Integrated passenger transport policy assessment within a computable general equilibrium framework

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Zusammenfassung

Gegenstand der vorliegenden Dissertation ist die Entwicklung eines methodischen Werkzeuges, konkret eines allgemeinen rechenbaren Gleichgewichtmodells (Computable General Equilibrium Model, CGE), welches zur Bewertung politischer Maßnahmen den Personenverkehr bzw. die Personenverkehrsleistung in Deutschland im volkswirtschaftlichen Kontext abbildet. Ziel der Arbeit ist die Anwendung dieses methodischen Instrumentariums zur Evaluierung politischer Maßnahmen im Verkehrssektor – wie der Einführung von Straßenbenutzungsgebühren für Pkw – hinsichtlich resultierender Effekte, einschließlich der gesamtwirtschaftlichen Folgen.

Zur Untersuchung ökonomischer Umverteilungseffekte einer Pkw-Maut werden im Modell nach Einkommens- und Wohnsiedlungsstruktur differenzierte Haushaltskategorien abgebildet. Dabei werden erhebungsbasierte Mikrodaten zur Mobilität und Einkommensverwendung privater Haushalte in ein rechenbares, allgemeines Gleichgewichtsmodell der gesamten deutschen Volkswirtschaft integriert. Damit wird die private Nachfrage nach motorisiertem sowie öffentlichem Verkehr in dem CGE Modell über realisierte Konsum- bzw. Nachfrageentscheidungen privater Haushaltskategorien abgebildet. Als wichtiges Ergebnis zeigt die Arbeit regressive Wirkung einer Pkw-Maut innerhalb der Einkommensverteilung privater Haushalte in Deutschland. Gleichzeitig würde eine Pkw-Maut von 5 Cent/km die CO_2 Emissionen in diesem Sektor bereits um bis zu 10 % senken. Die regressive Wirkung der Maßnahme kann durch eine adäquate Ausgestaltung der Einnahmenverwendung kompensiert werden. Damit kann die oft als fehlend diskutierte Akzeptanz der Pkw-Maut innerhalb der Bevölkerung erhöht werden.

Schlagwörter:

Personenverkehr, Allgemeine Gleichgewichtsmodellierung, Wohlfahrtseffekte, Umverteilungspolitik, Gerechtigkeit, Straßennutzungsgebühren

Abstract

The purpose of this dissertation work is the development of a methodological framework in terms of a computable general equilibrium (CGE) model in order to carry out an integrated impact assessment from road charging introduced in the passenger car sector for Germany. The pricing policy measure is applied to the private motorized travel demand covering the overall road network. The uniqueness of this work distinguishing it from the current state of the research in the area of CGE modeling is firstly the application of an existing methodological approach to a newly constructed database for Germany, secondly the extension of the model framework by integrating land use characteristics of private household residential location, and finally the funded assessment of distributional and equity implications within the private household sector from the introduction of road use charging. To give a better understanding of distributional, equity and welfare impacts from the introduction of car road pricing within the overall economic context, mode specific travel demand of private households is integrated into the CGE model. The modeling framework accounts for different household categories with respect to income and residential location through the integration of behavioral mobility parameters as well as household travel expenditures. The analyses of policy simulations are carried out introducing different road charging revenue redistribution schemes. The results of this work show that distributional effects and equity concerns are strongly related to the revenue use patterns as well as to country and household specific travel demand profiles. However, the introduction of road user charges can have a positive impact on environmental welfare through the reduction of car use and the corresponding CO_2 emissions, when mode shifts are induced through the implementation of the policy reform. They results of this work provide country specific insights concerning the public acceptance of road user charges applied to passenger car travel.

Keywords:

Passenger road travel, Computable general equilibrium model, Transport policy assessment, Road use charging, Distributional impacts, Equity

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Vorwort

Die Idee zu dieser wissenschaftlichen Arbeit entstand hauptsächlich entlang der Herausforderung, Inhalte und Empirie aus der angewandten ökonomischen Verkehrsforschung der Abteilung Energie, Verkehr, Umwelt des DIW Berlin mit einer innovativen Methodik von angewandten, rechenbaren allgemeinen Gleichgewichtsmodellen unter dem „Mantel" einer politisch und gesellschaftlich (aktuell) relevanten Fragestellung zu vereinen. Die Aufbereitung der Datenbasis erwies sich als zeitaufwendig und nicht frei von Mühen – unterschiedliche Datenquellen mussten hierfür herangezogen, ineinander integriert und zum Teil mithilfe ökonometrischer Verfahren ergänzt werden. Die Ausweitung der konkreten Fragestellung nach Wohlfahrts- und Umverteilungseffekten aus politischer Maßnahmenimplementierung um die normative Komponente nach ihrer Fairness erhöhte die Komplexität der Arbeit. Möge der Leser beurteilen, wie gut die aufgeworfenen Fragen in der Ausarbeitung beantwortet wurden.

Jedenfalls wäre diese Arbeit nicht ohne die Unterstützung einer ganzen Reihe von Personen möglich gewesen, bei denen ich mich auch noch mal an dieser Stelle herzlich bedanken möchte. Professor Karl Steininger hat das Ausgangsmodell für Österreich zur Verfügung gestellt und bei meinen vielen Fragen Hilfestellung gegeben. Besonderer Dank gilt Professor Georg Meran für seine Unterstützung dieses Forschungsprojektes. Ebenso hat mir meine Abteilungsleiterin Professor Claudia Kemfert ganz erheblich bei der Durchführung des Promotionsvorhabens geholfen. Mein ganz besonderer Dank gilt auch meinem lieben Kollegen Hartmut Kuhfeld.

Dominika Kalinowska

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1 Introduction

Policies of any kind – targeted or not targeted – influence demand. Growing concerns about energy consumption and supply issues, environmental externalities, and climate change matters emerge in the need for policy involvement. These concerns are closely linked to transportation, in particular the road travel sector. Hence, policy instruments are needed. They are being developed and partially implemented to tackle negative external impacts from motorised road travel on the environment and the society. Their effects require an assessment and a deeper understanding. The objective to provide a deeper understanding of the overall economic and environmental effects from car road charging in general and distributional impacts in particular are the driving motivation for this dissertation work. The development and the application of the methodological tool for an integrated assessment of such effects – with strong focus on household distributional and equity effects – is the core research task of this dissertation work.

There are several motivations for constructing a model for Germany: Obviously Germany is a large and therefore important economy. It also offers a good coverage of data that are required for the construction of the model database, i.e., input- output- and social accounting data as well as household travel, income and expenditure data. Germany is furthermore one of the countries, where the idea or the proposal for the introduction of car road charging shows up regularly on the policy agenda. Arguments propagating car road pricing are to finally introduce a road use charge on foreign drivers using German road network otherwise without paying for it. Furthermore, because a distance dependant road use charge applied to the freight sector is already in place since 2005, it is not unlikely to assume that with manageable technological enhancements the existing revenue collecting infrastructure in the freight transportation sector could be adapted to passenger cars. The technical feasibility of the measure is a strong criterion when discussing its realisation; an introduction of car road charging as discussed later on in this work is not an unrealistic undertaking.

Taxes or charges levied on car users are often designed to meet specific internalisation objectives of uncovered (external) costs associated with car use. In some cases they combine the price of negative environmental or social impacts from (fossil) fuel combustion and road use together with the payment for road infrastructure provision. No matter what is their exact definition, road charging measures share a common problem: they lack (broad) public acceptance. Introduction of a road use charges or an augmentation of the fossil fuel tax evokes strong welfare distributional and equity concerns, mainly among car users. Broad public opposition to car use related measures for reduction of fossil fuel consumption and therefore climate change mitigation is a well-known phenomenon and often discussed in the literature. However, the effective scope of the impacts on private car users and the overall economy from the augmentation of automobility cost depends on the exact design of the measure and on the accompanying revenue use or reallocation scheme. Relevant factors are therefore the magnitude and range of the policy measure or the level and implementation scheme of the charge – on what assumptions is it based – and what are the integrated (welfare) impacts on private households, as well as effects on environment and the overall economy. Still, it is common presumption and concern that distance dependent road use charges work regressively regarding their economic and social impacts. As households from the low income categories spend a greater proportion of their income on travel and energy, they are more likely to be adversely affected by imposed charges on car road use. In practice, the actual impact of road user charging on each economic sector or agent is closely linked to specific characteristics of the national economy, but also to car travel demand patterns conditioned upon the observable and implicit sociodemogarphic and economic structure of private households, accessibility and land use attributes. The strong influence of the initial living conditions of households on policy outcomes suggests the application of an assessment instrument that would account for these characteristics through the model specification and the construction of the database.

The methodological approach has to take into account the multidimensional and integrated impact of policy measures such as road use charging, especially when public revenue is collected and reallocated. The objective of the presented doctoral thesis is therefore to investigate equity and welfare distributional effects from car road charging on the private household sector in the specific case of Germany. The policy impact assessment covers the entire economy with special focus on the private households and their welfare situation before and after the introduction of the measure. To give a funded understanding of the mode of functioning of environmental and transport policy measures targeting car use, especially on their socioeconomic implications, an overall model of the German economy is extended by a more disaggregated private household representation. The methodology used in this work is a computable general equilibrium framework with integrated private household car travel and public transport demand, differentiated by combined income and spatial residence characteristics.

The work reveals the effectiveness of road use charging being the only approach of its kind carried out for Germany. Varying scenario assumptions as to the design of the policy reform provide the basis for the simulation analysis of the model. As a result the work quantifies the relationship between welfare and equity effects from road user charging and the formulation of the revenue reallocation schemes. The application of household category specific behavioural parameters in form of travel demand and travel demand elasticities approximate the practical real life situation of the policy implementation environment (in Germany). Results obtained are derived from a sound empirical basis providing a new insight in the integrated assessment modelling research. The uniqueness of this work distinguishing it from the current state of the research in the area of CGE modeling is therefore, firstly the application of an existing methodological approach to a newly constructed database for Germany, secondly the extension of the model framework by integrating household categories of equivalent income quartiles and land use characteristics of households' residential location, and finally the quantitative assessment of distributional and equity implications within the private household sector from the introduction of road use charging.

In Chapter 2 of this thesis work relevant theoretical aspects for the methodological application and the interpretation of the results are discussed. Research work on the basic economic concept behind road charging, on road charging acceptability, and on welfare, distributive and equity effects within the economic context are presented. Chapter 3 proceeds with an overview of the research done within the area of applied overall economic impact assessment of road pricing measures in the transport sector, taking into account welfare distribution and equity effects. The objective underlying this doctoral work and the description of the methodology used to obtain the results conclude Chapter 3.

Chapter 4 focuses on the detailed description of the model and the data applied. It starts with a brief introduction of some basics of the general equilibrium theory, goes over the model structure and its particularities, and ends with the description of the extensive database and the multiple data sources used to construct the CGE model with integrated private household demand. Emphasis is put on the specific incorporation of passenger travel demand into the economic modelling frame.

After the initial definition of varying scenarios underlying the policy simulations, Chapter 5 deals with the description, interpretation and discussion of the model results.

Chapter 6 concludes and gives a critical outlook on the research subject of this thesis work.

2 Theoretical discussion

In the following, relevant theoretical aspects for the methodological approach underlying this work are discussed. The discussion includes in particular relevant aspects for the interpretation of the modelling results and for answering the research question concerning distributional and equity impacts from road use charging in the passenger car sector.

2.1 Theoretical discussion of road pricing

In this Chapter, firstly relevant basics concerning the theoretical background of road pricing are revealed. The presented theoretical discussion about social cost pricing focuses exclusively on the road travel sector as the core subject of this work. Some of the theoretical aspects discussed are then linked to examples of the implementation of the measure referring to current European Union (EU) policy framework as well as national policies regarding road pricing. The Chapter concludes linking the theoretical discussion with the road charging policy implemented later on in this work.

2.1.1 Social, private, internalised, and external costs of road use

Road pricing or road charging defined as direct collection of user charges per km of infrastructure demand look back at nearly a century of economic research and literature. It is based on the simple reasoning of economic rationality that the individual willingness to pay for consumption of goods and services should reflect the marginal social cost of its production. Market pricing of transportation resources such as vehicles, fuel, insurance, etc. does not automatically bring about an efficient use of public roads. Direct cost of car ownership and use represent individual transportation costs and their payment does not cover the overall social cost caused by (car) transport. Social cost of car travel has to reflect the monetarised damage or negative externalities imposed through individual car use on society as a whole as well as on other car and road users. Pigou (1920) based his concept of externalities on the work of Marshall (1890) and referring to it as the "indirect effect of a consumption activity or a production activity on the consumption set of a consumer, the utility function of a consumer or the production function of a producer."[1] External costs are therefore induced by transport users but not borne by them, instead these costs are passed on to third parties and the general public. The idea of external costs and the implementation of road pricing goes beyond the mere application of an economic, market based pricing mechanism to the commodity "road space" reflecting its scarcity. Its application is extended to such goods as environmental quality, health, safety, even quality of life, and others. Jansson (1997) defines marginal social cost of infrastructure use as the sum of the following marginal costs:

- Costs borne directly by the motorist (provision of vehicle and fuel, travel time of the car user),
- Cost imposed on the infrastructure provider (provision and maintenance of the infrastructure),
- Costs imposed on the infrastructure users (delays and increased risk of accidents),
- Costs imposed on society as a whole (environmental pollution, noise, global warming, etc.).

Hence, firstly a distinction between private and other social costs is made, where private costs are most often borne by the road or vehicle user and therefore directly internalised. The social costs comprise the extern social costs not born the private road user and the internalised social costs borne by the private road user. The extern cost components of the social cost of road use are generally used as the basis for the social marginal cost pricing calculation.

Table 1 summarises the distinction by presenting common negative externalities associated with motorised travel and (marginal extern) social cost calculations as well as the individual or private costs of car use born by each user.

[1] External economies are mentioned in Marshall (1890, p. 266).

Table 1 Overview of social and private cost components of car use

Negative externalities their social costs components vs. private costs generated from motorised travel	
Negative externalities and extern social cost components from car use	Private, internalized costs from car use
Congestion cost:	Cost of car trip before taxes:
- time losses, i.e., extra time costs caused to other road users,	- car ownership,
	- maintenance,
- vehicle operating costs,	- fuel, parking,
- environmental pollution, etc.	- insurance, etc.
Health risks, fatalities and infrastructure damage from road accidents	Own time costs
Air pollution, e.g., CO_2 emissions	Taxes related to car and fuel expenditures
Noise exposure	Other car use related charges
Climate change	Own accident costs
Other externalities:	Insurance premium for accident costs caused to others
- damage of nature and landscape,	
- land use,	
- soil and water pollution,	
- up- and downstream processes,	
- additional costs in urban areas,	
- energy or fossil fuel dependency of the motor vehicle sector, etc.	
Sources: Delucchi (1997), Quinet (2004).	

The total amount of the social external costs results from the summation of the cost components enumerated in the first column of Table 1.

Externalities can be basically defined as a situation where the economic activity of one agent alters the profit or utility of at least one other agent in the economy and is not accounted for by the market. According to economic principles of the neoclassical economic theory this leads to a market failure providing a suboptimal or Pareto inferior solution. Some scholars argue that the growth of road traffic and resulting externalities are the result of distorted pricing policies for the different modes of transport, in particular road travel. The failure to account for external costs in transport prices have led to excessive growth of the more polluting modes of transport and on the other hand hampered the growth of more environmentally friendly modes.

Hence, many scholars, among them Marshall (1890), Pigou (1920), Smith (1937), Dupuit (1952 [1844] and 1962 [1849]), Vickery (1948 and 1968), Coase (1946), or Mohring (1964 and 1976), have been arguing in favour of (mainly) government intervention. The existence of externalities justifies therefore government intervention, e.g., through the introduction of prices to internalise given externalities.

2.1.2 Marginal social cost pricing principles

The efforts behind the assessment of social road use costs are induced by the need to set (road use) prices as a method of resource allocation. The argument that the “right” price does not exist has important implications for the discussion of road pricing where different cost calculation approaches have been developed over the last century. Hence, pricing is based on the principle that it should rather reflect optimal pricing strategies that allow reaching specific goals. The optimal profit maximising price may not coincide with the price that would lead to the welfare maximum (consumer oriented) vs. one that would cover long run investment decisions (supplier oriented). The main difficulty of pricing policies – in particular also in the case of road pricing – lies in finding the general consensus on the objective or the goal to be achieved by a price setting (Button, 1993a).

The theoretical argumentation behind the market failure due to the uncovered social cost in case of car and road use is often discussed based on the (graphical) reasoning behind the basic road pricing model as presented in Figure 1.

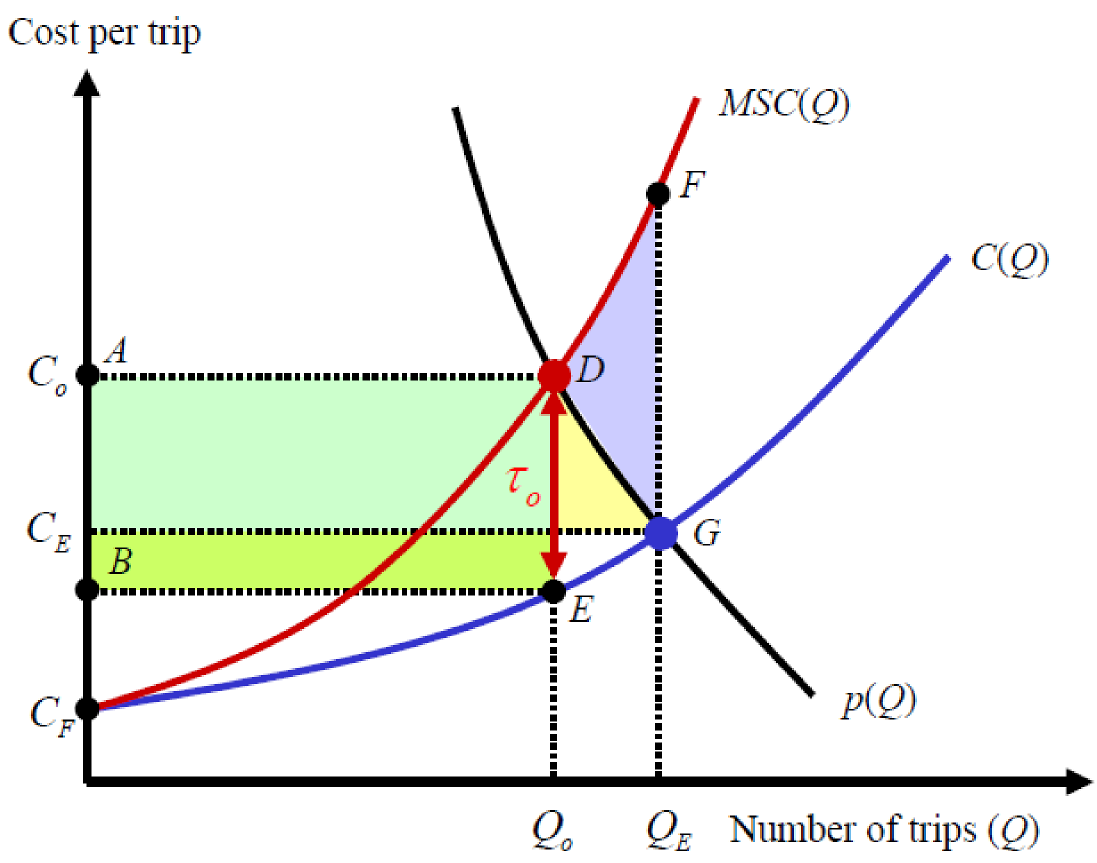

Figure 1 **Optimal taxation in the presence of social costs from car road travel with a basic road pricing model**

Sources: The presentation of the Figure 1 is a modified version of Walters (1961) Figure 1.

Within the figurative representation of the basic road pricing model – that can be basically applied mainly to congestion related externality calculations – (see Figure 1) the following assumptions are made: each individual makes one trip, as one person per vehicle, along a single section of road between a common origin and a common destination. The number of trips, measured as an hourly flow, is plotted on the horizontal axis. The cost per trip defined as vehicle operating costs plus the opportunity cost of travel time is plotted on the vertical axis. As the number of trips Q increases, congestion eventually forces drivers to slow down, increasing the average cost of a trip C(Q) through time delays. The motorist's marginal cost coincides with average cost when each motorist accounts for a negligible fraction of flow and all trips are identical in cost. Hence, the function C(Q) is assumed to represents both the average cost and the private marginal cost of car (and road) use.

Demand for trips (and trip utility) is described by a conventional downward-sloping inverse demand curve p(Q). Without road pricing equilibrium arises at the point of intersection G, where Q_E trips are made, each at a cost C_E. The equilibrium is inefficient because car users ignore the fact that they absorb road capacity and therefore leaving less space to the remaining road users. The excess demand of road capacity imposes time delays and therefore causes additional time cost to other motorists. Moreover, the private cost curve C(Q) does not consider additional costs imposed by the individual car user on the society as a whole, i.e. environmental damage, noise, etc. (see Table 1). The total social cost of Q trips is $TC(Q)=C(Q)*Q$, and the marginal social cost of a trip is $MSC(Q)=\partial TC(Q)/\partial Q=C(Q)+\partial C(Q)/\partial Q*Q$. The social optimum is therefore represented by the point D of intersection between the MSC(Q) and p(Q). The socially optimal number of trips Q_O is less than Q_E. To reach the social optimum road users must bear the cost of C_O including the cost they impose on other road users as well as on the general public. This can be realized by introducing an extra charge for road use at the level of $\tau_O=MSC(Q_O)-C(Q_O)=\partial C(Q_O)/\partial Q_O*Q_O$, where τ_O equals the marginal external congestion of a car journey and can be extended to include other social costs generated from car use. τ_O is also known in the literature as the "Pigouvian tax" or the "Pigouvian toll" and its formula is intuitive since it equals the marginal delay imposed by a driver on each other driver $\partial C(Q_O)/\partial Q_O$ multiplied by the number of other motorists Q_O. The social welfare gain from imposing the additional road use charge is measured by the increase in social surplus covered by the area DFG. It results from the reduction in total costs minus the reduction in total benefits due to the decrease in traffic.

The argumentation behind the model described in Figure 1 might be convincing, nevertheless the model implies a number of rather unrealistic assumptions and difficulties when it comes to the real world implementation of its formalized mechanism.

Some of the often criticized assumptions introduced into first best solution models for the sake of its simplification are:

- Ubiquity of user charges,
- A single road connecting one origin to one destination (no junctions),
- One user per vehicle,
- Travelers are assumed to have perfect information (no uncertainties),
- Vehicles contribute equally to congestion,
- Identical individuals except for their reservation price to make a trip,
- Traffic flow, speed and density are uniform along the road, and are independent of time,
- Congestion is the only market failure; i.e. there are no other transport externalities or distortions elsewhere in the economy and they would have to be additionally incorporated into the model framework, and
- There are no shocks due to accidents, bad weather, special events, etc.
- Rest of the economy operates under first best conditions

Moreover, not only the simplifying assumptions have been subject to critical discussion among scholars in the field of economics as well as engineering, the modeling framework and the theoretical idea behind road pricing has been bearing an important number of substantial concerns. Firstly, imposing road pricing increases drivers' private costs since it follows the objective of road capacity management in terms of car travel reduction. The road pricing revenue accrues to the pricing operator, which is usually assumed to be a government agency. Hence, after paying the additional road use charge motorists end up worse off in the first place. The Q_O users who continue to travel per unit of time suffer a cost increase of C_O-C_E, and the Q_E-Q_O motorists who give up road use suffer a loss of surplus that ranges from zero for the marginal user at Q_E in the pre-policy-intervention situation to C_O-C_E for the new marginal user at Q_O. This argumentation is limited to the road and car user society, if the analysis focuses on congestion externalities. However, the argumentation can be extended to the society as a whole, including its non-motorised members through the consideration of social marginal costs of externalities.

Undoubtedly, these losses give grounds for opposition to road charging. The welfare decline can be compensated only if the government uses at least part of the revenue to invest into road capacity expansion, to improve alternative transportation means, to cut other user charges, or to introduce rebates to drivers in some lump-sum manner. In his discussion of external economies Pigou (1920) implicitly promoted the use of appropriation suggesting that the revenue from the social cost internalization measure should be "devoted exclusively to the execution of new and specific road improvements", to the effect that "in the main, the motorist does not pay for the damage he does to the ordinary roads, but obtains in return for his payment an additional service useful to him rather than to the general public" (Webb and Webb, The King's Highway, p. 250 in Pigou 1920 p. 193). This argumentation refers to some extent to the idea that the internalisation of external effects from road use is indirectly linked through road damage to the aspect of infrastructure network financing.

Secondly, the mere collection of road charging entails infrastructure, operating and administration costs, including the inconvenience for motorists. Is the demand for car travel rather price inelastic – as it is generally the case in the short run – the charging revenue (covered under ADEB in Figure 1) is substantial compared to the welfare gain DFG. But it should be kept in mind that the net social benefit from road pricing can easily turn negative as soon as its proportional collection cost per unit of collected revenue becomes high.

Hence, Pigou's idea of government intervention through internalisation of externalities was not fully uncontroversial on the basis of regulatory policy principles. According to Knight (1924) and against the Marshallian tradition of external economies, government intervention and public transport management were less efficient than private transport management and were therefore considered superfluous. Almost half of a century later Coase (1960) brought into the debate the aspect of transaction costs, being in general higher for multilateral transactions when private parties are involved than for government intervention. In this case public regulations may be more efficient.

To overcome some of the simplifications and shortcomings of the theoretical approach as presented in Figure 1, especially with regard to congestion charge modelling, additional specifications were included in the time-independent model to make it time-dependent.[2] This is in line with the fact that travel demand is not constant over time. The additions refer to how travel demand depends on time and how traffic flows change over time and space. The aspect of special travel demand distribution and road capacity use results from the fact that road infrastructure supply can be considered as flexible (and extendible) in the long run, in the short run or at a given point in time it has a limited capacity. For the theoretical consideration of excess road use demand and congestion (externalities), the objective will be to model the welfare optimal level of congestion rather than to model congestion-free social optimum. Nevertheless, first best approaches to road pricing calculations remain subject to strong criticism. Significant barriers regarding the implementation or the calculation of the mathematical solution for the different first best optimization approaches are the unrealistic assumptions underlying the models as well as the estimation of the C(Q) and p(Q) curves.

With the introduction of second best approaches to marginal social costs calculations at least the dilemma with some of the difficult to meet assumptions underlying the first best models have been tackled. According to the economic principles underlying first best road pricing solutions tolls are calculated equivalent to the external costs generated by each motorist or traveller. The economically efficient first best solution is assumed to encompass the optimal road use at its maximum efficiency. Nevertheless, first best pricing has been criticized as of largely restricted practical relevance turning interest to second best pricing as being closer to the practical reality. In second best approaches to road pricing calculations, one or more of the restrictions or model assumptions required for the first best solution as enumerated above are modified or removed. Beckmann et al. (1956) argue for example that it is straightforward to compute first best tolls on a road network assuming the ubiquity of user charges and perfect information, but if tolls are restricted to only some links of the network or are held constant over time the second best approach becomes more

[2] The consideration of individual time values plays a particular role when road charging is applied given the objective of a congestion management mechanism. With regard to equity concerns it has been a general argument whether congestion charges work in a regressive manner, i.e. in favour of high income groups who are assumed to have higher values of time and therefore their profit from congestion reduction exceeds the burden of paying the congestion charge (Richardson, 1974; Evans, 1992; Arnott et al., 1994; Small, 1983; Transek, 2002).

suited for solving the problem. Some examples of the second best based pricing solutions are cordon pricing around city centres instead of overall network charging, the implementation of stepwise pricing instead of smoothly time varying pricing schemes, or road pricing according to fixed instead of varying daily traffic conditions. Thus, “in reality, the optimal prices are non-unique and deviate from marginal external costs, since they can be practically imposed only on a set of links, and/or include the effect of several other restrictions and market distortions, hence, yielding ‘second-best’ pricing settings” (Tsekeris and Voss, 2009).

In other words, the approximation of the theoretical model with its optimum calculations to the real life situation requires the relaxation of some of the Paretian optimum conditions. This is where the optimisation approach is being transferred from a first best to a second best solution. As it is known the attainment of a Paretian optimum requires the simultaneous fulfilment of all the specified optimum conditions. The general theorem of the second best indicates that if one of the Paretian optimum conditions cannot be met due to some constraints a second best optimum solution is achieved only by giving up all other optimum conditions. Hence, the failure of fulfilment of one of the optimum conditions makes the attainment of the remaining conditions obsolete, even if they are still attainable. The resulting second best optimum situation is therefore by definition attained subject to a constraint that hinders the realisation of a (first best) Pareto optimum situation (Lipsey and Lancaster, 1956).

Nevertheless, to solve mathematically for the optimum at point D and for the optimal pricing level at τ_O under first best or second best optimality conditions remains rather complex. Even the rules necessary for second best optimum attainment are quite challenging since they have to take into account an array of indirect effects. The computation of the optimum requires the estimation of the (individual) demand and cost functions, including elasticity parameters. Even with the current advances in computation techniques and data collection methods this remains a demanding undertaking, regarding the requirements and theoretical assumptions inherent in marginal social cost and efficient price calculations (Lindsey, 2003; Lindsey and Verhoef, 2001; Nash, 2001; Rouwendal and

Verhoef, 2006; Rothengatter, 2003).[3] They involve detailed information on the composition and the sum of the external costs caused by transport, including e.g. heterogeneous trip-time preferences and time values of individual road users, i.e. anonymous vs. non-anonymous, or type-specific pricing. Especially the estimation of overall congestion costs and the money value of lost travel time based on opportunity costs calculations face major theoretical and measurement obstacles (Button, 1993b).

Rothengatter (2003) points to additional restrictions implied by the simple textbook approach that throw a critical light on the implementation of the marginal social cost pricing approach:

- Complex measurement,
- Equity is ignored,
- Dynamic effects including investment decisions and technology choices are not taken into account,
- Financing issues are ignored,
- Institutional issues (public economics) are ignored,
- Price distortions elsewhere in the economy are ignored.

2.1.3 Alternative approaches to marginal social cost pricing

Another critical aspect of (social) marginal cost pricing taking into account some of Rothengatter's (2003) critical notes is the distinction implied between short run vs. long run marginal cost. In line with the short run marginal cost pricing approach no additional infrastructure provision is taken into account rendering infrastructure capital costs irrelevant. The long run marginal cost pricing approach assumes that infrastructure experiences an optimal expansion as response to additional traffic, reducing in turn the additional negative effects from traffic congestion externalities. Hence, if capacity is optimally adjusted up to the point where the additional capital costs of expanding capacity

[3] For extended literature review on road pricing theory also see Langmyhr (1995 and 1997), Morrison (1986), and Small (1992).

equal the reduction of the otherwise generated marginal costs from excess travel demand the short run marginal cost and long run marginal cost equalise. The main problem with equivalence assumption between the short run and long run marginal (social) cost pricing is the fact that in most cases road capacity cannot be easily and flexibly, optimally adjusted to demand.

As suggested by the neoclassical economic theory marginal social cost pricing, defined as the sum of the costs imposed by an additional user on the network, on other users, and on the society as the whole, is the welfare maximising, first best pricing scheme for charging transport infrastructure use. It is also general consensus that short run marginal cost is the proper pricing approach. Nevertheless, the considerations of long run marginal cost pricing methods may be appropriate when decisions about the provision of additional road capacity need to be accounted for within the optimal price calculation. This is for example the case when self- financing constraints of the network or an inter-modal transportation system are applied to the calculation of the marginal social cost optimum. The optimal road charge will then tend to exceed the intercept between the social marginal cost and the travel demand curve and be located above it, where the average cost curve and the car use demand curve cross each other.

However, on the theoretical basis and under certain assumptions Mohring and Harwitz (1962) accomplished to bring together the short run social marginal cost pricing approach and the postulate of infrastructure capacity coverage. The resulting cost-recovery theorem implies that the revenues from short run social marginal cost pricing suffice to pay for optimal capacity if capacity is perfectly divisible and supplied at constant marginal cost, and user costs are homogeneous of degree zero in usage and capacity. Therefore, the cost-recovery theorem seems to overcome the conflict between short run social marginal cost pricing and the average or the full cost pricing approach based on revenue coverage criterions. Part of the research that followed the idea of road pricing serving as a financing source to pay for (road) infrastructure provision explored the robustness of the cost-recovery theorem to relaxation of assumptions (Newbery, 1988 and 1989; Small and Winston 1988; Small, Winston and Evans, 1989). Again, already Dupuit (1962 [1849]) referred to road charging as to an instrument for covering long-run costs of road construction and maintenance in the sense of a “funding toll”, rather than to manage road use in terms of a “decongestion toll”.

Especially growing political interest in and willingness to actually implement road pricing schemes in practice helped to navigate the theoretical debate about second best marginal social cost based price calculations for road use towards alternative pricing theories, where the focus also lies on balanced budgets within as well as between the transportation sectors, similar to the idea of the cost recovery argument. To mention just two alternative pricing rules, average cost pricing and Ramsey (1928) pricing are both considered as deviations from marginal social cost pricing. According to the average cost pricing rule prices are equal to the sum of financial costs of the mode in consideration divided by its total volume. The structure of resource costs, i.e., fixed vs. variable, sunk or not, etc., and the type of the transported medium, i.e., goods vs. passengers, are not specifically taken into consideration within the calculation approach. The main objective of average cost pricing is cost recovery. Many forms of average cost pricing exist since the numerator and the denominator are to some extent arbitrary. Therefore, several volume indicators can be used for the cost calculation, e.g., trips or vehicle kilometres for passengers and ton kilometres or vehicle kilometres for freight. Furthermore, differences within accounting rules used within the average cost calculation are not always uniform, e.g., in terms of depreciation rules, etc. and can therefore result in different total cost concepts (Jha, 1998).

The discussion about the implementation of short run marginal social cost pricing to induce “efficient” usage of roads vs. average cost pricing to finance them goes back to the research era of Dupuit and Pigou. The difference between the two approaches lies especially in the requirements related to their calculation, where marginal social cost pricing requires the variation of charges with respect to space, time and vehicle, or user characteristics calling for finer pricing instruments than average cost pricing.

The rule applied for the calculation of Ramsey social cost prices is based on the idea that prices are set as optimal deviations from marginal social costs. The deviations are required to meet cost recovery targets for the transport sector as a whole. In the case when the revenues collected based on the marginal social cost pricing do not cover the financial cost of infrastructure (use), Ramsey pricing requires that the margins (price-marginal social cost) are increased in a way that is inversely proportional to the elasticity of demand in the relevant market (Proost and Van Dender, 2003).

In economic terms, the basic idea behind the emerging alternative cost calculation rules is to calculate the optimal (most efficient) deviation from the first best to the second best pricing solution. This may also include the calculation of “third best” pricing, i.e., setting “quasi” first best tolls as if second best distortions do not exist or the application of other “rules of the thumb” to make the pricing calculation more appropriate for implementation in practice. Variable pricing schemes can still be recognised as generalizations of the marginal social cost pricing approach. The advantage of variable pricing rules is that they bring about efficient behaviour in the Pareto equilibrium without knowing initially what the state of efficient behaviour is supposed to be.

2.1.4 Policy frameworks and road pricing calculations

The implementation of road pricing policies and the application of transparent and politically approved calculation approaches can be facilitated by the introduction of regulative policy frameworks.

Therefore, the implementation of market-based instruments for internalisation of external cost has been validate in EU Directives, particularly related to infrastructure cost pricing. Hence, according to the amendment of the Directive 1999/62/EC adopted on 27 March 2006 – better known as the Eurovignette Directive on road charges – the European Union allows member states to levy tolls on all roads. Regardless its constraints, the Eurovignette Directive is a substantial leap forward towards the implementation of a European road charging policy (EC 1999, 2008, 2006, and 2009).[4]

[4] An important constraints of the Eurovignette Directive is the requirement that revenues may not exceed related infrastructure costs. Furthermore, the Directive limits the differentiation of charges according to capacity or environmental criteria allowing a mark up of maximum 25 % only for mountainous areas to reflect the higher infrastructure costs.

Concerning the question about the methodological approach to calculate or estimate cost components or price elasticities as the relevant inputs for the application of the economic theoretical concept of marginal social cost pricing, the European Commission has raised the issue of internalisation in several strategy papers, such as the Green Book or the Green Paper ‘Towards Fair and Efficient Pricing in Transport’ (CEC, 1995), the White Paper on efficient use of Infrastructure, the European Transport Policy 2010 (CEC, 2001) and it’s midterm review of 2006 (EC, 2006), including a number of research projects. The EC White paper of the overall transport strategy and the midterm review emphasize the need of fair and efficient pricing considering external costs. As part of the 4th Framework Programme and the following[5], the Commission sponsored a large amount of research on how to implement pricing policies, in terms of feasibility and acceptability problems and on resulting implications from their implementation (Nash, 2001).

A great number of the studies carried out on the behalf of the EU are concerned with the evaluation and the quantification of external costs:

- EU-Research projects of several framework programmes to estimate external costs (such as UNITE, ExternE, GRACE, etc.),
- Other EU projects on external and Infrastructure costs, particularly marginal costs of Infrastructure use – towards a simplified approach (CE Delft, 2004),
- National research projects and studies on external costs (particularly for the UK, the Netherlands, Switzerland, Austria, Germany),
- International estimates of external costs,
- EU-proposals to standardize marginal cost estimation (High level group approaches),
- EU-Networking projects to discuss pricing instruments (CAPRI, IMPRINT, MC-ICAM).

A number of EU research projects has been undertaken to evaluate and draw conclusions on potentials of efficient transport pricing. As summarized by Sikow-Magny (2003) the EU projects TRENEN-II-STRAN, PATS and AFFORD investigated possible

[5] Detailed description of funded EU Framework Programmes can be found under “Find Funding”, under http://ec.europa.eu/research/index.cfm (25.12.2009).

operationalisation options of the marginal social cost pricing principle. The projects PROGRESS, CUPID, DESIRE, and MC-ICAM dealt with implementation possibilities of marginal cost pricing.[6]

Also the implementation and evaluation of existing (road use) pricing policies on the national level are of great importance for the extension and a better understanding of the pricing mechanisms. In Europe, most often national pricing strategies were introduced in the sector of heavy goods vehicle (HGV) charging including several countries, such as an HGV-fee mostly covering the intercity national road network (Autobahn) in Switzerland since January 2001, Austria since January 2004, or Germany since January 2005. Urban road pricing schemes, mostly aiming at the reduction or a better management of inner-city car traffic in terms of a congestion charge, were introduced for example in Bergen (Norway), London (United Kingdom), and Stockholm (Sweden), as well as in Valetta (Malta) and Milan (Italy).[7]

The advantages of road pricing are the flexibility of implementation, the direct reference to car use instead of to its inputs, and the ability to differentiate it between varying user categories. The implementation of marginal social road pricing in practice is likewise concerned with objectives of welfare distribution and social equity, especially when is discussed in practice focusing on public acceptance concerns.

Historically, the main fiscal instrument in practice affecting motor vehicle use has been the fuel tax. Its main purpose has been to raise revenue rather than to finance infrastructure investment. The mechanism behind road infrastructure finance in Germany is not based on a clear-cut (tax) revenue inflow and finance outflow account, i.e., not all of the finance outflows are covered from inflows collected for the exclusive purpose of road infrastructure investment but from other state funds. Due to the growing gap between rising motorised travel demand and limited budgetary sources provision of road capacity has become a major challenge. One reason for the expected melting away of traditional, primarily tax

[6] For an overview of EU research projects on potentials of efficient transport pricing see http://www.transport-pricing.net/ (01.11.2009).

[7] An overview of implemented road pricing schemes can be found under (http://portal.wko.at/wk/format_detail.wk?angid=1&stid=240298&dstid=7164&opennavid=31614 (01.11.2009).

based road infrastructure financing sources in the future is the likely revenue shortfall from fuel taxes entailed be fuel consumption efficiency gains. While technological improvements of fuel use efficiency lead to decreasing fuel consumption, car use and therefore infrastructure use stagnate or even continue to grow. Within the current EU context road charging has been also regarded as a more and more important revenue source for the construction of the trans-European transport networks and 30 additional transnational projects declared of particular interest to the European Union.[8] Therefore one objective mentioned in the White Paper of 2001 (CEC, 2001) states "The thrust of Community action should be to replace gradually existing transport system taxes with more effective instruments for integrating infrastructure costs and external costs (in the price of transport). These instruments are, firstly, charging for infrastructure use, which is a particularly effective mean of managing congestion and reducing other environmental impacts, and, secondly, fuel tax, which lends itself well to controlling carbon dioxide emissions".

2.1.5 Introduction of road charging in Germany

In Germany freight or heavy goods vehicles (HGV) have been charged a distance dependent toll for the use of the intercity national road network (Autobahn) since January 2005. So far charging of cars remained on the level of a political debate and feasibility studies. It is probably not unrealistic to assume that the existing HGV tolling technology could be extended to the sector of passenger cars as well as urban roads after advanced technological adjustments have been undertaken.[9]

In general, provision of public roads together with government intervention through the introduction of road charging can be considered also in Germany an efficient alternative to revenue seeking for infrastructure investment and traffic management. Often, practical

[8] Decision 884/2004/EC.

[9] According to the RECORDIT program the difference between external costs in interurban and urban road use varies depending on vehicle type from 5 to 60 Euro-Cents per km.

implementations of road pricing function rather as revenue generating mechanisms, than as road use demand management or restrain tools (Paulley, 2002).

The implementation of road charging policies requires the specification of the level and the type of charging. In this work it is assumed that imposing a road charge will align the private cost of a car travel closer with the marginal social cost of car use. For the model implementation described in Chapter 5 the level of road charging is set based on social marginal cost pricing calculations for Germany and with regard to the results obtained for other EU countries. The scenario analysis is carried out based on 0.05 Euro per km, distance dependent road charge imposed as a mark-up on the variable car travel costs on private car drivers. In line with the economic theory the charging measure applies to travel along a link, covering the entire road network. Hence, there is no incentive for road users to divert their traffic to uncharged roads. The 0.05 Euro per km road charge rate is a lower bound, averaged estimate drawn from a survey of German as well as European studies on road infrastructure cost assessment as well as external average and marginal social cost calculations. However, methods used for (full) road transport cost assessment vary and resulting numerical estimates differ since they are often based on different assumptions as to the kind of costs included into the calculation. The rate of 0.05 Euro is set as one half of the reference value from average external cost calculations for cars and is assumed to correspond to the lower bound from marginal external cost calculations taking into account the general external costs categories (see Table 1) (Herry and Sedlacek, 2003; IMPACT, 2008; IVT, 2004; Infras/ IWW, 2000 and 2004; RECORDIT; UNITE).[10] [11]

Albeit the historical tradition and established and uncontroversial theoretical reasoning – especially among economists – in favour of road charging, the pricing instrument has been

[10] Even though road charging schemes (when based upon Pigouvian taxation principles) are often related to the principles of internalization of external costs from motorized road use, they not always meet this maxim. Verhoef (1995) suggests therefore, the need to assess externalities occurring after implementation of “optimal” road charging policies. Despite the difficulty to determine prices for positive or negative externalities of a different spatial scope (Owens, 1995), this aspect is somehow relevant for the equity and distributive impact evaluation in the context of road use charging and revenue redistribution.

[11] In general, the implementation of a road charge is expected to bring about a more efficient utilization of the entire transport system and thus create a social surplus. However, the policy definition implied does not fully correspond to the marginal social cost pricing principles. To some extent, the implementation of the road charging policy follows the restrictions implied by the modeling framework applied in this work. A more detailed description of the policy scenario definition for the model implementation is included in Chapter 5.1.

ever since struggling for public acceptance and a broader dissemination in practice (see also Chapter 1.1.2) (Gaunt et al., 2007). Transport economists often endorse the positive economic effects from road charging. The research literature often cites the Smeed Report (U.K. Ministry of Transport, 1964) claiming road charging being irrefutable. Nevertheless, reluctance towards road pricing measures among politicians and the public is the common case. Only recently, the implementation of road charging has been gaining interest partially due to technological innovations and new electronic solutions, which could remedy some of the existing shortcomings. More sophisticated road charging adjusted to specific time frames, road categories, or even user groups could be implemented efficiently ensuring convenience and lower operating costs, also taking into account the controversial issue of data confidentially.

This implies the importance of investigating the interrelation between acceptance of road charging measures, its welfare and distributive effect, and the underlying sociodemographic and economic characteristics, land use structure, territorial population distribution within an overall macroeconomic picture. Oberholzer-Gee and Weck-Hannemann (2002) suggest the incorporation of environmental quality within the design of road charging instruments to ensure the fairness of the system and in this way to win public acceptance. Viegas (2001) discuss the influence of equity on political and public approval of road charging mechanisms. Hence, even though the overall economic net welfare effect from road pricing will most likely turn out positive, it may not enhance the public acceptance as long as it neglects distributional and equity effects concerning the burden and profit sharing of different socioeconomic groups. However, the expected individual welfare enhancing effect from the pricing measure can be generally brought about through the road charging revenue use. The design of the revenue redistribution scheme according to established technological, institutional and acceptability related barriers could be implemented to counteract welfare equity concerns. Based on results from standard neoclassical methods of welfare analysis and from equity assessment (Atkinson, 1970) simulation analyses of net benefit and equity implications can be carried out introducing different road charging revenue redistribution schemes between the general consumer sectors included in the model. Hence, the policy simulation studies varying in revenue redistribution are described in detailed in Chapters 5.1 and 5.2. Chapter 5.3 presents the results from the policy reform implementation within the modelling framework applied in this work. The results provide valuable implications for potential acceptability of such policy reforms. The modelling results for Germany lead to the conclusion that differences in distributional effects with respect to equity impacts are strongly related to the revenue recycling patterns as well as to household specific travel demand profiles that are depending on income and residential location.

2.2 Discussion: acceptability of road charging

Despite the (overall social) welfare improving function of road charging, hardly anybody imposed to such a measure values it as putting the society better off. This negative individual perception is one reason for the general lack of public acceptance of road charging. Also the aspect of public revenue generation is generally ignored. Another reason inhibiting the introduction of road charging comes from uncertainty about the negative equity impacts resulting from the measure. In many cases road charging is suggested to have a regressive impact (with regard to income), which means it is more disadvantageous for the poorer drivers. Therefore, even though in many countries the existence of institutional barriers is blamed for impeding the realisation of road charging schemes (Glazer et al., 2001; Schade and Schlag, 2003), the absence of public and of political acceptability remains the most difficult barrier to eliminate on the path to the introduction of road charging measures (Bartley, 1995; Luk and Chung, 1997; Jones, 1998 and 2003; Schade and Schlag, 2000a, 2000b, and 2003; Link and Polak, 2001; Jaensirisak et al., 2005). The examination of the acceptability of urban road pricing conducted in eight European cities within the European project PRIMA (2000) came to the conclusion that on average less than 30 % of the population support such measures. Consequently, only few implementations of road charging exist this far, of which some are suboptimal solutions of indirect charging and do not take into account the distance driven, hence the individual road use (e.g. cordon pricing, city toll, etc.). Except for urban road charging schemes established in Singapore, Oslo, Bergen, Trondheim, Stavanger, or London (often referred to as congestion charging), sophisticated systems of this kind have never reached beyond the planning stage. Gaunt et al. (2007) lists numerous cases, where intentions of implementing road charging never materialized. Yet, the set-up of road charging schemes has not only to satisfy public acceptance criteria, but it has to be effective in meeting its primary objectives of road use management, or revenue generation (Jones, 1998). The significance of public acceptance for an unobstructed functioning of road use charging is equally valued as and also dependent upon the technical success of the scheme. Also important is the integrated transport policy accompanying the pricing reform, e.g. in terms of the level of car ownership and use related taxes and levies other than road charging (Gray and Begg, 2001). Obviously, public acceptance of road charging depends on the amount charged, where lower charges are more likely to be accepted than higher ones (Safirova et al., 2002 and 2003; Jaensirisak et al., 2005).

However, public resistance to road use charging is neither a static nor an irreversible phenomenon. It is linked to numerous factors, such as sociodemographics, economics, residential geography, individual attitudes, political views, or the design together with the implementation characteristics of the charging scheme itself. Car ownership or car availability and perception of benefits to oneself and society have also a significant influence on the success of the implementation of road charging policies (Jaensirisak et al., 2003). Studies evaluating efficient pricing policies suggest, that pricing policy design and implementation need to consider in the first place resistance from car users. For a road charging policy to be publicly approved it has to be perceived as beneficial to each individual who is subject to the measure, to the overall public, or to both. Is the measure putting the society and its members better off, increasing their welfare, or environmental quality, it is more likely to be perceived as worth being paid for and as a result gains acceptance (Giuliano, 1994; Goodwin, 1997). According to Schlag and Schade (2000a) one of the most decisive factors in favour or against road charging reforms is the way in which the revenues from the measure are reallocated. Therefore, hypothecating revenues towards specific targets, such as e.g. public transport, increases significantly public support for road user charging reforms.

Another crucial factor related to the acceptance of road charging policies are equity concerns linked to distributional effects (Gaunt et al., 2007). Although it is known that road pricing will normally generate a net welfare surplus the argument alone may not be particularly convincing in a real-world situation. The reason is that the argument neglects equity effects in terms of the distribution of costs and benefits of the measure across socioeconomic groups. Equity and distributional impacts can embrace the social or geographic sphere, and have an adverse effect on population with lower income or disadvantaged social status or the economic prosperity of certain spatial zones. Putting the needy groups relatively worse off than others or than was their initial state before road charging, increases the chance for the measure to be rejected (Jones, 1998 and 1991; PATS Consortium, 2001; EURoPrice, 2002; Bell et al., 2004). A transparent and comprehensible design of the policy measure and the revenue use are likely to evoke public acceptance. The design of the revenue reallocation scheme can help to communicate the overall benefits from the measure making them more visible.

Putting the two aspects together, adequate compensation of disproportionately “penalized” entities by the road charge through the design of the revenue reallocation scheme affects the resulting welfare distribution and finally the acceptance and feasibility of the policy measure. As a number of studies concerned with acceptance of and equity effects from road charging reforms acknowledge, that revenue reallocation schemes designed to cut other taxes or improve the public transportation system contribute positively to the endorsement of road user charging (Jones 1991; Ison 2004; Harrington et al. 2001). The design of revenue redistribution schemes that will have a positive welfare outcome and lead to public support of road charging policies requires information on potential impacts from road charging on different population groups in the first place. This overlaps with the objective of this thesis work. There exist a number of theoretical studies concerning equity effects (Arnott et al., 1994; Glazer and Niskanen, 2000; Richardson, 1974; Richardson and Chang-Hee, 1998; Small, 1983). They all largely conclude that equity effects will in general depend on the design of the road charging policy including revenue recycling and on socioeconomic differences in travel patterns, i.e. how mode and destination choices differ across income or other population groups. However, there are significantly fewer studies on detailed, quantitative assessments on equity impacts. The objective of this dissertation work is to contribute in closing this knowledge gap using an adequate methodological approach and an extensive data basis for Germany. Chapter 2.3 sheds more light on the theoretical discussion about equity, welfare and distributive issues that arise in the context of road charging.

2.3 Equity concepts and criterions

The design of the charging policy as to the level of charges imposed on each road user and the revenue redistribution scheme are two important aspects of equity and redistribution considerations in the context of road charging policies.

In general, not all impacts induced by imposition of charges on road use can be perfectly assessed. Ex-ante assumptions for supply adjustment to changes in demand are not straightforward to make. Potential elasticity parameters gathered from different empirical studies and literature sources are afflicted with an array of uncertainties. Implications for road charging scheme designs, as to who is charged how much, where and at what time, are derived from for the most part simplistic, model based studies. Hence, it needs to be kept in mind when analysing impacts and discussing scheme designs of road charging and revenue recycling that the theory behind it is founded upon reduced assumptions compared to the reality (Pigou, 1920). However, when it comes to welfare impacts, high-income categories are most often recognised as ending up better off after road charging implementation than low-income groups (Else, 1986; Giuliano, 1992; Hau, 1992). With everyone paying the same amount of road use charge for a distance unit travelled (km), disproportional burden is likely to be levied on low-income car users. This aspect may be seen as controversial, nevertheless it lays down the link between road charging and economic concepts of welfare distribution, equity and acceptance.

Realised mobility patterns and travel expenditure profiles of individuals or private households reflect their choices made based on subjectively valued choice alternatives, taking into consideration the utility and the cost of the choice alternative. Travel cost increase through the imposition of road use charges or augmented fuel taxes introduced for example as measures to internalise the social marginal cost of negative externalities from motorised vehicle travel. They will generate (fiscal) revenue, but at the same time alter travel choice behaviour.

Social marginal cost based road charging generates a social welfare gain, which can be redistributed to the different economic sectors or groups within the society. Distributional and equity concerns entail the question to which aggregates and in what division the revenue should be reallocated. Aggregates such as car users or people belonging to the same income category still constitute a heterogeneous group of individuals. Transferring revenues from road charging according to households' income level might still miss the equity criterion in terms of welfare distribution (Morrison, 1986, p.93).

The concept of distributive equity is difficult to grasp from the economic theory perspective. Distributive effects, equity effects, equity distribution, welfare effects, welfare economics are some of the terms related to the effort to assess the "fairness" or "justice" of a policy intervention in the functioning of markets or the society.[12]

In economics the concept of equity or the idea of fairness originates from taxation or welfare economics, where it is distinguished from economic efficiency in overall evaluation of social welfare. Describing welfare distribution the equity concept is used to describe a fair and socially acceptable allocation in contrast to economic inequality. However, equity is used in a broader sense. In public finance horizontal equity describes the idea that individual ability to pay taxes should determine the tax amount paid and this applies to all individuals. Hence, same individual affordability means same tax burden and is in line with the concept of tax neutrality and against distortion of (economic) behaviour. On the other side, the concept of vertical equity used in public finance refers to the idea that people with a greater financial ability should pay higher taxes. In contrast to a tax burden proportional

[12] In established literature on equity distribution the terms equity, fairness, or justice are used as synonyms (Blanchard, 1986).

to income stands the concept of progressive taxation, where with increasing income an increasing proportion of it has to be allocated as tax contribution to the state budget. Progressive tax policy is further associated with distributive justice and redistribution. Hence, the total consumer welfare is not the only aspect to be examined. The way consumer welfare is distributed among society's members and how equitable that distribution is are at least as relevant. The general consideration of equity with respect to horizontal vs. vertical equity can be linked to Rawlsian principles of justice (Rawls, 1999). Hence, horizontal equity refers to the distribution of welfare among individuals who are otherwise identical, drawing from Rawls's "principle of equal opportunity". Vertical equity refers to the distribution of welfare among individuals who are unequal in other respects, drawing from Rawls's "principle of difference". Additionally, a third form of spatial equity has been specified by Raux and Souche (2004) implementing Rawls's "principle of liberty" as the right of access to any location in space.

Imposition of road charges on road users can be understood in a broader sense as a form of policy intervention. The difficulty with the assessment of fairness and equity is that it is in principle a normative criterion – the question is, can a universally accepted definition of fairness exist and be operationalised in terms of measurement. Distributive effects in terms of welfare reallocation between different population aggregates after policy reform implementation are possible to calculate. It is not an exception that policy evaluation integrates distributional considerations. To conclude, whether the observed shifts of burdens and benefits are consistent with equity conditions is much more ambiguous. Firstly, equity does not have to mean that everyone ought to bear equal gains or losses. Secondly, accounting for equity effects does not automatically mean, that equity concerns on all sides are equally taken into account. Defining and ensuring fairness is all too often an impasse rather than a straightforward decision.

There exist a number of partially even inconsistent concepts for equity (Blanchard, 1986). Langmyr (1997) takes on from the literature "thirteen distributive principles or criteria" pointing to the relevance of the specific environment to which they are applied. Examples for such analytical dichotomies proposed to assess equity distributive concerns are, e.g.

horizontal versus vertical equity, as being probably the most common approach, telelogical versus deontological ethics, or equality of chances versus equality of outcomes. Blanchard (1986) emphasizes seven rules to measure equity or fairness of policies, after exhaustively illustrating recent attempts in literature to prove different conceptions of justice in theoretical terms. He refers to such fundamental works as “A Theory of Justice” by Rawls (1971), equity norms as defined by Hochschild (1981), Levy et al. (1974), Ryan (1981), Miller (1976), or Lucy (1981).

Possible criterions for classifying or evaluating equity definitions are: explicitness, scope, or to what systematic extent they interrelate. Hochschild (1981) systematised the following equity norms: strict equality, need, effort made, money invested, results, ascription, and procedure. Overall equal shares are recovered by “strict equality”. “Need” and “effort” imply that redistribution takes place relative to given needs and expended efforts, respectively. An analogous implication applies to the equity norms “invested money” and “product”. If benefit or burden distribution is based on genetic or socially defined criterions, e.g. age, sex, or income, Hochschild (1981) talks about “ascription” being the underlying equity norm. Finally “procedure” links the distribution scheme to some specific procedural approach such as a certain kind of ordering or random lottery (Hochschild, 1981). Some of the equity concepts defined by Hochschild (1981) can be possibly applied for the impact assessment from car road charging; they can be used as guidelines for designing and evaluating revenue collection and redistribution schemes under equity considerations. However, the application of these norms depends on the formulation and the scope of the research question and is likely to be limited by the availability of data or information required for the assessment of these equity norms.

Other equity concepts found in the literature are “market equity”, “equal opportunity”, and “equal results” formulated by Levy et al. (1974). The concepts constitute a continuum with respect to the redistribution degree going from no redistribution when “market equity” is assumed to significant redistribution when the equity objective are “equal results”. Regarding the definitions underlying each of the three fairness concepts, differences as to the nature of the distributed or redistributed benefit need to be taken into account.

Distinction is therefore made between the quality and the monetary value of a service (-unit) that is being reallocated and the quality or scope to which the service has met the underlying objective. Applying this delimitation to the case of road charging revenue collection and redistribution, this would imply the distinction between provision of (road) infrastructure vs. assuring accessibility or meeting mobility demand financed by revenue from introduction of the policy measure. The latter concept corresponds better to the equity norm of “equal results”. Hence, “market equity” is achieved when the benefit redistributed to the individuals corresponds to the unique share provided at the cost of the benefit. This happens disregarding pre-existing inequalities in income or wealth distribution, which in fact are the prior basis for the distribution of the burdens and then for the allocation of the benefits. The “equal opportunity” principle implies that benefits are distributed at equal values irrespective the individual contributions made to the cost of the benefit provision. This depicts then a case of true redistribution, when the service is financed by a progressive scheme, meaning those better off contribute higher cost shares to finance it, but everybody is provided with equal shares of the service. Finally, fairness can be achieved when “equal results” are obtained. To translate this standard to the case of revenue redistribution from road user charging it could mean that after augmenting the price of private car use, revenue from the price increase is used to provide each individual with better or at least equal mobility opportunities with regard to the initial accessibility or the availability of “travel tools”.

Although existent definitions of equity norms originating from different “schools” are in some way comparable, their systematisation with regard to underlying implications can make a considerable distinction. The critical point is, how far does the equity norm refer to the allocation of resources vs. the allocation of outcomes. Is the road charging revenue distributed to equal monetary shares per car user, or is the objective of the road charging revenue redistribution to assure that each individual can reach his place of work and make the trip back home bearing an acceptable cost. It seems a reasonable assumption however, that the allocation of outcomes is determined by an initial distribution of resources. Ryan (1981) stresses the equity concepts “distribution of resources” (calling it “fair play”) vs.

“distribution of results” (terming it “fair shares”) contrasting them against each other within an ideological context.

Other examples of equity norms are the definitions formulated by Miller (1976). Hence distribution can arrive at fairness by “right”, “desert”, and “need”. “Right” implies that legislation ensures equity by entitling members of the society to receive services, benefits, and alike, irrespective the considerations. Within the concept of “desert” fairness is reached when benefits are earned and therefore merited. The fairness standard according to “need” assumes the existence of some basic “subsistence needs”, which have to be satisfied. Therefore, the subsistence needs define the share of benefit individuals are entitled to in order to establish fairness.

Lucy (1981) delineates five equity norms taking into consideration positions of practicing planers and particularly with regard to distribution of “urban services”: “equality”, “need”, “willingness to pay”, “demand”, and “preference”. New are the concepts “willingness to pay”, “demand”, and “preference”. Fairness is achieved when services are allocated only to those demanding the service and based on their individual “willingness to pay”. Therefore, only these users pay and their “willingness to pay” is determined by their ability to pay. This conception can again be critically contrasted against Ryan’s (1981) idea of “fair play” and “fair shares”. Since one’s willingness to pay reflects one’s ability to pay, the initial allocation of resources determines to some extent his demand for a specific service. It is likely to assume that one’s ability to pay does not reflect one’s need for the service, when referring to the norms “equality of results” or “fair shares”. According to the norms “demand” and “preferences” equity is satisfied when individuals are endowed with services or benefits they want. Individuals can communicate in different ways what it is they want, but they are not obliged to. “Demand” and “preferences” also consider the existence of individual desires that cannot or simply are not communicated or being asked for. The notion of what people or the society desires introduced into the summary of equity concepts is somehow different to what has been discussed so far. They basically address what individuals want rather than what they are entitled to (Lucy, 1981).

Referring the two types of commonly considered spatial (or horizontal) equity and social (or vertical) equity impacts, marginal social cost charging might be perceived as fair from the perspective of charging all road users for the externalities associated with their car travel. At the same time, marginal social road charging might be considered as “socially” unfair due to the fact that it is harder to bear for low income road users since it absorbs a relative greater proportion of their income (socially marginal journeys are not equal to economically marginal journeys). Distance based charging schemes applied to links and routes might appear more acceptable from a social equity perspective compared to cordon based charging. Potential existence of (temporally) uncharged links or routes implies a trade-off in routing and travel time choice depending on the individual value of time of the road user. Spatial equity refers to the road users’ residential location and travel destination, concerning in particular cordon or area charging policies. Cordon or area charging is likely to be regarded as inequitable if it is designed to apply a different charge to persons residing just within and just outside the boundary, both travelling the same distance within the boundary. Therefore a link or distance based system as is more likely to be viewed as favourable under equity concerns in contrast to an area or cordon based scheme.

In general, it has been argued if and to what extent road charges work in a regressive way, i.e. putting high income groups better off while penalizing population with lower income. The effect of road and in particular congestion pricing on (vertical) equity has been emphasised to work in opposite directions. On one hand high-income earners bear a higher tax burden by paying elevated income taxes as well as taxes and levies related to car use and car ownership (i.e. fuel or annual vehicle taxes), driving their cars more intensively and purchasing bigger and more expensive cars. The set-up of the current road finance policy is another aspect in this line of thought. Assuming the case when infrastructure provision is financed from taxes, e.g., income taxes, and the implementation of road charging would provide an alternative source to infrastructure financing, allowing to lower the initial tax burden, then through the substitution of tax funded infrastructure investment and tax rate cuts highly taxed income groups would experience a higher tax relief than low income earners. On the other hand the same population group is assumed to have higher values of time and therefore its profit from congestion reduction exceeds disproportionately the burden of paying the congestion or the general road charge.

However, the assumption that individuals with higher incomes attribute higher values to their time is not straightforward (Jones, 1992). As illustrated by the following example, people with a high marginal utility of time and of money (e.g. a single parent worker) may exhibit the same or similar value of time as people with a low marginal utility of both (e.g. a wealthy holiday maker) (Langmyhr, 1997).

On the contrary to affluent individuals, population groups with small economic margins are expected to experience higher welfare losses from road charging. Living in the suburban rather than the city centre area, low income groups face poorer public transport opportunities. They are also assumed to be less flexible in their time of activity, especially time of work choice to possibly avoid peak hour charges (Richardson, 1974; Small, 1983; Cohen 1987; Evans, 1992; Arnott et al., 1994; Transek, 2002).

However, reversed arguments exist saying that low income groups are likely to be the winner from road charging, especially when they live in an environment where the car is not the principal transport mode. Most European regions and almost all European cities are more or less car-independent where accessibility by public transport, walking or cycling is satisfactory and therefore a competitive substitute to car mobility. Assuming that less affluent population groups are more likely to patronise travel modes other than use the car, they will be less affected by road charging policies.[13] As a result, road charging will have a progressive impact (Glazer and Niskanen, 2000). Since in general road charging revenue is spend on public transport improvement (Evans, 1992), low income groups being frequent public transport users (often captives) are more likely to profit from the charging car road use than persons with higher incomes. These contrasting views indicate the difficulty in finding a clear-cut conclusion about the distributional and equity impact of road charging.

[13] Despite methodological uncertainties, quantitative studies of road and congestion charging carried out for cities such as San Francisco (Schiller, 1998), Oslo (Fridstrom, 2000), Gothenburg (Transek, 2002), and Cambridge, Northampton and Bedford (Santos and Rojey, 2004) indicate that high income population groups experience a greater negative welfare impact than low income groups due to their high car use intensities and their preference to reside in (suburban) areas with limited access to public transport. Given an equal redistribution of the road charging revenue those with low incomes would end up being better off (Arnott et al., 1994).

Even so, case-adequate or sufficiently progressive revenue recycling schemes could ensure that all income groups benefit overall (Small 1992), nevertheless each road charging policy needs its specific evaluation.

As Eliasson and Mattsson (2006) conclude from their studies of theoretical literature on equity and distributional effects on car users following the introduction of infrastructure pricing policies, equity outcomes will in general strongly depend on the design of the policy instrument as well as on varying travel patterns from socioeconomic differences of population groups.[14] Evaluation of road charging policies needs to consider distributional effects before and after the implementation of different revenue redistribution schemes, comparing net welfare surplus with the total distributional effects. Drawing the conclusion whether the measurable shifts in welfare distribution caused by implementation of the policy reform are equitable is far from straightforward. Even though different methods for quantifying equity effects exist, the concept of equity, however, is much more complicated to “grasp”.[15] For example, an equal distribution of costs and benefits suggests an equitable final effect. But as Harrison and Seidl (1994) point out, fairness does not automatically correspond to equal distribution because people do not necessarily prefer the “most equal” result. Instead, additional factors significantly influence the perception of fairness and they vary among different individuals as well as socioeconomic groups.[16] Therefore, it becomes obvious that even if one single concept of equity existed, it would hardly satisfy the preferences of all social entities involved. Thus, even though various concepts of what

[14] Eliasson and Mattsson (2006) refer in their literature review to studies conducted by Arnott et al. (1994), Glazer and Niskanen (2000), Richardson (1974) and Small (1983).

[15] Ochmann and Peichl (2006) present four sub-concepts of distributional effects: inequality, polarisation, progression in taxation and poverty and richness, where they propose common descriptive measures of inequality like the Gini-coefficient and the Lorenz curve as well as other variance measures. Franklin (2004) points to quantile-quantile plots and relative distributions and polarization indices as methods used for inequality and distribution assessment techniques. Abe (1975) assesses distributional changes by calculating the weighted consumer surplus, and Feldstein and Luft (1973) use linear programming to quantify consumer surplus. Furthermore, Thurman and Wohlgenant (1989) use a general equilibrium demand curve to calculate the surplus; single equation error correction models are an appropriate method to calculate short-run changes (Kelly, 2005).

[16] The contribution of Harrison and Seidl (1994) tries to link distributional and equity aspects. The authors depict that differing perceptions of equity among the test persons complicate the introduction of axioms as measures of equity of distributional impacts. Similarly, Atkinson (1970) criticises the current properties of the social welfare function lacking the proximity to actual social values, which in turn is one of the difficulties equity research is concerned with.

could be meant by the terms “equity”, “fairness” or “justice” exist, a universal consensus has not been found. Attempts to determine overall satisfying concepts are based on qualitative reflections rather than quantitative methods.[17]

Concluding, the discussion about equity concepts and equity assessment shows that its overall “construct” is very difficult to be captured quantitatively by the economic theory. Since there does not exist an indisputable consensus about the definition of equity, the concept (of an equitable distribution) lacks an applicable theoretical basis. It therefore remains questionable if equity can be measured normatively. Within the model implementation described in Chapter 5 a measure is implemented that accounts for welfare changes in terms of economic utility from transport as well as overall consumption. Hence, using the Hicksian welfare index the so called Hicksian equivalent variation is calculated to indicate the amount of income necessary to compensate an individual (in the pre-policy situation) in order to reach equality with the post-policy utility level (Just et al., 2004). The welfare measure is based on an agent-based utility function and therefore all changes in transportation and economic conditions affecting individuals are considered. It measures changes in money metric utility between the pre- and post-policy equilibrium, which is the amount of money required to bring a household back to the same level of utility as in the benchmark equilibrium following changes in prices in counterfactual equilibrium. Nevertheless, measuring changes in economic utility leaves the question about the fairness of the policy outcome unanswered. However, despite the apparent lack of a single, theory-based and measurable definition of equity, compiling a variety of concepts gives a sound framework for a normative evaluation of the equity effects from passenger car road charging in Germany, leaving the (dilemma of the) definition of the fairness norm to the evaluator.

[17] Among the qualitative research Adams established an equity theory in 1962 which has been elaborated by Walster, Walster and Berscheid (1978). This theory views fairness as a basic need that navigates social behaviour. Rawl’s (1985) concept of equity includes political and moral aspects, and King and Sheffrin (2002) apply a concept that includes even psychological elements based on prospect theory. Quantitatively, Bibi and Duclos (2003) for example use the average poverty gap to measure fairness, whereas Butler and Williams (2002) apply in their work cooperative game theory to approach the idea of equity.

3 Computable general equilibrium (CGE) and travel demand modelling – extension of the research

The general objective of this doctoral thesis is to investigate equity and welfare distributional effects from car road charging on the private household sector in the specific case of Germany. The policy impact assessment covers the entire economy with special focus on the private households and their welfare situation before and after the introduction of the measure. To give a funded understanding of the mode of functioning of environmental and transport policy measures targeting (private) car use, especially on their socioeconomic implications, the overall model of the German economy is extended by a more disaggregated private household representation. The methodology used in this work is a computable general equilibrium framework with integrated private household car travel and public transport demand, differentiated by combined income and spatial residence characteristics.

The work reveals the effectiveness of road use charging given an initial state of a single-country economy, being the only approach of its kind carried out for Germany. Differences in household budgets, motorisation, demographics and other road user characteristics govern the response to road charging, and thereby determine the factual scope of expected impacts. Varying scenario assumptions as to reaction parameters and policy reform designs provide the basis for policy simulations. The work demonstrates the strong dependence of welfare and equity effects from road user charging on the unique design of the revenue reallocation scheme. The application of micro survey data representative for the German population as well as the use of household category specific behavioural parameters in form of demand elasticities better approximate the practical real life situation of the policy implementation environment. Results are based on coherent micro and macro databases, partially obtained through sophisticated modelling work. They provide new insight to the integrated assessment modelling research in the field of car road pricing policy implementation and distributional effect.

4 Model and database

The purpose of this Chapter is to give a general overview on CGE modelling and the particular work done within the area of applied overall economic impact assessment of road pricing measures in the transport sector under consideration of welfare distribution and equity effects and using CGE models. Furthermore, a description is given of the methodology applied and the data developed to obtain the results of this thesis work, where the underlying objective is to conduct an integrated impact assessment of economic welfare for Germany, in particular for different households with regard to distributional and equity effects after the introduction of car road charging.

4.1 The general computable equilibrium model

The framework of a CGE model is a well suited approach to evaluate the socioeconomic and environmental impacts of different economic policy instruments. The method allows the introduction of a comprehensive empirical basis; the setting of the model is coherent as to linkages between the underlying social accounting matrix (SAM), budget constraints, macroeconomic agents or accounts, etc. and the rigorous theoretical constraints. Computable general equilibrium models offer a consistent framework based on neoclassical economic theory for conducting controlled experiments regarding policy scenarios concerning the economy as a whole.

The general equilibrium (GE) theory is the basis in economic theory of numeric GE models. The GE theory goes back to Walras (1874) who firstly constructed a general economic model. GE models are based on Arrow-Debreu economic theory approach (Arrow und Debreu (1954) that were the first to prove the existence of a general equilibrium within a competitive economy based on Walras' GE model (1874).

In General, CGE models include linkages between all sectors within the economy, while taking into account restrictions such as the limited endowment with different resources. These models are closed in a macroeconomic sense by including the equalization of economic accounts. Moreover, different policy interventions can be analyzed simultaneously. This is substantial characteristic of the CGE modelling framework as the overall impact might differ from the sum of all the isolated effects.

Most common economic fields of CGE model application are public finance, taxation issues, international trade policy questions, evaluation of alternative development strategies, implications of energy policies, regional questions, or issues of macroeconomic policy. The ex-ante evaluation of policy decision are of particular interest when they affect areas concerned with the intersectoral allocation of resources and distribution of income. This is also the case when changes in transport policy take place with regard to investment in transport infrastructure. Both come with substantial implications for the government budget as well as income distributional consequences. When high marginal rates of taxation exist, raising government revenue and redistribution income is associated with substantial distortionary and administrative costs. Hence, the evaluation of most transport policies needs to take this cost into account, especially since they generate fundamental general equilibrium effects.

In general a computable general equilibrium approach should take an array of aspects into account starting with the clarification of the policy issue to be addressed. Next, the methodology for the CGE based policy analysis should be specified, including the definition of the theoretical framework for use of the methodology for transport policy analysis, i.e., road charging. This encompasses the description of the concrete implementation of the measure, the assessment approach of the consequences from the introduction of road charging, and finally the interpretation of the simulation results.

The theoretical basis of the model may be formalised as a theoretical model with the theoretical statements being expressed in terms of mathematical relationships. In a fully parameterised theoretical model the mathematical relationships are specified in terms of parameterised functions so that the model can be applied to a database, including a set of estimates of the relevant parameters. The specification of a parameterised theoretical model is an intermediate step in constructing a CGE model. It generally involves the exact specification of the subsystems and variables of the model and of the parameterised functional relationships representing the behavioural assumptions. The procedure used to find values for the free parameters of functional forms is known as calibration (Mansur and Whalley, 1984). The consistency check of the deterministic calibration procedure is the replication of the initial benchmark: the calibrated model must be capable of generating the base-year (benchmark) equilibrium as a model solution without computational work. The consistency check of the model and the database is done with reference to the required theoretical restrictions of a general equilibrium. The reproduction of the base year data as a solution to benchmark check requires a rigorous consistency of parameters and the database used in the model implementation. Therefore, the initial stage of model-oriented database construction involves the transformation of often inconsistent raw data into fully consistent data set. After the benchmark calibration and before the implementation of an exogenous shock in terms of a policy intervention, the model is assumed to be in equilibrium. Hence, the construction and application of the (static) German CGE model included several working steps: the collection and analysis of the relevant data for the model database, the harmonization, organisation, and compilation of the data into a SAM (format), and the data adjustment in order to achieve an initial equilibrium, i.e., overall income must be equal to overall expenditures, producers' revenues have to be equal to total factor income, etc.

For the model application a model closure has to be specified. The closure of the model depends on the issue to be analysed and it indicates which variables are to be considered as exogenous (i.e. specified by the model user, e.g., instrument variables), or endogenous (i.e. values determined by the values of the exogenous variables and the equations of the model). The exogenous variables induce the change within the modelling framework and are therefore often referred to as “shocks”. To compute the model solution the number of endogenous variables has to be equal to the number of model equations. To qualify the performance or the “sensitivity” of the model, a “sensitivity analysis” is usually conducted testing the dependence of the model results on different parameter choices.

The implementation of a policy scenario is often referred to as the introduction of an exogenous shock. After the introduction of an exogenous shock a new equilibrium is computed by setting the prices and production quantities for all commodities such that market demand equals market supply for all inputs and outputs. In other words, after policy shocks (or simulations) a new counterfactual equilibrium is calibrated within the numeric empirically based modelling framework including an update of the initial database. The results between the initial equilibrium of the economy and the equilibrium after the policy (shock) implementation can be reported in percentage changes or in levels of economic variables. Thus, through model simulations using a fully specified CGE model that has been programmed in appropriate software and that contains a corresponding solution algorithm it is possible to undertake quantitative policy analyses. Results obtained after the policy shock implementation include changes in output quantities, factor use and prices as well as indicators such as consumer utility or welfare. Welfare measures are usually based on the underlying utility functions in the model. For the computation of welfare changes most often the Compensating and Equivalent Variation measures developed by Hicks (1939) are used. More in-depth technical description of the characteristics of CGE models including examples can be found in Shoven and Whalley (1992 and 1984) or Ginsburgh and Keyzer (1997).

4.2 CGE and travel demand modelling

The intention to introduce a nationwide road charging scheme in the passenger car sector comes together with a multitude of economic, ecologic as well as social questions, uncertainties, and concerns that need to be considered often simultaneously.[18] A consistent and integrated assessment of economic, environmental, and welfare distribution impacts from road charging implemented in the passenger travel sector is done more accurately when the overall interactions within the economy as well as the budgetary situation and travel choice behaviour of private households are taken into account. Information referring to private household travel can be represented by activity parameters such as number of trips, mode choice, trip purpose, distance travelled as well as monetary measurements such as travel expenditure in absolute terms and as proportion of the household dispensable

[18] In terms of sustainability impact assessment the European Union (EU) suggests a "careful assessment of the full effects of a policy proposal [that] must include estimates of economic, environmental and social impacts" (EC, 2001).

income. Given the different sorts of mobility indicators, travel behaviour in general including reaction to changes in travel costs – e.g., price increase of car use due to an imposed road charge – depends primarily on sociodemographic and economic attributes and choice alternatives. This implies that the sociodemographic and economic profile, e.g., the disposable income, as well as the residential location characteristic of an individual or a household determine the effect, which is imposed by travel supply side changes in form of price rises.[19] The integration of different household income and residential location categories within an overall economic framework of a computable general equilibrium (CGE) model under introduction of a policy reform such as road charging allows the investigation of general economic and ecological effects together with accompanying distributional and equity implications. The numerical property of a CGE model allows for a quantitative assessment of concerning impacts from a policy measure such as road use charging. Furthermore, the methodological consistency of the CGE approach gives the advantage of an integrated comparison of quantified effects in the overall sector context of “environmental quality, economic performance and income distribution" (Böhringer and Löschel, 2006, pp. 50-51).

Nevertheless, only a small number of one-country CGE models with focus on passenger travel demand integration exist. Most CGE models are global or multiregional, focussing on research questions of international or global relevance, e.g. trade, finance or market competition policies.[20] Even fever models tackle the area of passenger travel demand. Within these few models, where passenger travel demand or passenger transport are considered, most CGE models are somehow limited with respect to – in particular – the social impact assessment of policies introduced with regard to passenger road travel. Existing exceptions are described in Mayeres (1998 and 2004), Broecker (2002), Mayeres

[19] For documented studies on passenger travel demand modeling, car purchase, car ownership and car use modeling see, e.g., Hautzinger (1978), Dargay (2002), BMVBW (2002), Bresson et al. (2004), Kalinowska et al. (2005), van de Coevering and Schwanen (2005), Giuliano and Dargay (2006), Johansson et al. (2006), Kalinowska and Kuhfeld (2006), Limtanakool et al. (2006), Naess (2006) for examples of passenger travel demand modeling, car purchase, car ownership and car use modeling.

[20] For research work concerned with the topic of CGE model implementation see, e.g., Conrad (1999 and 2001), Bergman (1990), Gottfried et al. (1990), Borges (1986), Kehoe and Kehoe (1994), Klepper et al. (1995), Pereira and Shoven (1988), Robinson (1999), Shoven and Whalley (1984 and 1992), Fehr and Wiegard (1996), Piggot and Whalley (1985 and 1991), Bhattacharyya (1996), Gunning and Keyzer (1995).

and Proost (2002), Steininger (2002), Munk (2003), Steininger and Friedl (2004), Schaefer and Jacoby (2005 and 2006). Finally, no CGE model which accounts for passenger travel demand disaggregated for household income and residential location categories has been ever applied to Germany. In those CGE models yet applied to German data, demand for passenger travel is not explicitly included or it does not allow the evaluation of welfare distribution (equity) effects on a disaggregated household level (Meyer and Ewerhart, 1989; Broecker, 2001, 2002, 2004; Bach et al., 2001). To account for this shortcoming a CGE model including passenger travel demand for Germany – the German Road Travel Policy Model (GRTPM) – has been constructed based on the Austrian version – the Austrian Road Pricing Model (ARPM) introduced in Friedl and Steininger (2004).[21] The GRTP model represents a small open economy of a single country and it accounts for different private household types according to income and – as an extension to the original structure of the ARPM – residential location categories. The modelling framework and the underlying database are described in detail in Chapter 4.

4.2.1 Description of the German Road Travel Policy Model (GRTPM)

The methodological approach used in this dissertation work is based on standard (static) general equilibrium (GE) theory. The construction of the German CGE model is based on the Austrian version – the Austrian Road Pricing Model (ARPM) introduced in Steininger and Friedl (2004). Moreover, a German database was constructed for the standard CGE model and extended by a disaggregated incorporation of the private household sector. The constructed model will hereafter be referred to as the German Road Travel Policy Model (GRTPM). The underlying model code is written in the Mathematical Programming System for General Equilibrium Analysis (MPSGE), which is a programming language designed by Rutherford (1999) in late 80s for solving Arrow-Debreu (Arrow and Debreu, 1954) economic equilibrium models (Paltsev, 1999).[22]

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21 The ARPM has been developed and implemented at the Economics Department of University of Graz, it is documented in Steininger et al. (2007).

22 For the MPSGE based model specification the Generalised Algebraic Modelling Software (GAMS) is used (Brooke et al., 1992). GAMS is an optimization software used in general equilibrium model format by

The GRTP modelling framework consists of separated files containing the model code including the functional forms and some numerical parameters and the database in value terms. The value terms of the model variables, e.g., production or endowment values correspond to a quantity and a price variable. Solving the model for its equilibrium endogenously updates the values for quantities and prices.

35 production sectors are distinguished in the GRTP model, of which the following are directly linked to the representation of passenger travel demand: extraction of crude petroleum and natural gas, transport equipment, distribution, land transport, supporting and auxiliary transport, finance and insurance, as well as other market services. Agents are modelled using either a representative microeconomic consumption or production function (Varian, 1993). For an overview the main model equations and variables are enclosed in the Appendix 1 and Appendix 2.

A consumer is characterized by a preference ordering over the obtainable goods described by a utility function and by a budget set that is limited by his income. He is assumed to choose that bundle of goods in his budget set that maximally satisfies his preferences, i.e., his behaviour can be described by utility maximization over his budget set. The GRTP model distinguishes three agents: private households, the government, and the road pricing agency.

A (non-transport good) production sector j is assumed to use the optimal production technology that transforms an input bundle consisting of all goods in the economy and of the primary production factors into an amount of its output good. Production of non-passenger-transport goods follows a nested constant elasticity of substitution (CES) structure, with capital and labour as primary inputs, and intermediate inputs entering in a Leontief functional form (i.e. with substitution elasticity equal to zero). The producer chooses an input-output bundle that maximizes his profit, i.e., the producer behaves in a profit maximising (or cost minimizing way) over the production set defined by his technology. Equations (1) and (2) describe the gross production X_j and the factor aggregate H_j of sector j:

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introducing all required model equilibrium conditions into constraints on nonlinear optimization. It has a convenient and transparent format as to its syntax, or display, explanatory and diagnostic features.

(1) $X_j = \min\left(H_j / A_j, X_{ij} / a_{ij}\right) \; for \; j = 1,...,35$,

where A_j and a_{ij} denote the Leontieff-input-output-coefficients in sector j,

(2) $H_j = \left(\delta_j L_j^{(\sigma_j - 1)/\sigma_j} + \left(1 - \delta_j\right) K_j^{(\sigma_j - 1)/\sigma_j}\right)^{\sigma_j / \sigma_j - 1} \; for \; j = 1,...,35$,

with L_j as the labour and K_j as the capital input in sector j and σ_j as the production elasticity of substitution between labour and capital in sector j. δ_j denotes the constant elasticity of substitution (CES) distribution parameter in sector j.

Agents are assumed to take the prices of the goods as given. Prices in turn satisfy the market-clearing criterion, where total demand equals total supply. Thus, the equilibrium conditions imply that markets for goods, labour and capital clear, firms receive zero exess profits in equilibrium, and income is equal to expenditure for all households.[23]

The production of the passenger transport intermediate and final consumption goods as well as household demand are of special interest for this work and are therefore described extensively in Chapter 4.2.2 as to the functional specification and in Chapters 4.3.3 to 4.3.5 as to the empirical representation.

The government sector is endowed with income from direct (ad valorem on final sales) taxes and indirect taxes on production, capital and labour (income) as well as from fuel tax and vehicle tax collection and a social insurance premium contribution from private households. The government budget is spent on public consumption, investment and household net transfers of social benefits using a constant expenditure shares form. Moreover, the government has the function of affecting the distribution of income through road charging revenue financed household transfers. Government budget balance is a property of the equilibrium condition.

The foreign trade is subject to the Armington (1969) assumption of product differentiation. The input cost on each composite good is decomposed into the cost of obtaining the

[23] The current model incorporates all standard equilibrium conditions that are characteristics of the computable general equilibrium literature (Shoven and Whalley, 1992; Ginsburgh and Keyzer,1997).

domestically produced variant of this good and the cost of the imported variant of this good using a constant elasticity of substitution function with a finite elasticity of substitution between the domestically produced variant and the imported variant. Hence, a change in the price relation between foreign and domestic goods is followed by a trade balance shift according to the sector specific foreign trade elasticity. Equations (7) and (8) denote foreign trade in the GRTP model:

$$(7)\ EX_j = EX_j^o \left(P_j^w / P_j\right)^{\varepsilon_j} \ for\ j=1,\ldots,35\ ,$$

with EX_j denoting export of sector j at the quantity EX_j^0 for the reference year 0, P^w_j being the world market price of goods aggregate X in sector j and P_j being the (domestic) production price of goods aggregate X in sector j, and ε_j describing the foreign trade price elasticity parameter of demand in sector j;

$$(8)\ M_j = M_j^o \left(P_j / P_j^w\right)^{\varepsilon_j} \ for\ j=1,\ldots,35\ ,$$

with M_j denoting import of sector j at the quantity M_j^0 for the reference year 0.
For the analysis of the labour market impact of the transport policy introduced, it is assumed that the labour market does not clear and the unemployment is determined by classical, i.e. high minimum wage unemployment (equation (9)):

$$(9)\ \frac{w}{p_p} \geq \overline{w_{low}} \perp u$$

The road charging measure is implemented as a distance dependent markup on the price of car travel calculated based on the kilometres travelled. The overall effects of the charging policy depend on the reallocation of the revenues collected from its implementation. Implemented policy scenarios as well as the road charging revenue redistribution policies are subject to simulation analyses and are described in detail in Chapters 5.1 and 5.2.

The model is closed by a fixed foreign trade balance at the level of the reference year ("neoclassical closure", fixed foreign savings), such that investment is savings driven and the foreign exchange rate adjusts to achieve equilibrium.

4.2.2 Private household sector, travel demand and transport production

Private household demand is represented by a nested CES structure, with unity elasticity of substitution for consumption goods and services other than passenger travel. In equation (10) $C_{he,r}$ denotes the total consumption of household type $h_{e,r}$, differentiated by income level and/ or residential location attribute. Total household consumption is the sum of $X_{he,r}^{C}$ being the consumption of non-transport goods of household $h_{e,r}$ and $T_{he,r}$ being the transport consumption of household $h_{e,r}$. $\delta_{he,r}^{C}$ denotes the CES-distribution parameter in non-transport consumption for household $h_{e,r}$ and $\sigma_{he,r}^{C}$ the elasticity of substitution between transport and non-transport demand for household $h_{e,r}$:

$$(10)\ C_{h_{e,r}} = \left(\delta^{C}_{h_{e,r}}\ X^{C}_{h_{e,r}}{}^{\left(\sigma^{C}_{h_{e,r}}-1\right)/\sigma^{C}_{h_{e,r}}} + \left(1-\delta^{C}_{h_{e.r}}\right) T_{h_{e.r}}{}^{\left(\sigma^{C}_{h_{e,r}}-1\right)/\sigma^{C}_{h_{e,r}}} \right)^{\sigma^{C}_{h_{e,r}}/\left(\sigma^{C}_{h_{e,r}}-1\right)},$$

$$for\ h_{e,r} = \begin{pmatrix} h_{11} & \cdots & h_{14} \\ \vdots & \ddots & \vdots \\ h_{41} & \cdots & h_{44} \end{pmatrix}, \textit{where e is the income category and r the residential location attribute}$$

.

Consumption of non-transport goods of household $h_{e,r}$ follows equation (11) with $\delta_{he,ri}^{X}$ denoting the CES-distribution parameter in non-transport consumption for household $h_{e,r}$ and $\sigma_{he,r}^{X}$ the elasticity of substitution between non-transport goods in household $h_{e,r}$ consumption:

$$(11)\ X^{c}_{h_{e,r}} = \left[\sum_{i} \left(\delta^{X}_{h_{e,r},i} X^{c}_{h_{e,r},i}{}^{\left(\sigma^{X}_{h_{e,r}}-1\right)/\sigma^{X}_{h_{e,r}}} \right) \right]^{\sigma^{X}_{h_{e,r}}/\left(\sigma^{X}_{h_{e,r}}-1\right)} \quad with\ \sum_{i} \left(\delta^{X}_{h_{e,r},i} \right) = 1$$

For reasons of simplification, it is furthermore assumed that all households have the same consumption structure within the bundle of non-transport goods. This assumption is as far plausible as most of the consumption aggregates are sufficiently similar across the household categories defined for the purpose of this study. For the transport goods aggregate household category specific consumption structures are specified.

$T_{he,r}$ is the Transport consumption of household $h_{e,r}$ with $\delta_{he,r}^{T}$ as the CES-distribution parameter in transport consumption for household $h_{e,r}$ and $\sigma_{he,r}^{T}$ as the elasticity of substitution between private car transport and public transport demand for household $h_{e,r}$ as shown in equation (12):

$$(12)\ T_{h_{e,r}} = \left(\delta_{h_{e,r}}^{T} T_{h_{e,r}}^{p\ \left(\sigma_{h_{e,r}}^{T}-1\right)/\sigma_{h_{e,r}}^{T}} + \left(1-\delta_{h_{e,r}}^{T}\right) + T_{h_{e,r}}^{u\ \left(\sigma_{h_{e,r}}^{T}-1\right)/\sigma_{h_{e,r}}^{T}} \right)^{\sigma_{h_{e,r}}^{T}/\left(\sigma_{h_{e,r}}^{T}-1\right)}$$

The demand between the bundle of non-transport and the bundle of transport goods and services is governed by the calibrated elasticity of substitution of δ_{h}^{C}=0.275, used across all household categories defied within the model.

A calibrated elasticity of substitution δ_{h}^{T}=0.636 is used to express the relationship of the demand for the two different passenger transport goods, i.e., demand for motorized individual car travel and for public transport.[24]

Through the specification of elasticity of substitution parameters adapted from studies on country specific micro-econometric travel demand modelling (BMVBW, 2002), we consider the quantitative extent of the reaction potential to changes in the price of car travel induced by road charging.[25]

The use of uniform substitution elasticities across household income groups implies that

[24] An elasticity of substitution between private and public transport with a value of 0.5, for example, means that a 1 % price rise of car travel relative to public transport induces a 0.5 % change in the modal split, here in favour of public transport.

[25] For extensive literature surveys of car use and ownership elasticities see also Goodwin (1992), Johansson and Schipper (1997), Blum et al. (1988), Graham and Glaister (2002a, 2002b and 2004), Goodwin et al. (2004).

observed distributional effects from the road charging measure are induced by the household specific travel behaviour in terms of expenditure and activity parameters (Steininger and Friedl, 2004).

The elasticities of substitution governing the demand between the bundle of non-transport and the bundle of transport goods and services (δ_h^C=0.275) as well as the bundle between private and public transportation (δ_h^T=0.636) imply a fairly inelastic demand for everyday mobility. Hence, despite of the road charging induced price increase of private car travel, the demand for car kilometers will be only little affected. Therefore, the CGE simulation effects on the economy and welfare (re)distribution can be expected to be rather strong, where the extent of welfare redistribution is linked to the "generous" amount of revenues from the road charging policy that is in turn realisable also because of the fairly price rigid travel demand.

In case of easier substitution between transport and non-transport goods and/or between car and public transport, negative impacts on economic welfare as well as on output could ceteris paribus turn out to be weaker; i.e., the reduction in car travel demand would be higher due to the road charge measure causing also higher emission cutbacks. Given higher substitution elasticities for car travel also lower road charging revenues would have to be expected leading to a reduced redistribution policy effect.

The production of the passenger transport intermediate and final consumption goods follows the equations (13) to (16). Figure 2 illustrates the structure of household demand.

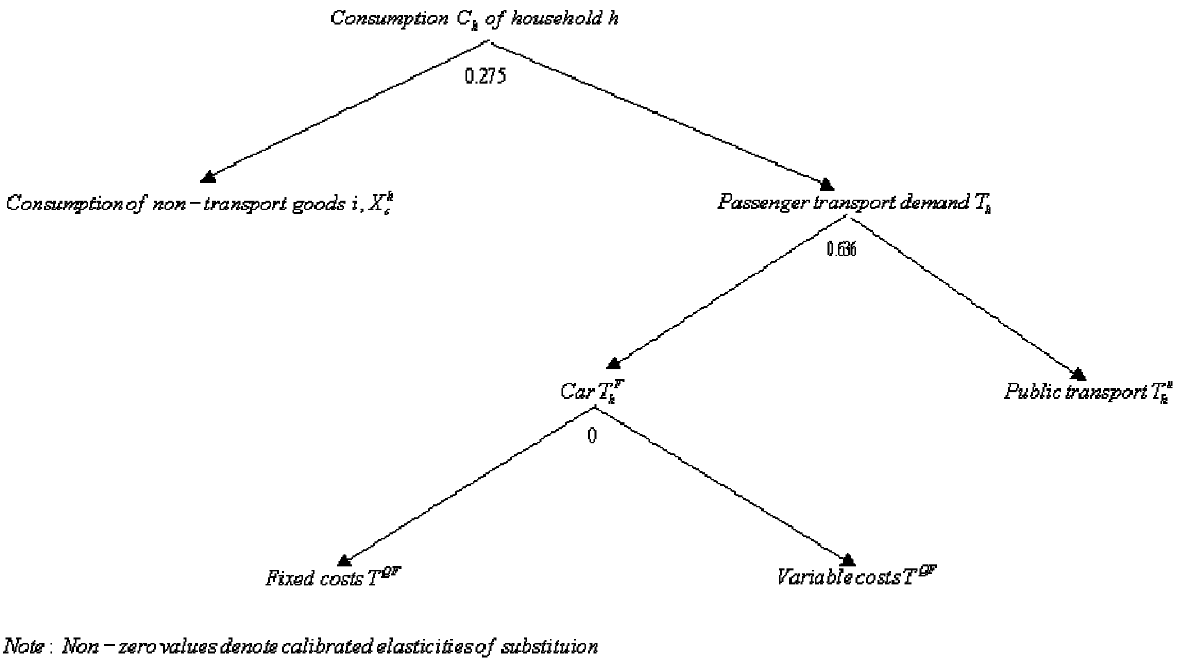

Figure 2 Structure of household h final demand

Source: Steininger and Friedl (2004).

Household travel demand enters the model in a disaggregated fashion by household category as to income and/ or residential location characteristic through data on transport expenditures and on transport activity quantified by passenger and vehicle kilometres travelled by mode and per year. Passenger transport consists of private and public travel expenditures and can be considered as being a newly constructed good within the production and the final consumption of private households.

As said before, identical structure but varying absolute levels are assumed across household groups with regard to all remaining consumption expenditures. This simplifying assumption is in line with findings based on data from the German Sample Survey of Income and Expenditure.[26]

Private travel expenses consist of variable household expenditures on car use and of fixed household expenditures on car purchase and ownership. The first category depends almost

[26] Source: Einkommens- und Verbrauchsstichprobe (EVS) 2003 (StaBuA, 2005a, 2005b, 2005c, and 2006).

entirely on household specific car use patterns and combines expenditure on car fuels, fuel taxes and levies, car repair and maintenance costs, and different kinds of costs for parking. Private household demand for these inputs is satisfied from corresponding (intermediate) sectors within the input-output table, such as the refined oil, transport equipment, distribution, finance and insurance, and inland transport.[27] Hence, all cost components of household travel demand are linked with the corresponding economic supply sectors of the German input-output table and social accounting matrix as well as the government budget in the case of vehicle or gasoline taxes.

Private car travel production is expressed through equation (12) to (14):

(13) $T^{p} = \min\left(T^{pf}/A^{pf}, T^{pv}/A^{pv}\right)$,

(14) $T^{pf} = \min\left(X_i/A_i^{pf}\right)$, and

(15) $T^{pv} = \min\left(X_i/A_i^{pv}, km^{p}/A^{kmp}\right)$,

where T^p denotes private car passenger transport with T^{pf} being the fixed and T^{pv} the variable, directly kilometre dependent input in the production (and consumption) process of private car passenger transport. A^{pf}, A^{pf}_i, and A^{pv} , A^{pv}_i are the corresponding Leontief-input-output-coefficients in private car passenger transport. A^{kmp} denotes the kilometre input coefficient in private car passenger transport and km^p are the vehicle kilometres driven by households in private car transport. Household demand for car travel is satisfied from the combination of fixed and variable inputs, where the corresponding cost components follow a Leontief function with an elasticity of substitution set at zero (see Figure 2). This implies that kilometre charges applying to the variable input cannot be substituted by other fixed input components, i.e., there are no technical devices to avoid kilometre charges other than reducing the driving activity.

[27] The German database in form of a social accounting matrix has been constructed based on the input-output table and other information available from the German Federal Statistical Office (for detailed description see Chapter 4.3).

The production of public passenger transport T^u follows a Leontief structure with A^u_j as input -output -coefficient in public transport:

$$(16)\ T^u = \min\left(X_i / A_i^u \right) ,$$

where X_j stands for inputs from sector j.

The data used for the representation of the private household sector were mainly derived from two separate data sources: the German Sample Survey of Income and Expenditure (Einkommens- und Verbrauchsstichprobe (EVS) 2003, StaBuA, 2005a, 2005b, 2005c, and 2006) and the survey data from Mobility in Germany (MiD, 2002). The exact processing and combining of the household micro data to generate household categories as to income and residential location as well as the data sources are described in detail in Chapters 4.3.3 to 4.3.5.

4.3 Database construction

For the construction of German travel patterns for different household income groups, several data sources were used: the German Sample Survey of Income and Expenditure (EVS 2003), the Continuous Household Budget Survey (Laufende Wirtschaftsrechnungen (LWR) 2003, StaBuA, 2005a, 2005b, 2005c, and 2006a), German Input-Output Matrix based on National Accounts (Volkswirtschaftliche Gesamtrechnungen (VGR) 2000, StaBuA, 2006b) and finally survey data from Mobility in Germany (MiD, 2002) and The Car Mileage Survey (Fahrleistungserhebung, 2002, BASt, 2005). In the following the main data sources, the merging of the data, and finally the construction of different household income and residential location categories are described in detail.

4.3.1 Input-output data

The core data basis of a CGE model is the social accounting matrix (SAM) of the economy considered. The fundament of the SAM is the input-output table derived from economic supply and use tables. The symmetric input-output table with regard to the classifications or units used in both rows and columns is the result of balanced supply and use tables for a given point in time, e.g., a base year.

Input-output tables portray in a detailed and clearly laid out way the complex processes of production and the use of goods and services (products) from domestic production and imports, the use of goods and services for primary inputs (labour, capital, or land), intermediate consumption and final use (consumption, gross capital formation, exports), and the corresponding income generation within an economy. Income or revenue of the government is obtained by tax and tariff collection. Input-output tables show therefore the structure of the costs of production and income generation in the production process, the flow of goods and services produced within the national economy, and the flows of goods and services with the rest of the world. Components of value added such as compensation of employees, other net taxes on production as well as consumption of fixed capital, net operating surplus are also considered within the input-output framework. The format of symmetric input-output tables can either be made on the basis of an industry by industry or product by product classification. The classification applied for industries is the General Industrial Classification of Economic Activities within the European Communities (NACE). Products are classified according to the Classification of Products by Activity (CPA). The coding systems of both classifications are compatible with each other. The selection of the classification type of input-output tables (product by product vs. industry by industry) depends on the specific objective of economic analysis (Eurostat, 2008).

Figure 3 shows the systematic setup of a symmetric input-output table according to the product by product classification as has been used to construct the SAM for the GRTPM.

Current and constant prices																		
	Homogeneous Branches	Homogeneous Branches							Final Uses									
	Products (CPA)	Agriculture	Industry	Construction	Trade, hotel, transport	Private services	Other services	Total	Final consumption expenditure by households	Final consumption expenditure by non-profit organisations	Final consumption expenditure by government	Gross fixed capital formation	Changes in valuables	Changes in inventories	Exports Intra EU FOB	Exports extra EU FOB	Total	Total use at purchasers' prices
No		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Products of agriculture	Intermediate consumption at basic prices							Final demand at basic prices									
2	Products of industry																	
3	Construction work																	
4	Trade, hotel, transport services																	
5	Private services																	
6	Other services																	
7	Total at basic prices																	
8	Direct purchases abroad by residents																	
9	Purchases on the domestic territory by non-residents																	
10	Taxes les subsidies on products																	
11	Total at purchasers' prices																	
12	Compensation of employees	Valua added at basic prices							Empty									
13	Other net taxes on production																	
14	Consumption of fixed capital																	
15	Operating surplus, net																	
16	Value added at basic prices																	
17	Output at basic prices																	
18	Imports CIF intra EU	Imports CIF							Empty									
19	Imports CIF extra EU																	
20	Imports CIF																	
21	Supply at basic prices																	
Source: Eurostat Manual of Supply, Use and Input-Output Tables.																		

Figure 3 Symmetric input-output table at basic prices (product by product)

The first quadrant of the table contains numeric data on the intermediate inputs used to produce each product. The second quadrant contains the data on the final use of products in the economy. Columns indicate the final demand of a product. Data in the first and second quadrant are not differentiated by the origin of the inputs, i.e., domestic vs. imports. Trade and transport margins as well as taxes and subsidies are explicitly accounted for in the input-output matrix. Therefore, data in the table are valuated at basic prices. Value added is distributed across the different products according to its origin. Finally, imports are added by each product category to the domestic output adding up to the total supply in the economy.

Final uses are outputs of economic activities exiting the economic cycle and divided into private consumption in terms of the purchases of private consumption goods and services as well as goods and services from non-profit institutions, government consumption in terms of all publicly provided service, fixed capital formation including change in stocks in terms of investment goods employed in the production process, and exports of goods and services. In general, it is assumed that consumer durables are consumed in one period. Traditionally, the flows between the national economy and the rest of the world only record goods and services, excluding, e.g., externalities.

The symmetric monetary input-output framework coherently and systematically links data of industries, products and sectors. It is balanced when total input equals total output for a given column and row of products and total value added equals total net final expenditure.

The input-output table provides the most important macroeconomic aggregates such as gross domestic product, value added, consumption, investment, imports and exports. To calculate the gross domestic product different approaches can be used in the input-output framework: the production approach, the income approach, and the expenditure approach (Eurostat, 2008). A systematic overview of the gross domestic product calculation approaches is presented in Appendix 3.

The production approach is applied to compute value added and the gross domestic product for all industries on an annual basis. In general it takes into account the contribution of each economic unit to production, i.e., the value of their total output less the value of employed inputs. It is based on information on total output at basic prices, intermediate consumption, and product taxes less subsidies. Data required for the production approach come from the annual business surveys, sales, purchases, inventories, gross fixed capital formation, employment cost, agricultural data and general government non-market data.

Based on the income approach gross domestic product is calculated as the addition of the different components of value added, i.e., taxes and subsidies on products, compensation of employees, other net taxes on production and gross operating surplus. The gross domestic product is the total of all income earned by resident individuals or businesses in the production of goods and services. Alternative to the income approach is the expenditure approach. It is used for calculation of the government final consumption expenditure based on government accounts and for exports and imports of goods and services based on foreign trade statistics and balance of payments statistics. It also computes the household final consumption expenditure and gross fixed capital formation. Final consumption expenditure of private households is estimated from a matrix of the main consumption activities of private households with products according to the classification of production activities (CPA) in the rows and the main categories of the classification of individual consumption by purpose (COICOP) in the columns using data from consumer expenditure surveys and retail trade statistics. The expenditure approach measures total expenditure on final goods and services produced in the domestic economy. It is equivalent with the sum of final uses of goods and services by resident institutional units less the value of imports of goods and services. The integral procedure of construction of input-output tables from use and supply data ensures the equality of the GDP estimates using the production, income, and the expenditure approach (Eurostat, 2008). The flowchart in Appendix 4 gives a detailed overview of the mechanism and data requirements underlying the construction of national accounting tables including input-output tables.

A social accounting matrix can be actually understood as an extended input-output table or national accounting matrix. The term social accounting matrix has a long history going back to the end of forties and beginning of the fifties (Stone, 1949, 1951, 1955a, and 1955b; Stone and Croft-Murray, 1959) and its definition has been gradually changing. The social accounting matrix emphasises the role of people in the economy representing them by a more detailed breakdown of the household sector or a disaggregated representation of the labour market taking into account various categories of employed persons or sociodemographic (e.g., age, sex or educational attainment) as well as economic categories The integration of human activities and interrelations of income and transfer flows between the different institutional units – among them private households, non-profit institutions serving households, and government – are other examples of the inclusion of the socioeconomic aspect into the economic input-output or national account analysis. For the input-output framework the consideration of the human factor can also mean that the final use or the final consumption expenditures by product group are further split by institutional sectors, such as household types, household sub-sectors, or other population groupings

(Eurostat, 2008).

Input-output data used for the construction of the GRTPM social accounting database were provided by the German Federal Statistical Office (StaBuA, 2004) and corresponded to the generally promoted product by activity classification that is regarded as being more homogeneous concerning the description of the transactions. The data are part of the German national accounting and integrated into the European System of Accounts (ESA 1995), which is fully consistent with the world wide System of National Accounts (SNA 1993).

The square matrix format of the input-output matrix within the social accounting table allows sector disaggregation according to the application of the model.

The database for the German road travel policy model has a standard formulation of a Social Accounting Matrix and consists of 35 sectors, as listed in Table 2.

Table 2 Sector data of the GRTPM

Input-output sectors in the GRTP model, passenger travel demand related sectors are highlighted		
No.	CPA*	
1.	01,02,05	Agriculture and Forestry
2.	10	Mining of Coal and Lignite
3.	11	Extraction of Crude Petroleum and Natural Gas
4.	23	Manufacture of Refined Petroleum Products
5.	40	Electricity, Gas, Steam and Hot Water Supply
6.	41	Collection, Purification and Distribution of Water
7.	27	Ferrous & Non Ferrous Metals
8.	13,14,26	Non-metallic Mineral Products
9.	24	Chemicals
10.	28	Metal Products
11.	29	Agricultural & Industrial Machines
12.	30	Office Machines
13.	31,32	Electrical Goods
14.	34,35	Transport Equipment
15.	15,16	Food and Tobacco
16.	17,18,19	Textiles, Clothing & Footwear
17.	20	Timber & Wood
18.	21	Paper
19.	22	Printing Products
20.	25	Rubber & Plastic Products
21.	37	Recycling
22.	33,36	Other Manufactures
23.	45	Construction
24.	50,51,52	Distribution
25.	55	Hotels and Restaurants
26.	60	Land Transport
27.	61,62	Water and Air Transport
28.	63	Supporting and Auxiliary Transport
29.	64	Communications
30.	65,66,67	Bank. Finance & Insurance
31.	70,71	Real Estate
32.	72	Software & Data Processing
33.	73,74	R&D, Business Services
34.	92,93,95	Other Market Services
35.	75,80,85,90,91	Non-market Services

Source: Database GRTPM, and own calculations.
* CPA (Classification of Products by Activity) is the European statistical classification of products linked to branches of economic activity in the European Economic Community, Edition 2002.

Corresponding to the schematic presentation shown in Figure 3 additional economic data such as direct taxes (on labour and capital), primary inputs like labour and capital, imports, and consumption, were included basically from the German national accounting data of the Federal Statistical Office to construct the database for the GRTPM.

4.3.2 Transportation sector input-output data

The economic input-output data related to private household travel activity expenditures were constructed based on the 2003 survey data of income and expenditure of households in Germany. Data representing private travel demand related household consumption expenditures were disaggregated according to household income and residential location (see Chapter 4.3.5) and attributed to the corresponding sectoral production activity of the GRTP model's SAM. Both data sources – the income and expenditure survey information and the input output national accounting data – were integrated for consistency purposes of the overall SAM database. The detailed illustration of all data incorporated into the model database as well as the disaggregation of the data is presented in Figure 4.

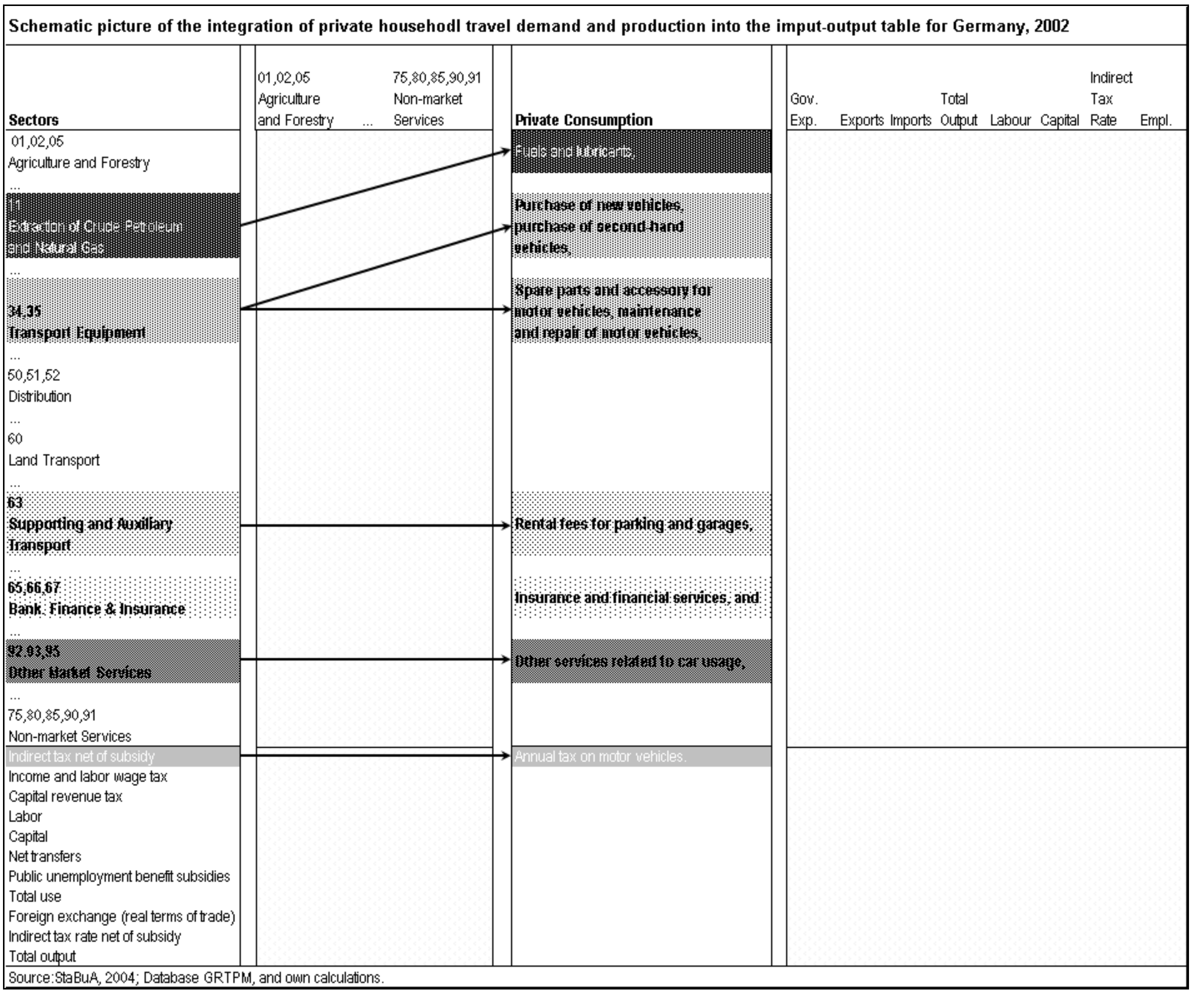

Figure 4 **Social accounting matrix of the GRTPM – attribution of private household travel expenditures to the sectoral input-output database**

The relevant numerical information on differentiated private household expenditure on travel activities as a consumption activity was derived from the micro data of the German Sample Survey of Income and Expenditure where it is calculated based on the classification by consumption purposes and included the indirect value added tax (VAT). It was then allocated to the sector systematisation of the input-output table by classes of production activities, excluding indirect taxes (see Figure 4). The correction for the VAT was made based on the assumption of implicit VAT rates. These were calculated from the difference between the sector specific private household consumption given in the national accounting framework compared with the corresponding values obtained from the income and expenditure survey data, after its reclassification from consumption purpose to production activity.

To obtain an accurate picture of the household car travel expenditure the following consumption purposes were taken into account:

- Purchase of new vehicles,
- Purchase of second-hand vehicles,
- Spare parts and accessory for motor vehicles,
- Fuels and lubricants,
- Maintenance and repair of motor vehicles,
- Rental fees for parking and garages,
- Other services related to car usage,
- Insurance and financial services, and
- (Annual) Tax on motor vehicles.

Information on the amount of fuel tax was separated from the household expenditure on fuels. Fuel as well as motor vehicle taxes were allocated to the government budget revenues (see Figure 4). Furthermore, expenditure on car travel was grouped into fixed and variable expenditures. Variable expenditures are directly related to car use, i.e. car kilometres and comprise expenditures on fuels and fuel taxes. The remaining expenditures make up the fixed costs of car use, i.e. annualised car purchase and car maintenance costs.

Household expenditure for public transportation was derived from expenditure attributed to the consumption purpose “external transport services without aviation and without holiday trips”. It includes expenditures on passenger transport by local and long-distance bus and coach services, urban light railways and tramways, mountain and funicular railways, taxis and chauffeur-driven hire cars. Hence, on household demand side separated consumption expenditures – private and public transportation – were merged into one combined passenger transport good of final household consumption. Expenditures for aviation and holiday travel were excluded.

4.3.3 Mobility data

To cover the need for information on household travel behaviour, primarily data from the National Travel Survey Mobility in Germany (MiD, 2002) were used. To check the coherence of selected mobility indicators additional data from the Car Mileage Survey (Fahrleistungserhebung, 2002) were taken into account. This data source will not be discussed here in detail due to its secondary importance for the GRTP model data base construction process.

The methodological groundwork and the technical realisation of the MiD 2002 survey was conducted by the German Institute for Economic Research DIW Berlin and the Institute for Applied Social Sciences infas, Bonn on behalf of the Federal Ministry of Transport, Building and Housing.[28]

The MiD 2002 survey was carried out by mail and telephone, where the interviewer collected information on the daily travel and other activities recorded in a diary for one randomly assigned day as well as the economic and sociodemographic attributes of the household members. Sampled households were chosen through a random selection from population registers of 300 municipalities stratified by types of regions. The register provides information on names, address, gender, age, and nationality of the survey unit. The sample contained 25,000 households. Institutionalized persons, foreigners, and children were included in the sample if they were registered within the municipality. The sample provides an observed database of 61,700 persons in 25,800 households owning 34,000 cars and reporting 168,000 trips, covering all days of the year.

The MiD is a large-scale, multipurpose cross-section survey financed and supervised by a national authority. The extensive data contained in the MiD 2002 allow the analysis of individual and household travel behaviour in the context of household income, sociodemographic or land use characteristics, accessibility (mixed-mode), or the

[28] From the beginning on the entire project Mobility in Germany MiD 2002 has been documented on its homepage including detailed information and downloads of interim and final reports (www.mid2002.de). The survey micro data are available via the Clearing House for Transport Data (www.clearingstelle-verkehr.de).

interactions of travel patterns on the household level, estimation of population totals, e.g. in car ownership, the amount of travel, vehicle kilometres, mode use, etc. Figure 5 gives an overview of the information included in the MiD 2002 survey.

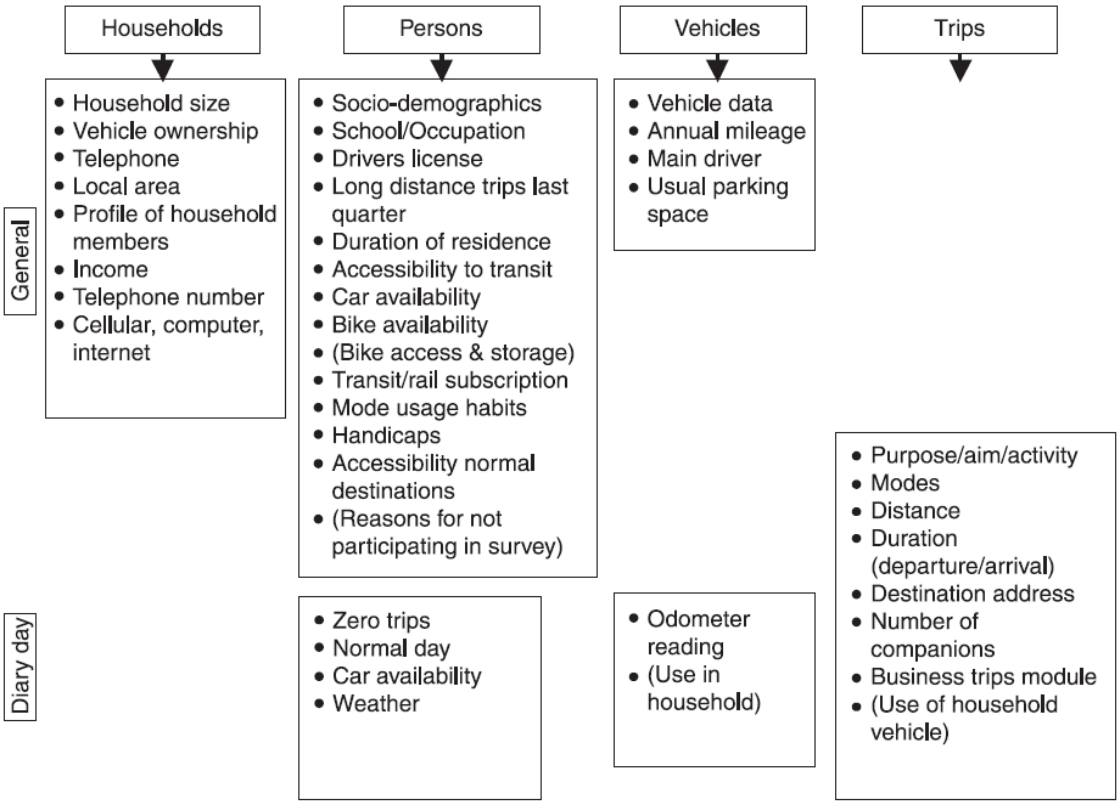

Figure 5 Contents of the Mobility in Germany 2002 survey

Source: U. Kunert and Follmer, R. (2005).

4.3.4 Household budget and expenditure data

The Sample Survey of Income and Expenditure (EVS, 2003, StaBuA 2005a, 2005b and 2006a) and the Current Household Budget Survey (LWR, 2003, StaBuA 2005c) are components of the voluntary system of household budget surveys. Both surveys provide important official statistics on the standards of living of households in Germany. The Sample Survey of Income and Expenditure was initiated in 1962/63 and is conducted every five years in cooperation between the Federal Statistical Office and the statistical offices of the German Laender. The Federal Statistical Office is responsible for the survey technical and administrative organisation as well as for the further reprocessing of the data; the German states recruit the households and conduct the interviews. The current household budget survey reports results on an annual basis and played a minor role in the GRTP model database construction. It has basically served as a secondary data source to crosscheck the consistency of the results obtained from the Sample Survey of Income and Expenditure and it will not be described here in detail.

For the purpose of representativity the survey covers every five years approximately 60,000 households of all social groups in Germany.[29] This number includes about 12,000 households in the New Laender and the former East-Berlin. The selection of the survey population follows a quota sampling plan based on quota variables and applied to the universe of households. By definition, the Sample Survey of Income and Expenditure does not provide data on persons living in communal establishments and institutions, neither on households with a monthly net income of over 18,000 Euro. The reason for putting a ceiling on the income category are privacy and representativity concerns resulting from the small number of observed survey units falling into this category. The quota variables such as type of household, social status of the main income earner, and net household income determine the number of households to be interviewed. The Sample Survey of Income and Expenditure comprises three components. The first part of the survey is a postal, reference day-based introductory interview completed by the households. It captures the basic sociodemographic and economic data of households and individuals, information about their housing situation and equipment with consumer durables. The introductory interview also contains a separate questionnaire about the tangible and financial property, consumer

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[29] The legal basis for the sample survey of income and expenditure is the Law on Household Budget Statistics in the amended version published in the Federal Law Gazette, Part III, Subsection No. 708-6, amended by Article 10 of the Law of 14 March 1980 (Federal Law Gazette I, p. 294), in conjunction with Article 2 of the Ordinance of 26 March 1991 (Federal Law Gazette I, p. 846) and the Federal Statistics Law of 22 January 1987 (Federal Law Gazette I, pp. 462, 565), last amended by Article 16 of the Law of 9 June 2005 (Federal Law Gazette I, p. 1534). The data are collected as specified by Article 2 of the Law on Household Budget Statistics (http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/EN/Navigation/Statistics/WirtschaftsrechnungenZeitbudgets/WirtschaftsrechnungenZeitbudgets.psml, 21.01.2009).

credit and mortgage debts of households. Both questionnaires are posted to the households at the beginning of the survey year. Within the second part of the survey households continuously (diary based) record their income and expenditure over a period of three months. To ensure an even distribution over the year the sample is subdivided into four parts, each for a given quarter of the reference year. The third part of the survey is the so-called "detailed log book" where every fifth participating household enters its detailed expenditure on food, beverages and tobacco by quantity and price for a given month of the year. Data on household income and expenditure are recorded according to the international classification of individual consumption by purpose (COICOP) and is available in the micro-data as continuous variables in Euro. This allows construction of household equivalent income quartiles as used for the GRTP model. For the construction of household income shares different income components such as labour, capital and government transfers were taken into account. The Sample Survey of Income and Expenditure contains comprehensive data on the households' different sources of income, their property and debt situation, equipment with consumer durables, and their final consumption expenditures. It is therefore regarded as the reference data source for the construction of household equivalent income quartiles later applied to the mobility data of the Germany Travel Survey. For an extensive description on the construction of household equivalent income quartiles see Chapter 4.3.5.

Data on household expenditure contain information on consumption spending as well as other expenditures, e.g., on insurance or vehicle taxation.

The anonymised and coded data contain also household information on residential location. Reported land use characteristics are the German federal state (Laender), population-size categories of municipalities, and a so-called “urban-rural-region” classification, containing seven classes:

- High density agglomeration areas,
- Agglomeration areas with outstanding centres,
- Urban areas with high population density,
- Urban areas with medium population density and a high level centre,

- Urban areas with medium population density and without a high level centre,
- Rural areas with medium population density, and
- Rural areas with low population density.

The "urban-rural-region" classification of households' residential location is based on the "basic regional settlement structure typification" (Siedlungsstrukturelle Regionsgrundtypen) developed and applied by the German Federal Office for Building and Regional Planning (BBSR, 2005; Schuert et al., 2005). It matches the corresponding classification applied in the National Travel Survey data and is therefore used to construct the four residential location classes used in the GRTP model (see Chapter 4.3.5).

In general the "urban-rural-region" classification distinguishes regional patterns based on population size and population density:

- "Basic regional settlement type 1" are agglomerations, characterised by a main centre area with more than 300,000 inhabitants or by a population density of about 300 inhabitants per km^2,
- "Basic regional settlement type 2" are urban areas with a population density over 150 inhabitants per km^2 or containing a main centre area with more than 100,000 inhabitants with a minimum population density of 100 inhabitants per km^2, and
- "Basic regional settlement type 3" are rural areas with a population density above 150 inhabitants per km^2 but without a main centre area with over 100,000 inhabitants or containing a main centre area with over 100,000 inhabitants but with a population density below 100 inhabitants per km^2.

Figure 6 gives an overview of the spatial distribution of the basic regional settlement types in Germany. 49 % of the German population and 57 % of all employed persons occupy 11 % of the country's are.

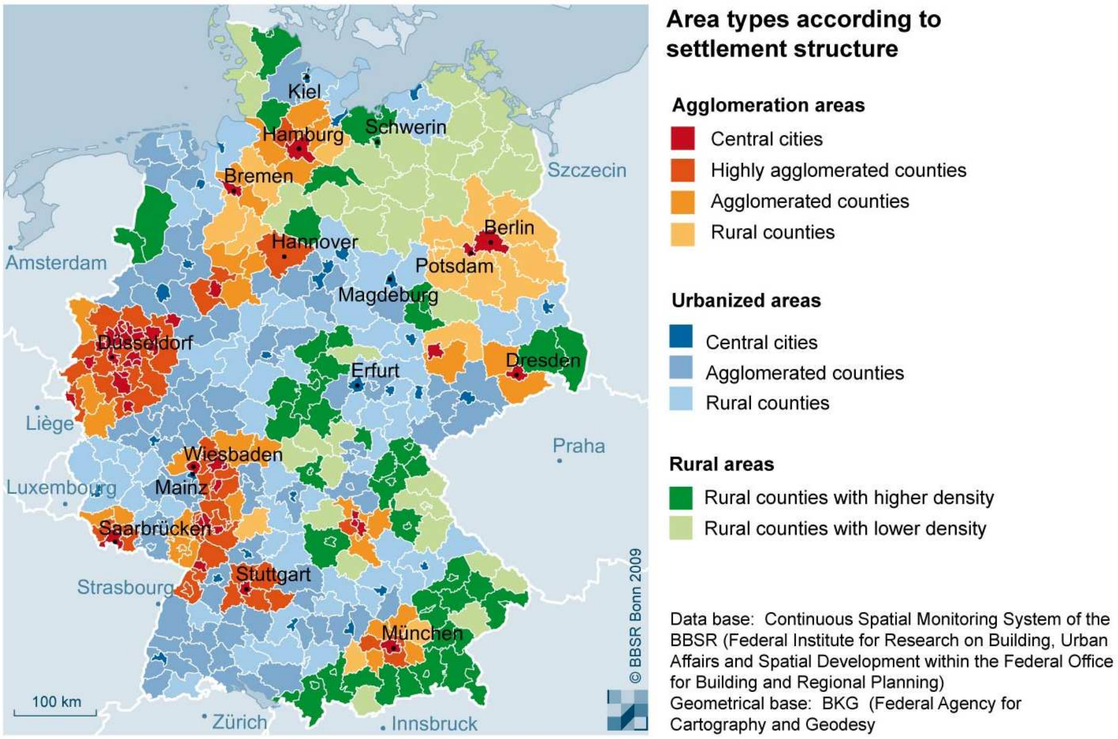

Figure 6 **Basic regional settlement structure typification" (Siedlungsstrukturelle Regionsgrundtypen), German Federal Office for Building and Regional Planning (BBSR)**

To obtain the four residential location classes used in the GRTP model (see Chapter 4.3.5), parameter values of the "urban-rural-region" variable were reassigned and partly merged:

- Categories 1) and 3) were combined to one category "Agglomerations",
- Categories 4) and 5) were merged into the category "Urban areas",
- Categories 6) and 7) were summed up into the category "Rural areas", and
- The residential location category 2) "Urban centres" constituted a unique category.

The residential location attribute used in this work describes the accessibility within the area occupied by the specified household income category. It has a number of advantages. Firstly, they are comprised in the two key household data sources: the German Sample

Survey of Income and Expenditure and the Mobility in Germany Survey.
Secondly, the construction of the regional typification used by the German Federal Office for Building and Regional Planning takes into account different administrative spatial units such as regions, districts, and municipalities. It is further based on the spatial distribution of population in terms of the population density and population size as well as the proximity to and the existence of regional kernels with their centre functions. Both attributes refer to accessibility potentials of residential areas. Densely populated areas with functional centres providing residential infrastructure such as social and other services and working activity areas are assumed to be well accessible, i.e. city centres, urban areas. On the other hand, areas with low population densities, located relatively far from functional centres indicate lower accessibility, i.e., rural areas, parts of agglomerations. Accessibility potential revealed by land use attributes implies the existence of travel mode alternatives as well as their service quality regarding public transportation. Thus, rural areas are assumed to be less accessible, especially by public transportation. They are not in direct proximity to functional centres and can be best travelled by private transport, i.e., car, bike or walking (see also Appendix 10).

4.3.5 Combining different data sources – private household income, expenditures, and mobility

To allow the application of the CGE model for evaluating the (re)distributional effects from road charging policy implementation in the passenger road travel sector, the model distinguishes among 4 different household income classes, i.e., equivalent income quartiles and 4 different residential location attributes describing the households. Each household category is characterized by a uniquely parameterized utility function, endowments of primary factors such as capital and labour as well as public income transfers and unemployment benefits. Household primary factor endowment determines its wage and capital income. For the construction of the model travel demand database by different household income and residential location categories, travel expenditure and travel activity data were required. Since no database exists containing both information, two different data

sources had to be used. Hence, household category specific travel demand patterns were included into the model through behaviour based mobility parameters (in km per mode) from the Mobility in Germany National Travel Survey. Travel expenditure coefficients (in €) were derived from the German Sample Survey of Income and Expenditure. Even though household model data were derived from two different data sources it had to allow for the assignment into the same income and residential location household population groups.
Furthermore, household equivalent income quartiles had to be calculated for the assessment of household redistributional and equity effects. The construction of household equivalent income quartiles requires reliable continuous household income data accompanied by further sociodemographic household information such as household size and composition together with the age structure of single household members. This data are required to derive the equivalent scale that is used to modify the original household net income to obtain household equivalent income.

4.3.5.1 Construction of equivalence-weighted income quartiles

While data from the Income and Expenditure Survey contain continuous information on household income and wealth status, income in the National Mobility Survey is reported as a categorical variable (differentiated for 8 monthly net household income categories, see Table 3) based on the self-assignment of surveyed households. Thus the German travel database contains only household income classes and not continuous household income information. Table 3 gives relevant details underlying the differences in the way household income is surveyed in the Sample Survey of Income and Expenditure compared to the National Travel Survey Mobility in Germany.

Table 3 Information available on household income comparing the Household Income and Expenditure Survey (EVS, 2003) and the German National Travel Survey (MiD, 2002)

Sample Survey of Income and Expenditure of the German Federal Statistical Office (Einkommens- und Verbrauchsstichprobe, EVS, 2003, StaBuA)	German National Travel Survey Mobility in Germany (MiD, 2002, infas and DIW Berlin)
Precise income is reported during a 3 month period by sampled household – widely differentiated income categories are reported, including different types of public and private transfers as well as lump sum annual bonuses	Surveyed households are asked to assign themselves to 8 income categories of monthly household net income – voluntary declaration based on self-assessment: Less than 500 € per month 500 € to less than 900 € 900 € to less than 1,500 € 1,500 € to less than 2,000 € 2,000 € to less than 2,600 € 2,600 € to less than 3,000 € 3,000 € to less than 3,600 € 3,600 € and above per month
Monthly household net income or disposable income are calculated based on detailed household income structure reporting	The highest category of "3,600 € and above" of monthly household net income is not restricted to a maximum value
Household income is a continuous variable and has unique observations for each (household) survey unit	The share of households without income reported is relatively high (14 % of the sample) – this is mainly due to refused income indication (about 9 %)
In line with the survey design and for the reason of a limited number of observations households with a monthly net income over 18,000 Euro are eliminated from the sample	
There are no missing values within the income variables – each survey unit carries income information	
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005).	

To carry out the analysis of household welfare distributional and equity effects, population segments (and their consumption and mobility profiles) had to be classified according to quartiles of equivalence-weighted household income. Hence, the income unit used here is the household consisting of individuals living together and participating in common resources, e.g., combined household incomes. The calculation of household equivalent income takes into account household size and household composition as to the age structure of the household members. It is based on the idea that household income is earned by individual household members and after it has been pooled its allocation depends on the size and structure of the household as a whole. In general, consumption and income allocation decisions take place depending on the household demographics. Hence, household income is shared when expenditure and consumption choices are made by individuals living together in a household context. The implementation of equivalence scales derived from household size and structure can be also understood based on cost of living functions derived from economic utility theory, applied to economies of scale for persons living together (Y=C(U), where income Y corresponds to the cost of living and therefore the utility or welfare U of the household). For some expenditure purposes and consumption goods or services household size and its composition as to the age of its members generate economies of scale with regard to household utility. Several types of economies of scale can be observed. The concept applies in particular to travel decisions and travel expenditures. The consideration of household economies of scale through the calculation of household equivalent income quartiles for the distributional analysis within the passenger travel sector is therefore essential. From the consumption theoretical point of view travel choices are made within the household context considering the utility maximisation of the household as an economic unit. Probably the best practical example is trip chaining of parents bringing their children to school on their way to work. Therefore, for the investigation of equity impacts it is essential to take into account equivalent income to provide a comparison of levels of individual well-being or utility across households, in particular when travel demand is considered. For a fundamental discussion of household composition and welfare comparison see also Muellbauer (1973 and 1974).

Equivalence scales are applied to derive the level of income of an equivalent adult, the equivalent income being weighted by the equivalence scale applied. Hence, the relevant population unit used in welfare analysis is the equivalent adult. The analytical framework is therefore based on a derived income distribution of equivalent adults where differences in (consumption) needs are taken into account corresponding to household formation.

To calculate equivalence-weighted household income the OECD equivalence scale was used (Atkinson et al., 1995; OECD, 1982 and 2008). The OECD equivalence scale is based on different weighting factors for adults and children: the main or first household member receives the factor 1.0, further household members older than 14 years are weighted with the factor 0.5; finally children at the age of 14 years and younger receive the factor 0.3.[30]

In the next step, income quartiles were computed based on the equivalence-weighted household income. The extrapolated household survey population was divided into four equal-sized groups under consideration of the household equivalent income distribution. Each quartile contains one fourth of the sampled population. Equivalence-weighted household income quartiles had to be calculated in both household data sources used in this work, i.e., the Sample Survey of Income and Expenditure and the National Travel Survey, the latter originally containing only a categorised household income characteristic (see Table 3).

4.3.5.2 From categorical to continuous income data in the National Travel Survey

Nevertheless, to compute equivalence weighted household income quartiles a continuous income variable is required together with additional household characteristics. Continuous household income values were only available in the Sample Survey of Income and Expenditure. Therefore, this data basis was used as the reference data source on household income information for the computation of equivalent income quartiles. Furthermore, explanatory coefficients from the estimation of a household equivalent income regression function were used to predict the continuous income for the households in the National Travel Survey data.

For the estimation of a linear regression model of household income a model was specified with the log-transformed form of the monthly household net income as dependent variable and significant household characteristics as explanatory variables. In the regression only comparable explanatory variables enclosed in both surveys could be considered. Explanatory variables used were: the size of the household/ number of household members, number of working persons within the household, number of children at the age of 14 years

[30] For example, a family consisting of five members, i.e., two adult parents and three children at the age of 14, 9 and 3 years, has a combined disposable income of overall 5,000 Euro per month. Their monthly net OECD-equivalence-weighted income amounts to 5,000/(1 + 0.5 + 0.3 + 0.3 + 0.3) = 2,083 Euro.

or younger, number of cars within the household, the German federal state (Bundesland), and a residential location characteristic as the “urban-rural-region” classification described in Chapter 4.3.4. The estimation was carried out using the econometric software Stata.[31] Since all of the explanatory variables are in categorical form a desmat-linear regression model was run in Stata.[32]

Given the limitations regarding the inclusion of explanatory variables into account, the model fit can be seen as satisfactory (Pseudo-R-Square of 0.5).

In the next step, data from the National Travel Survey were merged to the Sample Survey of Income and Expenditure that has been used to estimate the household income regression model. Since the National Travel Survey data contained exactly the same household income explanatory variables as have been used in the regression the income predictor was calculated for both databases using the parameter coefficients estimated from the Household Sample Survey of Income and Expenditure.

(OECD) Equivalence scales were calculated separately for each dataset using the specific household demographic characteristics. Based on the estimated household monthly net income and the calculated equivalence scale parameters, equivalence-weighted household incomes were calculated for each household in the two datasets – the Sample Survey of Income and Expenditure and the National Travel Survey.

Finally, based on the equivalence-weighted household incomes, household quartiles were constructed. Quartiles rather than quintiles or deciles were chosen for the model database to limit the number of household categories after the inclusion of the four residential characteristics. The construction of two-dimensional household categories based on, e.g., income deciles and the four residential location attributes would lead to 40 different household categories with a likely critical number of observations in each category. Besides, the interpretation of distributional effects between 40 two-dimensional categories could easily become fuzzy and unsound.

[31] Data Analysis and Statistical Software STATA, www.stata.com (24.11.2009).
[32] For a detailed description of categorical regression estimation procedures in Stata using desmat see http://ideas.uqam.ca/ideas/data/bocbocode.html. (15.07.2009).

4.3.5.3 Matching different data sources

An important precondition for merging information on travel expenditure and travel behaviour derived from two different data sources for the estimated equivalence-weighted household incomes quartiles is a good match of the household population within the quartiles. Therefore, households in the quartiles of each database should show similarities as to average household size, motorisation levels, age structure of household members, etc. The method used to estimate household income allows a satisfactory match of the household population of each survey sample according to the equivalence-weighted household income quartiles. Small differences between the quartile income intercepts in each dataset validate furthermore the comparability of the household population distribution within the household quartiles of both data sources (Table 4).

Table 4 Equivalence-weighted household income quartile intercepts calculated from the Sample Survey of Income and Expenditure and the National Travel Survey

Equivalence-weighted household income quartiles		Quartile income intercepts, in Euro	
		Sample Survey of Income and Expenditure	German National Travel Survey
Quartile 1	up to	1,569	1,496
Quartile 2	up to	1,893	1,840
Quartile 3	up to	2,233	2,141
Quartile 4	from	2,233	2,141

Source: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.

The analysis of distributional and equity effects from road charging will consider not only household income quartiles, but is also supposed to take into account the four residential location characteristics as described in Chapter 4.3.4. Therefore, the constructed equivalence-weighted household income quartiles are additionally combined with their corresponding parameter values from the “urban-rural-region” classification in each dataset. For the analysis of the model results categories are distinguished as presented in

Table 5.

Table 5 Household categories used in the application of the GRTPM

Household categories used in the GRTP model	
Income	
HIQ1	Equivalence-weighted household income quartile 1
HIQ2	Equivalence-weighted household income quartile 2
HIQ3	Equivalence-weighted household income quartile 3
HIQ4	Equivalence-weighted household income quartile 4
Residential location	
HRCent1	Urban Center
HRAgglo2	Agglomerations
HRUrb3	Urban areas
HRRul4	Rural areas
Combination of the equivalence-weighted household income quartiles and the residential location characteristic based on the "urban-rural-region" classification	
H1	HRCent1 + HIQ1
H2	HRCent1 + HIQ2
H3	HRCent1 + HIQ3
H4	HRCent1 + HIQ4
H5	HRAgglo2 + HIQ1
H6	HRAgglo2 + HIQ2
H7	HRAgglo2 + HIQ3
H8	HRAgglo2 + HIQ4
H9	HRUrb3 + HIQ1
H10	HRUrb3 + HIQ2
H11	HRUrb3 + HIQ3
H12	HRUrb3 + HIQ4
H13	HRRul4 + HIQ1
H14	HRRul4 + HIQ2
H15	HRRul4 + HIQ3
H16	HRRul4 + HIQ4
Sources: GRTPM, and own calculations.	

All categories used for the application of the GRTP model, i.e., 4 equivalence-weighted household income quartiles, 4 residential location classes, and the 16 combinations between income and land use attribute, are consistent between the two datasets as to the underlying household population. Table 6 shows selected statistics of the sample as to the number of observations as well as the extrapolated sample together with relevant indicators such as average household size or income.

Table 6 Selected statistics from the Survey of Income and Expenditure and the National Travel Survey

Selected household statistics, Germany 2002 and 2003								
	Number of observations		Aggregated total in million.		Average monthly net income in Euro		Average number of persons per household	
	MiD	EVS	MiD	EVS	MiD	EVS	MiD	EVS
Income category								
HIQ1	5,457	7,900	9.4	9.8	1,271	1,248	1.7	1.6
HIQ2	6,572	10,423	9.5	9.3	1,753	1,695	2.2	2.3
HIQ3	6,477	11,587	9.5	9.5	2,069	1,983	2.3	2.2
HIQ4	7,342	12,834	9.2	9.5	2,603	2,510	2.4	2.3
Total	25,848	42,744	37.7	38.1	1.920	1.856	2.2	2.1
Residential location								
HRCent1	6,757	8,987	9.1	9.2	1,865	1,784	2.0	1.9
HRAgglo2	10,049	18,982	16.5	16.5	2,020	1,947	2.2	2.1
HRUrb3	6,059	9,127	7.4	7.8	1,852	1,812	2.3	2.2
HRRul4	2,947	5,648	4.7	4.6	1,780	1,750	2.3	2.2
Income category together with residential location								
H1	1,688	2,289	2.9	3.1	1,281	1,256	1.6	1.6
H2	1,688	1,914	2.3	2.0	1,756	1,686	2.1	2.1
H3	1,508	2,202	1.8	1.9	2,078	1,962	2.3	2.2
H4	1,909	2,582	2.2	2.2	2,586	2,468	2.2	2.1
H5	1,359	2,419	3.1	3.2	1,292	1,269	1.6	1.6
H6	2,340	3,867	4.0	3.4	1,772	1,703	2.2	2.3
H7	2,703	5,759	4.6	4.8	2,079	1,982	2.2	2.1
H8	3,647	6,937	4.9	5.0	2,620	2,524	2.4	2.4
H9	1,617	1,908	1.9	2.1	1,240	1,230	1.8	1.8
H10	1,691	2,781	2.0	2.4	1,722	1,701	2.3	2.3
H11	1,545	2,283	2.0	1.8	2,053	2,006	2.4	2.4
H12	1,206	2,155	1.4	1.6	2,598	2,530	2.6	2.6
H13	793	1,284	1.5	1.3	1,248	1,203	1.9	1.8
H14	853	1,861	1.3	1.5	1,736	1,678	2.5	2.4
H15	721	1,343	1.1	1.0	2,036	1,988	2.4	2.3
H16	580	1,160	0.8	0.8	2,558	2,504	2.5	2.5

Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.

Based on the good comparability of the data within the Sample Survey of Income and Expenditure and the National Travel Survey it can be assumed that each category defined within the two survey samples comprises (nearly) the same household population as to demographic characteristics. Given consistent equivalence-weighted household income quartiles, including the residential characteristic input data on household income distribution, travel expenditures, mobility parameters and CO_2 emissions have been deducted from the two surveys and integrated into the GRTP model.

Household data from the Survey of Income and Expenditure were used to derive the income shares for sources of income according to the household categories specified in the GRTP model as shown in Table 5. Income types taken into account were: overall household net income, household labour income, income from capital, public transfers and finally unemployment benefits.

Furthermore, for each household category expenditures on travel related goods and services including fuel and vehicle tax as well as car insurance were derived from the Survey of Income and Expenditure database (for a detailed description see Chapter 4.3.2).

From the National Travel Survey mobility parameters were included in the GRTP model according to household categories. Mobility information for annual kilometres travelled by car and by public transportation means were used. Moreover, household category specific CO_2 emission parameters were computed, based on corresponding vehicle ownership attributes as reported in the survey.

After the integration of the household data in the model, numerous data checks and iterative (calibration) adjustments followed to encompass data consistency between the macro, top-down economic data from the input-output tables of the national accounts and the micro, bottom-up data from the two household surveys. This is not a trivial exercise, as empirical data sources often reveal inconsistencies and different sorts of deficiencies.

The GAMS code of the GRTP can be viewed in the Appendix 11.

5 Model implementation

5.1 Policy scenario definition

The implementation of road charging policies requires the specification of the level and the type of charging. The road use charge is imposed on a distance dependent basis (per km) and the level of per km charging fee is set based on marginal social or marginal average road use cost calculations. In the past growing research activity has been dedicated to the assessment of the full social costs of motor vehicle use, including external, or non-market costs imposed e.g. on the environment and the private, or market costs born by the car user. Results from social-costs assessment provide data for the specification of transport pricing policy measures (Lee, 1993; Murphy and Delucchi, 1998, Delucchi, 2000; Litman, 2003; Quinet, 2004). Nevertheless, methods used for (full) road transport cost assessment vary and resulting numerical estimates are often based on different assumptions as to the kind of costs included into the calculation.[33]

The scenario analysis is carried out based on 0.05 Euro per km, distance dependent road charge imposed as a mark-up on the variable car travel costs on private car drivers. The 0.05 Euro per km road charge rate is a lower bound, averaged estimate drawn from a survey of German as well as European studies on road infrastructure cost assessment as well as external average and marginal social cost calculations. The rate of 0.05 Euro is set as one half of the reference value from average external cost calculations for cars and is assumed to correspond to the lower bound from marginal external cost calculations (Herry and Sedlacek, 2003; IVT, 2004; Infras/ IWW, 2000, 2004; RECORDIT, UNITE). The decision to investigate a 0.05 Euro per km road charge, rather than a gas tax or a vehicle-specific charge is clearly related to the given probability of implementation of such an instrument in Germany, but also to the fact that energy tax on gasoline is already one of the highest compared to other countries in the European Union, and in particular compared to Germany's border countries. A further increase of the tax would worsen the already

[33] Cost accounted for in the calculation can be associated with road congestion, traffic accidents, local as well as global air pollution, oil dependency, and noise. Other external costs taken often into account are road infrastructure maintenance costs, land use such as urban sprawl and parking, etc. (Parry et al. 2007). For detailed description of road use externalities see Chapter 2.1.

existing adverse effect of “grey fuel imports and refuelling tourism”. As the study is future oriented it focuses on road charging as a policy instrument. At the same time it takes into account two important policy changes already or soon taking place in Germany: Firstly, the recent developments within the German vehicle taxation scheme with regard to the consideration of CO_2 emissions; and secondly, the European Commission regulation to come in 2012 forcing European car makers to curb down the CO_2 emissions of the newly vehicle registrations to 120 CO_2 g/km. Both policy regulations will improve fuel efficiencies of passenger cars, inducing decreasing fuel demand. It can be therefore expected that in the long run both policy changes will relax the impact of fuel taxation as policy instrument to regulate car use and generating state revenue and making it therefore necessary to set up an alternative policy instrument such as road use charging.

The level of 0.05 Euro is additionally linked to the fact that it makes up about 30 % of the per km cost of car use compared to the out-of-pocket cost of an average car driver in Germany. It is therefore high enough to trigger behavioural reactions of car users; at the same time 0.05 Euro per km is a rather small amount compared to the overall household spending on car purchase, ownership and use. Nevertheless, the implementation of full social cost pricing would require very high charging levels and therefore is bound to be controversial.

For the implementation of the GRTPM the following revenue use was assumed. Road charging is collected and redistributed within the CGE model structure, where 15 % of the revenues total is retained for system-financing purposes and redirected to intermediary input sectors such as insurance and banking, electronic devices and the factor labour.

The remaining revenue is divided between a direct transfer to private households and the investment in public transportation services. The different revenue use scenarios as to household refund are specified in detail in Chapter 5.2.

Besides the cost associated with operating the road charging mechanisms no additional costs from transactions or interactions between existing taxes and the introduced transportation policy are considered. The consideration of optimal tax structures and the discussion over the revenue share used to cover the operation of the road charging agency are both complex topics and their in-depth analysis goes beyond the scope of this work. The assumption about the transaction costs retained to finance the system operating the road charging revenue collection and redistribution agency has been ever since subject to critical discussion, in particular when the cost is set as share of the overall revenue. In this study the approximate value or share of the system cost has been derived from existing road infrastructure cost assessment studies, given the charge level of 0.05 Euro per kilometer and corresponding revenues (Herry and Sedlacek, 2003; IVT, 2004; Infras/ IWW, 2000, 2004; RECORDIT, UNITE). The question of an optimal or efficient revenue share of the road charging agency, especially when simulating changing road pricing levels is not further elaborated in this dissertation work. It certainly remains a relevant and interesting research topic.

The follow-up simulation analyses of different road charging revenue recycling schemes allow the assessment of welfare and equity impacts from such policies, where the choices of revenue redistribution reflect different policy objectives. The disaggregation of the private travel demand within a CGE model framework between different transport modes and household income and residential location categories enables this assessment, where the final effects from the pricing measure within the economy depend on the use or reallocation of the monetary returns collected from the road charge (Small, 1992; Meyers, 2000 and 2001; Mayeres and Proost, 2002; Farrell and Saleh, 2005; Hau 1998, 2005a, and 2005b).

The answer to the question about acceptance of the measure strongly depends on the definition of the acceptability criterion as well as the revenue recycling policy. The GRTP model allows the simulation of policy scenario assumptions required to design an acceptable policy reform, provided an applicable fairness and equity definition is assumed. This includes also the examination of the question how much redistribution has to take place before the median voter supports a 0.05 Euro per km road tax. At the same time the methodological approach used has the strong advantage of allowing the assessment of distributional as well as overall economic and environmental effects important for social welfare analysis under consideration of revenue redistribution decisions.

5.2 Revenue reallocation schemes – household refund

To examine the differences in the distributional impacts, the overall net welfare, and other economic effects depending on the road charging policy scenario, the varying road charge collection and reallocation schemes are specified in the CGE model for Germany. In each scenario the road charging measure is implemented as a distance dependent mark-up on the price of car travel calculated based on the kilometres travelled. The overall effects of the charging policy depends basically on the reallocation of the revenues collected from its implementation and is therefore subject to policy simulations described below. In each scenario road charging is collected and redistributed within the CGE model structure, where 15 % of the revenues total are retained for system-financing purposes and redirected to intermediary input sectors such as insurance and banking, electronic devices and the factor labour. 50 % of the revenue flows to the transport sector and is evenly used to improve or expand the public transport system and the road infrastructure. It is assumed that the value added for a household group by transport system amelioration financed from road charging revenue is proportional to the amount of public transport trip-km travelled by the household. Another possible interpretation of this public transport service and infrastructure improvement is that it indirectly lowers public transport fares. Depending on the policy design, the remaining proportion of the road charge revenue of 35 % is redistributed to the private household sector according to a specific household refund scheme or remains part of the public household budget.

The different road charging revenue use policies specified to carry out the simulation analyses with the GRTP are as follows: A all of the 35 % of the revenue is refunded in a lump-sum manner to the private household sector and distributed evenly, i.e., in equal proportions across the household categories, labelled "Equal household refund";[34] in scenario B "Proportional household refund" the private household refund is reallocated to

[34] A lump-sum distribution of the revenue might seem far from the practical implementation being rather theoretical. Nevertheless, there exist examples of a credit based pricing scheme similar to the lump-sum revenue distribution scheme, proposed to improve public acceptance of the measure (Kalmanje and Kockelman, 2004).

the household categories according to the specific fuel tax burden of each group as proportion of the overall fuel tax burden contributed by the private households to the state budget and therefore to some extent reflecting the “vertical equity” principle often referred to in public economics (see Chapter 2.3); and finally in scenario C no lump-sum road charging revenue redistribution to the private households takes place, labelled “No household refund”. Table 7 gives a summary overview of the three policy scenarios specified in the GRTPM for the conduction of the policy simulations.

Table 7 Overview of the policy scenarios implemented in the GRTPM

Overview of policy scenarios implemented in the GRTPM			
Scenario label	A "Equal household refund“	B “Proportional household refund“	C "No household refund"
Network coverage	Full network		
Time differentiation	None		
Charging level	5 Euro-Cent/km		
Revenue use	15 % System-financing, 50 % Transport sector, 35 % Private household refund		
Household refund policy	Evenly lump sum redistribution to all private household categories	%-Redistribution according to the specific fuel tax burden of each household category as proportion of the overall fuel tax burden	No redistribution to the private household sector
Source: GRTM.			

The redistribution structure of road charging revenues between household categories given in Table 7 and illustrated in the following Chapter 5.3 does not result from welfare optimizing assumptions. The simulation of different redistribution schemes of the road charging revenue is rather used to provide a better understanding of the welfare and equity impacts from the road charging measure.

5.3 Model results

For a comparative static impact assessment a distance dependent and time invariant overall road network charge for car use is implemented at the level of 0.05 Euro per km. The implementation of road charging changes the price in car travel and generates a shift in the modal split resulting in changing overall transport volumes, depending on the reaction parameters introduced in the model. Furthermore, economic, budgetary and environmental sectors related to the demand for passenger travel experience an impact from the shifts in the private travel mode choice.

The effects of road charging can be categorised as follows: 1) higher travel costs for car users according to the distance driven (in km) on the public road network, 2) rising unite cost of car use triggers travel behaviour reactions – reduction of car use and changes in modal split towards “slow travel modes” to avoid the charges, 3) revenue collection and redistribution to e.g., provision of road infrastructure, public transport service enlargement or improvments, tax cuts, or public sector spending policy in general. Since the road charging measure introduced in this work applies to the overall network and does not take into account the travel time of the day, travel behaviour changes will not include route choice effects, or changes in departure times. The combination of the three components, in particular the revenue use policy determine the net effect of the charging scheme and whether parts of the population will suffer or benefit from the measure (Small, 1992; Meyers, 2000 and 2001; Mayeres and Proost, 2002; Farrell and Saleh, 2005; Hau 1998, 2005a, 2005b).

5.3.1 Overall transport and macroeconomic impacts

In all road charging scenarios the impacts on the economic activity are rather small. It suggests that the policy can improve emission levels and shift mode choice towards public transportation without having negative secondary economic effects of significant magnitude. Table 8 summarizes the overall transport, environmental and macroeconomic effects for varying road charge revenue reallocation policies.

Table 8 Macroeconomic effects from different road charging scenarios, Germany 2002

Overall effects from different road charging schemes for Germany								
		Reference	A Equal household refund	Change in %	B Proportional household refund	Change in %	C No household refund	Change in %
Level of road charge	Euro/ km	-	0.05		0.05		0.05	
Transport variables								
Revenues total	Million Euro	**0**	23,042	-	23,051	-	22,954	-
Rev. (semi-public)	Million Euro	**0**	13,075	-	13,062	-	19,511	-
Car	Million km	**492,783**	460,848	-6.5	461,012	-6.5	459,072	-6.8
Public transport	Million km	**133,144**	140,725	5.7	140,633	5.6	140,080	5.2
Overall travel	Million km	**625,927**	601,572	-3,9	601,645	-3,9	599,152	-4,3
Environment								
CO_2	1,000 t	**110,698**	104,017	-6.0	104,051	-6.0	103,614	-6.4
CO_2 difference	1,000 t	**-**	-6,681	-	-6,647	-	-7,084	-
Macroeconomic variables								
Environmental welfare change	Million Euro		2,568		2,555		2,711	
GDP	Billion Euro	**2,143**	2,171	1.3	2,171	1,3	2,173	1.4
Number of employees	1,000	**39,096**	39,308	0,5	39,308	0.5	39,384	0,7
Number of unemployed	1,000	**4,061**	3,849	-5.2	3,849	-5.2	3,773	-7.0
Unemployment rate	%	**9.41**	8.9	-	8.9	-	8.7	-
Price of capital	%			-0.04		-0.04		-0.05
Budgetary effects								
Due to change in								
Rev. from direct taxes	Million Euro	**722,674**	725,302	0.4	725,312	0.4	726,284	0.5
Rev. from indirect taxes	Million Euro	**60,643**	60,857	0.4	60,857	0.4	60,957	0.5
Labour market expend.	Million Euro	**43,710**	41,432	-5.2	41,426	-5.2	40,615	-7.1
Government demand	Million Euro	**378,537**	381,071	0.7	381,096	0.7	382,888	1.2
Sources: GRTPM, and own calculations.								

The volume of car road charging revenue generated in Germany from charging car drivers using the overall road network is to a great extent determined by the population size, the number of car users or degree of motorization, the total car kilometre driven and finally the level of the per km road charge. For the different scenarios there are only slight differences in the total revenue of about 23 billion Euro, but sizeable differences between 13,062 and 19,511 million Euro, when the semi-public revenue volume is considered. The semi-public revenue is calculated as the difference between the revenue total and the amounts of revenues transferred to the road charging collecting agency and the household refund (as described in Chapter 5.2).

To have a better understanding of the total revenue volume from road charging (23 billion Euro) it can be compared to the annual volume of car tax or fuel tax collected in Germany. Hence, in 2002 the German state budget received 7,592 million Euro of car tax and 42,192 million Euro of fuel tax. The approximated road charging revenue would therefore vary between approximately twice the volume of the annual car tax and be close to half the amount collected from fuel tax. According to the National Accounts, household expenditure on overall transport amounted to 165,420 million Euro and for car fuel to 40,380 million Euro for the year 2002. Hence, on the aggregated basis households would have to pay for road use about one half of their annual fuel expenditure.

Before the implementation of the policy annual car kilometres amount to about 493 billion km. After the introduction of car road charge a reduction in car use accompanied by an increase in the use of public transportation can be observed for each scenario. Depending on the revenue reallocation scheme, private car travel declines between 6.5 % and 6.8 %. The reduction in car use after the introduction of car road charging is slightly higher, when there is no direct revenue transfer to the private household sector. The redistribution of a revenue share directly to the private households lowers the negative effect of road charging on car use. The decline in auto mobility due to the distance dependent cost rise in car travel is (partially) compensated by the use of public transit. Kilometres travelled with public transport modes rise on average by 5.2 % to 5.7 %. Therefore, road charging revenue redistribution to the private household sector promotes the switch from car to use of the public transportation. Nevertheless, taking the kilometres travelled in the car or in the modes of public transport as a homogenous “mobility” bundle, the net effect of road charging on travel activity is in general negative. As a result overall household mobility is reduced by 4.3 % to 3.9 % in distance travelled depending on the household income category.

In nominal terms, where the foreign price level is used as numeraire, gross domestic product (GDP) experiences a positive growth after the implementation of the policy scenarios. Since with the introduction of the new service “environment” this factor of production is now explicitly paid for GDP increases. Furthermore, the consumption in terms of GDP includes only market goods. However, paying a road charge increases the environmental consumption and this takes place at the expense of traditional consumption. Therefore the nominal increase in GDP are in line with the decline in domestic consumption by the private household sector discussed in Chapter 5.3.5.4.

The aggregated welfare calculated within the model quantifies the social benefit from the reduction of negative externalities from car use. Its level is based on an average external costs per kilometre calculation as an approximation of marginal external transport costs. The aggregate external cost is calculated by multiplying the average marginal costs with the total car kilometres travelled under the assumption of a linear relationship between the monetarized level of the negative externality and the car road kilometres made.[35] Assuming linearity of external costs in distance travelled is a simplification. In reality most functional relationships between car use and externality generation are non-monotonous, and non-linear. External effects from fuel consumption, e.g., emissions of CO, HC, NOx, CO_2, but also accidents, etc. are not only a function of the distance driven but also of vehicle speed, the technical characteristics of the vehicle, driving behaviour, and other factors. Nevertheless, to some extent the assumption of linearity between the external damage and car travel is legitimate when costs are aggregated over a large population, partially balancing out different non-linearities (Small and Kazimi, 1995). The resulting net welfare benefit is highest for the scenario without the transfer of the road charging revenues to

[35] In the approximated external cost calculation, the following categories are taken into account: infrastructure depreciation costs, external accident costs, and environmental costs (noise, local pollutants, climate effects), each differentiated by type of street and user, and net of public revenues raised, e.g., from taxes on insurance, vehicle registration and fuels (Herry and Sedlacek, 2003; Infras/ IWW, 2000 and 2004). For more details on marginal social cost pricing approaches see Chapter 2.1.

private households since the scenarios with transfer induce lower car use reductions. As external transport costs in fact can be assumed to rise progressively with transport volume rather than linearly as is approximated here, the benefit quantification can be considered rather conservative (Steininger et al., 2007).

5.3.2 Environment

The model implementation allows quantifying the reduction of fuel use related transport externalities, i.e. CO_2 emissions, depending on the scheme design. Thus, due to the reduction in car travel, CO_2 emissions generated in the motor vehicle sector go down on average by about 6 %, depending on the revenue redistribution policy. The positive environmental effect of CO_2 reduction is based on the fact that the average CO_2 emission per passenger-km is far lower for public transport use than for car travel (VDV-Statistik, 2006). Therefore, because of the sizeable reduction in car use and despite of the rise in the use of public transport due to the modal shift, the overall CO_2 emission level declines.

Overall results demonstrate that when the ultimate policy objective is a reduction in the fuel combustion externalities from car use, direct revenue transfer to private households should be minimized to avoid a response similar to a rebound effect. Results on individual household contribution to the reduction on CO_2 emissions are further elaborated in Chapter 5.3.5.3.

5.3.3 Sectors

Results obtained for selected economic sectors correspond to the results presented in Table 8 for transport related variables and macroeconomic indicators. As one would expect, the economic activity in sectors related to car travel demand decreases with the introduction of car road charging. The most significant decline can be observed for the sectors car manufacturing (i.e., transport equipment), retail activity (i.e., trading), market services such as repair, and foremost production of refined petroleum products. On the other hand, sectors related to the positively affected public transport demand and the use of road pricing revenues for qualitative improvement or a quantitative extension of the road infrastructure supply or public transport services exhibit higher production. These sectors are mainly construction, non-market services, or the land transport sector. The transfer of the RC revenues to sectors such as construction, transport or market services implies an investment and therefore a qualitative improvement or a quantitative extension of the road infrastructure supply or public transport services. Also sectors linked to the economic activity of the road charge collector agency, e.g., electrical goods or the banking and finance sector, increase their output.

5.3.4 Budget

The positive sector effects merge into a positive impact on GDP (see Table 8). The decrease in production lowers indirect tax revenues and exerts a downward pressure on employment. Nevertheless the negative impact on employment is outweighed by the positive labour market effect triggered by the sector shift in production. Therefore, the economy experiences after all a positive effect on indirect taxes that results from the positive labour market effect and the moderate effect on private household welfare (see Table 8 and Table 28). In summary, shrinking public tax revenues are compensated for by the (semi-public) net revenues collected from car road pricing.

5.3.5 Microeconomic impacts

The introduction of an overall road use charge on car travel at the level of 0.05 Euro per km means a considerable increase in the unit price of car travel compared to the variable car km cost before road use charging (on average of about 0.08 Euro) shown in Table 9.

Table 9 Car and public transport expenditures across household categories

Transportation cost in Euro per km for different household groups and different transportation means, Germany 2002					
Residential category					
Public transportation cost in [Euro/km]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	0.09	0.11	0.08	0.10	0.10
HIQ2	0.08	0.09	0.05	0.04	0.07
HIQ3	0.05	0.06	0.05	0.06	0.05
HIQ4	0.07	0.07	0.07	0.05	0.07
Total	0.07	0.08	0.06	0.06	0.07
Car variable cost in [Euro/km]					
HIQ1	0.07	0.06	0.08	0.05	0.06
HIQ2	0.07	0.09	0.08	0.09	0.08
HIQ3	0.08	0.08	0.08	0.09	0.08
HIQ4	0.07	0.07	0.08	0.09	0.07
Total	0.07	0.08	0.06	0.06	0.08
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.					

The resulting effects vary considerably across household income groups and with reference to the road charging revenue redistribution policy scenario as will be presented in Chapters 5.3.5.1 and 5.3.5.4.

5.3.5.1 Household travel expenditure

After the introduction of 0.05 Euro per km of car road charging, expenditure for car travel as well as for public transportation use increases with respect to the pre-policy situation for each household group, irrespective of the policy scenario introduced. In Table 10 transport expenditure impacts from car road charging are presented for different household groups as %-change relative to the reference scenario for different revenue redistribution schemes.

Table 10 Car and public transport expenditure impacts across household categories and road charging revenue reallocation scenarios

Distributional impacts across road pricing policy scenarios and household groups, Germany 2002											
Transport expenditure impacts from car road charging in % change relative to the reference scenario for different revenue redistribution schemes											
Equal household refund in [%-change]											
	Car						Public Transport				
Income Category	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total		HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ 1	13.5	13.0	14.1	23.3	15.6		4.7	4.5	5.9	9.8	5.3
HIQ 2	14.1	10.9	13.7	12.4	12.5		5.9	4.7	5.9	5.5	5.4
HIQ 3	12.5	13.5	15.5	14.1	13.8		5.3	5.7	6.8	6.4	5.8
HIQ4	14.7	13.8	12.7	12.2	13.6		6.2	5.9	5.6	5.6	5.9
Total	13.8	13.1	13.8	13.9	13.5		5.5	5.2	6.0	7.1	5.6
Proportional household refund in [%-change]											
HIQ 1	13.1	12.5	13.5	22.1	14.9		4.3	4.0	5.3	8.7	4.3
HIQ 2	13.9	11.0	13.7	12.1	12.5		5.7	4.8	5.9	5.3	5.7
HIQ 3	12.4	13.8	15.5	13.7	13.8		5.3	6.0	6.9	6.1	5.3
HIQ4	14.8	14.1	12.8	11.8	13.8		6.3	6.2	5.7	5.3	6.3
Total	13.8	13.4	13.8	13.5	13.6		4.0	4.8	6.0	6.2	5.5
No household refund in [%-change]											
HIQ 1	12.8	12.2	13.0	21.6	14.5		4.0	3.8	4.9	8.2	4.4
HIQ 2	13.4	10.6	13.1	11.5	12.0		5.2	4.3	5.4	4.7	4.9
HIQ 3	12.0	13.3	15.0	13.1	13.3		4.8	5.5	6.3	5.5	5.4
HIQ4	14.4	13.7	12.2	11.2	13.3		5.9	5.8	5.2	4.7	5.7
Total	13.3	12.9	13.3	12.9	13.1		4.9	4.9	5.4	6.0	5.1
Sources: GRTPM, and own calculations.											

Looking at all three policy scenarios, the increase in expenditures for car travel is much (two to three times) higher than for public transportation use. This mainly results from the limited substitutability of public transportation journeys for car trips. Moreover, with the redistribution of road charging revenues to the private household sector the increase in expenditure for travel related goods and services is higher than without the refund.

Expenditure changes also differ with household category and the differences are most pronounced for specific combinations of households by income and residential location. Irrespective of the policy scenario, i.e. with or without introduction of some form of household refund, households in the lowest income quartile experience the highest increase of car use expenditures and the lowest increase in public transportation spending. The highest income group experiences the lowest relative increase for car travel. Therefore, road charging works regressively on car use expenditures.[36] In contrast, changes in public transportation expenditures are clearly progressive across household income quartiles, i.e. they constitute a greater proportion of income as income rises. Thus, households in the lowest income quartile experience the lowest and households in the highest income quartile the highest change in public transportation expenditure. When residential location is considered as single distinction, results turn out rather homogeneous between household groups and their interpretation is therefore not straightforward.

When household refund is assumed (scenarios A and B) households in the two lowest income quartiles benefit most from the revenue transfer in terms of increasing spending on travel activities. Furthermore, while expenditure impacts vary between 12 to 15.6 % for car use and 4.4 to 6.1 % for public transportation when income and residential location characteristics are considered separately, they diverge between 10.6 and 23.3 % and 3.8 and 9.8 % respectively when household categories by both income and residence are taken into account.

For spatially and income disaggregated household categories, households in the lowest income quartile residing in a rural area experience by far the highest car expenditure increases, ranging from 21.6 % for scenario C to 23.3 % when scenario A is assumed. Therefore, for this household group the introduction of road charging has a clearly regressive impact on their car use expenditures. The same effect is also observed for the public transportation spending of this household group. On the other hand, households living in city centres display a rather progressive car expenditure change across household income quartiles. Again, a similar result is also here true for the expenditures on public

[36] The terms regressive and progressive will be used throughout the work to desctribe the income regressivity or progressibvity effect with regard to expenditures as well as to welfare impacts occuroing after the introduction of the policy reform, i.e., car road charging. Hence, a progressive effect in expenditure refers to a situation, where the percentage change according to household income category is higher for high income quartile groups than for low income quartile housheholds. Accordingly, a regressive distribution refers to an outcome where low income quartile households experience a higher relative change than high income quartile categories (Suits, 1977 and Kiefer 1983).

transportation.

Most of these important findings can be interpreted based on a range of different factors, above all to household specific travel expenditure as well as travel demand profiles in the pre-policy situation resulting among others from household demographics and motorisation, as will be discussed in more detail in Chapter 5.3.5.2 together with the description of mobility impacts from road charging.

In the pre-policy situation households display clearly different expenditure patterns for car use as well as for the use of public transportation, depending on their income level and their residential location. Table 11 shows selected household income and expenditure parameters in absolute numbers. An additional table with absolute household expenditures on fixed car use related components is presented in the Appendix 6.

Table 11 Household income, overall consumption and selected transportation expenditures for household categories

Household net income total consumption and transportation expenditure in Euro, Germany 2003					
Residential category					
Net income in [billion Euro]					
	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	60.6	60.7	41.5	27.0	189.8
HIQ2	58.0	109.9	77.1	48.8	293.8
HIQ3	71.0	170.2	68.2	39.0	348.4
HIQ4	101.5	244.8	79.0	38.3	463.6
Total	291.1	585.6	265.8	153.1	1,295.6
Consumption Total in billion Euro]					
HIQ1	51.3	51.9	35.1	22.7	160.9
HIQ2	46.7	89.1	62.1	39.0	236.8
HIQ3	56.4	133.6	49.8	28.1	267.9
HIQ4	72.4	173.3	57.0	27.6	330.3
Total	226.8	447.9	204.0	117.3	996.0
Total fixed car travel expenditure in million Euro]					
HIQ1	1,780	1,435	1,802	1,232	6,249
HIQ2	4,002	7,874	6,084	4,094	22,054
HIQ3	5,707	13,525	5,036	3,179	27,446
HIQ4	8,241	20,131	8,451	3,952	40,775
Total	19,730	42,965	21,372	12,456	96,524
Total variable car travel expenditure for fuels in million Euro]					
HIQ1	706.2	501.5	817.2	580.4	2,605
HIQ2	1,625	3,073	2,485	1,643	8,826
HIQ3	2,104	5,175	2,492	1,441	11,211
HIQ4	2,916	7,709	2,824	1,471	14,920
Total	7,351	16,458	8,618	5,135	37,562
Total car travel expenditure in million Euro]					
HIQ1	2,486	1,937	2,619	1,812	8,854
HIQ2	5,626	10,947	8,569	5,737	30,880
HIQ3	7,811	18,700	7,527	4,619	38,657
HIQ4	11,157	27,839	11,275	5,423	55,694
Total	27,081	59,423	29,990	17,592	134,085
Public transportation in million Euro]					
HIQ1	1,152	1,035	472.1	253.9	2,913
HIQ2	608.9	725.4	377.5	211.8	1,924
HIQ3	614.5	920.6	273.9	164.6	1,974
HIQ4	848.5	1,276	270.1	148.8	2,543
Total	3,224	3,957	1,394	779.2	9,353
Total travel expenditure in million Euro]					
HIQ1	3,638	2,972	3,091	2,066	11,767
HIQ2	6,235	11,673	8,946	5,949	32,803
HIQ3	8,426	19,620	7,801	4,784	40,631
HIQ4	12,006	29,115	11,545	5,571	58,237
Total	30,304	63,380	31,384	18,371	143,438*
Sources: EVS 2003 (StaBuA, 2005), and own calculations. *Total travel expenditure excludes aviation and holiday travel packages.					

For the interpretation of the expenditure impacts from road charging it is equally useful to look at relative expenditure shares in household income as shown in Table 12 and additionally in households' overall consumption expenditure as presented in Appendix 7. Additional information on household expenditures for fixed car use related components as shares in household income can be found in the Appendix 8. In the Appendix 9 shares of fixed car use related expenditure components in the overall consumption expenditure are presented.

Table 12 Household overall consumption and selected transportation expenditures as shares in household net income for household categories

Total consumption and transportation expenditures as net income shares in % for different household groups, Germany 2003					
Residential category					
Total consumption expenditure in [%-change]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	84.6	85.5	84.6	83.9	84.8
HIQ2	80.5	81.0	80.5	79.9	80.6
HIQ3	79.5	78.5	73.0	72.1	76.9
HIQ4	71.4	70.8	72.2	72.1	71.2
Total	77.9	76.5	76.7	76.7	76.9
Total fixed car travel expenditure in [%-change]					
HIQ1	2.9	2.4	4.3	4.6	3.3
HIQ2	6.9	7.2	7.9	8.4	7.5
HIQ3	8.0	7.9	7.4	8.2	7.9
HIQ4	8.1	8.2	10.7	10.3	8.8
Total	6.8	7.3	8.0	8.1	7.5
Total variable car travel expenditure for fuels in [%-change]					
HIQ1	1.2	0.8	2.0	2.1	1.4
HIQ2	2.8	2.8	3.2	3.4	3.0
HIQ3	3.0	3.0	3.7	3.7	3.2
HIQ4	2.9	3.1	3.6	3.8	3.2
Total	2.5	2.8	3.2	3.4	2.9
Total car travel expenditure in [%-change]					
HIQ1	4.1	3.2	6.3	6.7	4.7
HIQ2	9.7	10.0	11.1	11.8	10.5
HIQ3	11.0	11.0	11.0	11.8	11.1
HIQ4	11.0	11.4	14.3	14.2	12.0
Total	9.3	10.1	11.1	11.5	10.3
Total public transportation expenditure in [%-change]					
HIQ1	1.9	1.7	1.1	0.9	1.5
HIQ2	1.0	0.7	0.5	0.4	0.7
HIQ3	0.9	0.5	0.4	0.4	0.6
HIQ4	0.8	0.5	0.3	0.4	0.6
Total	1.1	0.7	0.5	0.5	0.7
Total travel expenditure in [%-change]					
HIQ1	6.0	4.9	7.5	7.2	6.2
HIQ2	10.8	10.6	11.6	12.2	11.2
HIQ3	11.9	11.5	11.4	12.3	11.7
HIQ4	11.8	11.9	14.6	14.5	12.6
Total	10.4	10.8	11.8	12.0	11.1*
Sources: EVS 2003 (StaBuA, 2005), and own calculations. *Total travel expenditure excludes household expenditures for aviation as well as for holiday travel packages.					

Regarding the distribution of absolute income and consumption expenditure volumes for household income quartiles and residential location characteristic separately and as combined category remarkable differences can be observed. Households in the lowest income quartile dispose of less than one half of the net income available to the highest income quartile, or about 15 compared to 36 % of the overall household income in 2003. The differences between the second and the third quartile are less pronounced with shares of 23 and 27 % in the overall household income.

By household residential location, highest income proportion (45 %) is allocated to households in agglomerations. This corresponds to the high household population share of about 43 % attributed to this residential location category (see Table 6). The next two big groups according to available overall income are residents of city centres with 23 % and of urban regions with 21 %. Households in rural regions comprise of about 12 % of the overall household population and they dispose of almost 12 % of the overall household net income available within the economy. For combined household income and residential location categories the row and column distribution of net income volumes looks more complex. While the distribution of net income volumes within each household income quartile over the four residential location groups follows the pattern of household population distribution and is comparable to the overall income distribution for aggregated household residential categories, the distribution within each location category and over household income quartiles is more differentiated and does not correspond exactly to the household population distribution across these categories (see Table 6). The pattern of clearly progressive income distribution across income quartiles observed when no residential characteristic is accounted for can only be found within agglomerations. Within households living in city centres, a share of 20 % in total household net income volume of this residential category is available to households in the lowest income quartile compared to the highest share of 34 % in household population falling in this group. From the second quartile on, income shares are distributed progressively and household population shares are distributed almost equally within city centres' residents.

The distribution of household net income shares across income quartiles within urban regions and rural regions are rather similar except for the highest income quartile. Hence, while in urban regions almost one third of the overall household income is available to the

4th quartile its share comprises only one fourth in rural regions. In both residential categories households attributed to the top income quartile comprise of the relatively smallest household population shares of no more than 20 %.

The distributional patterns of household income and household population volumes are reflected in the average monthly household net income presented in Table 6. Furthermore, the distributional pattern of income across household categories implies the structure for households' total consumption expenditure shown in Table 11 and Table 12, where overall consumption shares in net income behave regressively across income quartiles. This includes household overall expenditure for travel, foremost for car ownership and use related expenditures, but not so for public transportation.

Hence, households' income shares spend on overall travel goods and services rise from 6.2 % for the lowest to 12.6 % for the highest income quartile. This observation is in line with findings on significantly positive income elasticities for car ownership and car use.[37]

The patterns are different for car vs. public travel expenditures. While household income expenditure shares for car use increase with rising income from 4.7 to 12 %, they decline for the use of public transportation from 1.5 for the bottom to 0.6 % for the upper income quartile. Progressivity for car use expenditures and regressivity for public transportation spending across household income quartiles can be observed to a different extent within each of the four household residential location categories. Furthermore, as Table 12 shows expenditure income shares for car use increase with declining population density of the residential location category, from 9.3 for urban centre dwellers to 11.5 % for households living in rural areas. This is inline with the overall expectation assuming that households living in big cities with well developed accessibility are less dependent on their automobile, while for households resident in less populated, remote rural regions the automobile is often the only mean to meat their travel needs. This can be equally observed regarding the structure of expenditure income shares for use of public transportation across household residential location groups, falling from 1.1 % for households in urban centres to 0.5 % for

[37] For further reading on income elasticities for car ownership and car use see also Dargay and Gately, 1999; Dargay, 2001; Hanly et al., 2002; Johansson-Stenman, 2002; Pucher and Renne, 2003; Giuliano and Dargay, 2006; Kletzan et al., 2006.

those living in rural or small town urbanised areas.

The income spent on road use after the introduction of the 0.05 Euro per car km charge has similar shares (in income) and comparable distribution across household groups as the expenditure on car use related fuel tax as shown in Table 13. Table 14 additionally shows the absolute level of the road use charge spent by each household category.

Table 13 Household expenditures on road charging and fuel tax as share in income for different household categories

Income shares of fuel tax and road charge expenditures for different household categories, Germany 2002					
Residential category					
Fuel tax expenditure share in household income in [%-change]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	0.7	0.5	1.2	1.4	0.9
HIQ2	1.8	1.8	2.0	2.1	1.9
HIQ3	1.9	1.9	2.3	2.3	2.0
HIQ4	1.8	2.0	2.3	2.4	2.0
Total	1.6	1.8	2.0	2.1	1.8
Road charging expenditure share in household income in [%-change]					
HIQ1	0.8	0.6	1.2	2.0	1.0
HIQ2	1.8	1.4	1.9	1.8	1.7
HIQ3	1.7	1.9	2.2	2.0	1.9
HIQ4	2.0	2.0	2.2	2.1	2.1
Total	1.7	1.7	2.0	2.0	1.8
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.					

Table 14 Level of road charging payment and household refund according to scenario B in million Euro for different household categories

Road charging expenditure and refund for different household categories, Germany 2002					
Residential category					
Road charging payment in [million Euro]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	486	362	483	531	1,863
HIQ2	1,023	1,542	1,496	882	4,943
HIQ3	1,240	3,230	1,471	793	6,734
HIQ4	2,078	4,885	1,760	787	9,511
Total	4,827	10,020	5,210	2,993	23,049
Household refund from road charging revenue in [million Euro]					
HIQ1	123	87	142	101	453
HIQ2	282	534	432	286	1,535
HIQ3	366	900	433	250	1,949
HIQ4	507	1,340	491	256	2,594
Total	1,278	2,862	1,498	893	6,530
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.					

Hence, the road charging burden as share in household income is strongly progressive across household income quartiles varying from 1 to 2.1 % and only slightly progressive across residential categories with decreasing population density and deteriorating accessibility, changing from 1.7 for city residents to 2 % for inhabitants of less populated, rural or small urban areas. The progressivity of the road charging distribution across household income quartiles sustains within the different household residential categories. Furthermore, compared to the income shares spent by private households on the overall travel expenditure varying between 5 and 15 % (see Table 12) an expenditure share on road use charging between 1 and 2 % can be considered as economically still justifiable.

The examination of absolute road charge amounts paid by household income quartiles as well as received refund according to policy scenario B[38] (see Table 14) and corresponding

[38] In scenario 1) 1/3 of the collected road charging revenue is redistributed evenly, i.e. in equal proportions, across the household categories. In scenario B revenue from road charging is reallocated to the household categories according to the specific fuel tax burden of each group as proportion of the overall fuel tax burden contributed by the private households to the state budget (see Appendix 5).

shares in the revenue total (see Table 15) show a clearly progressive pattern, where the lowest income quartile contributes only 8 % to the road charging revenue total compared to over 40 % paid by households in the highest income quartile. Within the residential location categories households living in agglomerations – of which most are suburban areas of large or medium sized cities – pay the highest share (about 44 %) in the overall road charging revenue. Households in rural areas account for the lowest share of almost 14 % in the road charge revenue total.

The distribution of absolute amounts of household refund from road charging according to scenario B as presented in Table 14 follows the relative shares in fuel tax paid by each household category. Since the road charging payment depends on car kilometres travelled and therefore on fuel consumption, distributional structures shown in Table 15 are rather similar. In the case of scenario A each of the 16 household categories receives an equal refund amount of 408 million Euro or between about 2,000 to 12,000 Euro per household depending on the number of households in each category as shown in Table 6.

Table 15 Household share of the road charging payment and the policy refund in the revenue and refund total according to scenario B in % for different household categories

Distribution of road charging payment and revenue for different household categories					
Residential category					
%-distribution of road charging payment across household categories					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	2.1	1.6	2.1	2.3	8.1
HIQ2	4.4	6.7	6.5	3.8	21.4
HIQ3	5.4	14.0	6.4	3.4	29.2
HIQ4	9.0	21.2	7.6	3.4	41.3
Total	20.9	43.5	22.6	13.0	100.0
%-distribution of household refund from road charging revenue across household categories for the policy scenario B					
HIQ1	1.9	1.3	2.2	1.5	6.9
HIQ2	4.3	8.2	6.6	4.4	23.5
HIQ3	5.6	13.8	6.6	3.8	29.8
HIQ4	7.8	20.5	7.5	3.9	39.7
Total	19.6	43.8	22.9	13.7	100.0
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.					

For the comparison of road use charging burden vs. household refund from the road charging revenue Table 16 presents the individual household refund shares in income for different household groups depending on the road charging revenue redistribution policy.

Table 16 Road charging refund redistributed to private households as share in income, different household categories

Household road charging revenue refund %-share in income for different policy scenarios and different household categories					
Residential category					
Scenario A in [% of total]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	0.7	0.7	1.0	1.5	0.9
HIQ2	0.7	0.4	0.5	0.8	0.6
HIQ3	0.6	0.2	0.6	1.0	0.5
HIQ4	0.4	0.2	0.5	1.1	0.4
Total	0.6	0.3	0.6	1.1	0.5
Scenario B in [% of total]					
HIQ1	0.2	0.1	0.3	0.4	0.2
HIQ2	0.5	0.5	0.6	0.6	0.5
HIQ3	0.5	0.5	0.6	0.6	0.6
HIQ4	0.5	0.5	0.6	0.7	0.6
Total	0.4	0.5	0.6	0.6	0.5
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.					

Household refund shares from road charging revenue in income as shown in Table 16 as well as in the road charging expenditure as presented in Table 17 vary first of all with the revenue use scenario and also with the household group.

Road charging refund shares relative to income in policy scenario A ("Equal household refund") (see top of Table 16) can be described as regressive across household income quartiles. When residential location of the households is additionally taken into account the regressivity across income quartiles is somehow less pronounced. Is residential location the only household characteristic accounted for, households in rural areas receive the highest refund share in income of about 1.1 % compared to the lowest refund share of 0.3 % received by households living in agglomerations.

For the policy scenario B ("Proportional household refund") the results are a lot different than for policy scenario A, in particular for households in the lowest income quartile. The road charging redistribution scheme applied in scenario B has a strongly progressive effect across income quartiles. Relative to income households in the bottom income quartile receive from 0.1 to 0.4 % of the refund depending on their residential location. Therefore they are by far worse off than households in higher income quartiles, whose shares vary between 0.5 and 0.6 %.

As shown in Table 17 using shares of road charging refunds in road charging payments in case of scenario B each household category receives a rather similar share of refund of an average of about 30 % of their payment, whereas in scenario A road charging contributions of households in the bottom income quartile are nearly compensated and in one case even overcompensated by the refund they receive from the road charging revenue. On the other hand, households in the top income quartiles (HIQ3 and HIQ4) receive the lowest recompensation compared to the road use charged they contributed. This is in particular the case for households living in agglomerations – 8.4 and 12.6 % (for Scenario A are by far the lowest shares in what households had to pay for road use according to the car kilometres travelled.

Table 17 Road charging refund redistributed to private households as share in the amount of the road charging payment, different household categories

Household road charging revenue refund %-share in road charging payment for different policy scenarios and different household categories					
Residential category					
Scenario A in [% of total]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	84.0	112.7	84.5	76.8	87.6
HIQ2	39.9	26.5	27.3	46.3	33.0
HIQ3	32.9	12.6	27.7	51.5	24.2
HIQ4	19.6	8.4	23.2	51.8	17.2
Total	33.8	16.3	31.3	54.5	28.3
Scenario B in [% of total]					
HIQ1	25.3	24.0	29.4	19.0	24.3
HIQ2	27.6	34.6	28.9	32.4	31.1
HIQ3	29.5	27.9	29.4	31.5	28.9
HIQ4	24.4	27.4	27.9	32.5	27.3
Total	26.5	28.6	28.8	29.8	28.3
Sources: MiD 2002 (infas and DIW Berlin, 2002), EVS 2003 (StaBuA, 2005), and own calculations.					

5.3.5.2 Household travel demand

Selected descriptive characteristics of disaggregated household categories (economic, travel behaviour related, and sociodemographic) provide substantial insight into different mobility patterns and the explanation of the corresponding effects from road charging. As shown in Table 6, whereas by definition the number of private households is equally distributed over the four income quartiles, the distribution of income over the different household quartiles as well as the residential location categories is far less evenly distributed as discussed in Chapter 5.3.5.1 and shown in Table 11. Between income and the number of kilometres travelled by car in each household category a clearly progressive relationship can be observed (see Table 18 and Table 19).

Table 18 Car, public transportation, and total distance travelled in km per year and per household across household categories

Household travel activity across household categories, Germany 2002											
Total km per year in billion							Km per household and per year				
Residential category											
Car travel											
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total		HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ 1	10.7	8	10.5	12	41.1		3,431	2,468	5,083	8,944	4,215
HIQ 2	22	32.5	31.9	18.7	105.2		11,162	9,455	13,339	12,490	11,305
HIQ 3	26.4	68.9	31.5	16.9	143.7		13,784	14,350	17,597	16,417	15,069
HIQ4	44.7	104.2	37.3	16.6	202.8		20,278	20,943	24,095	21,063	21,312
Total	103.8	213.7	111.2	64.1	492.8		11,263	12,983	14,277	13,792	12,930
Public transportation travel											
HIQ 1	12.5	9.3	6.3	2.4	30.5		3,998	2,864	3,043	1,817	3,122
HIQ 2	7.9	8.1	8.1	5.2	29.5		4,027	2,363	3,394	3,508	3,165
HIQ 3	13.5	15	5.5	2.8	36.8		7,038	3,130	3,052	2,699	3,854
HIQ4	12.3	17.2	3.8	3.2	36.5		5,570	3,458	2,485	4,018	3,835
Total	46.2	49.6	23.7	13.6	133.1		5,012	3,016	3,042	2,930	3,494
Overall household travel											
HIQ 1	23.2	17.3	16.7	14.4	71.6		7,428	5,332	8,126	10,761	7,336
HIQ 2	30	40.7	40.1	23.9	134.6		15,189	11,818	16,733	15,999	14,470
HIQ 3	39.9	83.9	37	19.6	180.5		20,822	17,480	20,649	19,116	18,923
HIQ4	56.9	121.4	41.2	19.8	239.3		25,848	24,401	26,580	25,083	25,147
Total	150	263.3	134.9	77.7	625.9		16,275	15,999	17,319	16,722	16,424
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.											

Table 19 **Distribution of car, public transportation, and total distance travelled across household categories**

Distribution of car, public transportation, and total distance travelled across household categories in %, Germany 2002					
Residential category					
Car travel in [% of total]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	2.2	1.6	2.1	2.4	8.3
HIQ2	4.5	6.6	6.5	3.8	21.3
HIQ3	5.4	14.0	6.4	3.4	29.2
HIQ4	9.1	21.1	7.6	3.4	41.1
Total	21.1	43.4	22.6	13.0	100.0
Public transportation travel in [% of total]					
HIQ1	9.4	7.0	4.7	1.8	22.9
HIQ2	6.0	6.1	6.1	3.9	22.1
HIQ3	10.1	11.3	4.1	2.1	27.6
HIQ4	9.2	12.9	2.9	2.4	27.4
Total	34.7	37.3	17.8	10.2	100.0
Total travel activity in [% of total]					
HIQ1	3.7	2.8	2.7	2.3	11.4
HIQ2	4.8	6.5	6.4	3.8	21.5
HIQ3	6.4	13.4	5.9	3.1	28.8
HIQ4	9.1	19.4	6.6	3.2	38.2
Total	24.0	42.1	21.6	12.4	100.0
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.					

This relationship is valid for household annual total car kilometres as well as for car kilometres travelled per household and per year. Nevertheless, while the highest income quartile comprises almost 2.5 times the income of the lowest household quartile, households in this category make 5 times more car kilometres per year (overall and per household) than households in the bottom income group.

According to residential location characteristics, households in the rural area display the lowest annual car use intensities of about 64 million km compared to 214 billion km driven by households in agglomerations. This distribution can be partly explained by the number of households in each residential category. When annual car kilometres per household are calculated, households in large city centres have the lowest number in car kilometres travelled per year (11,263 km). The highest per household car use intensities in km have households in urban areas, often living in outer suburbs and having to commute to work longer distances. This distribution of car use intensities is in line with overall expectations, assuming that people residing in big cities have better accessibility than those in rural area or small-town urban regions, where commuting to work to larger neighbouring cities is often the case.

The assumption about poor accessibility found in rural areas is further confirmed by the distribution of public transportation kilometres travelled by households, as annual total as well as per household and per year (see Table 18). Hence, highest public transportation use intensities (as annual household totals in km) are found for households living in agglomerations and city centres and lowest for those living in rural areas. Public transportation kilometres made per household and per year underline the regional differences in mode specific household travel profiles, where households from big cities travel almost twice as many kilometres per household and per year (5,012 km) by public transportation means as do households in rural areas (2,930 km).

Regarding the distribution of public transportation kilometres travelled by household income quartiles, the progressivety between income and travel observed for car use is not observed, in particular when per household kilometres are taken into account (see Table 19 and Table 25). Furthermore, the differences in overall or per household distance travelled by public transportation according to income quartile are much more pronounced than for car travel. Car use intensities are more variable across household income categories than kilometres travelled by means of public transportation.

Even though it can be assumed that households in the top income quartile are less affine to take public transportation means compared to those in the bottom income category, households in the top income quartile are more likely to consist of more members including children who in general are more prone to use public transportation to reach school or other educational institutions. Table 6 shows the increasing average household size with rising household income. Moreover, households with children are in general more mobile than families without children. Table 20 shows overall daily household travel per household for different household types – with and without children – and different trip purposes.

Table 20 Overall kilometres travelled including all modes per day and per household by household type and trip purpose

Overall kilometres travelled per day and per household by household type and trip purpose, Germany 2002								
Trip purpose in [km/ day/ hh]								
Household type	Commuting	Education	Business related	Accompany	Private business	Shopping	Leisure	Total
Working single	14	0	11	1	3	3	18	51
Not-working single	1	1	0	1	4	3	12	21
Single parent	17	7	8	9	7	7	33	88
Couple without children both working	32	0	26	2	6	8	30	105
Couple without children one working	15	2	12	2	8	8	30	77
Couple without children not-working	1	1	0	2	10	9	29	51
Couple with children both working	32	7	24	13	9	11	53	149
Couple with children one working	25	6	17	16	9	12	52	136
Other household type	33	10	21	7	11	14	55	151
Average over all household types	16	3	12	4	7	8	31	81
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.								

Hence, couples with children or single parents on average display higher daily travel activities. Couples without children make per day from 51 to 105 km depending on their employment status. However, couples with children travel between 136 and 140 km per day. The reason is that children themselves have travel demands and at the same time generate extra household mobility since very often they need to be accompanied by older individuals or adults, mostly other family or household members. The differences in daily overall distance travelled according to household type and trip purpose as presented in Table 20 are characteristic for all settlement categories.

Comparing household type residential location distribution according to the presence of children in the household it can be seen that despite the dominating share of the overall households in Germany living in agglomerations and urban regions, families with children or multiple-member households are stronger represented in suburban and peripheral, or rural regions as shown in Table 21.

Table 21 Household distribution as to residential location and the presence of children in the household

Household distribution as to residential location and the presence of children in the household in %, Germany 2002				
Residential category in [% of total]				
Household type	HRCent1	HRAgglo2	HRUrb3	HRRul4
Household without children	72.7	68.4	63.6	63.2
Household with one or more children	16.5	19.8	21.2	22.3
Other household type	10.8	11.8	15.2	14.5
Total	100	100	100	100
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.				

Families with one or more children tend therefore to live in less accessible areas like suburbs or peripheral regions, where they have the opportunity to reside in a house rather than a flat. The less intense use of public transport due to lower accessibility in less populated rural or suburban areas is reflected in the household travel intensities according to travel mode and residential location attribute presented in Table 18 and Table 19.

Showing the correlation between household income and household size based on the distribution of single household shares according to household category Table 22 underpins the assumption that multi-member households are more likely to fall into the upper income quartiles, having higher car use preferences than those in the bottom ones. Thus, the bottom income quartile displays by far the highest single household rate (63 %). According to residential location category highest single household rates are found among city dwellers (41 %).

Table 22 Share in % of single households in the total number of households according to household category

Share of single households in the total number of households according to household category in %					
	Residential category in [% of total]				
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ 1	64	70	57	55	63
HIQ 2	43	34	30	25	34
HIQ 3	29	41	34	27	36
HIQ 4	19	9	1	4	10
Total	41	35	33	32	36
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.					

Summing up, households falling into higher income categories, who tend to be multiple-member households with children residing in suburban or rural areas, display higher car use intensities. Hence, the distribution of public transportation as well as car use intensities by household category can be largely explained by category specific household size and household composition.

In general, as shown in Table 19 selected German households appear to be rather automobile than public transportation use oriented, making annually almost 13,000 km per household by car and only 3,500 km by public transportation means. Also, the average workday use of public transportation (12 km) is strongly outweighed by distance travelled using a car (51 km) as shown in Table 23. Remarkable differences can be also found when examining the distances travelled per household and per workday according to household income quartile as well as to the residential location. Variations in household category specific daily travel patterns underpin in general the structures presented in Table 18 and Table 19.

Table 23 Car and public transportation distance travelled in km per household and per workday for household categories

Car and public transportation distance travelled in km per household and per workday across household categories					
Residential category					
Public transportation travel in [km/ hh/ workday]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	12.2	10	10	5.3	10
HIQ2	13.5	9.4	9.7	12.3	10.7
HIQ3	22.1	10.7	10.7	11.8	13
HIQ4	17.7	13.9	11.6	17	14.6
Total	15.7	11.2	10.4	10.6	12
Car travel in [km/ hh/ workday]					
HIQ1	14.5	8.3	17.1	23.3	14.4
HIQ2	38.6	35.9	51.8	61.8	43.5
HIQ3	53.6	59.5	67.3	72	61.5
HIQ4	83.6	83.4	100.7	90	86.7
Total	44.4	51.2	56.7	55.9	51.2
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.					

The assumption about an existing "dependency" of some household categories more than others on car use is in line with single- and multi-motorisation rates (together about 81 %) compared to the relatively low share of non-motorised households (almost 20 %) presented in Table 24.

Table 24 Household shares according to motorization level for different household categories

Household %-share in the total number of households according to motorization level across household categories					
Residential category					
No car in [% of total]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	74.8	86.4	60.5	52.3	72
HIQ2	11.7	4.4	0.7	0.7	4.9
HIQ3	2.1	1	0.1	0	0.9
HIQ4	0	0.1	0	0	0
Total	26.9	17.4	16.2	17.5	19.5
1 car in [% of total]					
HIQ1	23.4	12.3	36	41.5	25.4
HIQ2	78.8	90	83.2	76.8	84.1
HIQ3	70.9	73.1	61.9	60.7	68.9
HIQ4	47.9	33.6	17.6	17.4	33.1
Total	52.6	54.1	52.4	51.6	53.1
2 and more cars in [% of total]					
HIQ1	1.8	1.2	3.5	6.2	2.7
HIQ2	9.5	5.6	16.1	22.5	11
HIQ3	27	25.9	38	39.3	30.2
HIQ4	52.1	66.4	82.4	82.6	66.8
Total	20.5	28.5	31.4	30.9	27.4
Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.					

Moreover, household motorisation and non-motorisation shares across income quartiles and residential location characteristics exhibit the positive correlation between household income and car ownership as well as a negative relationship between population density of residential location, i.e. accessibility potential. By far highest non-motorisation rates are found in the lowest income quartile (on average 72 %) and for the city centres (about 27 %). In fact, considerable regional differences exist in household mode choice preferences. In some urban agglomerations more then half of all households do not own a car, in some rural areas a high share up to 50 % and more of households never has used any kind of public transportation.

The variations in public and car transport demand over the disaggregated household categories are relevant for the assessment of the acceptability towards road charging measures since income, the availability of alternatives and household demographics determine the reaction potential to price increases of car travel (Dargay and Gately, 1999; Dargay, 2001; Hanly et al., 2002; Giuliano and Dargay, 2006).

Travel mode use differences across household income groups correspond on the whole with the differences in mode specific expenditure shares by household income, as shown in Chapter 5.3.5.1. While household expenditure shares on fixed car cost components are clearly progressive with increasing income, relative expenditures on variable car travel, mainly fuel, is lowest for the highest income group. This implies that the highest household income category is relatively less "sensitive" to the introduction of road charges on car use if they are implemented proportional to distance travelled.

As shown before, expenditure shares for public transport in monthly household income decline considerably with rising income. Regarding the relative household expenditure patterns for travel services, the lowest income group has the highest income expenditure share on public transport, and the lowest on car use. This may by a tentative indicator that households in this category satisfy their mobility demand as far as possible by public transport and the mobility demand allocated to private car use cannot be easily shifted to other transport modes. Real-life examples of such mobility patterns found in Germany are households living in remote areas of mainly former Eastern Germany with high unemployment and low population densities, and therefore poor accessibility, where the only way to get to work is to commute long distances by car. Due to low disposable income, such households find it often difficult to leave their residential area and move closer to their economic activity. These households stand as an example for the population group at risk to experience the highest welfare losses from the introduction of distance dependent road charging.

Altogether, the structure of mobility parameters presented in this chapter is on the whole in line with mode specific household travel expenditures presented in Chapter 5.3.5.1. The initial differences in household expenditure shares on mobility services and the corresponding travel activity parameters reveal the asymmetric availability of reaction potentials to the pricing measure, and are therefore relevant for the interpretation of the mobility, but in particular the welfare and equity impacts from car road charges.

Hence, the implementation of road pricing changes the price of car travel and generates a shift in the modal split resulting in changing overall transport volumes, the extent of which depends on the reaction parameters introduced in the model. Table 25 presents the effects the introduction of road use charging has on travel behaviour of different household categories and according to the policy scenario set in place.

Table 25 Car and public transportation distance travelled impacts across household categories and road charging revenue reallocation scenarios

Travel behavior impacts across road pricing policy scenarios and household income categories										
Impacts on distance travelled from car road charging in % change relative to the reference scenario for different revenue redistribution schemes										
Equal household refund in [% change]										
Car km						Public transportation km				
Income Category	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ 1	-8.9	-8.8	-7.0	-10.3	-8.8	4.8	4.5	5.9	9.8	5.3
HIQ 2	-6.9	-5.3	-6.4	-5.4	-6.0	5.9	4.7	5.9	5.6	5.5
HIQ 3	-6.0	-6.5	-6.7	-5.6	-6.4	5.4	5.8	6.9	6.5	5.8
HIQ4	-7.0	-6.6	-5.7	-4.8	-6.4	6.3	5.9	5.6	5.7	6.0
Total	-6.9	-6.4	-6.3	-6.2	-6.5	5.6	5.4	6.1	6.5	5.7
Proportional household refund in [% change]										
HIQ 1	-9.3	-9.3	-7.5	-11.2	-9.4	4.4	4.0	5.3	8.7	4.8
HIQ 2	-7.1	-5.2	-6.3	-5.6	-6.0	5.7	4.8	6.0	5.3	5.5
HIQ 3	-6.1	-6.3	-6.7	-5.9	-6.3	5.3	6.0	6.9	6.1	5.9
HIQ4	-6.9	-6.2	-5.6	-5.1	-6.2	6.4	6.2	5.7	5.3	6.1
Total	-7.0	-6.2	-6.3	-6.6	-6.4	5.4	5.5	6.0	6.1	5.6
No household refund in [% change]										
HIQ 1	-9.5	-9.4	-7.9	-11.6	-9.7	4.1	3.8	4.9	8.3	4.5
HIQ 2	-7.5	-5.6	-6.8	-6.0	-6.5	5.3	4.4	5.4	4.8	5.0
HIQ 3	-6.5	-6.7	-7.1	-6.4	-6.7	4.9	5.6	6.4	5.6	5.4
HIQ4	-7.3	-6.6	-6.0	-5.6	-6.6	6.0	5.8	5.2	4.8	5.7
Total	-7.3	-6.6	-6.7	-7.1	-6.8	5.0	5.1	5.5	5.6	-5.2
Sources: GRTPM, and own calculations.										

Irrespective of the revenue reallocation or household refund scheme introduced along with road charging, each household category reduces its car use and in turn increases its utilization of public transportation (in km). Comparing these general results with the impacts on travel expenditures shown in Table 10 it can be observed that despite falling demand in car kilometres, expenditure for car travel still goes up, basically as a consequence of low elasticity. In contrast, expenditure for public transportation use rises, but so does the kilometres demand for the corresponding transportation means. Considerable differences across household categories exist in travel behaviour reaction to road charging. Regarding car travel, the highest kilometre reductions are displayed by the lowest household income quartile (comparing all three policy scenarios between 7 and 11.6 %). Noteworthy, within the lowest income quartile by far the highest reductions in car use intensities take place in the category of households living in rural areas – depending on policy scenario between 10.3 and 11.6 %. Income quartiles two to four display rather moderate car use reductions compared to the other household categories. This can be explained by the fact that the relative share of motorized travel in overall travel of households living in remote rural areas with low population densities is already rather high to begin with, i.e. before the introduction of road charging (benchmark scenario). Poor accessibility of these regions leads to the assumption that longer car travel distances result mainly from necessary service trips of different kinds as well as travel to work. Such trips are often difficult to resign and due to the lack of public transportation alternatives, and sometimes also due to the length of the trip, they become impossible to substitute by other modes. Therefore, households in rural areas will react in general with lower car use reductions to rising car use costs. On the other hand, a radical cut in leisure or other less necessary trips will take place in households with small budgets in order to afford the maintenance of the indispensable car trips, such as travel to work, getting medical care, etc. This can be observed for the bottom income quartile residing in rural regions compared to the remaining households income groups that show relatively weaker reactions.

Regarding solely the income quartiles, the biggest drop in car use as reaction to road charging takes place when scenario C is introduced (9.7 %). The progressivity at which car use falls across income quartiles holds for all residential location categories.

The distribution of the negative impact on car kilometres after the introduction of road charging across households' residential location categories is more homogenous than across income quartiles. Irrespective of the revenue redistribution policy car use falls highest in the category of city residents.

After the introduction of road charging, household demand for public transportation travel augments between 3.8 and 9.8 %. Interestingly, households in the lowest income quartile with residential location in a rural area display the highest increases for public transportation travel, irrespective of the household refund policy. This reaction reflects the strong budgetary restrictions faced by these households that require the abatement of not obligatory car trips and the substitution of as many car trips as possible by the use of public transportation means. On the other hand, households in the bottom income quartile who live in city centres show on the whole the lowest growth rates in public transportation use induced by the introduction of road charging. Obviously, households in this category are only little dependent on car use due to good public transportation coverage generally available in highly concentrated urban centres. Since most of their trips are already carried out by modes of public transportation, only limited potential is left for further substitution. Moreover, because households in this category bear a rather small (variable) car use expenditure burden due to their overall low use intensities, the impact from increasing car use costs as consequence from road charging will hit them to a comparatively limited extent.

As shown in the policy simulation, the redistribution of only a small part of the road charging revenue to the private households will only moderately mitigate the negative road charging impact on car use. Therefore, the redistribution of a proportion of the road charging revenue will not noticeably counteract the environmental objective of CO_2 (and NOx) emission reduction. However, a differentiated household refund structure can significantly absorb the negative net effect on mobility (and welfare) induced by rising cost of car use (see "Overall travel" in Table 8).

5.3.5.3 Households' contribution to the reduction in CO_2 emissions

Based on household vehicle ownership information such as engine size, vehicle model and year of its first registration and the information on corresponding kilometres travelled available from the MiD survey, household category specific CO_2 emission parameters were calculated. The parameters were incorporated in the GRTP model to account for the observation that households who are better off in terms of income tend to own bigger and therefore (for the most part) less fuel efficient cars than do poorer households. On the other hand richer household tend to have newer and therefore more fuel efficient cars. The two arguments are somehow counterbalancing. However, the assumption of more CO_2 emission intensive car travel among richer households cannot be confirmed when household income quartiles are considered. Hence, while differences in the distribution of CO_2 emissions in 1,000 t across household categories are quite remarkable because they are mainly driven by household specific car use, differences in household CO_2 emissions per car-km as well as per overall km travelled where household use of public transport is taken into account are rather small (see Table 26). In line with the positive correlation between household income and car use, household share related CO_2 emissions vary with rising income level from 8.7 % for the lowest to 40.8 % for the highest income quartile.

Table 26 Selected CO_2 emission characteristics of household categories in the pre-policy situation, Germany 2003

CO_2 emissions from household travel across household categories, Germany 2002					
Residential category					
Total CO_2 emission distribution across household categories in [% in total]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	2.4	1.8	2.2	2.3	8.7
HIQ2	4.5	6.7	6.5	3.8	21.4
HIQ3	5.5	14.0	6.3	3.3	29.1
HIQ4	9.2	20.8	7.3	3.4	40.8
Total	21.6	43.2	22.3	12.9	100.0
Total CO_2 emissions in [kg/overall km travelled]*					
HIQ1	0.115	0.114	0.144	0.180	0.134
HIQ2	0.166	0.182	0.179	0.175	0.176
HIQ3	0.152	0.184	0.189	0.188	0.179
HIQ4	0.179	0.190	0.197	0.192	0.189
Total	0.159	0.182	0.183	0.184	0.177
Car CO_2 emissions in [kg/car km travelled]					
HIQ1	0.213	0.211	0.213	0.210	0.212
HIQ2	0.215	0.220	0.217	0.216	0.217
HIQ3	0.215	0.218	0.216	0.214	0.217
HIQ4	0.220	0.216	0.214	0.223	0.217
Total	0.217	0.217	0.215	0.216	0.217
CO_2 in [1,000 t]					
HIQ1	2,659	1,964	2,414	2,583	9,619
HIQ2	4,973	7,403	7,175	4,193	23,744
HIQ3	6,081	15,474	6,974	3,691	32,220
HIQ4	10,193	23,026	8,099	3,797	45,115
Total	23,906	47,867	24,661	14,264	110,698

Sources: MiD 2002 (infas and DIW Berlin, 2002), and own calculations.
*The total CO_2 emissions are calculated based on (car) driver km for private car transport and on passenger km for public transport, under the assumption of an average occupancy of 20 person per bus km.

After the introduction of charges for passenger car road use CO_2 emissions fall mainly due to decreases in car travel and therefore fuel consumption shown in Table 25. Following the differences across households in the reduction of car use after the implementation of road charging, different household categories contribute differently to the decrease of car related

CO_2 emissions as shown in Table 27. According to household equivalence-weighted income quartile the lowest household income quartile has the highest CO_2 emission reduction contributions in each revenue reallocation scenario.

Independently of household income quartile the policy scenario where no private household refund takes place encompasses the highest CO_2 declines. In the scenario with equal household refund shares income quartiles 1 and 4 display highest CO_2 reductions, reflecting shifts in car and public transport travel after the introduction of a car road use charge.

Table 27 Overall CO_2 emission impacts across household income groups and road charging revenue reallocation schemes

Overall CO_2 emission impacts from car road charging in % change relative to the reference scenario for different revenue redistribution schemes, Germany 2002					
Residential location					
Equal household refund in [%-change]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ 1	-7.0	-7.0	-6.0	-9.8	-7.5
HIQ 2	-6.3	-5.0	-6.0	-5.0	-5.7
HIQ 3	5.3	-6.1	-6.4	-5.3	-5.6
HIQ4	-6.5	-6.3	-5.5	-4.6	-6.1
Total	-6.2	-6.1	-6.0	-5.8	-6.0
Proportional household refund in [%-change]					
HIQ 1	-7.4	-7,4	-6.5	-10.6	-8.0
HIQ 2	-6.5	-4.9	-5.9	-5.3	-5.6
HIQ 3	-5.3	-5.9	-6.4	-5.7	-5.6
HIQ4	-6.5	-6.0	-5.5	-4.9	-5.8
Total	-6.3	-5.8	-6.0	-6.2	-6.4
No household refund in [%-change]					
HIQ 1	-7.6	-7.6	-6.9	-11.0	-8.3
HIQ 2	-6.9	-5.3	-6.4	-5.6	-6.0
HIQ 3	-5.7	-6.3	-6.8	-6.1	-6.0
HIQ4	-6.8	-6.3	-5.9	-5.3	-6.3
Total	-6.6	-6.2	-6.4	-6.7	
Sources: GRTPM, and own calculations.					

The distribution of the CO_2 emission reduction looks less differentiated when household groups according to residential location are examined.

Overall, results in CO_2 reductions as effects from the introduction of road charging demonstrate that when the ultimate policy objective is the reduction in the fuel combustion externalities from car use, direct revenue transfer to private households should be minimized.

5.3.5.4 Household distributional welfare and equity effects

The set-up of the GRTPM allows the assessment of welfare that accounts for the changes in transportation as an economic variable. The welfare measure is based on an agent-based utility function and therefore all changes in transportation and economic conditions affecting individuals are incorporated in the welfare measure. In Table 26 welfare impacts calculated as Hicksian welfare index consisting of all household expenditures and Hicksian transportation welfare index are reported. The Hicksian equivalent variation indicates the amount of income necessary to compensate an individual (in the pre-policy situation) in order to reach equality with the post-policy utility level (Just et al., 2004). It therefore measures changes in money metric utility between the pre- and post-policy equilibrium, which is the amount of money required to bring a household back to the same level of utility as in the benchmark equilibrium following changes in prices in counterfactual equilibrium. Furthermore, the calculated welfare index does not account for the environmental welfare improvement but measures only the change in traditional marketed goods consumption.[39]

As shown in Table 28 the welfare change of unique household categories turns throughout negative, but varies considerably with the road charging revenue redistribution scenario and with household category.

[39] Depending on the road charging revenue redistribution policy households in the lowest income quartile would have to be compensated by a fraction between 0.4 and 1.2 % of their income in order to maintain their pre-policy overall consumption utility level after the implementation of the road charging policy.

Table 28 Welfare impacts across household categories and road charging revenue reallocation scenarios

Consumption welfare impacts from car road charging in %-change relative to the reference scenario for different revenue redistribution schemes, Germany 2002					
Hicksian welfare index overall household expenditure					
Residential location					
Equal household refund in [%-change]					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ 1	-0.3	-0.1	-0.4	-0.8	-0.4
HIQ 2	-1.0	-0.9	-1.3	-0.9	-1.0
HIQ 3	-1.0	-1.4	-1.2	-0.7	-1.2
HIQ4	-1.2	-1.4	-1.3	-0.7	-1.3
Total	-1.0	-1.2	-1.1	-0.8	
Proportional household refund in [%-change]					
HIQ 1	-0.8	-0.6	-1.0	-1.7	-0.9
HIQ 2	-1.2	-0.8	-1.3	-1.1	-1.1
HIQ 3	-1.1	-1.1	-1.2	-1.1	-1.1
HIQ4	-1.2	-1.1	-1.2	-1.0	-1.1
Total	-1.1	-1.0	-1.2	-1.2	
No household refund in [%-change]					
HIQ 1	-1.0	-0.8	-1.4	-2.2	-1.2
HIQ 2	-1.6	-1.3	-1.8	-1.6	-1.5
HIQ 3	-1.5	-1.5	-1.7	-1.5	-1.6
HIQ4	-1.5	-1.5	-1.6	-1.5	-1.5
Total	-1.4	-1.4	-1.6	-1.7	
Sources: GRTPM, and own calculations.					

In general, negative overall household consumption welfare changes are rather small, depending on the policy scenario ranging between 0.3 for households in the bottom income quartile living in big cities when scenario A is implemented and 2.2 % for those in the bottom income quartile and in a rural area in case of scenario C. Examining overall consumption welfare changes according to income quartiles after the introduction of road charging none of the policy scenarios encompasses a clearly regressive distributional impact, where the bottom income quartile bears the highest negative welfare burden from the implementation of the measure. For scenario A the opposite is clearly the case, where imposing a road charge induces a strongly progressive effect, reducing welfare from 0.4 % for the bottom to 1.3 % for the top household income quartile. Even though, negative welfare changes across income quartiles in scenario B and C are not straight forward to characterise as to their distributional impacts, especially the results obtained for scenario B display an interesting pattern of close to equal welfare losses across the household income categories. Moreover, for scenario B the only regressive welfare distributional outcome can be observed across household income quartiles within the rural residential category. Remarkable differences in welfare losses can be observed between scenarios A and B compared to scenario C where no household refund from road charging revenue takes place, in particular for the lowest income quartile(s), but also for households in rural areas. Each household category is better off when household transfers are introduced. Nevertheless, the gains from the revenue redistribution towards the private household sector are most pronounced in the bottom income quartile. With regard to possible equity implications drawn from the welfare impacts presented in Table 28, scenario B yields the most evenly distributed welfare losses within the household income or residential location categories.

The interpretation of overall welfare losses across the four residential location categories as well as across households disaggregated by income and residential location are not straightforward. For residential location categories the differences between the groups and within each policy scenario are less pronounced than for income quartiles. Nevertheless, when no direct refund is introduced households experience the highest welfare losses when solely their residential location is taken into account. The introduction of household transfers reduces the welfare losses according to residential location considerably, foremost for households living in rural (1.7 compared to 0.8 %) as or small town, urban areas (1.6 compared to 1.1 %) of the country.

Regarding household categories disaggregated with respect to both substantial differences exist between the row- and column averages and we observed mixed results. The progressivity of the distribution of the negative welfare effects across income quartiles observed for scenario A cannot be easily transferred onto the income quartiles within each residential location group. In the residential location categories 1 through 3 a “close to” or “interrupted” progressivity across income quartiles can be observed (see Table 28). Furthermore, welfare losses across income quartiles within the 4th residential location category for scenario A are very similar, compared to the same categories for scenarios B and C.

All observation discussed are important for the design of possible refund policies with the introduction of car road charging. Results obtained based on scenario C show which household categories are to what extent at risk to bear the highest negative welfare burden from the implementation of road charging. In Germany households at risk have a low income (bottom quartile) and live in rural areas or have a moderate income (2^{nd} quartile) and live in small town, suburb areas. Nevertheless, despite the considerable welfare losses among better situated households (top income quartiles) one can argue if these households are most affected by road pricing. The interpretation of corresponding results is not straightforward. In general they are in line with the findings that car use increases with rising income, even though it is equally important to take into account the residential location of the household to draw conclusions about the distributional and equity effect of car road charging in Germany. Findings obtained for Germany from the implementation of the GRPM are in line with results from studies conducted for European countries arguing that those with low incomes would gain the most from different kinds of road use charging (see acceptability discussion in Chapter 2.2). This is mainly explained through the fact that in the European travel context car is often not the dominant mode of transport, in particular for citizens living in bigger cities who have access to public transportation and are provided with good conditions for using the so called ‘‘slow modes’’, i.e., cycling and walking.

Assuming that those using the fast mode (car) usually are the more affluent travellers, car road charging will be progressive (Glazer and Niskanen, 2000; Evans, 1992). Since low-income groups more often use public transport, not only will they be less affected by the charges, but they will also profit more from the revenues if they are spent on improving public transport as designed in the implemented policy scenarios for part of the revenues.

Furthermore, the distributive effects illustrated in Table 28 reproduce on the whole the pre-policy mobility profiles of the different household income categories and therefore their “vulnerability” to the road charging policy. The results show that the negative welfare effect from road charging can be best compensated by revenue redistribution directly to households. The relatively highest benefit from revenue redistribution is allocated to the bottom income category. An important implication of this result is that the net welfare or equity effect, and therefore the social acceptance of road charging policies is clearly linked to the redistribution scheme of the revenues from the measure. This is in line with research done by Small (1992) showing that different use of revenues will imply different net effects, and accordingly will determine whether the road use charging policy as a whole will be progressive or regressive.

As shown in the simulation study, the redistribution of only a small part of the revenue to specific household groups will induce a rather moderate positive effect on their (car) travel demand and therefore not counteract the environmental objectives of the measure. However, a differentiated household refund structure can significantly absorb the negative welfare effect of the rising cost of car use.

5.3.5.5 Equity measurement

In the economic theory diferent approaches exist to assess income or welfare distributional as well as equity or inequality issues. Most often some kind of income or welfare function is defined to apply a summary statistics for comparing different frequency distributions in order to conclude with a result on inequality measurement. However, the choice of the inequality or distributional measurement approached depends on the initial data (-distribution) used to conduct the analysis. Some examples for common empirical approaches to income or welfare distribution or inequality assessment are the use of ex ante or ex post (microeconometric) microsimulation modelling using a variety of indices depending on the underlying data and the specific research question of interest. In general, within the literature on the measurement of income distributional effects from policy measures – very often taxation reforms – four different subconcepts can be outlined: first being the traditional concept of inequality, second being the rather novel concept of polarisation, third representing the concept of progression in taxation, and fourth concerning the concept of income poverty. The basis for the development and application of distributional and inequality indicators is the introduction of an appropriate concept of income. The appropriate definition of the underlying income is crucial for the interpretation of the results from the distributional analysis. The most prominent descriptive indices of inequality – mainly based on econometric calculations using descriptive statistics – are, e.g., the Gini coefficient, the relative mean deviation, the coefficient of variation, the logarithmic variance, the variance of the logarithms, the Mehran index, and the Piesch index.[40]

Another group of indices of inequality is derived based on the concept of probability of the occurrence of events that is based on information theory.

A special and rather normative group of inequality indices is concerned with the concept of social welfare, where the welfare analysis of distributional effects takes into account individual preferences, coherent utility functions, the formulation of riskiness, and the concept of risk aversion. The underlying social welfare function provides the link between welfare theory and inequality measurement, as they become a function of the equity of an income distribution. Using the concept of inequality aversion it is assumed that social welfare increases the more equal incomes are distributed. Examples of welfare measurement indices are e.g., different formulations of the Atkinson welfare index.

Given the complexity of data base definition and theoretical justification of the distributional measure to be applied, the calculation of a critical number of even a small number of distributional indicators goes beyond the data available in this work. In this study only household income quartiles were constructed, based on the equivalence-weighted household incomes. This provides a critical number of only four observations for a possible application of inequality or distributional measures. The reason quartiles rather than quintiles or deciles were chosen for the model database was to limit the number of household categories after the inclusion of the four residential characteristics. The construction of two-dimensional household categories based on, e.g., income deciles and the four residential location attributes would lead to 40 different household categories with a likely critical number of observations in each category. Besides, the interpretation of distributional effects between 40 two-dimensional categories could easily become fuzzy and unsound. On the other hand, the calculation of distributional indices based on the four

[40] A detailed description and the mathematical derivation of the indices can be found in Ochmann and Peichl (2006).

measurement points used in this work is likely to be critical as far as the interpretation, comparison, and the reliability of the results is concerned. However, this aspect remains a crucial point concerning the definition of future research resulting from the results obtained from this thesis (see Chapter 6).

6 Conclusion

The objective of this dissertation work is the (integrated) quantitative impact assessment of car road charging on welfare and travel demand across private household categories as well as on selected economic and environmental indicators.

To be able to investigate the research question a computable general equilibrium model for Germany was constructed. The CGE model for Germany (GRTPM) and the database were built on the basis of an existing standard model code. The model was furthermore extended through the inclusion of different household categories. Differentiated household categories as to equivalence-weighted income and residential location were introduced to allow the assessment of distributional and equity effects from the implementation of road charging policies within the model based economic framework. Household categories were specified through individual road and public transportation demand profiles as to distances travelled and transportation expenditures. Hence, heterogeneous reaction potentials in response to the policy scenarios within the private household sector were taken into account. Expenditures on car travel were further disaggregated into fixed cost of car purchase or ownership and variable costs of car use. After calibration of the model on the new database, effects of distance dependent road charging policy reforms implemented in the private passenger car travel sector were calculated. The policy measure introduced is a distance dependent and time invariant road charge of 0.05 Euro per car kilometre. The analyses of different road charging revenue recycling schemes served as the basis for the evaluation of welfare, distributional, and equity impacts from charging road use of private cars.

Depending on the revenue recycling policy accompanying the road charging scheme a general reduction in car use together with an increase in the use of public transportation across household categories can be observed. Household consumption and therefore household welfare decrease independent of the initial pre-policy income level due to the road charge. Nevertheless, it needs to be emphasised that this effect depends on how far the internalisation benefits are taken into account and what kind of revenue use policy is introduced. However, the magnitude of the distributional impact depends on the initial household travel behaviour and its socioeconomic profile. The top household income quartile experiences the highest welfare losses, irrespective of the road charging revenue reallocation scheme. The bottom household income quartile reacts more sensitively to the introduction of a road charging revenue redistribution policy. Hence, when some proportion of revenue from road charging is transferred towards the private household sector, households in the bottom income groups experience the relatively highest mitigation effect of the negative welfare impact from road charging. This implies that negative welfare or equity effects – especially burdensome for financially disadvantaged households – and therefore the social acceptance of road charging policies can be determined by the redistribution scheme of the road charging revenues. This conclusion holds also for household net welfare effects according to residential location. When no revenue redistribution takes place, households from rural areas are clearly the losers of the road charging policy reform. They can be put significantly better off by the implementation of household refunds financed from the road charging revenues.

The redistribution of the road charge revenue share directly to the private households lowers the negative effect on car use as well as on household welfare. At the same time it prevents the switch from car to public transportation. However, the net effect on car travel of levying a road charge and the redistribution of a part of the revenue is negative. As a result, overall household mobility is reduced depending on the household income category. This is an important implication when pursuing environmental objectives. The introduction of road charging can clearly lead to the reduction of car use whereas the increase in e.g. fuel taxes might lead to the use of more fuel efficient cars in the first place without actually reducing car road use. Moreover, the relevance of car fuel efficiency in the case of a gasoline price increase is ambiguous in its distributional implications, since richer households tend to have bigger (and thus less efficient) cars, they are also more likely to have newer and thus more efficient models. The decision to investigate a per-km road charge, rather than a gas tax or a vehicle-specific charge is also related to the given probability of implementation of such an instrument in Germany, as well as to the fact that energy tax on gasoline is already one of the highest compared to other countries in the European Union, and in particular compared to Germany's border countries. A further increase of the tax would worsen the already existing adverse effect of “grey fuel imports and refueling tourism. At the same time it takes into account two important policy changes already or soon taking place in Germany: Firstly, the recent developments within the German vehicle taxation scheme with regard to the consideration of CO_2 emissions; and secondly, the European Commission regulation to come in 2012 forcing European car makers to curb down the CO_2 emissions of the newly vehicle registrations to 120 CO_2 g/km. Both policy regulations will improve fuel efficiencies of passenger cars, inducing decreasing fuel demand. It can be therefore expected that in the long run both policy changes will relax the impact of fuel taxation as policy instrument to regulate car use and generating state revenue and making it therefore necessary to set up an alternative policy instrument such as road use charging.

Model results show furthermore that due to the reduction in car travel, the carbon emissions generated in the motor vehicle sector are also diminished.

The labour market and public demand experience a positive impact after the implementation of the policy scenarios, whereas the gross domestic product experiences a negative impact after its deflation with the decreasing purchasing power parities relative to abroad resulting from the initial increase in the national production. Hence, the nominal GDP increases by about 1.3 %, the number of unemployed is reduced by about 2 percentage points, leading to a change in the unemployment rate from 9.3 % to 8.9 % in the reference year 2002.

The research approach used in this study, including the methodology and the database are unique for Germany. The construction of the database underlying this study as to the combination of two different micro data sources, including income estimation for the delimitation of equivalence-weighted household income quartiles can serve as a good example for future studies of this kind. Furthermore, households included in the data base were categorised as to their residential location attribute, and therefore including information on immanent accessibility potentials. As shown through the results obtained from this work this is an important extension for the evaluation of travel demand related policy instruments. Thus, the results obtained together with the methodological tool constructed for this study are a new contribution to the literature of CGE modelling with integrated passenger travel demand for different household categories and the assessment of distributional and other economic and environmental effects after the implementation of a policy measure, e.g., road use charging.

Hence, the study results confirm the assumption that negative individual consumption welfare effects from implementing road user charging can be best compensated by revenue redistribution towards the private household sector. The redistribution of only a small part of the revenue will moderately mitigate the negative effect on household (car) travel demand induced by road charging and therefore not offset the environmental objective of the measure. However, an adequate household refund structure can significantly mitigate the negative welfare effect from rising cost for car use, especially for the household groups at risk, i.e. bottom income quartile and rural areas' residents. The pre-policy variations in public and private passenger transport demand across household income categories are relevant for the assessment of the acceptability towards road charging measures since income and the availability of alternatives determine the reaction potential to price increases of car travel. Pre-policy settlement structures, car availability and public transport use across household income and residential location groups – all interconnected parameters – have a decisive impact on the distributional impact of a car road pricing scheme. The quantitative results of welfare or equity shifts induced by road charging imply to what extent social acceptance towards the policy measure can be expected. In that sense, the distributional impact assessment suggests how to design an adequate road charging revenue redistribution scheme in order to improve its social acceptance across different population groups, since a differentiated household refund structure can significantly absorb the negative welfare effect from the rising cost for car use.

To have a better understanding of equity and fairness implications derived from quantification of distributional and welfare effects from road charging in Germany, the relevant literature concerning current equity and fairness concepts was examined. Varying reflections on equity and different methods of its assessment were surveyed to subsequently investigate the possible outcomes of such public programme regarding the changes and effects on equity. In fact, surveyed literature reveals strongly contrasting views on the question, indicating the difficulty in finding a clear-cut conclusion about the distributional and equity measure of road charging. Nevertheless, the broad consensus says that case-adequate or sufficiently progressive revenue recycling schemes can ensure that all income groups benefit from the measure, even though each road charging policy will still require its specific evaluation.

Another conclusion is that equity outcomes will in general strongly depend on the design of the policy instrument as well as on varying travel patterns from socioeconomic differences of population groups. This argument could be also confirmed from results obtained within this work. Evaluation of road charging policies needs to consider distributional effects before and after the implementation of different revenue redistribution schemes, comparing net welfare surplus with the total distributional effects. Whether the measurable shifts in welfare distribution are equitable is much more difficult to answer. Even though different methods for quantifying equity effects exist, the concept of equity, however, is much more complicated to “grasp”. A multitude of factors influence the perception of fairness and they vary among different individuals as well as socioeconomic groups. Various concepts of what could be meant by the terms “equity”, “fairness” or “justice” exist, nevertheless a universal consensus has not been found. Attempts to determine overall satisfying concepts are based on qualitative reflections rather than quantitative methods.

Another aspect to be kept in mind concerning the evaluation of the equity question is the fact that although it might be feasible to design a revenue disbursement package that will compensate aggregate losses across income classes, it is rather impossible to try to compensate all losses to all individuals. Therefore, irrespective of the efforts behind the design of the policy scenario and the revenue redistribution scheme, it is likely that some travellers will be made worse off as a result of road charges. This is one core aspect concerning the implementation of road charging that is in the focus of fairness concerns when discussing such policy reforms. It has been also suggested by scholars that because of the large number of factors determining the impacts of car road charging, revenue redistribution cannot solve all equity and fairness concerns. It is unrealistic to believe that a road charging policy program can be designed in a way that is both completely equitable and administratively feasible.

Nevertheless, researchers can provide policy makers with useful information regarding equity issues comparing the distribution of costs and benefits for various road use charging policies and estimating the total amount of revenue available from the measure implementation. This partially reflects the objective of this work. The information provided from the implementation of integrated economic impact assessment tools is essential for determining redistributions that are equitable enough to satisfy relevant social groups (of concern) and gain their acceptance for the policy reform.

Road charging policies are most often discussed within the context of such concepts as efficiency and equity. Both concepts are crucial to the evaluation of the policy measure from the research point of view. They will have rather little appeal on politicians and in particular the concerned public. The distribution of benefits and costs is generally considered more important politically than the size of the net benefits. Benefits and costs may be either diffuse or concentrated, where the concentration of benefits and the diffusion of costs are likely to have a positive effect on the acceptance of the measure when compared to the reverse case. Still, individuals are more likely to oppose to new costs than to support new benefits. Furthermore, even sophistically designed redistribution schemes cannot resolve all equity concerns due to individual- and household-level variation in flexibility and reaction potentials (alternatives) to the charging measure.

Concluding, the discussion about distributional effects and equity shows that the overall “construct” of equity is very difficult to capture by the economic theory and quantitatively. Since there does not exist an indisputable consensus about the definition of equity, the concept (of an equitable distribution) lacks an applicable theoretical basis. Furthermore, it remains questionable to what extent a universally equitable welfare situation can be achieved through road charging revenue redistribution taking into account the plurality of individual interests of car drivers and their unique perception of equity and fairness. Nevertheless, due to the relevance of road charging as a “multifunctional” policy instrument the evaluation of its economic impacts remains indispensable since it can significantly help to develop a policy scheme that will be equitable enough to satisfy a majority of the public involved in the measure implementation.

Finally, some ideas for future research in the field of this study shall be mentioned. Depending on the policy concern to be examined using the modeling tool developed within this work, the modeling mechanism can be further extended and refined. One possible idea is the introduction of a bundle of strategies or policy instruments to reduce environmental impacts of transport, besides road use charging and their simultaneous impact analysis. An approach of this kind could help to better understand the effects from the implementation of road charging and a simultaneous reduction in fuel and/ or other car related taxes.

Furthermore, the household income quartiles integrated in the model database could be further disaggregated, e.g., as to income deciles. This would allow the implementation of quantitative methods in the assessment of distributional and equity effects.

Another model extension could concern the combination of the travel demand data with road infrastructure network data to allow for the modelling of road congestion. This kind of model refinement could also include the introduction of household social utility functions that would consider individual value of time and time use preferences.

The existence of valuable research ideas related to the work done within this dissertation show – together with the results discussed above –the value of the research carried out here and the benefit of the modelling tool developed within this work.

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8 Appendix

Appendix 1 List of core model equations

Source: Steininger and Friedl (2004).

Production

(1) $X_j = \min\left(H_j / A_j, X_{ij} / a_{ij}\right) \ for \ j = 1,...,35$

(2) $H_j = \left(\delta_j L_j^{(\sigma_j - 1)/\sigma_j} + \left(1 - \delta_j\right) K_j^{(\sigma_j - 1)/\sigma_j}\right)^{\sigma_j / \sigma_j - 1} \ for \ j = 1,...,35$

(3) $T^p = \min\left(T^{pf} / A^{pf}, T^{pv} / A^{pv}\right)$

(4) $T^{pf} = \min\left(X_i / A_i^{pf}\right)$

(5) $T^{pv} = \min\left(X_i / A_i^{pv}, km^p / A^{kmp}\right)$

(6) $T^u = \min\left(X_i / A_i^u\right)$

Foreign Trade

(7) $EX_j = EX_j^o \left(P_j^w / P_j\right)^{\varepsilon_j} \ for \ j = 1,...,35$

(8) $M_j = M_j^o \left(P_j / P_j^w\right)^{\varepsilon_j} \ for \ j = 1,...,35$

Labour Market

(9) $\frac{w}{p_p} \geq \overline{w_{low}} \perp u$

Household Demand

(10)

$$C_{h_{e,r}} = \left(\delta^C_{h_{e,r}} \; X^{C\,\left(\sigma^C_{h_{e,r}}-1\right)/\sigma^C_{h_{e,r}}}_{h_{e,r}} + \left(1-\delta^C_{h_{e.r}}\right) T_{h_{e.r}}^{\left(\sigma^C_{h_{e,r}}-1\right)/\sigma^C_{h_{e,r}}} \right)^{\sigma^C_{h_{e,r}} / \left(\sigma^C_{h_{e,r}}\text{-}1\right)}$$

$$\textit{for } h_{e,r} = \begin{pmatrix} h_{11} & \cdots & h_{14} \\ \vdots & \ddots & \vdots \\ h_{41} & \cdots & h_{44} \end{pmatrix}, \textit{where e is the income category and } r \textit{ the residential location attribute}$$

$$X^c_{h_{e,r}} = \left[\sum_i \left(\delta^X_{h_{e,r},i} X^{c\,\left(\sigma^X_{h_{e,r}}-1\right)/\sigma^X_{h_{e,r}}}_{h_{e,r},i} \right) \right]^{\sigma^X_{h_{e,r}} / \left(\sigma^X_{h_{e,r}}-1\right)}$$

(11) $$\textit{with } \sum_{\mathrm{i}} \left(\delta^X_{h_{e,r},i} \right) = 1 \textit{ for } h_{e,r} = \begin{pmatrix} h_{11} & \cdots & h_{14} \\ \vdots & \ddots & \vdots \\ h_{41} & \cdots & h_{44} \end{pmatrix},$$

$$\textit{where e is the income category and } r \textit{ the residential location attribute}$$

$$T_{h_{e,r}} = \left(\delta^T_{h_{e,r}} T^{p\,\left(\sigma^T_{h_{e,r}}\text{-}1\right)/\sigma^T_{h_{e,r}}}_{h_{e,r}} + \left(1-\delta^T_{h_{e,r}}\right) + T^{u\,\left(\sigma^T_{h_{e,r}}\text{-}1\right)/\sigma^T_{h_{e,r}}}_{h_{e,r}} \right)^{\sigma^T_{h_{e,r}} / \left(\sigma^T_{h_{e,r}}-1\right)}$$

(12) $$\textit{for } h_{e,r} = \begin{pmatrix} h_{11} & \cdots & h_{14} \\ \vdots & \ddots & \vdots \\ h_{41} & \cdots & h_{44} \end{pmatrix},$$

$$\textit{where e is the income category and } r \textit{ the residential location attribute}$$

Appendix 2 Variables

Source: Steininger and Friedl (2004).

Factor demand	
L	Total labour demand
K	Total capital demand
Production	
X_j	Gross production of sector j
K_j	Capital input in sector j
L_j	Labour input in sector j
H_j	Factor aggregate in sector j
A_j, a_{ij}	Leontief-input -output -coefficients in sector j
δ_j	CES-distribution parameter in sector j
σ_j	Elasticity of substitution in production between labour and capital in sector j
Foreign trade	
EX_j	Export of sector j
M_j	Import of sector j
P_j	Production price of goods aggregate X in sector j
P^w_j	World market price of goods aggregate M in sector j
EX^0, M^0	Export and import quantities in sector j in the reference year
ε_j	Foreign trade price elasticity of demand in sector j
Labour Market	
w	Nominal wage rate
w_{low}	Lower bound on the real wage rate
p_p	Paasche index of the aggregate price level
u	Rate of unemployment

Transport	
T^p	Private car passenger transport
T^{pf}	Private car passenger transport production fixed input
T^{pv}	Private car passenger transport production variable input (directly kilometre dependent)
T^u	Public passenger transport
A^{pf}, A^{pv}, A^{pf}_i, A^{pv}_i	Leontief-input -output -coefficients in private car passenger transport
A^{kmp}	Kilometre input coefficient in private car passenger transport
A^u_i	Leontief-input -output -coefficients in public transport
km^p	Vehicle kilometres driven in private car transport
Consumption	
C_h	Total Consumption of household type h[41]
X_h^C	Consumption of non-transport goods of household h
T_h	Transport consumption of household h
δ_h^C	CES-distribution parameter in consumption for household h
δ_h^T	CES-distribution parameter in transport consumption for household h
$\delta_{h,i}^X$	CES-distribution parameter in non-transport consumption for household h
σ_h^C	Elasticity of substitution between transport and non-transport demand for household h
	Elasticity of substitution between private car transport and

[41] Household type can be distinguished by income level and/ or residential location attribute:

$$h_{e,r} = \begin{pmatrix} h_{11} & \cdots & h_{14} \\ \vdots & \ddots & \vdots \\ h_{41} & \cdots & h_{44} \end{pmatrix}, \textit{ where } e \textit{ is the income category and } r \textit{ the residential location attribute}$$

σ_h^T	public transport demand for household h
σ_h^X	Elasticity of substitution between non-transport goods in household h consumption

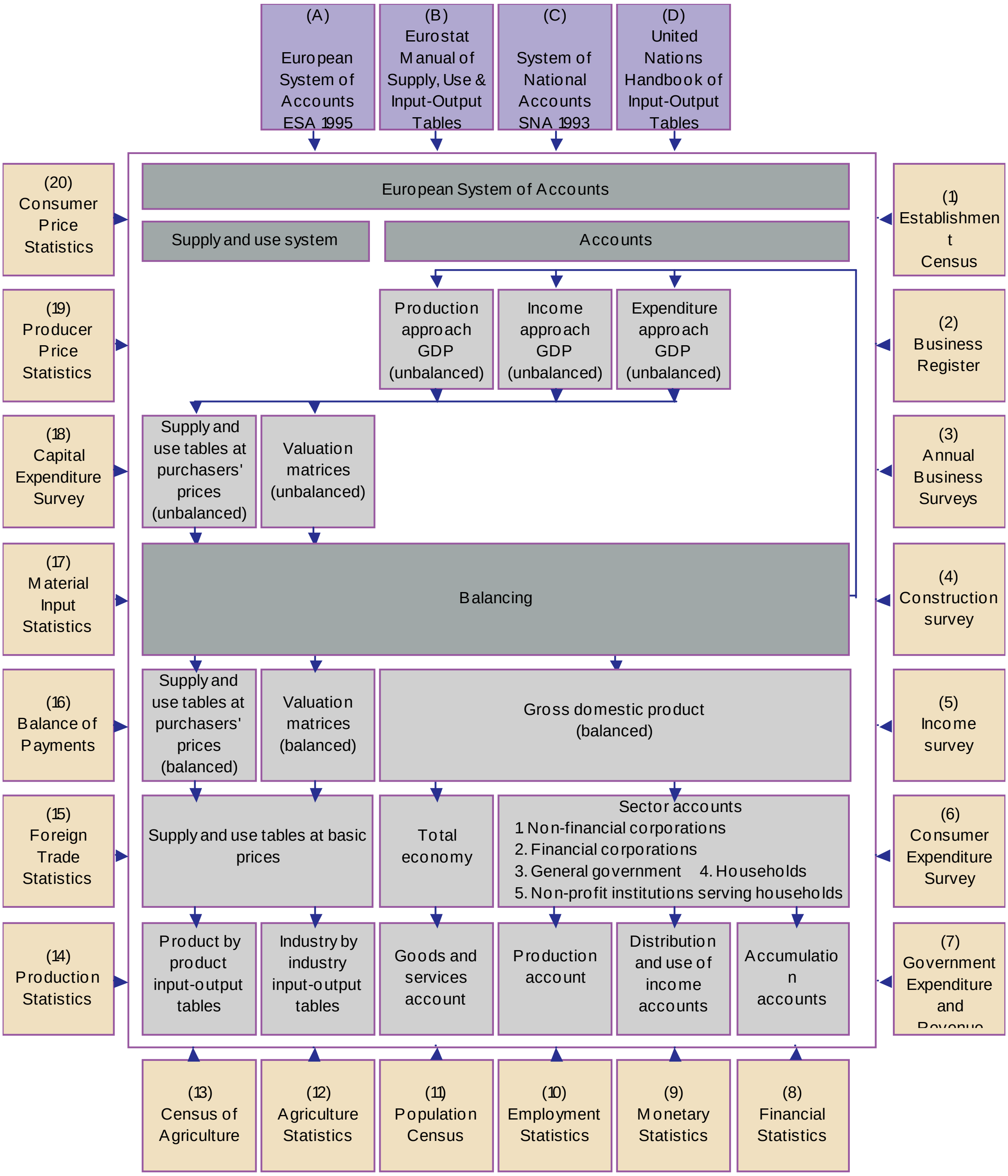
Appendix 3 Gross domestic product calculation approaches for an input-output table

Source: Eurostat (2008).

Production approach	Income approach	Expenditure approach
Total output at basic prices	Compensations of employees	Household final consumption expenditure
– Intermediate consumption	+ Other net taxes on production	+ NPISH final consumtion expenditure
– Taxes less subsides on products	+ Capital consumption	+ Government consumtion expenditure
	+ Net operating surplus	+ Gross fixed capital formation
		+ Changes in inventories
= Value added at basic prices	= Value added at basic prices	+ Acquisitions less disposals of valuables
		+ Exports of goods and services
+ Taxes less subsides on products	+ Taxes less subsides on products	– Imports of goods and services
		– Direct purchases abroad by residents
= Gross domestic products	= Gross domestic products	= Gross domestic products

Appendix 4 Input-output tables and data sources within the national and European system of accounts

Source: Eurostat (2008).



Appendix 5 Household refund distribution in scenario B according to fuel tax payments

Household fuel tax share in the overall fuel tax state contribution, in %	
Income	
HIQ1	6.9
HIQ2	23.5
HIQ3	29.8
HIQ4	39.7
Residential location	
HRCent1	19.6
HRAgglo2	43.8
HRUrb3	22.9
HRRul4	13.7
Income and residential location	
H1	1.9
H2	4.3
H3	5.6
H4	7.8
H5	1.3
H6	8.2
H7	13.8
H8	20.5
H9	2.2
H10	6.6
H11	6.6
H12	7.5
H13	1.5
H14	4.4
H15	3.8
H16	3.9

Sources: EVS 2003 (StaBuA, 2005), and own calculations.

Appendix 6 Household expenditures on fixed car use related components for household categories

Transportation expenditure in million Euro					
Residential category					
Purchase of new and second-hand vehicles					
Income quartlie	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	730.6	763.7	724.5	544.4	2,763
HIQ2	1,988	3,771	2,862	1,968	10,590
HIQ3	3,026	6,914	2,222	1,488	13,650
HIQ4	4,372	10,611	5,061	2,158	22,203
Total	10,117	22,060	10,870	6,159	49,206
Spare parts and accessory					
HIQ1	85.0	104.9	141.9	73.8	405.6
HIQ2	244.8	479.2	350.2	235.4	1,310
HIQ3	338.3	761.5	337.8	235.8	1,673
HIQ4	434.0	1,188	501.7	247.2	2,371
Total	1,102	2,534	1.332	792.3	5,760
Maintenance and repair					
HIQ1	352.1	153.7	346.7	212.2	1,065
HIQ2	638.2	1,409	1,084	681.9	3,813
HIQ3	961.5	2,291	949.2	499.8	4,702
HIQ4	1,368	3,126	1,026	566.1	6,087
Total	3,320	6,980	3,406	1,960	15,666
Other services related to car use					
HIQ1	173.0	109.7	105.3	59.3	447.3
HIQ2	170.5	356.9	242.1	136.4	905.9
HIQ3	228.2	493.0	206.1	118.1	1,045
HIQ4	332.3	717.6	234.2	127.6	1,412
Total	904.1	1,677.3	787.6	441.5	3,810
(Annual) Tax on motor vehicles					
HIQ1	90.9	63.9	122.9	80.2	357.9
HIQ2	231.3	520.4	393.0	267.1	1,412
HIQ3	286.9	778.1	318.4	199.8	1,583
HIQ4	415.6	1,048	377.0	207.8	2,048
Total	1,025	2,410	1,211	754.8	5,401
Car insurance and related financial services					
HIQ1	348.4	239.3	360.4	261.9	1,210
HIQ2	729.4	1,337	1,152	804.8	4,023
HIQ3	865.9	2,287	1,002	637.2	4,792
HIQ4	1,319	3,440	1,251	644.7	6,655
Total	3,262	7,303	3,766	2,349	16,680
Total fixed car travel expenditure					
HIQ1	1,780	1,435	1,802	1,232	6,249
HIQ2	4,002	7,874	6,084	4,094	22,054
HIQ3	5,707	13,525	5,036	3,179	27,446
HIQ4	8,241	20,131	8,451	3,952	40,775
Total	19,730	42,965	21,372	12,456	96,524
Sources: EVS 2003 (StaBuA, 2005), and own calculations.					

Appendix 7 Household expenditures on transportation as shares in the overall consumption expenditure for household categories

Fix car travel related expenditures as total consumption expenditure shares in % for different household categories					
Residential category					
Total fix car travel expenditure					
Income quartlie	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	3.5	2.8	5.1	5.4	3.9
HIQ2	8.6	8.8	9.8	10.5	9.3
HIQ3	10.1	10.1	10.1	11.3	10.2
HIQ4	11.4	11.6	14.8	14.3	12.3
Total	8.7	9.6	10.5	10.6	9.7
Total variable car travel expenditure for fuels					
HIQ1	1.4	1.0	2.3	2.6	1.6
HIQ2	3.5	3.5	4.0	4.2	3.7
HIQ3	3.7	3.9	5.0	5.1	4.2
HIQ4	4.0	4.4	5.0	5.3	4.5
Total	3.2	3.7	4.2	4.4	3.8
Total car travel expenditure					
HIQ1	4.8	3.7	7.5	8.0	5.5
HIQ2	12.0	12.3	13.8	14.7	13.0
HIQ3	13.8	14.0	15.1	16.4	14.4
HIQ4	15.4	16.1	19.8	19.7	16.9
Total	11.9	13.3	14.7	15	13.5
Total public transportation expenditure					
HIQ1	2.2	2.0	1.3	1.1	1.8
HIQ2	1.3	0.8	0.6	0.5	0.8
HIQ3	1.1	0.7	0.6	0.6	0.7
HIQ4	1.2	0.7	0.5	0.5	0.8
Total	1.4	0.9	0.7	0.7	0.9
Total travel expenditure					
HIQ1	7.1	5.7	8.8	9.1	7.3
HIQ2	13.4	13.1	14.4	15.3	13.9
HIQ3	14.9	14.7	15.7	17.0	15.2
HIQ4	16.6	16.8	20.2	20.2	17.6
Total	13.4	14.2	15.4	15.7	14.4
Sources: EVS 2003 (StaBuA, 2005), and own calculations.					

Appendix 8 Household expenditures on fixed car use related components as shares in household net income for household categories

Fix car travel related expenditures as net income shares in % for different household categories					
Residential category					
Purchase of new and second-hand vehicles					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	1.2	1.3	1.7	2.0	1.5
HIQ2	3.4	3.4	3.7	4.0	3.6
HIQ3	4.3	4.1	3.3	3.8	3.9
HIQ4	4.3	4.3	6.4	5.6	4.8
Total	3.5	3.8	4.1	4.0	3.8
Spare parts and accessory					
HIQ1	0.1	0.2	0.3	0.3	0.2
HIQ2	0.4	0.4	0.5	0.5	0.4
HIQ3	0.5	0.4	0.5	0.6	0.5
HIQ4	0.4	0.5	0.6	0.6	0.5
Total	0.4	0.4	0.5	0.5	0.4
Maintenance and repair					
HIQ1	0.6	0.3	0.8	0.8	0.6
HIQ2	1.1	1.3	1.4	1.4	1.3
HIQ3	1.4	1.3	1.4	1.3	1.3
HIQ4	1.3	1.3	1.3	1.5	1.3
Total	1.1	1.2	1.3	1.3	1.2
Other services related to car use					
HIQ1	0.3	0.2	0.3	0.2	0.2
HIQ2	0.3	0.3	0.3	0.3	0.3
HIQ3	0.3	0.3	0.3	0.3	0.3
HIQ4	0.3	0.3	0.3	0.3	0.3
Total	0.3	0.3	0.3	0.3	0.3
(Annual) Tax on motor vehicles					
HIQ1	0.1	0.1	0.3	0.3	0.2
HIQ2	0.4	0.5	0.5	0.5	0.5
HIQ3	0.4	0.5	0.5	0.5	0.5
HIQ4	0.4	0.4	0.5	0.5	0.4
Total	0.4	0.4	0.5	0.5	0.4
Car insurance and related financial services					
HIQ1	0.6	0.4	0.9	1.0	0.6
HIQ2	1.3	1.2	1.5	1.7	1.4
HIQ3	1.2	1.3	1.5	1.6	1.4
HIQ4	1.3	1.4	1.6	1.7	1.4
Total	1.1	1.2	1.4	1.5	1.3
Total fixed car travel expenditure					
HIQ1	2.9	2.4	4.3	4.6	3.3
HIQ2	6.9	7.2	7.9	8.4	7.5
HIQ3	8.0	7.9	7.4	8.2	7.9
HIQ4	8.1	8.2	10.4	10.3	8.8
Total	6.8	7.3	8.0	8.1	7.5
Sources: EVS 2003 (StaBuA, 2005), and own calculations.					

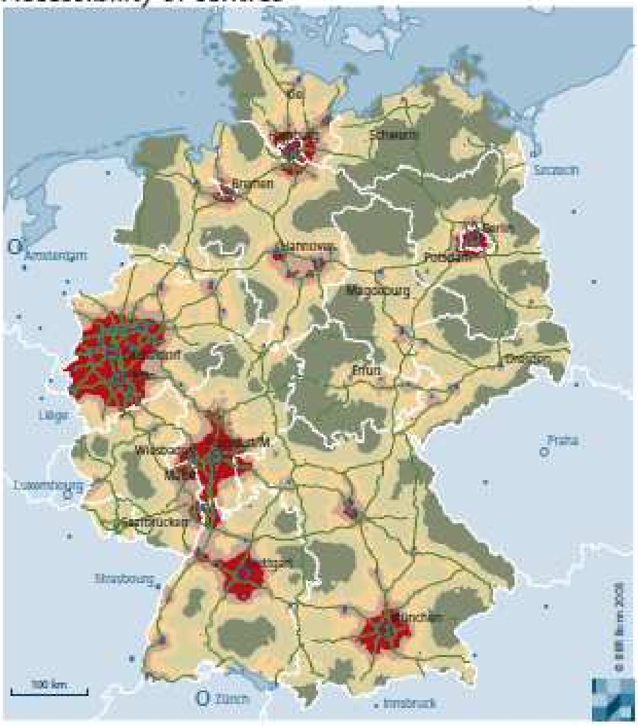
Appendix 9 Household expenditures on fixed car use related components as shares in household overall consumption expenditure for household categories

Fix car travel related expenditures as total consumption expenditure shares in % for different household categories					
Residential category					
Purchase of new and second-hand vehicles					
Income quartile	HRCent1	HRAgglo2	HRUrb3	HRRul4	Total
HIQ1	1.4	1.5	2.1	2.4	1.7
HIQ2	4.3	4.2	4.6	5.1	4.5
HIQ3	5.4	5.2	4.5	5.3	5.1
HIQ4	6.0	6.1	8.9	7.8	6.7
Total	4.5	4.9	5.3	5.2	4.9
Spare parts and accessory					
HIQ1	0.2	0.2	0.4	0.3	0.3
HIQ2	0.5	0.5	0.6	0.6	0.6
HIQ3	0.6	0.6	0.7	0.8	0.6
HIQ4	0.6	0.7	0.9	0.9	0.7
Total	0.5	0.6	0.7	0.7	0.6
Maintenance and repair					
HIQ1	0.7	0.3	1.0	0.9	0.7
HIQ2	1.4	1.6	1.7	1.8	1.6
HIQ3	1.7	1.7	1.9	1.8	1.8
HIQ4	1.9	1.8	1.8	2.1	1.8
Total	1.5	1.6	1.7	1.7	1.6
Other services related to car use					
HIQ1	0.3	0.2	0.3	0.3	0.3
HIQ2	0.4	0.4	0.4	0.4	0.4
HIQ3	0.4	0.4	0.4	0.4	0.4
HIQ4	0.5	0.4	0.4	0.5	0.4
Total	0.4	0.4	0.4	0.4	0.4
(Annual) Tax on motor vehicles					
HIQ1	0.2	0.1	0.4	0.4	0.2
HIQ2	0.5	0.6	0.6	0.7	0.6
HIQ3	0.5	0.6	0.6	0.7	0.6
HIQ4	0.6	0.6	0.7	0.8	0.6
Total	0.5	0.5	0.6	0.6	0.5
Car insurance and related financial services					
HIQ1	0.7	0.5	1.0	1.2	0.8
HIQ2	1.6	1.5	1.9	2.1	1.7
HIQ3	1.5	1.7	2.0	2.3	1.8
HIQ4	1.8	2.0	2.2	2.3	2.0
Total	1.4	1.6	1.8	2.0	1.7
Total fixed car travel expenditure					
HIQ1	3.5	2.8	5.1	5.4	3.9
HIQ2	8.6	8.8	9.8	10.5	9.3
HIQ3	10.1	10.1	10.1	11.3	10.2
HIQ4	11.4	11.6	14.8	14.3	12.3
Total	8.7	9.6	10.5	10.6	9.7
Sources: EVS 2003 (StaBuA, 2005), and own calculations.					

Appendix 10 Accessibility of centres and functional urban areas in Germany by car, German Federal Office for Building and Regional Planning (BBSR)

The spatial distribution of a car accessibility index calculated by the BBSR as shown (below) accounts more for the proximity in terms of travel time than travel distance. The structural picture reveals the rather heterogeneous, mono- and polycentric distribution of functional urban areas in Germany and the functional linkages implied by the network of national road infrastructure. In Germany road infrastructure has in general a significant influence on accessibility. 58 % of the German country area can be attributed to rural regions or peripheries. Their population densities are about 100 inhabitants per km^2 compared to the national average of about 230 people per km^2. Nevertheless, these areas comprise one quarter of the entire German population. The resulting spatial dispersion of scarcely populated rural areas in Germany contributes to the car dependency observed in some places (Schuert et al., 2005).

Accessibility of centres



Accessibility by car of High Level Centres and Functional Urban Areas, weighted by required travel time and the importance of trip purpose

- Central area
- Extended central area
- Close to central area
- Peripheric area
- Very peripheric area
- Federal Highways

Functional Urban Areas classified by importance

1
2
3
4
5

High level centre classified by population size

5
4
3
2
1

Source: Continuos Spatial Monitoring System of the BBSR (Federal Institute for Research on Building, Urban Affairs and Spatial Development within the Federal Office for Building and Regional Planning)
Database: Accessibility model of the BBSR
Project results ESPON 2006, Project No. 1.1.1

Appendix 11 GAMS code of the German Road Travel Policy Model (GRTPM), 2002

```
* Multihousehold hh version GRTPM
* Year of calculation: 2002
* Dissertation Kalinowska Dominika

scalar         urbase     unemployment rate base year /9.41/
               uabase     unemployed in 1000 base year /4061/
               lbase      tot labor force avail incl unempl in 1000
/43157/
               emp        total labor force employed base year in 1000
/39096/;

* PUBLIC FINANCE

scalar         lwtaxr     labor wage tax rate   /0.930681064/
               ktaxr      capital revenue tax rate  /0.289784016 /
               pubdef     public deficit in mio euro /-64300/;

*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz

$ontext
LAWI
KOHLE
OELBB
OELVER
ELEK
WASSER
EISEN
STEIN
CHEMIE
METALL
MASCH
BUEROM
ELEINR
FAHRZ
NAHR
TEXTIL
HOLZ
PAPIER
VERLAG
GUMMI
RECYC
SPROD
BAU
HANDEL
GAST
VERK
SUL
SVERK
KOMM
GELD
```

```
REAL
DATEN
FUE
SODIEN
NMDIEN
UALLO
$offtext

*222222222222222222222222222222222222222222222222222222222
*            D E F I N I T I O N S
*222222222222222222222222222222222222222222222222222222222

set     esps    economic sectors and primary factors
 /LAWI, KOHLE, OELBB, OELVER, ELEK, WASSER, EISEN, STEIN, CHEMIE, METALL,
        MASCH, BUEROM, ELEINR, FAHRZ, NAHR, TEXTIL, HOLZ, PAPIER, VERLAG,
         GUMMI, RECYC, SPROD, BAU, HANDEL, GAST, VERK, SUL, SVERK, KOMM,
         GELD, REAL, DATEN, FUE, SODIEN, NMDIEN, ITAX, LTAX, KTAX,
         L, K, TXTRNS, UBEN, W, FX, ITAXRT, OUTPUT, EX, IM/,

        espw    economic sectors and agents
 /LAWI, KOHLE, OELBB, OELVER, ELEK, WASSER, EISEN, STEIN, CHEMIE, METALL,
        MASCH, BUEROM, ELEINR, FAHRZ, NAHR, TEXTIL, HOLZ, PAPIER, VERLAG,
         GUMMI, RECYC, SPROD, BAU, HANDEL, GAST, VERK, SUL, SVERK, KOMM,
         GELD, REAL, DATEN, FUE, SODIEN, NMDIEN, W, CONS, GOV, EX, IM,
         OUTPUT, L, K, ITAXRT, BESCH/,

        es(esps)    economic sectors
 /LAWI, KOHLE, OELBB, OELVER, ELEK, WASSER, EISEN, STEIN, CHEMIE, METALL,
       MASCH, BUEROM, ELEINR, FAHRZ, NAHR, TEXTIL, HOLZ, PAPIER, VERLAG,
         GUMMI, RECYC, SPROD, BAU, HANDEL, GAST, VERK, SUL, SVERK, KOMM,
         GELD, REAL, DATEN, FUE, SODIEN, NMDIEN/,

        ess(espw)    economic sectors again
 /LAWI, KOHLE, OELBB, OELVER, ELEK, WASSER, EISEN, STEIN, CHEMIE, METALL,
        MASCH, BUEROM, ELEINR, FAHRZ, NAHR, TEXTIL, HOLZ, PAPIER, VERLAG,
         GUMMI, RECYC, SPROD, BAU, HANDEL, GAST, VERK, SUL, SVERK, KOMM,
         GELD, REAL, DATEN, FUE, SODIEN, NMDIEN/,

        hh           household types
/h1, h2, h3, h4, h5, h6, h7, h8, h9, h10, h11, h12, h13, h14, h15, h16 /,

*households
hs          household sums
        /all_hh,he1,he2,he3,he4,hr1,hr2,hr3,hr4/,
 hzu(hs,hh) / all_hh.(h1, h2, h3, h4, h5, h6, h7, h8, h9, h10, h11, h12,
h13, h14, h15, h16)
   he1.(h1, h5, h9, h13)
   he2.(h2, h6, h10, h14)
   he3.(h3, h7, h11, h15)
   he4.(h4, h8, h12, h16)
   hr1.(h1, h2, h3, h4)
   hr2.(h5, h6, h7, h8)
   hr3.(h9, h10,h11, h12)
   hr4.(h13,h14,h15, h16)/,
```

```
   he1(hh)      household income type1
   /h1, h5, h9, h13/,
   he2(hh)      household income type2
   /h2, h6, h10, h14/,
   he3(hh)      household income type3
   /h3, h7, h11, h15/,
   he4(hh)      household income type4
    /h4, h8, h12, h16/,
   hr1(hh)      household regional type1
    /h1, h2, h3, h4/,
   hr2(hh)      household regional type2
    /h5, h6, h7, h8/,
   hr3(hh)      household regional type3
   /h9, h10, h11, h12/,
   hr4(hh)      household regional type4
   /h13, h14, h15, h16/,
   he           household income types
   /he1, he2, he3, he4/,
   hr           household regional types
   /hr1, hr2, hr3, hr4/;

ALIAS (ES,SS);

*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
*           E C O N O M I C    D A T A
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz

table sam(esps,espw)  benchmark social accounting matrix
$ondelim
$include d:\diss\ARPM Model\samd2002.csv
$offdelim
display sam;

set r(esps)
       /LAWI, KOHLE, OELBB, OELVER, ELEK, WASSER, EISEN, STEIN, CHEMIE,
METALL,
        MASCH, BUEROM, ELEINR, FAHRZ, NAHR, TEXTIL, HOLZ, PAPIER, VERLAG,
        GUMMI, RECYC, SPROD, BAU, HANDEL, GAST, VERK, SUL, SVERK, KOMM,
        GELD, REAL, DATEN, FUE, SODIEN, NMDIEN, ITAX, LTAX, KTAX,
        L, K, TXTRNS, UBEN, W, FX, OUTPUT/,c(espw)
       /LAWI, KOHLE, OELBB, OELVER, ELEK, WASSER, EISEN, STEIN, CHEMIE,
METALL,
        MASCH, BUEROM, ELEINR, FAHRZ, NAHR, TEXTIL, HOLZ, PAPIER, VERLAG,
        GUMMI, RECYC, SPROD, BAU, HANDEL, GAST, VERK, SUL, SVERK, KOMM,
        GELD, REAL, DATEN, FUE, SODIEN, NMDIEN, W, CONS, GOV, EX, IM,
        OUTPUT/;

parameter       rchk(r)  row sum check
                cchk(c)  column sum check;

rchk(r) = sum(c, sam(r,c));
cchk(c) = sum(r, sam(r,c));
table sams(es,es)       input table per sector
LOOP(es,LOOP(ss, sams(ss,es)=(sum(ess,sam(ss,ess)$(ord(ess)=ord(es))))))
```

```
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
*            MULTIHOUSEHOLD INCOME DISTRIBUTION
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz

*16 new hh categories as follows
*In Kernstaedten< 500 TEW/u. 1500              h1
*In Kernstaedten< 500 TEW/1500-u.2600          h2
*In Kernstaedten< 500 TEW/2600-u.3600          h3
*In Kernstaedten< 500 TEW/3600                 h4
*Agglom oh.Kernstaedte>500TEW/u.1500           h5
*Agglom oh.Kernstaedte>500TEW/1500-u.2600      h6
*Agglom oh.Kernstaedte>500TEW/2600-u.3600      h7
*Agglom oh.Kernstaedte>500TEW/3600+            h8
*verstaedt.Raeume/u.1500                       h9
*verstaedt.Raeume/1500-u.2600                  h10
*verstaedt.Raeume/2600-u.3600                  h11
*verstaedt.Raeume/3600+                        h12
*laendl.Raeume/u.1500                          h13
*laendl.Raeume/1500-u.2600                     h14
*laendl.Raeume/2600-u.3600                     h15
*laendl.Raeume/3600+                           h16

*total income incorporates selfemployed and employees
parameter    incs(hh)    share of total income per hh
/h1        0.046775117
h2        0.044767507
h3        0.054814582
h4        0.078308642
h5        0.046817928
h6        0.08485037
h7        0.131373693
h8        0.188990716
h9        0.032021855
h10        0.059536605
h11        0.05261998
h12        0.060985583
h13        0.020858652
h14        0.037630954
h15        0.030092354
h16        0.029557284        /;

parameter    incls(hh)    share of labour income per hh
/h1        0.014128817
h2        0.042987016
h3        0.04476612
h4        0.112594548
h5        0.019543136
h6        0.062671388
h7        0.116643931
h8        0.266955381
h9        0.013081157
h10        0.039955945
h11        0.066044755
```

```
h12        0.085483168
h13        0.008848666
h14        0.026795984
h15        0.037595981
h16        0.041904007        /;

parameter  ubens(hh)    share of unemployed transfer income per hh
/h1        0.086020576
h2        0.078657124
h3        0.055243187
h4        0.036505936
h5        0.08875567
h6        0.107662339
h7        0.087543123
h8        0.108706424
h9        0.071250367
h10        0.075176916
h11        0.035015962
h12        0.030805725
h13        0.053374574
h14        0.048256089
h15        0.019780496
h16        0.01724549        /;

parameter    transfs(hh)    share of transfers income per hh
/h1        0.146448135
h2        0.039522829
h3        0.082206489
h4        0.019764343
h5        0.109499189
h6        0.105249511
h7        0.158270127
h8        0.043497748
h9        0.085661845
h10        0.079260119
h11        0.01720345
h12        0.009928888
h13        0.050918837
h14        0.043375241
h15        0.005940016
h16        0.003253232        /;

*NEU090709
parameter    ks(hh)      share of capital income per hh
/h1        0.040395493
h2        0.045704825
h3        0.062946637
h4        0.07809991
h5        0.036546907
h6        0.090294066
h7        0.150426334
h8        0.18457952
h9        0.023643368
h10        0.06225439
```

```
h11         0.048943646
h12         0.061348323
h13         0.01701506
h14         0.040860167
h15         0.027117022
h16         0.029824332        /;


parameter    fxs(hh)      share of foreign exchange income per hh
/h1         0.161407197
h2         0.037914051
h3         0.125314168
h4         0.054621517
h5         0.063942647
h6         0.07495688
h7         0.216406296
h8         0.086412885
h9         0.069888877
h10         0.044075831
h11         -0.009550738
h12         0.020401341
h13         0.043387442
h14         0.023455465
h15         -0.021518899
h16         0.00888504        /;


*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
*            SAM ADJUSTMENT
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz

parameter     kfzsteuer(hh)     car tax per hh
/h1         90.868
h2         231.321
h3         286.896
h4         415.613
h5         63.891
h6         520.411
h7         778.117
h8         1047.807
h9         122.912
h10         393.012
h11         318.424
h12         376.950
h13         80.185
h14         267.095
h15         199.760
h16         207.769        /;

parameter     moest(hh)       energy tax per hh
/h1         444.915
h2         1023.445
h3         1325.382
h4         1837.088
```

```
h5         315.961
h6         1936.243
h7         3260.101
h8         4856.374
h9         514.848
h10         1565.248
h11         1569.780
h12         1779.233
h13         365.662
h14         1035.338
h15         907.527
h16         926.704        /;

parameter     oevexp(hh)   variable public transport expenditure per hh
/h1         1470.036
h2         777.158
h3         784.409
h4         1083.058
h5         1321.336
h6         925.970
h7         1175.035
h8         1628.086
h9         602.604
h10         481.844
h11         349.595
h12         344.734
h13         324.140
h14         270.303
h15         210.141
h16         189.975        /;

parameter     inpfz(hh)       production input from vehicle prduction
sector per hh
/h1         541.904
h2         1474.276
h3         2244.736
h4         3243.163
h5         566.425
h6         2797.244
h7         5128.568
h8         7870.527
h9         537.414
h10         2123.023
h11         1647.955
h12         3753.873
h13         403.781
h14         1460.038
h15         1103.675
h16         1600.764        /;

parameter        inpha(hh)       production input from trade etc. per hh
/h1         63.018
h2         181.590
h3         250.953
```

```
h4         321.932
h5         77.835
h6         355.422
h7         564.827
h8         881.188
h9         105.269
h10         259.781
h11         250.534
h12         372.096
h13         54.749
h14         174.633
h15         174.918
h16         183.388        /;

parameter  inpge(hh)  production input from finance and insurance per hh
/h1         348.385
h2         729.367
h3         865.853
h4         1318.850
h5         239.289
h6         1336.873
h7         2286.981
h8         3440.181
h9         360.428
h10         1152.320
h11         1002.348
h12         1250.917
h13         261.894
h14         804.822
h15         637.204
h16         644.747        /;

parameter     inpso(hh)       production input from aux. services per hh
/h1         161.144
h2         158.829
h3         212.540
h4         309.497
h5         102.196
h6         332.401
h7         459.174
h8         668.389
h9         98.034
h10         225.449
h11         191.913
h12         218.169
h13         55.201
h14         127.080
h15         110.027
h16         118.881        /;

parameter     inpoe(hh)      production input from fuel per hh
/h1         261.300
h2         601.071
h3         778.399
```

```
h4        1078.925
h5        185.564
h6        1137.158
h7        1914.663
h8        2852.156
h9        302.371
h10        919.272
h11        921.935
h12        1044.946
h13        214.754
h14        608.055
h15        532.992
h16        544.255        /;

parameter     inphav(hh)     production inpurt from trade to variable
cost per hh
/h1        261.149
h2        473.352
h3        713.208
h4        1014.772
h5        114.021
h6        1045.238
h7        1699.309
h8        2318.786
h9        257.185
h10        804.197
h11        704.024
h12        761.166
h13        157.408
h14        505.767
h15        370.747
h16        419.914        /;

parameter     oeltaxr(hh)    energy tax rate on fuel use per hh;
oeltaxr(hh)=(moest(hh)+inpoe(hh))/inpoe(hh)-1;

* sum fixed and variable car use expenditure and variable public
transport expenditure
parameter     vausg(hh)       total private hh transport expenditure per
hh
              mivfix(hh)      fixed car expenditure per hh
              mivvar(hh)      variable car expenditure per hh
              mivcar(hh)      total car expenditure per hh
mivfix(hh)=kfzsteuer(hh)+inpfz(hh)+inpha(hh)+inpge(hh)+inpso(hh);
mivvar(hh)=moest(hh)+inpoe(hh)+inphav(hh);
vausg(hh)=oevexp(hh)+mivfix(hh)+mivvar(hh);
mivcar(hh)=mivfix(hh)+mivvar(hh);
parameter capo(hh)       calibrated price for oelverbr;
              capo(hh)=1+oeltaxr(hh);

*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
*            ROAD PRICING BASE DATA
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
```

```
sam("OELVER","W") =sam("OELVER","W")- (sum(hh, inpoe(hh)));
sam("FAHRZ","W")  =sam("FAHRZ","W")-  (sum(hh, inpfz(hh)));
sam("HANDEL","W") =sam("HANDEL","W")- (sum(hh, inpha(hh)+inphav(hh)));
sam("VERK","W")   =sam("VERK","W")-   (sum(hh, oevexp(hh)));
sam("GELD","W")   =sam("GELD","W")-   (sum(hh, inpge(hh)));
sam("SODIEN","W") =sam("SODIEN","W")- (sum(hh, inpso(hh)));

* REFUND OF ROAD PRICING REVENUE
scalar          netrev     road pricing revenue net of system costs;
                netrev=0.85;
scalar          hhref      share of road pricing revenues refunded to hh;
               hhref=1/3;
*                hhref=0.00001;
scalar          revshare   share of road pricing revenues used for oev;
                revshare=0.5;

parameter     ivlevel    level of car transport relative to base;
ivlevel=1.0;

parameter     rotax      road pricing tax level in Euro per km (mio Euro
per mio km);
rotax=0.000000001;

parameter     oetax      hypothetic oev tax level in Euro;
oetax=0.000000001;

parameter     mivkm(hh)  car km per hh in mio
/h1        10721.794
h2        22023.285
h3        26403.228
h4        44656.949
h5        7988.711
h6        32541.210
h7        68914.639
h8        104213.152
h9        10450.981
h10        31939.475
h11        31527.906
h12        37304.760
h13        11952.024
h14        18684.331
h15        16858.702
h16        16601.439        /;

parameter     oevkm(hh)  public travel pkm per hh in mio
/h1        12493.715
h2        7945.830
h3        13480.591
h4        12267.291
h5        9272.907
h6        8131.870
h7        15029.183
h8        17209.019
h9        6256.236
```

```
h10        8125.774
h11        5468.459
h12        3848.100
h13        2427.785
h14        5247.550
h15        2771.863
h16        3167.449        /;

parameter  re1(hh)   refund share per hh
            /  h1     0.0625
               h2     0.0625
               h3     0.0625
               h4     0.0625
               h5     0.0625
               h6     0.0625
               h7     0.0625
               h8     0.0625
               h9     0.0625
               h10    0.0625
               h11    0.0625
               h12    0.0625
               h13    0.0625
               h14    0.0625
               h15    0.0625
               h16    0.0625 /;

*different revenue redistribution scenario
*parameter  re1(hh)   refund share per hh
*           /  h1     0.019
*              h2     0.043
*              h3     0.056
*              h4     0.087
*              h5     0.013
*              h6     0.082
*              h7     0.138
*              h8     0.205
*              h9     0.022
*              h10    0.066
*              h11    0.066
*              h12    0.075
*              h13    0.015
*              h14    0.044
*              h15    0.038
*              h16    0.039 /;

parameter     CO2emifctr(hh)  CO2 emission factors
/        h1        0.213
        h2        0.215
        h3        0.215
        h4        0.22
        h5        0.211
        h6        0.22
        h7        0.218
        h8        0.216
```

```
        h9         0.213
        h10         0.217
        h11         0.216
        h12         0.214
        h13         0.21
        h14         0.216
        h15         0.214
        h16         0.223        /;

scalar ckmmax     car km highest possible value /1000000000/;
parameter ckmbase    car km base year 2002;
ckmbase=sum(hh,mivkm(hh));
scalar oekmmax   public travel pkm highest possible value /1000000000/;
parameter oekmbase  public travel pkm base year 2002;
oekmbase=sum(hh,oevkm(hh));

*22222222222222222222222222222222222222222222222222222222222222222222222
*           F O R E I G N   T R A D E   P A R A M E T E R S
*22222222222222222222222222222222222222222222222222222222222222222222222

parameter  telas(es)   Elast of substitution Armington from Reinert and
Holst

                 /LAWI        1.9
                 KOHLE        1.5
                 OELBB        1.5
                 OELVER       1.5
                 ELEK         1.5
                 WASSER       1.5
                 EISEN        1.7
                 STEIN        1.7
                 CHEMIE       0.7
                 METALL       0.8
                 MASCH        0.85
                 BUEROM       0.85
                 ELEINR       1.7
                 FAHRZ        1.4
                 NAHR         1.5
                 TEXTIL       1.17
                 HOLZ         1.6
                 PAPIER       1.4
                 VERLAG       1.4
                 GUMMI        1.55
                 RECYC        1.6
                 SPROD        1.6
                 BAU          0.5
                 HANDEL       1.0
                 GAST         1.0
                 VERK         1.9
                 SUL          1.9
                 SVERK        1.5
                 KOMM         1.0
                 GELD         0.5
                 REAL         0.5
```

```
                 DATEN        0.5
                 FUE          0.5
                 SODIEN       0.8
                 NMDIEN       0.4/;

*22222222222222222222222222222222222222222222222222222222222222222222222
*           L A B O R   M A R K E T
*22222222222222222222222222222222222222222222222222222222222222222222222

parameter       urate       unemployment rate
                refurate    reference is base case unemployment rate
                uabs        unemployed in 1000
                unemp       unemployment base year in foregone wage
earnings
                emplchange  change in employment absolute
                usubsr      unemployment subsidy rate
                pusb        price incl unemployment subsidy rate;
unemp=((-sam("L","Cons"))/emp)*uabase;
usubsr=((-sam("UBEN","CONS"))/unemp)*(-1);
pusb=1+usubsr;

*222222222222222222222222222222222222222222222222222222222222222222222222222222
*  G O V E R N M E N T   R E V E N U E   A N D   E X P E N D I T U R E
*222222222222222222222222222222222222222222222222222222222222222222222222222222

scalar          nettransf  net direct tax and transf payments plus public
saving
                ubpwork    unemployment benefit per worker
                govdem     government demand;
parameter       pcalibl    price level for calibration of factor labor
                pcalibk    price level for calibration of factor capital;
pcalibl=1+lwtaxr;
pcalibk=1+ktaxr;
govdem=sum(es,sam(es,"GOV"));
nettransf=(-sam("TXTRNS","CONS"));
ubpwork=(-sam("UBEN","CONS"))/uabase;
parameter       def        public deficit
                defref     public deficit reference base year level;
def=pubdef;
defref=def;
parameter       tix(es)     indirect tax rate net of subsidy;
tix(es)=sam(es,"ITAXRT");

*22222222222222222222222222222222222222222222222222222222222222222222222
*           F U R T H E R   V A R I A B L E   D E F I N I T I O N
*22222222222222222222222222222222222222222222222222222222222222222222222

parameter       opchp(es)  sectoral output change in percent
                test       capital supply factor
                dschp(es)  sectoral output direct change first round in
percent
                chemp(es)  absolute change in sectoral employment
                empchcorr  correction term change in employment rounding
error
```

```
                chex(es)   change in exports
                chim(es)   change in imports
                chva(es)   change in value added per sector
                tdirch     direct tax revenue change absolute
                tindch     indirect tax revenue change absolute
                ubench     change in public unemployment benefit
subsidies absol
                govch      change in governement expenditure absolute
                fch        change in capital account
                pxch(es)   change in domestic production prices in %
                pgch(es)   change in domestic sales prices in %
                pkch       change in capital price
                dirch(es)  direct change first round in sectoral demand
                dirchp(es) direct change first round in sectoral demand
in %
                emivkm     car km total
                eoevkm     public travel km total
                mivch      relative change in car travel km in %
                oevch      relative change in oev km in %
                consch(hh) change in household consumption transport
                vch(hh)    change in total transport expenditure
                exoev(hh)  expenditure for public travel per hh group
                exoevch(hh) change in expenditure for public travel per
hh
                exiv(hh)   expenditure for travel per household group
                exivch(hh) expenditure for travel change in %
                eivkm(hh)  total km car travel per household group
                eovkm(hh)  total km public travel per household group
                hmivch(hh) relative change in miv km in % per household
group
                hoevch(hh) relative change in oev km in % per household
group
                rprev      road pricing revenue total;

*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
*           M P S / G E        M O D E L
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz

$ontext
$model:rp_G16
$sectors:
        x(es)           ! output of domestic production sectors
        y(es)           ! level of domestic supply of domestic production
        m(es)           ! level of sectoral imports
        ex(es)          ! level of sectoral exports
        g(es)           ! level of domestic composite good supply
        w               ! Hicksian welfare index
        v(hh)           ! private transport demand bundle
        iv(hh)          ! car transport
        ivv(hh)         ! car transport variable components
        ivf(hh)         ! car transport fixed components
        oev(hh)         ! public transport

$commodities:
```

```
        px(es)          ! market price for sectoral domestic production
        py(es)          ! market price of domestic supply of domestic
production
        pex(es)         ! export price
        pm(es)          ! import price
        pg(es)          ! domestic composite good price
        pl              ! wage rate
        pk              ! capital rent
        pw              ! price index for welfare without transp
(expenditure function)
        pv(hh)          ! price index of passenger transport
        piv(hh)         ! price index of car tranpsort
        pivv(hh)        ! price index car transport variable components
        pivf(hh)        ! price index car transport fixed components
        poev(hh)        ! price index for public transport
        pfx             ! price foreign exchange (real terms of trade)
        ptax            ! price of tax payments
        plinc           ! price index of labour income
        protax          ! car road pricing tax level
        poetax          ! hypothetic publi ctransport pricing tax level
        pkfzst          ! car tax price index

$consumers:
        cons(hh)        ! representative agent
        lmarket         ! labour market overall
        govt            ! government
        schick          ! use of rp revenues agency
        rps             ! use of rp system expenditures

$auxiliary:
        u               ! unemployment rate
        ufkmro          ! restriction on car km
        upkmoe          ! restriction on public travel pkm

$prod:x(es)      s:0     elk(s):0
        o:px(es)         q:(-sam(es,"OUTPUT"))    A:govt T:TIX(es)
        i:pg(ss)         q:sams(ss,es)
        i:pl             q:sam(es,"L")     P:pcalibl      A:govt T:LWTAXR
elk:
        i:pk             q:sam(es,"K")     P:pcalibk      A:govt T:KTAXR
elk:

$prod:y(es)      t:telas(es)
        o:py(es)          q:((-sam(es,"OUTPUT"))-sam(es,"EX"))
        o:pex(es)         q:sam(es,"EX")
        i:px(es)          q:(-sam(es,"OUTPUT"))

$prod:g(es)      s:telas(es)
        o:pg(es)          q:((-sam(es,"OUTPUT"))-sam(es,"EX")-
sam(es,"IM"))
        i:py(es)          q:((-sam(es,"OUTPUT"))-sam(es,"EX"))
        i:pm(es)          q:(-sam(es,"IM"))

$prod:m(es)
```

```
        o:pm(es)         q:(-sam(es,"IM"))
        i:pfx            q:(-sam(es,"IM"))

$prod:ex(es)
        o:pfx            q:sam(es,"EX")
        i:pex(es)        q:sam(es,"EX")

$prod:iv(hh)  s:0
        o:piv(hh)        q:(mivfix(hh)+mivvar(hh))
        i:pivf(hh)       q:mivfix(hh)
        i:pivv(hh)       q:mivvar(hh)

$prod:ivf(hh) s:0
        o:pivf(hh)       q:mivfix(hh)
        i:pg("FAHRZ")    q:inpfz(hh)
        i:pg("HANDEL")   q:inpha(hh)
        i:pg("GELD")     q:inpge(hh)
        i:pg("SODIEN")   q:inpso(hh)
        i:pkfzst         q:kfzsteuer(hh)

$prod:ivv(hh) s:0
        o:pivv(hh)       q:mivvar(hh)
        i:pg("OELVER")   q:inpoe(hh)  P:capo(hh)  A:govt  T:oeltaxr(hh)
        i:pg("HANDEL")   q:inphav(hh)
        i:protax         q:mivkm(hh)

$prod:oev(hh)      s:0
        o:poev(hh)      q:oevexp(hh)
        i:pg("VERK")    q:oevexp(hh)
        i:poetax        q:oekmbase

*Welfare

$prod:w   s:1
        o:pw               q:(-sam("W","W")-sum(hh,vausg(hh)-
kfzsteuer(hh)-moest(hh)))
        i:pg(es)           q:(sam(es,"W"))

$prod:v(hh)   s:0.635
        o:pv(hh)           q:vausg(hh)
        i:piv(hh)          q:(mivfix(hh)+mivvar(hh))
        i:poev(hh)         q:oevexp(hh)

$demand:cons(hh)  s:0.275
         d:pw              q:((sam("W","CONS")*incs(hh))-
vausg(hh)+kfzsteuer(hh)+moest(hh))
         d:pv(hh)          q:vausg(hh)
         e:plinc           q:((-sam("L","CONS"))*incls(hh))
         e:pk              q:((-sam("K","CONS"))*ks(hh))
         e:pfx             q:((-sam("FX","CONS"))*fxs(hh))
         e:ptax
q:(nettransf*transfs(hh)+kfzsteuer(hh)+moest(hh))
         e:ptax            q:((-sam("UBEN","CONS"))*ubens(hh))    R:u
         e:protax          q:(re1(hh)*hhref*netrev*ckmmax)
```

```
         e:protax          q:(re1(hh)*hhref*netrev*(ckmbase-ckmmax))
R:ufkmro

$demand:lmarket
        d:plinc           q:(-sam("L","CONS"))
        e:pl              q:((-sam("L","CONS"))+unemp)
        e:pl              q:(-unemp)            R:u

$demand:govt
        d:pg(es)          q:sam(es,"GOV")
        e:ptax            q:(-nettransf-sum(hh,moest(hh)+kfzsteuer(hh)))
        e:ptax            q:sam("UBEN","CONS")       R:u
        e:pkfzst          q:(sum(hh,kfzsteuer(hh)))

*no system costc included, revshare for public transport sector
$demand:schick
        d:pg("BAU")       q:((1-revshare)*0.9)
        d:pg("NMDIEN")    q:((1-revshare)*0.1)
        d:pg("VERK")      q:(revshare*0.9)
        d:pg("NMDIEN")    q:(revshare*0.1)
        e:protax          q:((1-hhref)*netrev*ckmmax)
        e:protax          q:((1-hhref)*netrev*(ckmbase-ckmmax))
R:ufkmro
        e:poetax          q:oekmmax
        e:poetax          q:(oekmbase-oekmmax)
R:upkmoe

*redistribution of system costs
$demand:rps
        d:pg("GELD")      q:(1/3)
        d:pg("ELEINR")    q:(1/3)
        d:pl              q:(1/3)
        e:protax          q:((1-netrev)*ckmmax)
        e:protax          q:((1-netrev)*(ckmbase-ckmmax))
R:ufkmro

$constraint:u
        pl=E=pw;

$constraint:ufkmro
        protax=G=rotax;

$constraint:upkmoe
        poetax=G=oetax;

$REPORT:
        V:domestic_output(es)           O:px(es)        PROD:x(es)
        V:domestic_supply(es)           O:py(es)        PROD:y(es)
        V:domestic_composite_supply(es) O:pg(es)        PROD:g(es)
        V:import(es)                    O:pm(es)        PROD:m(es)
        V:export(es)                    O:pfx           PROD:ex(es)
        V:car_transport(hh)             O:piv(hh)       PROD:iv(hh)
        V:car_transport_fix(hh)         O:pivf(hh)      PROD:ivf(hh)
        V:car_transport_var(hh)         O:pivv(hh)      PROD:ivv(hh)
```

```
        V:public_transport(hh)          O:poev(hh)      PROD:oev(hh)
        V:welfare_cons                  O:pw            PROD:w
        V:welfare_trans(hh)             O:pv(hh)        PROD:v(hh)
        V:wcons(hh)                     W:cons(hh)
        V:revenues_rp                   W:schick
        V:GovDemand(es)                 D:pg(es)        DEMAND:govt

$offtext
$sysinclude mpsgeset rp_G16

plinc.l=1;
ptax.fx=1;

*foreign price as numeraire
pfx.fx=1;
pkfzst.fx=1;

*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz
*           B A S E    R U N
*zzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzzz

pex.l(es)=1.0;
pm.l(es)=1.0;
u.l=1.0;
rotax=0.0000000001;
protax.l=0.0000000001;
oetax=0.0000000001;
poetax.l=0.0000000001;
ufkmro.l=1;
upkmoe.l=1;
rp_G16.iterlim=9999;
OPTION MCP = PATHC;

$include rp_G16.GEN
         solve rp_G16 using mcp;

* O U T P U T
parameter   gdpfactor      gdp factor definition
            govprice       price index public demand
            gdpuse         gdp use definition
            gdpref         gdp adjusted for welfare price index
            gdpbase        gdp base level
            govpbase       govprice base
            wcoref(hh)     welfare index consumers hh reference level of
base year
            gdpgrowth      growth rate of gdp in use definition
            CO2base(hh)    C02 base run
            CO2basecar(hh) CO2car base run
            CO2basepub(hh) C02pub base run
            mivkmges       overall travel km
            mivkmbase(hh)  car km base
            oevkmbase(hh)  public travel km base
            vbase          travele exp base
            vausgg(hh)     travel exp
```

```
            oevexpbase(hh) public transport exp base
            mivfixbase(hh) fixed car exp base
            mivvarbase(hh) Varcarausgaben base
            mivcarbase (hh) total car exp base
            hhilabor(hh)   hh income labour
            hhicapit(hh) hh income capital
            hhitrans(hh) hh income transfers
            hhitransbase(hh) hh income transfers base
            consbase(hh) consbase
            CO2(hh)     CO2 passenger travel
            CO2car(hh) C02 car
            CO2pub(hh) C02 pub ;

*2222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222
*
*       C O U N T E R F A C T U A L
*
*2222222222222222222222222222222222222222222222222222222222222222222222222222222222222222222

rotax=0.05;
protax.l=0.05;

rp_G16.iterlim=9999
$include rp_G16.GEN
       solve rp_G16 using mcp;
```