradation factor i.e. level of conventional car	
KMS	baseline annual mileage	km p car p year
KMSC	baseline cumulated mileage	km p car
KMSG	mileage per car per period	100 000 km
KMSGL	mileage per car per period by L	100 000 km
KMSGLPK	mileage per car per period by N	100 000 km
KTI	relative price of add-on technical improvements	
KVM1	degradation factor of the previous period kept in memory	
LAMBDAF	delta coefficient in cost curves Max techn feas	l per 10 km
LIFECOST	additional annual cost	10000 ECU p car p period
LTRIP	trip length by MS	km
LTRIPAVG	avg EU trip length km	
MILEAGE	total urban mileage per country	1000 km
MINKM	compulsory mileage during five years	
NC	number of cars	Mio cars
NCPP	producer price of new vehicles i.e. without taxes	10 000 ECU
OCP	purchase taxes part of price net of tax	
OMEGAF	omega coefficient in cost curves mult	
PCRC	value of rest consumption	
PCTA	price of cars and car services (avg) including time costs	
PCTGA	price of cars and cars services by G (avg) time costs incl.	
PCTSA	price of cars and cars services by S (avg) time costs incl.	
PFUEL	fuel price net of taxes	ECU per litre
PROBS	observed survival probability from 1990 to 1995	
PTAX	tax or subsidy at purchase	10 ECU per kgpkm
RATIO	ratio of time cost per km between PU and PR	
RATIOCO2	1990 part of CO2 emissions from cars attributed to public trp	
RATIOCOLD	ratio COLD HOT per pollutant	
RATIOCOLDF	ratio COLD HOT for fuel consumption	
RATIOF	ratio entre FEFFTECH for T et FEFFTECH for T-1	
RATIOFEFF	ratio entre FEFFTECH for T et FEFFTECH for T-1	
RCMU	mean of reparation costs following breakdown	10 000 ECU
RCSIGMA	standard deviation of reparation costs	10 000 ECU
RED	reduction factor for evapo emiss	
REDV	reduction factor for evap related to chosen car technology	
RELWELF	relative to BUDG1 welfare costs changes	
REV	government tax revenues	
S1	sigma CES function	first level
S2	sigma CES function	second level
S3	sigma CES function	third level
S4	sigma CES function	fourth level
S7	sigma CES function	seventh level
S8	sigma CES function	eighth level
S9	sigma CES function	ninth level
SHAREMIN	share of committed mileage in total mileage in 1990	
SHAREPU	location shares for public transport	
SPEED	average speed by Location	
SPEEDL	average speed by S and L in km per hour	
TARGETEXH	emissions target	kg per km
TAX	tax or rebate given at purchase on the basis of fuel use	
TAXEM	annual tax on emissions	10 ECU p g
TAXEMF	annual tax on emission factors	
TAXFUEL	tax on fuel emissions reference rate	ECU p l
TECVINT	conversion matrix from vintages to technologies	
TECVINT2	correspondance matrix between new techno and vintages	
TEMP	avg EU temperature	
TEMPS	seasonal temperature per country	
TFEFF	target technical fuel use	l per 10 km
TIMEFACTOR	indicates autonomous technical progress	
TIMEFIXPU	time for 100 km public transport non sensitive to congestion	
TIMEL	speed by S and Network	
TIMEREST	time spent for rest consumption in milliard h per unit RC	
TIMES	ratio between AVGTIMEz and TIMEz	
TOTALKM	total mileage during the period	100 Mrd km
TOTALKMG	total mileage during the period by G	100 Mrd km
TOTALKMGL	total mileage during the period by G L	100 Mrd km
TOTALKML	total mileage during the period by L	100 Mrd km
TOTALKMPK	total mileage during the period by PK	100 Mrd km
TOTALKMS	total mileage during the period by S	100 Mrd km
TOTALKMSG	total mileage during the period by S G	100 Mrd km
TOTPOP	milliards individuals	
TOTTIMERC	total time budget in milliards hours for RC per period	
TRIPTYPE	determination matrix from trip types to locations	
TVACAR	TVA on new car part of price net of tax	
TVAFUEL	TVA on fuel percentage	
VAOT	value of time per activities	10 ECU per h

VARTIMEPU	part of PU sensitive to congestion	
VCE	exogenous variable cost components ECU per 10 km	
VCP	fuel taxes excises ECU per litre	
VCTA	volume of cars and of car services	
VCTGA	volume of car services by generation and aspect	
VCTSA	volume of cars by size and aspect	
VEF	urban mileage by TEC and S	
VIE	expected lifetime of a car in the production block	
VINT	estimated volume of new cars in previous periods	Mio cars
VINTTEC	conversion matrix from technologies to vintages	
VINTTEC2	correspondance matrix between vintages and new techno	
VINTTEC3	conversion factor between techno and vint	
VINTTECZ	1990 conversion matrix from technologies to vintages	
VMAX	average speed in a congestion-free situation	kmph
W1RC	share rest of consumption in total consumption value	1st level
W1TR	share transport consumption in total consumption value	1st level
W2PR	share private transport in total transport value	2nd level
W2PU	share public transport in total transport value	2nd level
W3	shares third level	
W4	shares fourth level	
W5	shares by S G and C	
W7	shares by TT seventh level	
W8	shares by L eighth level	
W9	shares by N ninth level	
WELF	welfare	
WELFCOST	relative change in WELF times BUDG0 + change in REV	
XPCPU	public trp price	
XPCTA	price of cars and car services (avg) without time value	
XPCTGA	price of cars and cars services by G (avg) time not incl.	
XPCTSA	price of cars and cars services by S (avg) time not incl.	
XW1RC	share rest consumption in total monetary consumption	1st level
XW1TR	share transport consumption in total monetary consumption	1st level
XW2PR	share private transport in total transport price	2nd level
XW2PU	share public transport in total transport services price	2nd level
Z	discounted mileage taken into account for purchase decision	
ZZ	speed curve parameter	

A2.3 Variables

AVGTIME	average travel time by network	hour per 100 km
BUDG1	budget total transport services	
BUDG2	budget private transport services	
BUDG3	budget by size	
BUDG4	budget by size and generation	
BUDG5	budget by size generation and characteristic	
BUDG6	budget by size generation and aspect	
BUDG7	budget by size generation and motive	
BUDG8	budget by size generation motive and location	
CAPC	capital costs of vehicle ownership	10 000 ECU
CAPUT	index of infrastructure utilisation	
CONTROL	control costs	10 000 ECU p car
CONTROLC	control costs	1 000 000 ECU
DEPR	depreciation of vehicle	10 000 ECU
DUMMY	dummy var for optimisation model TRANSPORT	
DUMMY2	dummy variable for optimisation	
EFEFFTECH	technical fuel efficiency	l per 10 km
EMISC	emissions costs	1 000 000 ECU
EMISCOST	discounted emission costs with TAXEM or TAXEMF	10 000 ECU p car
EMISCOSTT	total discounted emission costs with PTAX	10 000 ECU p car
EMISPOL	expected emissions per car (IeM included)	kg pol p car
EMISPOLC	total emissions over 5 year of a S G car	0.1 g pol p car
EMISPOLP	expected emissions per car	kg pol p car
ENCPC	new vehicles consumer price 10 000 ECU	
ENCPP	new vehicles producer price 10 000 ECU	
ESCRAP	endogenous scrappage Mio cars	
EXTRA	extra variable for optimisation model EFFIC	
FEFF	total on road fuel use by S G and N	l per 10 km
FEFFCOLD	extra cold start fuel consumption	l per 10 km
FEFFT	total on road fuel use by S TEC and N	l per 10 km
FEFFTP	on road fuel use by S TEC and N no cold start	l per 10 km
NCPC	consumer new car prices (after tax)	10 000 ECU
OCMP	second-hand car prices	10 000 ECU
PCPR	value private vehicle services	
PCPU	value public transport services	
PCTR	value total transport services	
PCTS	value by size	

PCTSG	value by size and generation	
PCTSGA	value by size generation and aspect	10 000 ECU
PCTSGAT	value by size generation and trip type	
PCTSGATL	value by S G motive and location	
PCTSGATN	generalised price by S G motive and network	ECU per 10 km
PCTSGC	value by size generation and characteristic	10 000 ECU
SPDUMMY		
TIME	travel time by S of car and depending on N	hour per 100 km
TIMEPU	public transportation traveltime	hour per 100 km
TOTALC	total cost to be minimised	1 000 000 ECU
TOTALCOST	total cost to be minimised (objective variable)	10 000 ECU p car
UPDUMMY		
VALPH	speed curve parameter	
VCPR	volume of private transport services	
VCPU	volume of public transport services	
VCRC	volume of non-transport goods and services	
VCTR	volume of total transport services	
VCTS	volume by size	
VCTSG	volume by size and generation	
VCTSGA	volume by size generation and aspect	Mio cars
VCTSGAT	volume by size generation and trip type	
VCTSGATL	volume by size generation motive and location	
VCTSGATN	volume by size generation motive and network	100 Mrd km
VCTSGC	volume by size generation and characteristic	Mio cars
VELA		
X	choice of instrument J intensity I car type S	
XX	choice of fuels package II	

A2.4 Equations

EQ1	current values in 1985
EQ2	current tangent value in 1985
EQ2BPRICE	
EQ2PRICE	
EQ3PRICE	
EQ4PRICE	
EQ5PRICE	
EQ6APRICE	
EQ6BPRICE	
EQ7PRICE	
EQ8PRICE	
EQ9PRICE	
EQBUDG1	budget total transport services
EQBUDG2	budget private transport services
EQBUDG3	budget by size
EQBUDG4	budget by size and generation
EQBUDG5	budget by size generation and characteristic
EQBUDG6	budget by size generation and aspect
EQBUDG7	budget by size generation and motive
EQBUDG8	budget by size generation motive and location
EQCAPCN	capacity costs new cars
EQCAPCO	capacity costs old cars (more than 10 y of age)
EQCAPCOB	capacity costs old cars (5 to 10 y old)
EQCAPUT	index of infrastructure utilisation
EQCONTROL	control costs
EQCOST	control costs
EQDEM1RC	CES demand non-transport goods and services
EQDEM1TR	CES demand total transport services
EQDEM2PR	CES demand private transport services
EQDEM2PU	CES demand public transport services
EQDEM3	CES demand by size
EQDEM4	CES demand by size and generation
EQDEM5	LES demand by size generation and aspect
EQDEM6A	ownership demand by size and generation
EQDEM6B	usage demand by size and generation
EQDEM7	CES demand by size generation and motive
EQDEM8	CES demand by size generation and location
EQDEM9	mileage demand by size generation motive and network
EQDEPRN	depreciation of new cars
EQDEPRO	depreciation of old cars (more than 10 y of age)
EQDEPROB	depreciation of old cars (5 to 10 y old)
EQDUMMY	dummy equation for optimisation
EQDUMMY2	
EQEFEFFTC	technical fuel efficiency of new vehicles
EQEMISC	total emission costs
EQEMISCIRC	discounted emission costs with TAXEMF

```
EQEMISCT    total discounted emission costs  with       (TAXEM +) PTAX
EQEMISF     total emission costs
EQEMISPOL   discounted emission costs per pollutant  for TAXEM(F)
EQEMISPOLC  emission costs per car and pollutant for 5 years
EQEMISPOLF  emission costs per car and pollutant for 5 years
EQEMISPOLL  emission costs per pollutant  for            PTAX
EQEMISS     discounted emission costs  with              TAXEM
EQENCPC     consumer price of new vehicles
EQENCPP     producer price of new vehicles
EQEXTRA     extra equation for optimisation
EQFEF1      total consumption incl cold start 'urban'
EQFEF2      total consumption incl cold start 'rural'
EQFEF3      total consumption incl cold start 'hgw'
EQFEFF1     CORINAIR relationship   quadratic form
EQFEFF1B    CORINAIR relationship   for small ece1504 cars urban cdtns
EQFEFF3     CORINAIR relationship   expo type
EQFEFF4     CORINAIR relationship   for preece cars rural cdtns
EQFEFF5     CORINAIR relationship   for diesel cars
EQFEFF6     CORINAIR relationship   for lpg cars   urban cdtns
EQFEFF7     CORINAIR relationship   for lpg cars   rural cdtns
EQFEFF8     CORINAIR relationship   for lpg cars   highway cdtns
EQFEFFC1    conversion FEFFT by TEC to FEFF by G
EQFEFFC2    conversion FEFFT by TEC to FEFF by G new technologies
EQFEFFCOLD  cold start relationship
EQNCPC      consumer new car prices
EQNCPCT     consumer price of a new car  with PTAX
EQOBJ       total costs to minimise
EQOBJF      total cost to minimise
EQPFIX      fixed price of vehicle services (ownership)
EQPFIXC     fixed price of vehicle services  with TAXEMF
EQPFIXM     fixed price of vehicle services  with TAXEM
EQPFIXS     fixed price of vehicle services + add costs of IeM scheme
EQPVAR      variable price of vehicle services (usage)
EQPVARF     variable price of vehicle services  with TAXFUEL
EQPVARM     variable price of vehicle services  with TAXEM
EQSCAPUT
EQSCRAP     scrappage
EQSCRAPM    scrappage  with additional scrappage due to IeM
EQSPCTR
EQSPCURVE1
EQSPCURVE2
EQSPCURVE3
EQSPDUMMY
EQTECH      sum of XXii must equal 1
EQTECH1     sum of Xijs eq 1              for each S and J
EQTECH2     IeM 2 implies CAR 4 5  or 6   for each P
EQTECH2B    IeM 2 implies CAR 4 5  or 6   for each P
EQTIMEPU    travel time using public transport
EQTTIME     average travel time on the network
EQTTIMES    travel time by network and size of the car
EQVOLD      volume of old cars  remaining after scrappage
```

A2.5 Models

```
CARCIRCUL   production block with annual tax on emission TAXEMF
CARPROD     production block with annual emission tax TAXEM
CARPRODTAX  production block with emission tax TAXEM and purchase tax or
            incentive PTAX
CARTAX      production block with purchase tax or incentive PTAX
EFFIC
FUELCHOICE  fuel block
FUELTAX     fuel block
SPEEDCURVE
TRANSPORT   transport block without specific policies to control conv. emis.
TRANSPORTC  transport block with annual tax TAXEMF based on emiss. factors
TRANSPORTF  transport block with fiscal incentives for clean fuels
TRANSPORTM  transport block with annual emission tax TAXEM
TRANSPORTS  transport block with IeM scheme
TRANSPORTT  transport block with purchase incentives PTAX
TRANSPOTTM  transport block with purchase incentives PTAX and IeM scheme
TRPMP       transport block with TAXEM and purchase incentives PTAX
```

ANNEX3. LISTING OF MODEL VARIABLES AND EQUATIONS

```
**********************************************************
*                                                        *
*           MODEL VARIABLES and EQUATIONS (partim)       *
*                                                        *
*                                                        *
*        2. Models                                       *
*        2.1. Declaration of endogenous variables        *
*        2.2. Equations declaration                      *
*        2.3. Equations definition                       *
*        2.4. Model definition                           *
*                                                        *
*                                                        *
*                                                        *
**********************************************************

*** EUCARS is composed of two blocks:
***
*** the first block is commonly referred to as the production block:
***  these models determine the technical characteristics of fuel and new cars
***  (EFFIC, CARPROD type, FUELTAX),
***
*** the latter one (TRANSPORT type) uses the results of the production block
***  and groups all the other features of EUCARS in 5 main modules.

*=====================================================================
*             A. M o d e l   E F F I C
*=====================================================================

*** Fuel efficiency model
*** Part of the production block, where fuel efficiency and price
***  of new cars are calculated on the basis of the comparison of the technology cost
***  curve, and of the expected total discounted costs of fuel during the vehicle
***  lifetime

            *** A.1.  V a r i a b l e s

FREE VARIABLE
EXTRA               extra variable for optimisation   model EFFIC

POSITIVE VARIABLES
ENCPP(V,S)          new vehicles producer price   10 000 ECU
ENCPC(V,S)          new vehicles consumer price   10 000 ECU
EFEFFTECH(V,S)      technical fuel efficiency     l per 10 km
;

            *** A.2   E q u a t i o n s   d e c l a r a t i o n

EQUATIONS

EQEXTRA             extra equation for optimisation
EQEFEFFTC(V,S)      technical fuel efficiency of new vehicles
EQENCPP(V,S)        producer price of new vehicles
EQENCPC(V,S)        consumer price of new vehicles
;

            *** A.3   E q u a t i o n s   de  f i n i t i o n

EQEFEFFTC(T,S)..  EFEFFTECH(T,S) =E=
  (  (1+OCP(T,S)+TVACAR(T,S)) * ENCPP(T,S) * ALPHAF(S)
    /( (PFUEL(T,S)+VCP(T,S))*(1+TVAFUEL(T,S))*Z(T,S)
     + TAX(T,S)*(1+OCP(T,S)+TVACAR(T,S)) )
   ) **.5 + LAMBDAF(S);
EQENCPP(T,S)..
ENCPP(T,S) =E= OMEGAF(S)*TIMEFACTOR(T)*EXP(ALPHAF(S)/(EFEFFTECH(T,S)-LAMBDAF(S)));
EQENCPC(T,S)..
  ENCPC(T,S) =E= (1+OCP(T,S)+TVACAR(T,S)) *
  ( ENCPP(T,S) + TAX(T,S) * (EFEFFTECH(T,S)-TFEFF(T,S)) );
EQEXTRA..
  EXTRA =E= SUM(T,SUM(S,ENCPC(T,S)));

            *** A.4   M o d e l   d e f i n i t i o n
```

```
MODEL EFFIC /EQEFEFFTC, EQENCPP, EQENCPC, EQEXTRA/;

*=======================================================================
*            B. M o d e l s   C A R P R O D
*=======================================================================

*** Car technology models
*** Part of the production block: choice of anti-polluting devices
***  depending on norms and tax/incentives provided by the government
***
*** The model has different variants depending on the taxation/incentives system
*** Wheter annual tax based on emission factors * mileage   (TAXEM)
***  or    annual tax based on emission factors            (TAXEMF)
***  or    purchase tax/incentive based on emission factors (PTAX/TARGETEXH)

            *** B.1.  V a r i a b l e s

FREE VARIABLES
TOTALCOST            total cost to be minimised (objective variable)   10 000 ECU p car
EMISPOL(S,POLL)      expected emissions per car (IeM included)         kg pol p car
EMISPOLP(S,POLL)     expected emissions per car                        kg pol p car
EMISCOST(S)          discounted emission costs  with TAXEM or TAXEMF   10 000 ECU p car
EMISCOSTT(S)         total discounted emission costs  with PTAX        10 000 ECU p car

POSITIVE VARIABLES
X(J,I,S)             choice of instrument J intensity I car type S
CONTROL(S)           control costs                                     10 000 ECU p car
;

            *** B.2   E q u a t i o n s   d e c l a r a t i o n

EQUATIONS

EQEMISPOL(S,POLL)    discounted emission costs per pollutant  for TAXEM(F)
EQEMISPOLL(S,POLL)   emission costs per pollutant  for            PTAX
EQEMISS(S)           discounted emission costs  with              TAXEM
EQEMISCT(S)          total discounted emission costs  with       (TAXEM +) PTAX
EQEMISCIRC(S)        discounted emission costs  with              TAXEMF

EQCOST(S)            control costs

EQOBJ(S)             total costs to minimise

*** Technical constraints
EQTECH1(J,S)         sum of Xijs eq 1              for each S and J
EQTECH2(S)           IeM 2 implies CAR 4 5  or 6   for each P
EQTECH2b(S)          IeM 2 implies CAR 4 5  or 6   for each P
;

            *** B.3   E q u a t i o n s   d e f i n i t i o n

EQEMISPOL(SS,POLL)..
  EMISPOL(SS,POLL) =E= EVAPEMIS(SS,POLL)*((1+IRATE)**VIE - 1)/IRATE/(1+IRATE)**(VIE-1)
                                        * SUM(I, X('EVAP',I,SS)*(1-RED(I,SS)) )
    +SUM(  YEAR, KMS(YEAR,SS)*AVGEXHAUST(SS,POLL)
           * SUM(I, X('CAR',I,SS)*KF(I,SS,POLL))
           * (1+MIN(  SUM(I,X('CAR',I,SS)* DEGRA('CAR',I,POLL))
                     *SUM(I,X('IeM',I,SS)* DEGRA('IeM',I,POLL)) * KMSC(YEAR,SS)/80000
                    ,KMAX('2000',SS,POLL)-1 ))
         / (1+IRATE)**(AN(YEAR)-1)  );
EQEMISPOLL(SS,POLL)..
  EMISPOLP(SS,POLL) =E= AVGEXHAUST(SS,POLL) * SUM(I, X('CAR',I,SS)*KF(I,SS,POLL))
                        -TARGETEXH(POLL);
EQEMISS(SS)..
  EMISCOST(SS) =E= SUM(POLL, TAXEM(POLL)*EMISPOL(SS,POLL) );
EQEMISCT(SS)..
  EMISCOSTT(SS) =E= EMISCOST(SS)
     +SUM(POLL, PTAX(POLL)*EMISPOLP(SS,POLL) )*(1+TVACAR('2000',SS) + OCP('2000',SS));
EQEMISCIRC(SS)..
  EMISCOST(SS) =E= SUM(POLL, TAXEMF(POLL)*EMISPOL(SS,POLL)
                / (SUM(YEAR, KMS(YEAR,SS)/(1+IRATE)**(AN(YEAR)-1))) );

EQCOST(SS)..
  CONTROL(SS) =E= SUM(J, SUM(I, X(J,I,SS)*
  (  COST(J,I,SS)*(1+OCP('2000',SS)+TVACAR('2000',SS))
   + LIFECOST(J,I)/5 * ((1+IRATE)**VIE - 1)/IRATE/(1+IRATE)**(VIE-1)
   ) ));
```

```
EQOBJ(SS)..
  TOTALCOST =E= CONTROL(SS) + EMISCOST(SS);

EQTECH1(J,SS)..
  SUM(I, X(J,I,SS)) =E= 1;
EQTECH2(SS)..
  X('IeM','0',SS) + X('IeM','1',SS)
  + X('CAR','4',SS) + X('CAR','5',SS) + X('CAR','6',SS) =E= 1;
EQTECH2b(SS)..
  X('IeM','2',SS)
  + X('CAR','0',SS) + X('CAR','1',SS) + X('CAR','2',SS) + X('CAR','3',SS) =E= 1;

            *** B.4  M o d e l s  d e f i n i t i o n

MODEL CARPROD         production block with annual emission tax TAXEM
   / EQCOST, EQEMISS, EQEMISPOL, EQTECH1, EQTECH2, EQTECH2b, EQOBJ /;
MODEL CARTAX          production block with purchase tax or incentive PTAX
   / EQCOST, EQEMISCT, EQEMISPOLL, EQTECH1, EQOBJ /;
MODEL CARCIRCUL       production block with annual tax on emission TAXEMF
   / EQCOST, EQEMISCIRC, EQEMISPOL, EQTECH1, EQTECH2, EQTECH2b, EQOBJ /;
MODEL CARPRODTAX        production block with emission tax TAXEM and purchase tax or
incentive PTAX
   / EQCOST, EQEMISS, EQEMISCT, EQEMISPOL, EQEMISPOLL, EQTECH1, EQTECH2, EQTECH2b,
     EQOBJ /;

*======================================================================
*            C. M o d e l   F U E L T A X
*======================================================================

*** Fuel technology model
*** Choice of a fuel package (gasoline + diesel)

            *** 2C.1.  V a r i a b l e s

FREE VARIABLE
TOTALC              total cost to be minimised                       1 000 000 ECU;

POSITIVE VARIABLES
XX(II)              choice of fuels package II
CONTROLC            control costs                                    1 000 000 ECU
EMISC               emissions costs                                  1 000 000 ECU
EMISPOLC(S,G,POLL)  total emissions over 5 year of a S G car         0.1 g pol p car
;

            *** C.2  E q u a t i o n s  d e c l a r a t i o n

EQUATIONS

EQCONTROL                 control costs
EQEMISPOLC(S,G,POLL)      emission costs per car and pollutant for 5 years
EQEMISPOLF(S,G,POLL)      emission costs per car and pollutant for 5 years
EQEMISC                   total emission costs
EQEMISF                   total emission costs

EQOBJF              total cost to minimise

*** Technical constraint
EQTECH              sum of XXii must equal 1
;

            *** C.3  E q u a t i o n s  d e f i n i t i o n

EQCONTROL..
  CONTROLC =E= SUM(II, XX(II) * CC(II));
EQEMISPOLC(S,G,POLL)..
  EMISPOLC(S,G,POLL) =E= 1000000*KMSG(S,G) * AVGEMISF(S,G,POLL)
                          * SUM(II, XX(II)*(1-FRED(II,S,POLL)));
EQEMISPOLF(S,G,POLL)..
  EMISPOLC(S,G,POLL) =E= 10000*SUM(L,SUM(PK, KMSGLPK(S,G,L,PK) * FEFFF(S,G,L,PK) ))
                          * SUM(II, XX(II)*(1-FRED(II,S,POLL)));
EQEMISC..
  EMISC =E= SUM(S,SUM(G,SUM(POLL, NC(S,G) * EMISPOLC(S,G,POLL) * TAXEM(POLL) )))
      -SUM(G,SUM(POLL, NC('LPG',G) * EMISPOLC('LPG',G,POLL) * TAXEM(POLL) ))
      +SUM(P,SUM(G, TAXEM('VOC')*EVAPOGF(P,G)*SUM(II, XX(II)*(1-FREDEVAP(II)) ) ))*10;
EQEMISF..
  EMISC =E= SUM(S, CORR(S) *SUM(G,SUM(POLL, NC(S,G)*EMISPOLC(S,G,POLL)
                                    *TAXFUEL(POLL,S)*(1+TVAFUEL('2000',S)) )) )
```

```
           -SUM(G,SUM(POLL, NC('LPG',G)*EMISPOLC('LPG',G,POLL)
                     *TAXFUEL(POLL,'LPG')*(1+TVAFUEL('2000','LPG')) ))
           +SUM(P,SUM(G, TAXFUEL('VOC',P)*(1+TVAFUEL('2000',P))
                    *SUM(II, XX(II)*(1-FREDEVAP(II)) ) )) *10;
EQTECH..
  SUM(II, XX(II)) =E= 1;
EQOBJF..
  TOTALC =E= CONTROLC + EMISC;

            *** C.4   M o d e l   d e f i n i t i o n

MODEL FUELCHOICE                    fuel block
  / EQCONTROL, EQEMISPOLC, EQEMISC, EQTECH, EQOBJF /;
MODEL FUELTAX                       fuel block
  / EQCONTROL, EQEMISPOLF, EQEMISF, EQTECH, EQOBJF /;

*=======================================================================
*             D. M o d e l   T R A N S P O R T
*=======================================================================

FREE VARIABLE

DUMMY               dummy var for optimisation        model TRANSPORT

      *=================================
      *==== Da. Price module     ======
      *=================================

            *** Da.1.  V a r i a b l e s

*** The variables below do not generally represent real prices, but aggregated prices,
***  most often geometric averages of the prices in the inferior nests.
*** 'Real' prices are PCTSGATN: generalised price per km, and
***  PCTSGAownership: total fixed costs of owning a car.
*** PCPU is arbitrarily fixed since PUblic transport volume is only measured
***  by an index.

POSITIVE VARIABLES

PCTSGATN(V,S,G,TT,L,PK)   generalised price by S G motive and network  ECU per 10 km
PCTSGATL(V,S,G,TT,L)      value by S G motive and location
PCTSGAT(V,S,G,TT)         value by size generation and trip type
PCTSGA(V,S,G,A)           value by size generation and aspect          10 000 ECU
PCTSGC(V,S,G,C)           value by size generation and characteristic  10 000 ECU
PCTSG(V,S,G)              value by size and generation
PCTS(V,S)                 value by size
PCPU(V)                   value public transport services
PCPR(V)                   value private vehicle services
PCTR(V)                   value total transport services
TIMEPU(V)           public transportation traveltime              hour per 100 km
TIME(V,S,L,PK)      travel time by S of car and depending on N    hour per 100 km
;

            *** Da.2   E q u a t i o n s   d e c l a r a t i o n

EQUATIONS

EQ9PRICE(V,S,G,TT,L)
EQ8PRICE(V,S,G,TT)
EQ7PRICE(V,S,G)
EQ6APRICE(V,S,G)
EQ6BPRICE(V,S,G)
EQ5PRICE(V,S,G)
EQ4PRICE(V,S)
EQ3PRICE(V)
EQ2PRICE(V)
EQ2BPRICE(V)
;

            *** Da.3   E q u a t i o n s   de  f i n i t i o n

*** The following equations aggregate prices of the inferior nest into
***  a composite value used in the superior nest.

EQ9PRICE(T,S,G,TT,L)..
  PCTSGATL(T,S,G,TT,L) =E=
  SUM(PK, A9(T,S,G,TT,L,PK)*PCTSGATN(T,S,G,TT,L,PK)**(1-S9(S,G,TT,L)))
```

```
              ** (1/(1-S9(S,G,TT,L)));
EQ8PRICE(T,S,G,TT)..
  PCTSGAT(T,S,G,TT) =E=
  SUM(L, A8(T,S,G,TT,L)*PCTSGATL(T,S,G,TT,L)**(1-S8(S,G,TT)))  **  (1/(1-S8(S,G,TT)));
EQ7PRICE(T,S,G)..
  PCTSGA(T,S,G,'USAGE') =E=
  SUM(TT, A7(T,S,G,TT)*PCTSGAT(T,S,G,TT)**(1-S7(S,G)))  **  (1/(1-S7(S,G)));
EQ6APRICE(T,S,G)..
  PCTSGC(T,S,G,'SUPPL') =E= PCTSGA(T,S,G,'USAGE');
EQ6BPRICE(T,S,G)..
  PCTSGC(T,S,G,'COM') =E= PCTSGA(T,S,G,'OWNERSHIP')
                        + MINKM(S,G)*PCTSGC(T,S,G,'SUPPL');
EQ5PRICE(T,S,G)..
  PCTSG(T,S,G) =E= PROD(C, PCTSGC(T,S,G,C)**W5(T,S,G,C));
EQ4PRICE(T,S)..
  PCTS(T,S) =E= SUM(G, A4('1985',S,G)*PCTSG(T,S,G)**(1-S4(S)))  **  (1/(1-S4(S)));
EQ3PRICE(T)..
  PCPR(T) =E= SUM(S,A3(S)*PCTS(T,S)**(1-S3))  **  (1/(1-S3));
EQ2PRICE(T)..
  PCTR(T) =E= (  A2PU*PCPU(T)**(1-S2) + A2PR*PCPR(T)**(1-S2) )  **  (1/(1-S2));
EQ2BPRICE(T)..
  PCPU(T) =E= XPCPU(T) + TIMEPU(T)*VAOT(T,'PUBLICTRP');

      *=================================
      *=== Db. Consumption module =====
      *=================================


            *** Db.1.  V a r i a b l e s


*** As for the prices, the demand variables do not generally represent real
***  quantities.
*** 'Real' volumes are VCTSGATN: kmage per age and type of car, and also per
***  trip type, and motive, and
*** VCTSGAownership: number of cars per type and age.

POSITIVE VARIABLES

VCTSGATN(V,S,G,TT,L,PK)   volume by size generation motive and network    100 Mrd km
VCTSGATL(V,S,G,TT,L)      volume by size generation motive and location
VCTSGAT(V,S,G,TT)   volume by size generation and trip type
VCTSGA(V,S,G,A)     volume by size generation and aspect                  Mio cars
VCTSGC(V,S,G,C)     volume by size generation and characteristic          Mio cars
VCTSG(V,S,G)        volume by size and generation
VCTS(V,S)           volume by size
VCPU(V)             volume of public transport services
VCPR(V)             volume of private transport services
VCRC(V)             volume of non-transport goods and services
VCTR(V)             volume of total transport services
BUDG8(V,S,G,TT,L)   budget by size generation motive and location
BUDG7(V,S,G,TT)     budget by size generation and motive
BUDG6(V,S,G,A)      budget by size generation and aspect
BUDG5(V,S,G,C)      budget by size generation and characteristic
BUDG4(V,S,G)        budget by size and generation
BUDG3(V,S)          budget by size
BUDG2(V)            budget private transport services
BUDG1(V)            budget total transport services
;
PARAMETER
BVCTSGA(V,S,G,A)    baseline volume by size generation and aspect         Mio cars
;

            *** Db.2   E q u a t i o n s   d e c l a r a t i o n

EQUATIONS

EQDEM9(V,S,G,TT,L,PK)     mileage demand by size generation motive and network
EQBUDG8(V,S,G,TT,L)       budget by size generation motive and location
EQDEM8(V,S,G,TT,L)  CES demand by size generation and location
EQBUDG7(V,S,G,TT)   budget by size generation and motive
EQDEM7(V,S,G,TT)    CES demand by size generation and motive
EQBUDG6(V,S,G,A)    budget by size generation and aspect
EQDEM6A(V,S,G)      ownership demand by size and generation
EQDEM6B(V,S,G)      usage demand by size and generation
EQBUDG5(V,S,G,C)    budget by size generation and characteristic
EQDEM5(V,S,G,C)     LES demand by size generation and aspect
EQBUDG4(V,S,G)      budget by size and generation
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```
EQDEM4(V,S,G)       CES demand by size and generation
EQBUDG3(V,S)        budget by size
EQDEM3(V,S)         CES demand by size
EQBUDG2(V)          budget private transport services
EQDEM2PU(V)         CES demand public transport services
EQDEM2PR(V)         CES demand private transport services
EQBUDG1(V)          budget total transport services
EQDEM1RC(V)         CES demand non-transport goods and services
EQDEM1TR(V)         CES demand total transport services

*highest level
EQDUMMY             dummy equation for optimisation
;

            *** Db.3   E q u a t i o n s   d e f i n i t i o n

*ninth level
EQDEM9(T,S,G,TT,L,PK)$(PCTSGATNZ(S,G,TT,L,PK) $A9(T,S,G,TT,L,PK))..
  VCTSGATN(T,S,G,TT,L,PK) =E= BUDG8(T,S,G,TT,L) /
  ( PCTSGATN(T,S,G,TT,L,PK)*
   (  (PCTSGATN(T,S,G,TT,L,PK)/PCTSGATN(T,S,G,TT,L,'PEAK'))**(S9(S,G,TT,L)-1)
       * A9(T,S,G,TT,L,'PEAK')/A9(T,S,G,TT,L,PK)
    + (PCTSGATN(T,S,G,TT,L,PK)/PCTSGATN(T,S,G,TT,L,'OFFPK'))**(S9(S,G,TT,L)-1)
       * A9(T,S,G,TT,L,'OFFPK')/A9(T,S,G,TT,L,PK) )      ) ;
EQBUDG8(T,S,G,TT,L)..
  BUDG8(T,S,G,TT,L) =E= VCTSGATL(T,S,G,TT,L)*PCTSGATL(T,S,G,TT,L);
*eight level
EQDEM8(T,S,G,TT,L)$(PCTSGATLZ(S,G,TT,L) $A8(T,S,G,TT,L))..
  VCTSGATL(T,S,G,TT,L) =E= BUDG7(T,S,G,TT) /
  ( PCTSGATL(T,S,G,TT,L)*
   (  (PCTSGATL(T,S,G,TT,L)/PCTSGATL(T,S,G,TT,'URBAN'))**(S8(S,G,TT)-1)
       * A8(T,S,G,TT,'URBAN')/A8(T,S,G,TT,L)
    + (PCTSGATL(T,S,G,TT,L)/PCTSGATL(T,S,G,TT,'RURAL'))**(S8(S,G,TT)-1)
       * A8(T,S,G,TT,'RURAL')/A8(T,S,G,TT,L)
    + (PCTSGATL(T,S,G,TT,L)/PCTSGATL(T,S,G,TT,'HIGHWAY'))**(S8(S,G,TT)-1)
       * A8(T,S,G,TT,'HIGHWAY')/A8(T,S,G,TT,L)  )      ) ;
EQBUDG7(T,S,G,TT)..
  BUDG7(T,S,G,TT) =E= VCTSGAT(T,S,G,TT)*PCTSGAT(T,S,G,TT);
*seventh level
EQDEM7(T,S,G,TT)$(PCTSGATZ(S,G,TT) $A7(T,S,G,TT))..
  VCTSGAT(T,S,G,TT) =E= BUDG6(T,S,G,'USAGE') /
  ( PCTSGAT(T,S,G,TT)*
   (  (PCTSGAT(T,S,G,TT)/PCTSGAT(T,S,G,'COMMUTING'))**(S7(S,G)-1)
       * A7(T,S,G,'COMMUTING')/A7(T,S,G,TT)
    + (PCTSGAT(T,S,G,TT)/PCTSGAT(T,S,G,'PRIVATE'))**(S7(S,G)-1)
       * A7(T,S,G,'PRIVATE')/A7(T,S,G,TT)
    + (PCTSGAT(T,S,G,TT)/PCTSGAT(T,S,G,'PROF'))**(S7(S,G)-1)
       * A7(T,S,G,'PROF')/A7(T,S,G,TT)  )      ) ;
EQBUDG6(T,S,G,A)..
  BUDG6(T,S,G,A) =E= VCTSGA(T,S,G,A)*PCTSGA(T,S,G,A);
*sixth level
EQDEM6A(T,S,G)$W5(T,S,G,'COM')..
  VCTSGA(T,S,G,'OWNERSHIP') =E= BUDG5(T,S,G,'COM') /
    ( PCTSGA(T,S,G,'OWNERSHIP') + MINKM(S,G)*PCTSGA(T,S,G,'USAGE') );
EQDEM6B(T,S,G)$W5(T,S,G,'SUPPL')..
  VCTSGA(T,S,G,'USAGE') =E= VCTSGC(T,S,G,'SUPPL')
     + ( BUDG5(T,S,G,'COM') - PCTSGA(T,S,G,'OWNERSHIP')*VCTSGA(T,S,G,'OWNERSHIP') )
       / PCTSGA(T,S,G,'USAGE') ;
EQBUDG5(T,S,G,C)..
  BUDG5(T,S,G,C) =E= PCTSGC(T,S,G,C)*VCTSGC(T,S,G,C) ;
*fifth level
EQDEM5(T,S,G,C)$W5(T,S,G,C)..
  VCTSGC(T,S,G,C) =E= B5(T,S,G,C)
 + ( A5(T,S,G,C)* ( BUDG4(T,S,G) - B5(T,S,G,'COM')*PCTSGC(T,S,G,'COM')
                                 - B5(T,S,G,'SUPPL')*PCTSGC(T,S,G,'SUPPL') ) )
   /PCTSGC(T,S,G,C);
EQBUDG4(T,S,G)..
  BUDG4(T,S,G) =E= VCTSG(T,S,G)*PCTSG(T,S,G);
*fourth level
EQDEM4(T,S,G)$PCTSGAZ(S,G,'OWNERSHIP')..
  VCTSG(T,S,G) =E= BUDG3(T,S)  /  (  PCTSG(T,S,G)*
(  (PCTSG(T,S,G)/PCTSG(T,S,'NEW'))**(S4(S)-1)*A4(T,S,'NEW')/A4(T,S,G)
 + (PCTSG(T,S,G)/PCTSG(T,S,'MOINS1'))**(S4(S)-1)*A4(T,S,'MOINS1')/A4(T,S,G)
 + (PCTSG(T,S,G)/PCTSG(T,S,'MOINS2'))**(S4(S)-1)*A4(T,S,'MOINS2')/A4(T,S,G)
 + (PCTSG(T,S,G)/PCTSG(T,S,'MOINS3'))**(S4(S)-1)*A4(T,S,'MOINS3')/A4(T,S,G)
 + (PCTSG(T,S,G)/PCTSG(T,S,'MOINS4'))**(S4(S)-1)*A4(T,S,'MOINS4')/A4(T,S,G)
 )                                  ) ;
EQBUDG3(T,S)..
```

```
  BUDG3(T,S) =E= VCTS(T,S)*PCTS(T,S);
*third level
EQDEM3(T,S)..
  VCTS(T,S) =E= BUDG2(T)  /  ( PCTS(T,S)*
(  (PCTS(T,S)/PCTS(T,'SMALL'))**(S3-1)* A3('SMALL')/A3(S)
 + (PCTS(T,S)/PCTS(T,'MEDIUM'))**(S3-1)* A3('MEDIUM')/A3(S)
 + (PCTS(T,S)/PCTS(T,'LARGE'))**(S3-1)* A3('LARGE')/A3(S)
 + (PCTS(T,S)/PCTS(T,'DIESEL'))**(S3-1)* A3('DIESEL')/A3(S)
 + (PCTS(T,S)/PCTS(T,'LPG'))**(S3-1)*A3('LPG')/A3(S) )  );
EQBUDG2(T)..
  BUDG2(T) =E= VCPR(T)*PCPR(T);
*second level
EQDEM2PU(T)..         VCPU(T) =E= BUDG1(T) /
  ( PCPU(T) * (1 + (PCPU(T)/PCPR(T))**(S2-1) * (A2PR/A2PU)) );
EQDEM2PR(T)..         VCPR(T) =E= BUDG1(T) /
  ( PCPR(T) * ( (PCPR(T)/PCPU(T))**(S2-1) * (A2PU/A2PR) + 1 ) );
EQBUDG1(T)..          BUDG1(T) =E= VCTR(T)*PCTR(T);
*first level
EQDEM1RC(T)..         VCRC(T) =E= BUDG0(T) /
  ( PCRC(T) * (1 + (PCRC(T)/PCTR(T))**(S1-1) * (A1TR/A1RC)) );
EQDEM1TR(T)..         VCTR(T) =E= BUDG0(T) /
  ( PCTR(T) * ( (PCTR(T)/PCRC(T))**(S1-1) * (A1RC/A1TR) + 1 ) );

*highest level
EQDUMMY..             DUMMY =E= 1 ;

      *=================================
      *==== Dc. Car market     ========
      *=================================


            *** Dc.1.  V a r i a b l e s

POSITIVE VARIABLES

FEFF(V,S,G,L,PK)    total on road fuel use by S G and N   l per 10 km
*old cars
OCMP(V,S,O)         second-hand car prices                10 000 ECU
ESCRAP(V,S,O)       endogenous scrappage                  Mio cars
*new cars
NCPC(V,S)           consumer new car prices (after tax)   10 000 ECU
*all cars
DEPR(V,S,G)         depreciation of vehicle               10 000 ECU
CAPC(V,S,G)         capital costs of vehicle ownership    10 000 ECU
;

            *** Dc.2   E q u a t i o n s   d e c l a r a t i o n


*** For some equations, some variants exist, depending on the tax
***  incentive scheme, or the technological regulation in force.

EQUATIONS

*old cars
EQDEPRO(V,S,Q)      depreciation of old cars (more than 10 y of age)
EQDEPROB(V,S)       depreciation of old cars (5 to 10 y old)
EQCAPCO(V,S,Q)      capacity costs old cars (more than 10 y of age)
EQCAPCOB(V,S)       capacity costs old cars (5 to 10 y old)
EQSCRAP(V,S,O)      scrappage
 EQSCRAPM(V,S,O)     scrappage  with additional scrappage due to IeM
EQVOLD(V,S,O)       volume of old cars  remaining after scrappage
*new cars
EQDEPRN(V,S)        depreciation of new cars
EQCAPCN(V,S)        capacity costs new cars
EQNCPC(V,S)         consumer new car prices
 EQNCPCT(V,S)        consumer price of a new car  with PTAX
*all cars (without TAXEM)
EQPVAR(V,S,G,TT,L,PK)     variable price of vehicle services (usage)
EQPFIX(V,S,G)             fixed price of vehicle services (ownership)
*all cars (with policies controlling conv. emissions)
EQPVARM(V,S,G,TT,L,PK)    variable price of vehicle services  with TAXEM
EQPVARF(V,S,G,TT,L,PK)    variable price of vehicle services  with TAXFUEL
EQPFIXM(V,S,G)      fixed price of vehicle services  with TAXEM
EQPFIXC(V,S,G)      fixed price of vehicle services  with TAXEMF
EQPFIXS(V,S,G)      fixed price of vehicle services + add costs of IeM scheme
;
```

```
          *** Dc.3   E q u a t i o n s   d e  f i n i t i o n

*old cars
EQDEPRO(T,S,Q)..       DEPR(T,S,Q) =E= 5* (OCMP(T,S,Q)/5);
EQDEPROB(T,S)..        DEPR(T,S,'MOINS1') =E= 5* (OCMP(T,S,'MOINS1')/6);
EQCAPCO(T,S,Q)..       CAPC(T,S,Q) =E= INT(T)*3*OCMP(T,S,Q);
EQCAPCOB(T,S)..
  CAPC(T,S,'MOINS1') =E= INT(T)*20/6*OCMP(T,S,'MOINS1');
EQSCRAP(T,S,O)$RCSIGMA(S,O)..
  ESCRAP(T,S,O) =E= ( ( 1-ERRORF( (OCMP(T,S,O)-RCMU(S,O))/RCSIGMA(S,O) ) )
                     + EXSCRAP(S,O) )  * ( VINT(T,S,O)-CSCRAP(T,S,O) );
 EQSCRAPM(T,S,O)$RCSIGMA(S,O)..
  ESCRAP(T,S,O) =E= ( ( 1-ERRORF( (OCMP(T,S,O)-RCMU(S,O))/RCSIGMA(S,O) ) )
                   + EXSCRAP(S,O) )  * ( VINT(T,S,O)-CSCRAP(T,S,O) )
                 + SUM( I, X.L('IeM',I,S) * ADDSCRAP(I) ) * VCTSGA(T,S,O,'OWNERSHIP');
EQVOLD(T,S,O)..
  VCTSGC(T,S,O,'COM') =E= VINT(T,S,O) - CSCRAP(T,S,O) - ESCRAP(T,S,O);
*new cars
EQDEPRN(T,S)..         DEPR(T,S,'NEW') =E= 0.6 * NCPC(T,S);
EQCAPCN(T,S)..
  CAPC(T,S,'NEW') =E=  INT(T)*3.8*NCPC(T,S)
                     + (  0.4*NCPC(T,S) - ( OCMP(T,S,'MOINS1')*(1+KTI(T,S)) )  );
EQNCPC(T,S)..
  NCPC(T,S) =E= (1 + OCP(T,S) + TVACAR(T,S))
               *( NCPP(T,S) + TAX(T,S)*(FEFFTECH(T,S) - TFEFF(T,S)) );
 EQNCPCT(T,S).. NCPC(T,S) =E= (1 + OCP(T,S) + TVACAR(T,S))
  *( NCPP(T,S) + TAX(T,S)*(FEFFTECH(T,S) - TFEFF(T,S))
    +SUM(POLL, PTAX(POLL)*( BAVGEMSG(T,S,'NEW',POLL)/1000*KFV(T,S,'NEW',POLL)
                          -TARGETEXH(POLL) ) ) );
*all cars  (without TAXEM)
EQPVAR(T,S,G,TT,L,PK)$N(L,PK)..
  PCTSGATN(T,S,G,TT,L,PK)  =E= VCE(T,S,G) + TIME(T,S,L,PK)*VAOT(T,TT)
                    + FEFF(T,S,G,L,PK) * (PFUEL(T,S)+VCP(T,S))*(1+TVAFUEL(T,S));
EQPFIX(T,S,G)..
  PCTSGA(T,S,G,'OWNERSHIP') =E= FCE(T,S,G) + FCP(T,S) + DEPR(T,S,G) + CAPC(T,S,G);
*all cars  (with policies controlling conv. pollution)
EQPVARM(T,S,G,TT,L,PK)$N(L,PK)..  PCTSGATN(T,S,G,TT,L,PK)  =E=
  VCE(T,S,G) + FEFF(T,S,G,L,PK) * (PFUEL(T,S)+VCP(T,S))*(1+TVAFUEL(T,S))
  + 100*SUM( POLL, TAXEM(POLL)* BAVGEMSG(T,S,G,POLL) * KFV(T,S,G,POLL)
                                                     * KDEGRA(T,S,G,POLL)
                                                     * (1-FREDV(T,S,POLL)) )
  + TIME(T,S,L,PK)*VAOT(T,TT);
EQPVARF(T,S,G,TT,L,PK)$N(L,PK)..  PCTSGATN(T,S,G,TT,L,PK)  =E=
  VCE(T,S,G) + FEFF(T,S,G,L,PK) * ( (PFUEL(T,S)+VCP(T,S))*(1+TVAFUEL(T,S))
  + SUM(POLL, TAXFUEL(POLL,S) * (1-FREDV(T,S,POLL))) )
  + TIME(T,S,L,PK)*VAOT(T,TT);
EQPFIXM(T,S,G)..      PCTSGA(T,S,G,'OWNERSHIP') =E=
  FCE(T,S,G) + FCP(T,S) + DEPR(T,S,G) + CAPC(T,S,G)
  + SUM(I, X.L('IeM',I,S) *LIFECOST('IeM',I)*MAX(INDIC3(G),INDICIM(I)))
  + TAXEM('VOC')/1000 *EVAPOG(T,S,G)/BVCTSGA(T,S,G,'OWNERSHIP')
                       *(1-REDV(T,S,G))
                       *(1-FREDEVAPV(T));
EQPFIXC(T,S,G)..      PCTSGA(T,S,G,'OWNERSHIP') =E=
  FCE(T,S,G) + FCP(T,S) + DEPR(T,S,G) + CAPC(T,S,G)
  + SUM(I, X.L('IeM',I,S) *LIFECOST('IeM',I)*MAX(INDIC3(G),INDICIM(I)))
  + SUM(POLL, TAXEMF(POLL)/1000 * BAVGEMSG(T,S,G,POLL)
                               * KFV(T,S,G,POLL) * KDEGRA(T,S,G,POLL) );
EQPFIXS(T,S,G)..      PCTSGA(T,S,G,'OWNERSHIP') =E=
  FCE(T,S,G) + FCP(T,S) + DEPR(T,S,G) + CAPC(T,S,G)
  + SUM(I, X.L('IeM',I,S) *LIFECOST('IeM',I)*MAX(INDIC3(G),INDICIM(I)) );

      *=================================
      *==== Dd. Speed curves   ========
      *=================================

          *** Dd.1.  V a r i a b l e s

POSITIVE VARIABLES

AVGTIME(V,L,PK)     average travel time by network               hour per 100 km
CAPUT(V,L,PK)       index of infrastructure utilisation
;

          *** Dd.2   E q u a t i o n s   d e c l a r a t i o n

EQUATIONS

EQCAPUT(V,L,PK)     index of infrastructure utilisation
```

```
EQTTIME(V,L,PK)      average travel time on the network
EQTTIMES(V,S,L,PK)   travel time by network and size of the car
EQTIMEPU(V)          travel time using public transport
;

            *** Dd.3   E q u a t i o n s   d e  f i n i t i o n

EQCAPUT(T,L,PK)$N(L,PK)..
  CAPUT(T,L,PK) =E=  BETA(L,PK)* SUM(S, SUM(G, SUM(TT, VCTSGATN(T,S,G,TT,L,PK))))
                                 / INFRA(T,L,PK);
EQTTIME(T,L,PK)$N(L,PK)..
  AVGTIME(T,L,PK) =E= 100* ( ZZ(L,PK)*EXP(CAPUT(T,L,PK)) + ALPH(L,PK) );
EQTTIMES(T,S,L,PK)$N(L,PK)..
  TIME(T,S,L,PK) =E= TIMES(S,L,PK) * AVGTIME(T,L,PK);
EQTIMEPU(T)..
  TIMEPU(T) =E= (1-VARTIMEPU) * TIMEFIXPU
         + VARTIMEPU * RATIO * SUM(L, SUM(PK$N(L,PK), SHAREPU(L,PK)*AVGTIME(T,L,PK)));

      *=================================
      *== De. Fuel use relationships ==
      *=================================


*** Real on road fuel use, as modelled by CORINAIR-Copert relationships
***  i.e. formulae linking fuel consumption to the speed
*** NB: The same formulae are used in FOREMOVE

            *** De.1.  V a r i a b l e s

POSITIVE VARIABLES

FEFFTP(V,S,TEC,L,PK)   on road fuel use by S TEC and N  no cold start   l per 10 km
FEFFCOLD(V,S,TEC)      extra cold start fuel consumption                l per 10 km
FEFFT(V,S,TEC,L,PK)    total on road fuel use by S TEC and N            l per 10 km
;

            *** De.2   E q u a t i o n s   d e c l a r a t i o n


*** The following equations correspond to the different functional forms used to
***  express the speed-fuel consumption relation.

EQUATIONS

EQFEFF1(V,S,TEC,L,PK)     CORINAIR relationship   quadratic form
EQFEFF1B(V,S,TEC,L,PK)    CORINAIR relationship   for small ece1504 cars urban cdtns
*** if speed inf to 25 kmph *** EQFEFF2(V,S,TEC,L,PK)      CORINAIR relationship
EQFEFF3(V,S,TEC,L,PK)     CORINAIR relationship   expo type
EQFEFF4(V,S,TEC,L,PK)     CORINAIR relationship   for preece cars rural cdtns
EQFEFF5(V,S,TEC,L,PK)     CORINAIR relationship   for diesel cars
EQFEFF6(V,TEC,PK)         CORINAIR relationship   for lpg cars   urban cdtns
EQFEFF7(V,TEC,PK)         CORINAIR relationship   for lpg cars   rural cdtns
EQFEFF8(V,TEC,PK)         CORINAIR relationship   for lpg cars   highway cdtns

*** Extra cold start consumption is a fraction of normal consumption added to
***  consumption in urban cdtns. The size of extra cold start consumption depends
***  on the technology stage.

EQFEFFCOLD(V,S,TEC)       cold start relationship
EQFEF1(V,S,TEC,PK)        total consumption incl cold start 'urban'
EQFEF2(V,S,TEC,PK)        total consumption incl cold start 'rural'
EQFEF3(V,S,TEC,PK)        total consumption incl cold start 'hgw'

*** CORINAIR-Copert formulas are given by car technology type (TEC).
*** Conversion is needed to have average consumption by vintage (G).

EQFEFFC1(V,S,G,L,PK)      conversion FEFFT by TEC to FEFF by G
EQFEFFC2(V,S,TEC,G,L,PK)  conversion FEFFT by TEC to FEFF by G new technologies
;

            *** De.3   E q u a t i o n s   d e  f i n i t i o n

EQFEFF1(T,P,TEC,L,PK)
 $(N(L,PK)$(SIZETEC(P,TEC)$(INDIC(TEC,L)$(COEFF('AA',P,TEC)))))..
  FEFFTP(T,P,TEC,L,PK) =E=
  1/80 * (  COEFF('AA',P,TEC) + COEFF('BB',P,TEC)*(100/TIME(T,P,L,PK))
                              + COEFF('CC',P,TEC)*((100/TIME(T,P,L,PK))**2) );
EQFEFF1B(T,'SMALL','ECE1504','URBAN',PK)..
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  FEFFTP (T,'SMALL','ECE1504','URBAN',PK) =E=
  1/80 * (  COEFF('AA','SMALL','ECE1504')
          + COEFF('BB','SMALL','ECE1504')*(100/TIME(T,'SMALL','URBAN',PK))
          + COEFF('CC','SMALL','ECE1504')*(100/TIME(T,'SMALL','URBAN',PK)**2));
*** EQFEFF2(T,V,TEC,L,PK)
*** $(N(L,PK)$(100/TIME(T,P,L,PK)) LT TCOEFF(P,TEC)$COEFF('DD',P,TEC)))..
***  FEFFTP (T,P,TEC,L,PK) =E=
*** 1/80 * ( COEFF('EE',P,TEC) - COEFF('DD',P,TEC)*LOG( 100/TIME(T,P,L,PK) ) );
EQFEFF3(T,P,TEC,'URBAN',PK)
 $(COEFF('FF',P,TEC)$(SIZETEC(P,TEC)$(INDIC(TEC,'URBAN') NE 1)))..
  FEFFTP (T,P,TEC,'URBAN',PK) =E=
  1/80 * (COEFF('EE',P,TEC) * (100/TIME(T,P,'URBAN',PK))**COEFF('FF',P,TEC));
EQFEFF4(T,P,'PREECE','RURAL',PK)$(N('RURAL',PK)$(SIZETEC(P,'PREECE')))..
  FEFFTP (T,P,'PREECE','RURAL',PK) =E= 1/80 * COEFF('AA',P,'PREECE');
EQFEFF5(T,'DIESEL',TEC,L,PK)
 $(N(L,PK)$(SIZETEC('DIESEL',TEC)$(COEFF('AA','DIESEL',TEC))))..
  FEFFTP (T,'DIESEL',TEC,L,PK) =E=
  1/90 * (  COEFF('AA','DIESEL',TEC)
          + COEFF('BB','DIESEL',TEC)*(100/TIME(T,'DIESEL',L,PK))
          + COEFF('CC','DIESEL',TEC)*((100/TIME(T,'DIESEL',L,PK))**2) );
EQFEFF6(T,TEC,PK)$(N('URBAN',PK)$(SIZETEC('LPG',TEC)$(COEFF('AA','LPG',TEC))))..
  FEFFTP (T,'LPG',TEC,'URBAN',PK) =E= 1/50 * COEFF('AA','LPG',TEC);
EQFEFF7(T,TEC,PK)$(N('RURAL',PK)$(SIZETEC('LPG',TEC)$(COEFF('BB','LPG',TEC))))..
  FEFFTP (T,'LPG',TEC,'RURAL',PK) =E= 1/50 * COEFF('BB','LPG',TEC);
EQFEFF8(T,TEC,PK)$(N('HIGHWAY',PK)$(SIZETEC('LPG',TEC)$(COEFF('CC','LPG',TEC))))..
  FEFFTP (T,'LPG',TEC,'HIGHWAY',PK) =E= 1/50 * COEFF('CC','LPG',TEC);

EQFEFFCOLD(T,S,TEC)
 $( SUM(G, TECVINT(T,S,G,TEC)) NE 0)..
  FEFFCOLD(T,S,TEC) =E= BETACOLD
  *SUM(L,SUM(PK$N(L,PK), FEFFTP(T,S,TEC,L,PK) * SHARENETZ(S,L,PK)/100 ))
  *(RATIOCOLDF(S,TEC) - 1)
  *SUM(G, TECVINT(T,S,G,TEC)*SUM(TT,SUM(L,SUM(PK$N(L,PK), VCTSGATN(T,S,G,TT,L,PK) ))))
  /SUM(G, TECVINT(T,S,G,TEC)*SUM(TT,SUM(PK, VCTSGATN(T,S,G,TT,'URBAN',PK) )) );
EQFEF1(T,S,TEC,PK)$(N('URBAN',PK)$SUM(G,TECVINT(T,S,G,TEC)))..
  FEFFT(T,S,TEC,'URBAN',PK) =E= FEFFTP(T,S,TEC,'URBAN',PK) + FEFFCOLD(T,S,TEC);
EQFEF2(T,S,TEC,PK)$(N('RURAL',PK)$(SUM(G,TECVINT(T,S,G,TEC))))..
  FEFFT(T,S,TEC,'RURAL',PK) =E= FEFFTP(T,S,TEC,'RURAL',PK);
EQFEF3(T,S,TEC,PK)$(N('HIGHWAY',PK)$(SUM(G,TECVINT(T,S,G,TEC))))..
  FEFFT(T,S,TEC,'HIGHWAY',PK) =E= FEFFTP(T,S,TEC,'HIGHWAY',PK);

EQFEFFC1(T,S,G,L,PK)$(N(L,PK)$(INDIC2(G)))..
  FEFF(T,S,G,L,PK) =E= SUM(TEC$(SIZETEC(S,TEC)$(VINTTEC(T,S,TEC,G))),
                           VINTTEC(T,S,TEC,G) * VCTSTAZ(S,TEC,'USAGE')
                           * FEFFT(T,S,TEC,L,PK) * SHARENETZ(S,L,PK)/100)
                      / VCTSGANZ(T,S,G,L,PK);
EQFEFFC2(T,S,TEC,G,L,PK)$(N(L,PK)$VINTTEC2(T,S,TEC,G))..
  FEFF(T,S,G,L,PK) =E=  FEFFT(T,S,TEC,L,PK);
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**** D.4 M o d e l d e f i n i t i o n*

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MODEL TRANSPORT     transport block without specific policies to control conv. emis.
*** price module
 /EQ9PRICE, EQ8PRICE, EQ7PRICE, EQ6APRICE, EQ6BPRICE, EQ5PRICE, EQ4PRICE, EQ3PRICE,
  EQ2PRICE, EQ2BPRICE,
*** consumption module
  EQDEM9, EQBUDG8, EQDEM8, EQBUDG7, EQDEM7, EQBUDG6, EQDEM6A, EQDEM6B, EQBUDG5,
  EQDEM5, EQBUDG4, EQDEM4, EQBUDG3, EQDEM3, EQBUDG2, EQDEM2PU, EQDEM2PR, EQBUDG1,
  EQDEM1RC, EQDEM1TR, EQDUMMY,
*** car market
  EQDEPRO, EQDEPROB, EQCAPCO, EQCAPCOB, EQSCRAP, EQVOLD, EQDEPRN, EQCAPCN, EQNCPC,
  EQPVAR, EQPFIX,
*** speed curves
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
*** fuel consumption
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
 /;

*** Other variants exist
  EQPVARM, EQPFIXM,
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
/;

MODEL TRANSPORTs    transport block with IeM scheme
 /EQ9PRICE, EQ8PRICE, EQ7PRICE, EQ6APRICE, EQ6BPRICE, EQ5PRICE, EQ4PRICE, EQ3PRICE,
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  EQ2PRICE, EQ2BPRICE,
  EQDEM9, EQBUDG8, EQDEM8, EQBUDG7, EQDEM7, EQBUDG6, EQDEM6A, EQDEM6B, EQBUDG5,
  EQDEM5, EQBUDG4, EQDEM4, EQBUDG3, EQDEM3, EQBUDG2, EQDEM2PU, EQDEM2PR, EQBUDG1,
  EQDEM1RC, EQDEM1TR, EQDUMMY,
  EQDEPRO, EQDEPROB, EQCAPCO, EQCAPCOB, EQSCRAPM, EQVOLD, EQDEPRN, EQCAPCN, EQNCPC,
  EQPVAR, EQPFIXS,
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
/;

MODEL TRANSPORTf    transport block with fiscal incentives for clean fuels
 /EQ9PRICE, EQ8PRICE, EQ7PRICE, EQ6APRICE, EQ6BPRICE, EQ5PRICE, EQ4PRICE, EQ3PRICE,
  EQ2PRICE, EQ2BPRICE,
  EQDEM9, EQBUDG8, EQDEM8, EQBUDG7, EQDEM7, EQBUDG6, EQDEM6A, EQDEM6B, EQBUDG5,
  EQDEM5, EQBUDG4, EQDEM4, EQBUDG3, EQDEM3, EQBUDG2, EQDEM2PU, EQDEM2PR, EQBUDG1,
  EQDEM1RC, EQDEM1TR, EQDUMMY,
  EQDEPRO, EQDEPROB, EQCAPCO, EQCAPCOB, EQSCRAPM, EQVOLD, EQDEPRN, EQCAPCN, EQNCPC,
  EQPVARF, EQPFIXS,
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
/;

MODEL TRANSPORTT    transport block with purchase incentives PTAX
 /EQ9PRICE, EQ8PRICE, EQ7PRICE, EQ6APRICE, EQ6BPRICE, EQ5PRICE, EQ4PRICE, EQ3PRICE,
  EQ2PRICE, EQ2BPRICE,
  EQDEM9, EQBUDG8, EQDEM8, EQBUDG7, EQDEM7, EQBUDG6, EQDEM6A, EQDEM6B, EQBUDG5,
  EQDEM5, EQBUDG4, EQDEM4, EQBUDG3, EQDEM3, EQBUDG2, EQDEM2PU, EQDEM2PR, EQBUDG1,
  EQDEM1RC, EQDEM1TR, EQDUMMY,
  EQDEPRO, EQDEPROB, EQCAPCO, EQCAPCOB, EQSCRAP, EQVOLD, EQDEPRN, EQCAPCN, EQNCPCT,
  EQPVAR, EQPFIX,
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
/;

MODEL TRANSPOTTM    transport block with purchase incentives PTAX and IeM scheme
 /EQ9PRICE, EQ8PRICE, EQ7PRICE, EQ6APRICE, EQ6BPRICE, EQ5PRICE, EQ4PRICE, EQ3PRICE,
  EQ2PRICE, EQ2BPRICE,
  EQDEM9, EQBUDG8, EQDEM8, EQBUDG7, EQDEM7, EQBUDG6, EQDEM6A, EQDEM6B, EQBUDG5,
  EQDEM5, EQBUDG4, EQDEM4, EQBUDG3, EQDEM3, EQBUDG2, EQDEM2PU, EQDEM2PR, EQBUDG1,
  EQDEM1RC, EQDEM1TR, EQDUMMY,
  EQDEPRO, EQDEPROB, EQCAPCO, EQCAPCOB, EQSCRAPM, EQVOLD, EQDEPRN, EQCAPCN, EQNCPCT,
  EQPVAR, EQPFIXS,
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
/;

MODEL TRANSPORTC    transport block with annual tax TAXEMF based on emiss. factors
 /EQ9PRICE, EQ8PRICE, EQ7PRICE, EQ6APRICE, EQ6BPRICE, EQ5PRICE, EQ4PRICE, EQ3PRICE,
  EQ2PRICE, EQ2BPRICE,
  EQDEM9, EQBUDG8, EQDEM8, EQBUDG7, EQDEM7, EQBUDG6, EQDEM6A, EQDEM6B, EQBUDG5,
  EQDEM5, EQBUDG4, EQDEM4, EQBUDG3, EQDEM3, EQBUDG2, EQDEM2PU, EQDEM2PR, EQBUDG1,
  EQDEM1RC, EQDEM1TR, EQDUMMY,
  EQDEPRO, EQDEPROB, EQCAPCO, EQCAPCOB, EQSCRAPM, EQVOLD, EQDEPRN, EQCAPCN, EQNCPC,
  EQPVAR, EQPFIXC,
  EQCAPUT, EQTTIME, EQTTIMES, EQTIMEPU,
  EQFEFF1, EQFEFF1B, EQFEFF3, EQFEFF4, EQFEFF5, EQFEFF6, EQFEFF7, EQFEFF8, EQFEFFCOLD,
  EQFEF1, EQFEF2, EQFEF3, EQFEFFC1, EQFEFFC2
/;
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