Impacts of four road pricing scenarios on individual welfare
- the case of the German motorways -

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ABSTRACT

The present paper analyzes distributive effects of a future user charge system on German motorways. Two scenarios are assessed: a time- vs. a mileage-based system. It is assumed that for political reasons (acceptance of the user charge) compensation measures such as reductions on the vehicle and/or fuel tax (energy tax) are simultaneously implemented. The analysis is based on disaggregated mobility diaries (German mobility panel). In contrast to other studies, households are grouped by their equivalized disposable income levels as proxy for the household's social status and as recommended by the Organization for Economic Co-operation and Development (OECD). It is found that the distributional impact varies significantly depending on the implemented pricing scheme and the compensation measures. The present analysis shows that only mileage-based user charges combined with reductions of the vehicle as well as the energy tax can be regarded as a social equitable scheme which, in addition, assures a sustainable road infrastructure financing and positive environmental impacts.

Keywords: road user charges, welfare economics, household income, social equity

INTRODUCTION

Road pricing as a mechanism for infrastructure financing, for the internalization of external costs as well as for congestion reduction has come into public focus for the last decades. The motivation for the introduction of road pricing has changed over time. These days, the connection between public budget and infrastructure expenses and the precarious public household situation as well as the current debt crisis of many OECD countries with still public and free of charge road infrastructures has further brought road pricing into discussion as additional revenue source.

Discussions on road user charges are always very controversial: Proponents argue for higher quality infrastructures, reduced travel times as well as cost-by-cause principle whereas opponents especially point out social exclusion, overtrading of people and the freedom of mobility. The present paper analyzes the situation in Germany with a dedicated focus on distributional impacts and therefore on social exclusion. Several road pricing scenarios which are currently discussed in Germany and their impacts on the household income of user groups' are analyzed. Real data of a German household and mobility survey are used to objectify the emotional discussion and can serve as code of practice also for other countries. The paper is organized as follows: After these introductory remarks, section 2 gives a brief review of literature on road pricing issues. The third section describes the methodology and data sources utilized for the analysis of welfare impacts on German households. Section 4 presents the results of the analysis and discusses them with respect to previous studies. Final conclusions and recommendations for further work are given in the last section.

LITERATURE REVIEW

The economic foundation of road pricing dates back to Pigou (1) and Knight (2): free access to public roads leads to a misallocation of resources because of external effects where drivers do not have to pay for the additional costs he imposes on others (3). Following the ground-breaking works of Pigou and

Knight, numerous publications on road pricing issues emerged in literature. Among the many topics which are treated by researchers and practitioners are the relation between investments in infrastructure and optimal tolling (see 4, 5). Surveys of the literature can for example be found in Small (6) and Lindsey and Verhoef (7). Only very few publications analyze distributional impacts of road pricing on households. Especially social research questions on equity and fairness of road pricing initiatives are seldom discussed in scientific publications. Small (8) analyzes the welfare effects of urban road pricing on income groups using an equilibrium model of modal choice. He argues that road pricing has regressive effects because, although higher income groups are charged more, they have a higher value of time and hence benefit more than lower income groups. However, if there is a redistribution of toll revenues, there are benefits for all income groups. Anderson and Mohring (9), studying the effects of congestion pricing in Minneapolis and Saint Paul, and Friedström et al. (10), analyzing the introduction of marginal cost transport pricing in Edinburgh, Helsinki and Oslo, come to the same conclusion.

Further studies analyzed the effects of implementing road user charges on selected user groups who are particularly affected. A study on the welfare effects and distributional impacts on commuters in Dresden, Germany, was carried out by Teubel (11). The results of the different scenarios show that congestion pricing without revenue distribution affects the poor more than the rich, but differences are rather small. Bonsall and Kelly (12) tested the effects of six different cordon pricing schemes on selected groups in the city of Leeds using a transport demand model and synthetic populations as a basis for modeling (Popgen-T methodology). They conclude that the groups who are most affected by charges are in most cases the low income, car-captive groups. Santos and Rojey (13) tested cordon schemes in three cities in the United Kingdom, Cambridge, Northhampton and Bedford. They examine that road pricing can be both regressive and progressive depending on the transport structure of the city, where people live and work, which travel mode they use and to what extent compensation measures are used. This hypothesis is supported by Eliasson and Mattsson (14) who analyze equity effects of congestion pricing in the city of Stockholm, using a sample enumeration model.

Compared to urban road pricing, literature on road pricing schemes for whole networks, such as the federal trunk road network is very limited. In 2005, Steininger et al. (15) published a report in which they analyze, inter alia, the distributional effects across income groups of five different kilometer-based road pricing scenarios in Austria. The analysis is based on a passenger transport demand model. The macroeconomic impacts and individual effects on different household groups are analyzed with the Austrian Spatial Passenger and Income Transport (ASPIT) model, a computable general equilibrium model (CGE). Steiniger et al. (15) show that road pricing in general is progressive, since households in higher income groups are more affected by the charges than poorer households. This is because they have a higher car mileage and rarely show themselves willing to use public transportation. Furthermore Steiniger et al. (15) states that road pricing based on the cost-by-cause principle is more equitable than a tax-based financing system.

Graham et al. (16) analyzed the impacts of the national road pricing implementation in the UK. They could identify neither a positive nor a negative correlation between the level of charges and the level of income, but a strong positive relationship between the level of urbanization and the level of charges exist.

For Germany, very few studies exist on the distributional effects of car user road pricing schemes across different income groups. Some of the few studies, as Rothengatter and Krail (17), Kalinowska and Steiniger (18 and 19) and Kalinowska (20), conclude that, when a distance-based road pricing scheme in combination with revenue redistribution (i.e. tax reductions) is implemented, households are on average not made worse off than before. Households in lower income groups are less negatively affected because of their lower annual mileages and they will benefit from compensation measures most. Baum et al. (21) come to the opposite conclusion. Baum et al. (21) analyzed the impacts of a kilometer-based road pricing scenario on different income groups. In this scenario, the entire road network is charged and a complete abolition of the motor vehicle tax to unburden households is assumed. The results show that road pricing has regressive impacts that cannot be compensated by tax reductions. The top income groups are less affected than the lower ones. The middles income groups with a higher number of household members experience the highest negative welfare effects which rise with increasing household size because of the disproportional increase of demand for mobility. Hence, Baum et al. (21) assume that families are more affected than other groups because they are in general more mobile. The deep disagreement between these publications is the first motivation for the present analysis. Second motivation is the still shrinking budget for maintenance and replacement of the aging road infrastructure that alternative ways of funding are required for future. Furthermore, shrinking fuel tax and motor vehicle tax revenues due to the trend to low-emission cars with low fuel consumption query sustainable road infrastructure financing based on taxes in the future. Finally, the unfairness that taxes burden tax payers whereas foreigners use the road network free of charge can be avoided by the cost-by-cause principle. The following sections introduce the present assessment methodology as well as possible road pricing schemes and discuss differences to the mentioned literature.

ASSESSMENT

The present paper analyzes the financial burden of German households caused by a road user charge compared to the present situation without a user charge. A simple individual welfare measure that takes account of the price increase, compensation measures and users´ reactions is applied.

Methodology

Calculation of Welfare Changes

Every political decision on the implementation of economic policy measures should be based on the question in what way a planned scheme affects the welfare of society. Social welfare is closely tied to the well-being of each individual member of society. This is the principle of Pareto efficiency (22). In reality, Pareto efficiency is difficult to apply as there will be always winners and losers as a result of any political decision. To decide whether a project should be implemented or not, interpersonal comparisons are necessary. So individual welfare measures, such as the consumer surplus (CS) or the compensating variation (CV), are used to measure how much a consumer is affected by a price change (see 23). The concept of consumer surplus dates back to Dupuit and Marshall (23, 24). They assume that the utility of a consumer is cardinally measurable. CS is the difference between the total amount consumers are willing and able to pay for a good and the actual amount that they do pay. It is the area under the demand curve and above the market price as shown in Figure 1 (23):

$$CS = \int_0^{x_1^*} p\,(x_i)dx_i \; - p_1^* x_1^*. \qquad (1)$$

The Marshallian concept is a very simplified description of individual welfare changes assuming that the marginal utility of income remains constant and there are no substitution effects. This weakness can be solved with the concept of compensating variation that was introduced by Hicks (23). Hicks (23) measures welfare effects of a price change by using indifferent curve analysis (ordinal measurement of utility). CV is the amount of money that, after a price change, leaves a person just as well of as before (24). The problem is that a precise knowledge of the consumer´s utility function, which is not observable, is essential (25).

The individual welfare is not only influenced by price increase or decrease, but also by the user´s value of time, by consideration of revenue distribution and by various possible reactions of the users to the price change. When a road pricing scheme is implemented some users might reduce their trip frequency, use another transport mode (i.e. bus, train, underground), take other routes, plan their routes more carefully (string together trips in the same route that as yet were made separately) or form carpools. In the long term, users might relocate their work or living place or even go so far as to give up car driving (see 11, 26).To take all these factors into account, a very complex and extensive analysis is needed. In this paper, the calculation of distributional effects of road pricing focuses on the possibility of reducing trip frequency and of compensation measures that are described below. The present analysis utilizes the Marshallian consumer surplus as approximation procedure which is often used to analyze the impacts of political decisions (see Figure 1).

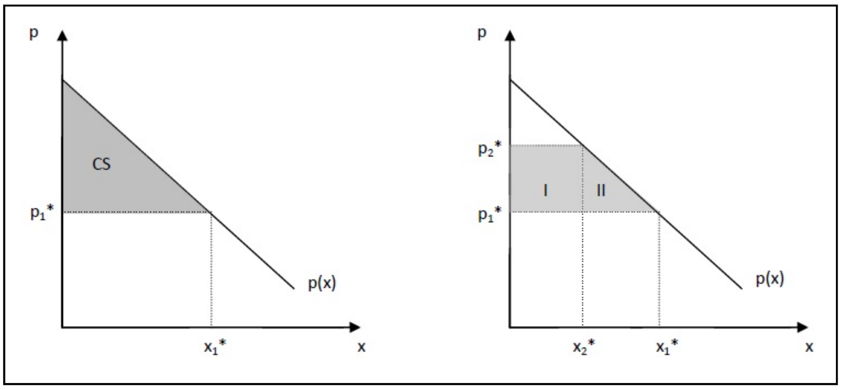

FIGURE 1: Concept of consumer´s surplus according to Marshall (Source: own presentation based on Varian (27))

The decrease in consumer surplus is equal to the sum of area I and II. Area I represents the welfare loss due to higher costs, area II represents the loss due to the loss of mobility (reduction of trip frequency). x is the amount of kilometers (miles) driven on motorways, p is the unit price (cost per km (miles)) and p(x) the demand curve of kilometers (miles) driven on motorways. p_1* (= vehicle costs) is interpreted as the fuel cost per kilometer (mile) before the implementation. For reasons of simplicity there is no difference between gasoline and diesel-powered vehicles in this analysis. It is assumed that the average fuel price per liter (per gallon) is 1.40 EUR (0.51 USD). According to Hautzinger et al. (28) the price elasticity of demand is -0.3. Because of the low price elasticity, area II only has little influence on welfare changes that area I is dominant.

This concept merely describes a standardization of individual welfare. To specify changes in individual welfare of a household, welfare changes are calculated in relation to the household income which is represented by the "Equivalized Disposable Income" (EDI). The EDI is calculated by dividing the household´s total net income by an equivalent weight of the household members. The assessment of the equivalent weight (adult equivalent) in this study is based on a modified OECD equivalence scale (see 29). This scale gives a weight to each household member according to its age: a weight of 1 to the first adult, of 0.5 to each subsequent person of 14 years and older and of 0.3 to each person under 14 years.

Because the present data base only provides information on children less than 10 years, the equivalence scale was minimally modified as follows: a weight of 1 is assigned to the first adult, of 0.5 to each subsequent person ≥ 10 years and of 0.25 to each person ≤ 10 years. The EDI takes account of savings which occur in households with a higher number of members (economies of scale) and allows comparing households of different sizes and compositions properly. Therefore, the OECD approach is often applied for the calculation of social exclusion indicators.

The road pricing scenarios

The present paper analyzes four different scenarios of road user charging with respect to the distributional impacts across different user groups. For all these scenarios it is assumed that only motorways are charged. For reasons of political and public acceptance, compensation measures on traffic related taxes are considered in two scenarios as follows:

The German fuel tax rate is very high compared to those of neighboring countries. The differences range between 0.05 EUR per liter (0.02 USD/gallon) compared with France and 0.17 EUR per liter (0.06 USD/gallon) compared with Austria. This paper assumes a reduction of the energy tax to align the German energy tax rate with those of neighboring countries and to reduce gas tank tourism in this way. The amount of the motor vehicle tax is composed of an engine-based component of 2 EUR/cm^3 cylinder volume (0.17 USD/in^3) for gasoline vehicles and 9.50 EUR/cm^3 cylinder volume (0.79 USD/in^3) for diesel powered vehicles and an emission-based component of 2 EUR/g carbon dioxide per kilometer (0.06 USD/oz carbon dioxide per mile). Since there is an observable trend towards cars with smaller cylinder capacity, this analysis considers the abolition of the engine-based component of the motor vehicle tax. The emission-based component will be retained for reasons of environment protection. Four scenarios are developed which are close to reality and which are currently discussed in Germany. The underlying assumptions are introduced in the following:

Scenario A: a time-based scenario where every road user is obligated to buy one vignette for every passenger car for the unlimited use on German motorways within a fixed period (one year). Foreign users have the opportunity to decide between the same annual Vignette and a ten days Vignette for i.e. holiday, leisure or weekend trips. The price for a one-year vignette is determined to 140 EUR (191.80 USD) and is based on the cost model of Rommerskirchen et al. (30) whereas the 10-day vignette amounts to 11 EURO (15.07 USD), including a service fee surcharge for the shorter time period. This system guarantees a low-cost and quick implementation.

Scenario B: a time-based scenario like scenario A with compensation in form of the reduction of the energy tax by 0.05 EUR per liter fuel (0.02 USD/gallon) and the reduction of the motor vehicle tax by 4.5 EUR per 100 cm^3 (1.01 USD/in^3) cylinder capacity (average value of the engine-based component).

Scenario C: distance-based scenario where tolls are charged according to the distance travelled on motorways. The toll rate for passenger cars is based on Rommerskirchen et al. (30) and amounts to 0.04 EUR per kilometer (0.03 USD/mi).

Scenario D: a distance based scenario like scenario C with compensation in form of the reduction of the energy tax by 0.05 EUR per liter fuel (0.02 USD/gallon) and the reduction of the motor vehicle tax by 4.5 EUR per 100 cm^3 (1.01 USD/in^3) cylinder capacity (average value of the engine-based component).

Data Source

The data for the present analysis are based on the German Mobility Panel (31) which surveys information about the everyday mobility behavior (e.g. travel mode use, travel time, length of trips, vehicle-specific data) of the German population as well as general characteristics of German households (e.g. household income/size/type, car availability). The survey is commissioned and financed by the German Federal Ministry of Transport, Building and Urban Affairs (BMVBS).

The present study uses data of the 2008 panel (1.062 households, 1.783 persons). After filtering out households without driving performances as well as households with erroneous information, the final sample composes of 584 households and 1.374 persons (55 % of the respondents). These households represent about 20.5 Mio German households (50 % of total).

Considering that the present objective is to analyze the distributive effects of road pricing scenarios on car users, the households are classified into five homogenous income groups. The classification is based on a quintile household distribution according to the report "*Indikatoren der Einkommensverteilung in Deutschland 2003*" by the Federal Statistical Office (see 32).

According to their household EDI households of the panel can be classified as follows:

Group 1: < 1,125 EUR/AEQ[1]*month (1,541 USD/AEQ*month)

Group 2: 1,125 EUR/AEQ*month to 1,375 EUR/AEQ*month (1,541 USD/AEQ*month to 1,884 USD/AEQ*month)

Group 3: 1,376 EUR/AEQ*month to 1,700 EUR/AEQ*month (1,885 USD/AEQ*month to 2,329 USD/AEQ*month)

Group 4: 1,701 EUR/AEQ*month to 2,167 EUR/AEQ*month (2,330 USD/AEQ*month to 2,969 USD/AEQ*month)

Group 5: > 2,167 EUR/AEQ*month (2,969 USD/AEQ*month)

All developed road pricing scenarios have in common that motorways are charged and only mileages on motorways impact the disposable income of households. Data of the German Mobility Panel (31) state the total mileages travelled per day that an analytical function for the percentage of daily mileage on motorways is needed which has been developed and applied in the present study. It is assumed that the percentage of daily mileage on motorways follows an exponential function and calibration of parameters is based on data of mileage of the panel´s households (including weighting factors of each household) and data on the total mileages on motorways in Germany for the year 2008 (33).

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1 AEQ = adult equivalent

The following function was deduced from these data:

$$A(x) = 1 - e^{-0,01144*x},$$

where x is the total daily mileage of a person and A(x) the percentage of daily mileage of this person on motorways.

There have been extensive plausibility checks and the function turned out to be very stable. The run of the function is shown in Figure 2.

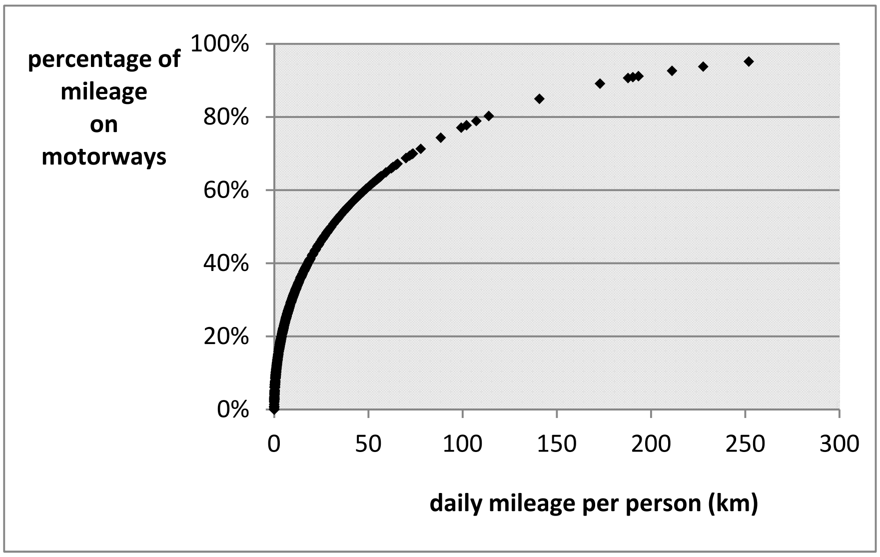

FIGURE 2: Percentage of daily mileage on motorways[1] (Source: author´s own composition)

RESULTS

Characteristics of the households

The general characteristics of the samples´ households (e.g. household size, average number of household members, cars per household, etc.) are introduced first (Table 1 and 2) whereas income specific results of road user charges are discussed afterwards.

TABLE 1: General characteristics of households[2]

Income group	Average household EDI (EUR/month)	Average no. of household members	Average no. of adults per household	Average no. of children per household	Available cars per household	Available cars per adult
1	847	2,9	2,2	0,7	1,3	0,66
2	1222	1,9	1,6	0,3	1,2	0,82
3	1527	2,9	2,4	0,5	1,5	0,67
4	1959	2,3	1,8	0,5	1,3	0,8
5	2787	1,6	1,6	0	1,3	0,93

The average number of household members is higher in the lower income groups and decreases with increasing income (despite the exceptional position of income group 2). This also applies for the average number of children per household. Therefore, the highest income group (group 5) mainly consists of single respectively couple-households (double income). Contrarily, large families with children are mainly classified in the lower income groups and have less disposable income.

The car availability per household (cars/household) is approximately the same in every income group. This means that on average, every German household has around 1.3 cars. If we consider the average number of adults per household we can see that the car availability per adult increases with increasing income. In households of group 1 (lowest income) two persons usually share one car, while persons of high income households have their own vehicle.

[2] 1 USD = 1.37 EUR

TABLE 2: Traffic behavior of households[3]

Income group	Total mileage per adult (km/year)	Total mileage per car (km/year)	Mileage on motorways per adult (km/year)	Mileage on motorways per car (km/year)	Average engine size per car (ccm)	Average fuel consumption (litre/year)
1	5277	8378	1294	2880	1551	964
2	6069	8715	1732	2926	1550	840
3	6108	9298	1778	3492	1587	983
4	7556	9811	2611	3966	1702	1112
5	9593	10544	3707	4159	1736	1042

The mileage per car is closely related to the car availability. Households in higher income groups display higher car use intensities (mileage/(car∗year)).

Table 2 displays the average engine size as well as the total fuel consumption per household and per year which are important factors when considering cost savings from tax reductions. It is obvious that the upper income groups tend to have more powerful engines than the lower income groups, but differences are small. Possible reasons for this could be on the one hand that high income households often have a second car with lower engine size and on the other hand that low income households often possess older cars with high cylinder capacity. This fact weakens the frequently used argumentation that the motor vehicle tax is a more equitable solution than road user charges because the motor vehicle tax charges the rich over-average because of their larger engines. The present analysis disproves this argument.

[3] 1 mi = 1.61 km, 1 CID = 16.387064 ccm, 1 gal = 3.785 litre

Impacts of the scenarios

Figure 3 summarizes the distributional effects of the four road pricing scenarios on German households.

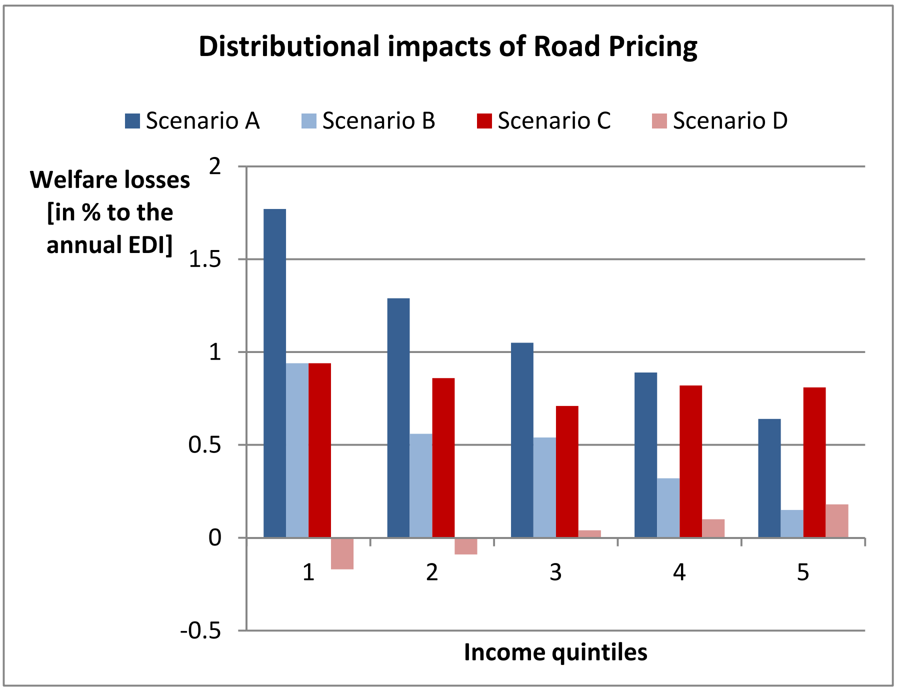

FIGURE 3: Distributional impacts of the four road pricing scenarios

As shown by the dark blue bars all income groups except group 5 (top incomes) bear the highest negative welfare burden from **Scenario A** (annual Vignette without compensation measures). An annual vignette leads to relative welfare losses (in relation to the EDI) across all income groups but decreasing losses with increasing income can be observed because of a fixed Vignette price. A regressive distributional outcome is clearly identifiable. For households in the top income group a charge of 140 EUR (191.80 USD) would amount to 0.64 % of their EDI which is less twice to three times the amount of charges for the lower income groups. Considering the household compositions across the five income groups especially families with children or large households will be affected negatively by the road pricing scheme whereas the beneficiaries are better situated single- or couple-households.

In **Scenario B** (annual Vignette with compensation measures) a lower negative welfare effect across the five income groups can be observed but the developed compensation measures (reduction of the energy tax by 0.05 EUR per liter fuel (0.02 USD/gallon) and the reduction of the motor vehicle tax by 4.5 EUR per 100 cm^3 (1.01 USD/in^3) cylinder capacity) can only partly counterbalance the road charges, especially in the higher income groups. Also in this scenario regressive effects are not avoided. If the amount of compensations would be increased, this would mean that, indeed, poorer households could be compensated, but richer households, who have already experienced neutral effects before, would even realize welfare gains. Furthermore, this scenario would lead to high additional revenues for the government from charges paid by German users as well as foreign users and from reduced gas tank tourism due to lower fuel taxes in Germany. Therefore, it is very difficult to gain political and social acceptance of Scenario B.

In **Scenario C** (distance-based scenario without compensation measures) the relative welfare losses across all income groups are more even distributed (from 0.81 % to 0.94 %) in contrast to scenario A and B. Users with higher annual mileages (and respectively higher mileages on motorways) have to pay for the use of motorways more than other income groups (cost-by-cause principle). Table 2 has shown that users with higher mileages are usually better earning households (household group 4 and 5).

In **Scenario D** (distance-based scenario with compensation measures) the observations of Scenarios A and B are reversed. A distance dependent toll in combination with compensations in the form of tax reductions has nearly a neutral effect. Households of the top income group use motorways three times more often than households of group 1 but their overall mileage only doubles. The high mileages on motorways for the top income groups can be explained by frequent holiday/weekend trips as well as longer commuting distances to the workplace (see 34). In average, in Scenario D all households (independent of the income group) are brought back to the level of utility as they had before the implementation of road user charges. Compared to scenario A and scenario B where multi-person households and families are worse off, especially better situated single- and couple-households are affected by the road user charges but their relative welfare losses are rather small (0.04 to 0.18%).

Conclusions and further research

The results of the present analysis support conclusions of previous studies that distributional impacts of road user charges are highly dependent on the structure of the pricing scheme as well as the way compensations are used. The German case showed that if a time-based scheme (e.g. Vignette) is implemented, social concerns of road pricing opponents can be confirmed by the present results: users with lower car mileages are relatively charged higher by a vignette than those who use motorways more frequently. In Germany, benefits for frequent drivers are equivalent to charging richer households relatively lower (see Table 1 and 2). Considering the household compositions across income groups in Germany the beneficiaries of a time-based road user charge are usually well-situated single- and couple-households. Both scenarios that apply time-based road pricing schemes (scenario A and B) can be considered to be implemented without greater handling time as a HGV charge is already in progress on German motorways since 2005. However, because of their regressive effects they will fail to achieve social acceptance as well as political majorities. Furthermore, time-based schemes do not have sustainable impacts on car use and as a consequence on the environment as well.

Baum et al. (21) concluded that a distance-based road pricing system, even if tax reductions are considered, has regressive impacts and especially affects the lower and middle income groups. The present analysis disproves the conclusions of Baum et al. (21) because a kilometer-based road pricing system (Scenario C and D) guarantees that every user only pays for the kilometers driven on motorways (cost-by-cause principle). Consequently, in both scenarios richer households have to bear higher costs than in scenarios A and B because of their higher mileages. The major difference between Baum et al. (21) and the present analysis is the size of the charged road network. Baum et al. (21) analyze a scenario which incorporates the entire German road network whereas the present analysis focuses on motorways only and public discussions in Germany support this approach. Baum et al. (21) assumes a fixed toll for every road type of 0.05 EUR/km (0.04 USD/mi) whereas a stringent application of the pay-per-use principle necessitates a diversification of tolls according to the road type.

Furthermore, another classification of income groups according to their EDI instead of their total net income leads to a different outcome. Although Baum et al. (21) differentiate the income groups according to the number of household members but abdicates from the age of the family member (adult vs. child). Economies of scale are therefore not covered by their elaborations. The classification of the present analysis that weights household members according to their age and takes into account savings which occur in households with a higher number of family members and that enables to compare the distributional impacts on different households effectively. Here, families and large households are situated in the lower income groups and as shown in Figure 3 are less affected by road user charges based on kilometer-based charges. Therefore, a road pricing scheme based on Scenario D can be regarded as social equitable because costs are paid by those who use the infrastructure.

The present analysis has incorporated some of the many influencing factors on the impacts of road pricing schemes. Trip suppressions are included in the analysis but mode choice, vehicle occupancy, route choice or destination choice, as well as time savings due to reduced congestion and improved road conditions are not covered by the present analysis. Further research is needed on these issues. Finally, the present results support the hypothesis of former studies, such as Rothengatter and Krail, (17), Kalinowska and Steiniger (18,19), and Kalinowska (20) that on average, a distance-based road pricing scheme combined with adequate compensating measures does not debit the poor disproportionately high.

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