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Fuel for Inequality: Distributional Effects of Environmental Reforms on Private Transport

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Abstract

This paper provides the first empirical evidence of the distributional effects of subsidies for the purchase of alternative vehicles based on an extended version of Hausman's exact consumer surplus. Consistently with economic theory, we estimate changes in household welfare, inequality and social welfare corresponding to different reforms. First, we find that an additional tax on conventional fuel is regressive. However, returning the additional tax revenue via lump-sum transfers can alleviate this effect. Second, when the additional revenue is also used to finance subsidies for electrical and compressed natural gas (CNG) vehicles, households that own such vehicles experience welfare gains. However, this policy also increases income inequality and decreases social welfare.

JEL-codes: Q41, R48, C33.
Keywords: Transport policies, Distributional effects, Electrical vehicles, Passenger cars

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1 Introduction

Reducing carbon dioxide (CO_2) emissions and other pollutants in the transport sector is a key component of the climate protection obligations agreed in the Kyoto Protocol. Furthermore, the European Union (EU) committed itself to these goals in the Voluntary Agreement for the European Union. In 2012, the transport sector accounted for 29% of total CO_2 emissions in the EU [1] . Modifying driving behaviour and increasing the number of alternative vehicles are the key policy instruments used in Europe to cut down CO_2 emissions.

On the one hand, fuel taxes on conventional cars can reduce the distance travelled by households (Fullerton et al., 2015) and induce households to buy more efficient vehicles (De Borger and Rouwendal, 2012). On the other hand, the electrification of the road transport will be one of the key elements of the European roadmap[2] . High purchase costs and a slow expansion of the infrastructure for recharging electrical vehicles (EVs) still constitute major barriers that need to be overcome in order to succeed with the introduction of these vehicles (Perdiguero and Jimenez, 2012). In the UK, Germany and the US, subsidies are common instruments to increase the household demand for these vehicles, which is mainly done by reducing the purchase costs. There are concerns that the burden of increases in fuel taxes is unequally distributed across households (Poterba, 1991; Safirova et al., 2004; West 2004 and 2005; Fullerton and West, 2010; Nikodinoska and Schröder, 2016). Moreover, subsidies for the purchase of non-conventional vehicles could increase social inequality if high-income households are the only ones being able to afford these vehicles. Skerlos and Winebrake (2010) argue that subsidy designs need to consider differing regions and income levels and have to be adjusted to these in order to increase their social benefit, To analyse the distributional effects of a policy of increasing fuel taxes and subsidies for the purchase of alternative vehicles, we propose applying for the first time a theory-consistent framework to analyse household welfare, inequality and

[1]European Commission, DG ENER, Unit A4, ENERGY STATISTICS, June 2015 Transportation includes (Transport+international aviation + maritime transport)

[2]White Paper (last retrieved 15. Jan. 2016) available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:en:PDF.

social welfare where the kilometres driven are characterised by a linear demand function in a panel data context. Our study makes a twofold contribution to this debate. It provides methodological as well as politically relevant information. Concerning our methodological contribution, we extend the exact consumer approach proposed by Hausman (1981) to estimate household welfare, inequality and social welfare. Most of the literature on fuel taxes uses the approximation of the "rule of one-half" for household welfare losses. This measure neglects the effects of changes in income in the demand of the analysed commodity and it does not allow obtaining inequality and social welfare measures consistently with economic theory.

Contrary to the conclusion on the regressive nature of carbon taxes, current research also shows that the tax burden of low income households is not as severe as expected (Sterner, 2012) and can be overcome by returning the additional tax revenue through transfers (Bento et al., 2009). However, research on the effects of returning the tax revenue via lump-sum transfers after fuel tax implementation is still narrow. In the literature, there are only very few analyses on how subsidies which were granted to households for the purchase of durable goods with environmental purposes affect welfare and income inequality. In the case of Photovoltaic (PV) cells installation in Germany, subsidies have been found to be regressive (Grösche and Schröder, 2014). We study the distributional effects of fuel taxes and the effects of returning the additional revenue to every household. In addition, we investigate the effects of subsidies for the purchase of energy-efficient vehicles on welfare and inequality.

In the past, Germany along with several European countries adopted an ecological tax and in the present, various initiatives aim at introducing or modifying environmental taxes within the European Union and constitute an important part of the European environmental policy (Withana et al., 2014). Germany is an interesting example representing the European case very well because the contribution of the transport sector to the overall CO_2 emissions is similar to the one of the entire European Union. More precisely, the transport sector accounted for 22% of total German CO_2 emissions in 2012 (European Commission, 2015, p. 43). Moreover, Germany has a very strong automotive industry. There are political attempts to raise the share of electrical vehicles so as to have one million electrical vehicles in Germany by 2020. With this end in view, the German government introduced a bonus of 4,000 € for the purchase of an electrical vehicle in summer 2016.[3] This comes on top of existing government initiatives to improve the charging infrastructure for electrical vehicles and a minimum quota for electrical vehicles of 20% among new purchases for the car fleet of the federal government.

We estimate the distributional effects of the additional fuel taxes introduced in Germany at the beginning of the last decade. We use panel data in order to reduce the underlying endogeneity problem between the car choice and its use (as in Bureau, 2011). In a second scenario, we analyse the distributional effects of returning the additional revenue to each household as a counteractive measure against possible regressive effects of additional fuel taxes. We believe that these two scenarios are close to the current tax scheme in Germany. To analyse the distributional effects of subsidies for the purchase of alternative vehicles, we identify which households would potentially buy an alternative vehicle under the different subsidies by using experimental data. Then, we compute the various resulting changes to the household income and the additional tax revenue for subsidising the purchase of these vehicles. We then compute inequality and social welfare changes. Subsidising EVs requires a considerable amount of public funds. In this line, Kazimi (1997) shows that supporting compressed natural gas (CNG) vehicles can yield the same environmental gains as supporting EVs at a lower social cost. Therefore, we directly compare subsidies for EVs and CNG vehicles and take CO_2 emissions as well as income inequality into consideration.

Our results provide three important insights. First, additional road fuel taxes have regressive effects. However, this regressivity can be alleviated by returning the additional tax revenue to the households. When the allocation of the additional revenue also includes non-vehicle owners, inequality decreases and social welfare increases. Second, when revenue is also used to finance subsidies for the purchase of alternative vehicles, low-income households that own one vehicle experience welfare gains. However, at the aggregate level, inequality increases and social welfare decreases. Therefore, this result supports the argument of Grösche and Schröder (2014) that subsidies for the purchase of durable

[3]http://www.bmvi.de/SharedDocs/DE/Artikel/G/foerderung-elektromobilitaet.html, last retrieved 8.Aug.2016.

goods with environmental purposes increase inequality. We also compare EV subsidies in opposition to CNG-vehicle subsidies. Yielding the same CO_2 emissions reductions, the CNG subsidy scheme increases income inequality by a much larger degree than the EV scheme. Therefore, these results demonstrate that the subsidisation of electrical vehicles is the superior alternative compared to the subsidisation of CNG vehicles.

This paper is structured as follows. Section 2 describes the methodology and the models which are estimated later. Section 3 describes the simulated scenarios. Then, section 4 describes the data used in combination with descriptive statistics. The results are presented in Section 5. Section 6 concludes.

2 Models and Methodology

2.1 Modelling Driving Behaviour

Our econometric specification builds on the specification by Bureau (2011), linking the number of owned vehicles with fuel price and income as follows:

$$(1) \qquad \begin{aligned} KM_{it} &= \gamma_0 + \alpha_1 * Pkm_{it} + \alpha_2 car2_{it} * Pkm2_{it} + \alpha_3 Rural * Pkm_{it} + \\ &\qquad \beta_1 car1_{it} * y_{it} + \beta_2 * y_{it} + \gamma_1 W_{it} + \gamma_2 X_{it} + a_i + \epsilon_{it} \end{aligned}$$

where i indexes vehicles and t indexes years. The dependent variable KM is the monthly mileage of the vehicle, $car1$ is an indicator variable for the first car of a household and $car2$ indicates car number two or a higher number. y represents the household income, Pkm denotes the price per kilometre which is vehicle-specific because it differs across size, fuel type and age. W is the vector of variables indicating whether the car is used for work, private purposes or holidays and whether the driver uses mainly rural roads.[4] X is a vector of car characteristics. a_i denotes the vehicle fixed effect and ϵ_{it} is the usual error term. In order to analyse the effect of carbon taxes on driving behaviour, conventional approaches

[4]We use the type of roads that are mainly chosen for driving as a proxy for the place of residence of the respective households due to data availability of this variable in the survey.

use cross-sectional data on vehicle choice and the number of kilometres driven by these vehicles. These estimations use a two-stage procedure. The first step of this method is to model a technology choice by using discrete choice data. In the second stage, households determine the distance they will travel with the chosen vehicle which will be captured by using continuous data. The connection of these two stages has been proposed by Durbin and McFadden (1984). Their procedure links the discrete and continuous estimations through the predicted probabilities obtained by the discrete choice model which was estimated in the first stage (i.e. investment level choice). This methodology has been applied to the transport sector using American cross-sectional data (e.g. West, 2004; Goldberg, 1998; Hensher et al., 1992). Other approaches use more complex estimation procedures in order to account for the endogeneity of car choice and usage (see Bento et al., 2009). The availability of panel data can help to control the endogeneity problem by estimating a model for driving behaviour in only one stage. Few analyses of tax incidences in the transport sector use this type of data due to data availability reasons.

2.2 Simulation of Vehicle Choice

In this step, we identify the households that are potential buyers of alternative vehicles under the subsidy. For this estimation, we use data available from a choice experiment (Achtnicht, 2012 and Daziano and Achtnicht, 2013). Based on these data, we estimate the probabilities of choosing electrical and CNG vehicles by means of a conditional logit model.

Both subsidy schemes comprise a reduction of 30% in the purchase price and an extension of 180% in the size of the service station network. We estimate the probability of purchasing conventional, electrical, and CNG vehicles for different household types, using experimental data. Hereafter, we impute these probabilities to similar households that reported buying a new vehicle, using our panel data. A household is assumed to purchase an alternative vehicle and to receive the subsidy if the probability of purchasing the alternative vehicle (under the additional tax and subsidy) is larger than the one of buying a conventional vehicle.

2.3 Simulation of Welfare Loss

Most of the well-known studies on the distributional effects of additional fuel taxes use Arnold Harberger's welfare triangle estimated as one half times the product of the quantity change times the price changes. This measure relies heavily on the own price elasticities. Consequently, Arnold Harberger's measure neglects the effect of changes in income when estimating changes in welfare due to a tax or subsidy policy. Hausman (1981) has proposed a metric for the estimation of the exact consumer surplus based on different specification of demand functions. Arjan (2009) has developed a framework based on the Hausman's exact consumer surplus to evaluate distributional effects of increases in water prices under a block price systems where consumption is taxed progressively across consumption thresholds to protect low income households. However, increases in taxes via fuel prices are not set in blocks and consequently this method is not directly applicable in this case. Hence, we derive a suitable framework to analyse the distributional effects of different reforms in private transportation. Our linear demand specification to model driving behaviour can be written as follows:

$$KM(pkm, y, z) = \alpha pkm_{ht} + \beta y_{ht} + \gamma z_{ht} \tag{2}$$

where pkm_{ht} is the price per kilometre, y_{ht} is the income level and z_{ht} is for other socio-economic and vehicle characteristics. By expressing the income level (y) in terms of price levels from Equation (2) and solving the differential equation, Hausman (1981) obtains the following expression:

$$y(p_i) = ce^{\beta p_i} - \left[\frac{1}{\beta}(\alpha p_i + \frac{\alpha}{\beta} + z\gamma)\right], \tag{3}$$

where c is the constant of integration. By making $c = u$, the following indirect utility function was obtained by the author:

$$V(p_i, y_i) = e^{-\beta p_i}\left[y_i + \frac{1}{\beta}(\alpha p_i + \frac{\alpha}{\beta} + z\gamma)\right], \tag{4}$$

where $V(p_i, y_i)$ is the indirect utility function that depends on the commodity price p_i and income level y_i. Note that β, α and γ are the parameters from expression (2). The index i denotes the reference period and post-policy implementation period. By using this expression and solving for income, the expenditure function can be obtained:

$$e(p_i, \bar{u}) = e^{\beta p_i}\bar{u} - \frac{1}{\beta}\left[(\alpha p_i + \frac{\alpha}{\beta} + z\gamma)\right]. \tag{5}$$

Where $e(p_i, \bar{u})$ is the expenditure function that depends on the commodity price p_i and utility level .

Based on this finding, we derive our metrics for equivalent variation and equivalent income (EI) corresponding to Equation (2). Equivalent variation is defined as the maximum amount a consumer would be prepared to pay at the budget level y_1 to avoid the change from p_0 to p_1 (see Hausman, 1983). Formally it is defined as $e(p_1, U_1) - e(p_0, U_1)$. Where the sub-index 0 and 1 denote before and after the policy implementation. By using (4) and (5), we obtain the following metric:

$$\text{Equivalent variation} = 1/\beta\left[KM(p_0, y_1) + \frac{\alpha}{\beta}\right] - \frac{1}{\beta}e^{\beta(p_0 - p_1)}\left[KM(p_1, y_1) + \frac{\alpha}{\beta}\right].$$

Where KM is the simulation of driving behaviour given a set of prices and income. Equivalent income is defined as the value of income, y_e which gives the same utility as the actual income level, when y_e is at some reference set of prices p_0. By using King (1983)'s definition of equivalent income, $V(p_0, y_e) = V(p_1, y_1)$, we obtain the following expression:[5]

$$y_e = y_1 + \frac{1}{\beta} e^{\beta p_i (p_0 - p_1)} \left[KM(p_1, y_1) + \frac{\alpha}{\beta} \right] - 1/\beta \left[KM(p_0, y_1) + \frac{\alpha}{\beta} \right] \tag{6}$$

2.4 Additional revenue and transfers

Following West and Williams III (2004) we describe the government budget constraint given the additional revenue raised by fuel taxes using the next expression:

$$G = \sum_{h,N} (p_{h1} - p_{h0}) KM_{1h} - \sum_{h,N} T_h \tag{7}$$

where $(p_1 - p_0)KM_1$ denotes the additional tax revenue and T_h are the transfers to households. The additional tax revenue is allocated in equal amounts to all households including non-vehicle owners. In each scenario after fuel taxes are implemented, the additional revenue is exhausted. Note that tax revenue will change in the scenario where subsidies for the purchase of alternative vehicles are granted because on the one hand, the vehicle buyers of these vehicles will not pay conventional fuel taxes any longer. On the other hand, the additional tax revenue will be used to financed the subsidies. Therefore this will change the value of T_h in each scenario[6].

[5]Note that this expression is equivalent to the one obtained by King (1983). However, our derivation has the advantage of being one in terms of the simulated driving behaviour which is easier to be implemented. As in King's derivation, one can obtain the demand function by differentiating expression (6) with respect to reference prices and using $p_0 = p_1$.

[6]Unlike West and Williams III (2004) the panel data used in the estimation do not provide data on wages and working hours and consequently, we cannot simulate changes in labour taxes. Nevertheless, modelling a lump-sum transfer of the additional revenue will still mimic increases in household income as reductions in labour taxes would do. A more refined mechanism to represent the government budget is a topic for further research

2.5 Social welfare and inequality

It is interesting to analyse to what extent the fuel taxes in combination with subsidies for the purchase of alternative vehicles affects low-income and high-income households differently. This is an important contribution to the literature on this topic which usually lacks this type of income inequality analysis. We follow Grösche and Schröder (2014) by estimating the different monetary components which will affect household incomes in sequence, as shown below. Household income will be different before (e.g. p_0) and after the fuel taxes (e.g. p_1) have been implemented. The income level that drivers would have had had not fuel taxes been implemented is estimated as follows:

$$y_{t0} = \left\{ \; y + (p_1 - p_0) K M_1 \; \right\}. \tag{8}$$

Moreover, the income level after taxes and revenue returning is computed using the next expression:

$$y_{t1} = \left\{ \; y + \text{flat allocation} \; \right\}, \tag{9}$$

where flat allocation is the value of T_h in (7) transferred equally to each household.

Regarding households that buy an alternative vehicle, their income will experience the following additional changes:

$$\Delta y_1 = \left\{ \begin{array}{c} \Delta \text{vehicle prices} - \text{purchase subsidies} \\ + \Delta \text{Fuel cost} + \text{Taxes avoided} \\ \text{if the alternative vehicle was purchased} \\ 0 \\ \text{otherwise} \end{array} \right\} \tag{10}$$

We compute Δvehicle prices as the difference in the purchase price of conventional and unconventional vehicles. The term Δ Fuel cost describes the difference in the running costs compared to conventional vehicles. The amount of higher taxes on conventional fuels which the household will avoid to pay by switching to alternative technologies is denoted by "Taxes avoided" in expression (10). Given that income and the kilometres driven are provided on a monthly basis, subsidies, prices and the remaining elements of expression (10) costs are scaled on the same basis.[7] For more details on Purchase cost and Δ *Fuel cost*, see Section 4 on data description.

The simulation of different policies will be accomplished by simulating income changes at the household level. Thus, by means of this design, we will obtain the entire distribution of simulated individual incomes. Based on the entire distribution, we will generate a measure of income inequality. Our measure of social welfare is estimated as follows:

$$\text{Social Welfare} = \underbrace{\frac{\sum_h (y_{eh}) / \sqrt{\text{hsize}_h}}{\sum_h \text{h}}}_{\text{Mean equivalent income (MEI)}} \times (1 - A\epsilon), \quad (11)$$

where y_e is equivalent income as defined in expression (10) and $A\epsilon$ is Atkinson's inequality index at a given level of the inequality aversion parameter ϵ (see King, 1983).

3 Scenarios

Fuel taxes in Germany increased gradually between 1999-2003 reaching an increase of more than 40% of fuel prices by the end of the period. Currently, mineral oil taxes and an extra environmental tax (Ökosteuer) are the main components of the fuel-tax scheme in Germany. These taxes together represent more than 30% of the current fuel price. We simulate the welfare losses and the additional revenue caused by this policy. In a second scenario we estimate the distributional effect of returning the additional tax revenue in equal amounts to every household. Then we estimate the household and social welfare changes of using the additional tax revenue to fiance subsidies for the purchase of alternative vehicles and the remaining revenue is allocated across households. We estimate

[7] We divided the purchase price over a period of five years which equals the standard re-payment period for paying off the total purchase price of a car in Germany.

four scenarios:

(a) Before fuel tax

(b) After fuel tax

(c) Subsidies for the purchase of EVs

(d) Subsidies for the purchase of CNG vehicles

In the first scenario, we estimate a reduced price by 30% from its current value to simulate the welfare losses that could have been caused by the current energy taxes in Germany. In the second scenario, we estimate the additional revenue caused by this policy and simulate a flat allocation of this revenue. Note that these two scenarios are a close representation of the current German fuel tax scheme. Regarding the last two scenarios, the subsidies for both schemes, i.e. for EVs and CNG vehicles, amount to 30% of the purchase price, respectively (see Table 5). The literature gives reason to simulate this scenario, as it is commonly argued that high purchase costs are a barrier to the introduction of alternative vehicles (see Perdiguero and Jiménez, 2012). We follow Kazimi (1997) who uses a subsidy of 30% to simulate the technology penetration of CNG and electrical vehicles. Simultaneously, the service station network is extended by 180%. Regarding the extension of the service station network, the low number of recharging stations can cause the fear of getting stranded when driving an alternative vehicle. This circumstance has been called "range anxiety" by Chaudhary (2014) which is, according to the author, another main barrier for adopting those vehicles. Note that the revenue obtained in the first scenario will be used to finance the subsidies for the purchase of alternative vehicles.

4 Data Set and Descriptive Statistics

The empirical analysis is mainly based on two different data sets that are explained in the following. Corresponding to each data set, the relevant descriptive statistics will are provided as well.

German Mobility Panel ("MOP") for Car Use

The German Mobility Panel (MOP) is a survey that has been carried out since 1994. It is a rotating panel which tracks individuals for three years. Once a year, participants are asked about their transportation behaviour over the course of the previous six weeks. The panel includes individual, household and vehicle information. Respondents report the price paid for fuel, the quantity of fuel consumed and the kilometres driven for every car of the household. More information is available on this data set at Frondel et al. (2008) and Frondel et al. (2012) who take advantage of the rich information on vehicle and household characteristics to analyse the rebound effect. Our data set consists of 8,200 observations of which 6,259 are households that own at least one car. The survey covers a period of 12 years, from 2002 to 2014. We disregard previous years because information on income is not available for that time. The main drawback of the data set is that the income variable is measured in categories. For this reason, we impute household income by using the German Socio-Economic Panel (SOEP). When carrying out the imputation we follow Berkhout et al. (2004) and consider household size as well as the difference between rural and urban households over the course of time (for details, see the corresponding Additional Appendix). The mean monthly net income per households that own at least one vehicle amounts to about 2,901€. After equivalising the total household income by dividing it by the square root of household members, the average equivalised income amounts to 1,917€. The summary statistics in Table 1 show the main variables used in the estimations. The fuel price per kilometre is vehicle-specific and is obtained from the information provided by the household. It ranges between 0.028 and 0.51€ per km with an average of 0.11€ per km. Overall, in our sample 81% of the households state that their car is not a company car. Moreover, 31.6% state that their driving behaviour in the observation week was unusual due to e.g. holidays. Still, it is important to include these observations in the analysis because driving behaviour comprises both regular and irregular trips. The survey provides information on the kind of roads where the cars were mainly being driven on. This piece of information is relevant for our application because households that drive their vehicles mainly on country roads might face more restrictions when substituting private with public transportation, unlike those households that mainly use inner-city roads. In our sample, 14% of all vehicles are primarily being driven on country roads. In addition, the type of location where the household is situated will be measured in three dummy variables later.

ECOCAR Data for Vehicle Choice

For the vehicle technology choice, we use the ECOCAR data set which has been analysed by Achtnicht (2012) as well as Daziano and Achtnicht (2013). The survey was carried out between August 2007 and March 2008 considering potential car purchasers. Respondents were asked to choose between different technologies, including petrol, diesel, hybrid, gas, biofuel, hydrogen and electric. They were also asked to assume that the vehicle characteristics were equal for all technologies, except for purchase price and fuel costs, horse power, fuel availability and CO_2 emissions. In this paper, we will use the following socio-economic variables in order to reach results that match the MOP-data explained above: *Small children*, *Full time*, *Man*, *Rural household*, *kilometers driven*, *Under45, Income* and *Education* (i.e. households with higher education qualification, *"HEQ"*). See Table 11 in the Additional Appendix for a further description of this data set.

Additional Data

Table 5 shows the underlying purchase cost of conventional vehicles (i.e. petrol and diesel vehicles) as well as electrical and CNG vehicles. Data on the purchase price and fuel costs for conventional and CNG vehicles were obtained from a consultancy firm specialised in the car industry.[8] The purchase prices for electrical vehicles were taken from Crist (2012). In addition, the table shows the percentage of reduction in fuel costs per kilometre and CO_2 emissions saving compared to conventional vehicles. The investment costs per EV

[8]Purchase prices were produced for the project "H2 incentives - market introduction scenarios for mobility based on hydrogen" carried out by the Centre for European Economic Research (ZEW). These estimates were originally provided for 2011 only. We use the consumer price index in order to transfer these prices to previous years.

and CNG service station amount to €10,000 and €6,000, respectively.[9]

5 Empirical Results

The outline of the empirical results follows the methodological Section 2 in describing the policy changes step by step.

5.1 Estimation of the Model of driving behaviour

The model of car use from Equation (2) is estimated by ordinary least squares (OLS), random effects (RE) and fixed effects (FE), respectively. The results are shown in Table 2 of the Appendix. Comparing the estimates that focus on prices per kilometre of the first and the second car, it becomes clear that the kilometre demand of the second car reacts more elastically to price changes. The results for household incomes are not always significant in our models (as in Bureau, 2011). Irregular timings, e.g. a week including holidays are factors which increase the kilometre demand. At the same time, the usage of private vehicles is significantly lower than the one of company vehicles. Moreover, smaller households drive fewer kilometres than larger households. Focusing on vehicle age and size, the estimates show that households tend to drive more kilometres in larger and more recent vehicles. These estimates will later be used to simulate the welfare effects of the fuel tax reform.

Model selection

Most of the coefficients estimated by using OLS and RE models are rather close to each other. Note that the estimates from the FE model differ from these two options. Bureau (2011) takes this as an indicator that individual effects a_i are correlated with the explanatory variables, and therefore, the author opts for the fixed effects model. In order to choose one of these models to proceed, we apply different tests. We reject the

[9] These values are taken from US Energy Department and cleantechnica.com. We assume that there is an additional service station for each extra CNG and EV vehicles.

null hypothesis that the a_i values are equal across households by using the F-test which confirms that the OLS model would be inappropriate. When applying the Hausman test for choosing a specification between the FE and RE models, we do not find evidence of the validity of the RE model.[10] For this reason, we opt for the fixed effects model which allows the individual effects to be correlated with the regressors (Wooldridge 2001). As in Bureau (2011), we need to acknowledge that this econometric model addresses some aspects of the endogeneity problem between vehicle characteristics and the distance driven, but some of them will still remain. We also apply the test for sample selection bias which might arise because households with more than one vehicle could possibly face a higher burden when participating in the questionnaire for the first time. After carrying out the test suggested by Wooldridge (2001), we do not find any evidence for sample selection bias.[11]

Using these results, we estimate own price elasticities (OPE) for different income quintiles.[12] The results from this calculation exercise are shown in the left panel of Table 4. Households respond to the increase of the carbon tax by reducing the number of kilometers they drive. Own price elasticities (OPE) are important because they will define the tax incidence and revenue size (West, 2005). Regarding estimates of OPE, we find important variations across income quintiles. The results are in line with West (2004) who also find that low income drivers have a larger response in the face of increases in fuel prices. We also find that rural drivers show slightly larger estimates in absolute values than urban drivers. Regarding the size of elasticities, they are comparable to the ones estimated by Bureau (2011) for France.

[10]We also used the test proposed by Wooldridge (2002, pp. 290-291) which is robust to heteroskedasticity and serial correlation. We accept the alternative hypothesis that FE model performs better than the RE model at the 5% significance level.

[11]A variable that takes the value of one if the household has been present in the previous waves of the panel is used in this test by including it in the fixed effects regression. The statistical significance of the parameter associated to this variable will serve as evidence of sample selection bias.

[12]Elasticities are estimated by using mean values of prices as follows: $\frac{\Delta Q}{\Delta P} * \frac{P}{Q}$.

5.2 Simulation of Vehicle Choice

The results from the model for vehicle choice are displayed in Table (3). We extend the model estimated in Achtnicht (2012) by including variables for small children, driving distance, and whether the household lives in a city or in a rural area[13]. The estimated parameters of purchase and fuel price, engine power, fuel availability and CO_2 emissions are in line with the estimates by Achtnicht (2012) for the standard logit. The results show that households living in rural areas and those ones with small children will prefer CNG vehicles to EVs. This may indicate that the fear of getting stranded when driving an electrical vehicle is larger for these household types.

5.3 Welfare Loss

In this section, we analyse the welfare changes at the household level caused by the increases in fuel taxes and the lump-sum transfer financed by the additional revenue. We also simulate the welfare changes caused by granting subsidies for the purchase of alternative vehicles. Here, we focus only on households that own a vehicle which represent 78% of vehicle owners in our sample. We focus on this type of households because in our sample they have a smaller mean income than owners of two or more vehicles and consequently they may experience the largest tax burden. In the following section we simulate changes in social welfare and inequality where we consider multiple vehicle owners and non-vehicle owners. In this section, we estimate equivalent variation relative to the household income (see Expression 6) for vehicle owners by simulating income, prices and obtain KM changes under different policies and by using expression (1). Note that the results in Table 6 display changes in consumer surplus which are differentiated by income group and the type of roads that are mainly used. One can see that welfare *losses* are larger for poorer households, thus indicating that this tax is regressive. We find smaller losses for rural driver which is consistent with this group having larger own price elasticities which

[13]The author included the interaction of purchase price and a dummy variable indicating an upper price bound as a proxy for income. Given that this variable cannot be matched with any variable in our panel, we included instead driving distance and multiple car ownership in our specification

allows us them to modify their driving behaviour and consequently to have a smaller tax burden than other drivers .

Regarding the effect of subsidies on drivers welfare, note that once the alternative vehicle is purchased, drivers will be excluded from paying a fuel tax which provides them with welfare gains. Households will also gain from reductions in fuel costs compared to conventional vehicles (see Table 5). Concluding that subsidies have a progressive effect as poorer households in Tables 7 and 8 have the largest welfare gains is a biased conclusion and could possibly underestimate the distributional effects of this policy. In this line Creedy and Sleeman (2006) point out how important it is to include the effects of such policies on income inequality. We will examine this subject more closely in this section. Note that CNG vehicles lead to higher savings in fuel costs per driven km than EVs (see Table 5). These factors explain the large changes in welfare losses when subsidies are granted. Note that welfare gains are generally larger for urban drivers when EVs are supported, while the opposite occurs when CNG vehicles are subsidised. This is not surprising considering the results from the discrete choice model which shows that rural drivers prefer CNG vehicles.

5.4 Simulating Effects on Income Inequality and Social Welfare

In this section, we include the full sample that includes households that own one or more vehicles and households that do not own a vehicle. Table 9 shows changes in social welfare and inequality for different scenarios [14]. After fuel taxes are imposed the levels of inequality reduce due to the flat allocation. This confirms the current findings that the concerns that low income households face the largest burden can be overcome by using revenues for counteractive measures[15]. However, when subsidies are granted the levels of these two metrics decrease. One the one hand, the additional revenue decreases because the buyers

[14] Creedy and Sleeman (2006) use $\epsilon = 0.2$ and $\epsilon = 1.2$. Our choice of ϵ seems to be a reasonable upper bound for the inequality aversion parameter, even though Pirttillä and Uusitalo (2010) suggest that under certain circumstances, even higher values of ϵ may apply.

[15] Note that without revenue returning, inequality will increase as shown by Nikodinoska and Schröder, 2016

of alternative vehicles do not pay the fuel tax. On the other hand, the additional revenue is used to finance the subsidies. This provides for the first time empirical evidence that subsidies for the purchase of alternative vehicles can cause inequality and decrease social welfare. Turning to the subsidies for EVs or CNG vehicles, increases in inequality and social welfare are much more pronounced for CNG subsidies. The different numbers of recipients of the subsidy provide an explanation for this. Given that CNG vehicles have larger CO_2 emission factors per kilometre than EVs, the subsidies for CNG vehicles have to be larger. Thus, the number of households receiving a subsidy is larger in the CNG subsidy scheme as compared to the EV scheme. This explains the higher increase in income inequality under the CNG subsidy. In this regard Table 10 shows that subsiding CNG vehicles reduces the additional tax revenue by 24% compared to a reduction by 9% when EVs are subsidised. This corresponds to an increase of alternative vehicles of 27% and 8% for CNG and EV vehicles. Note also that the tax increase of 30% will reduce CO_2 emissions of 9%. [16]

6 Conclusions

Private transport constitutes a significant aspect of climate policies. Increases in fuel taxes and the number of alternative vehicles are key policy instruments to cut down CO_2 emissions in the European Union. However, their implementation has led to distributional concerns. Moreover, empirical evidence of the effect of these policies on household welfare and inequality is still narrow.

In this paper, we used for the first time a theory-consistent framework to analyse the effects of these policies for private transport on household and social welfare and on income inequality for Germany. We first estimate the welfare losses due to the increases

[16]Emission factors for conventional vehicles were taken from Smokers et al. (2011) while for alternative vehicles, Daziano and Achtnicht (2013) provide emission factors for CNG vehicles. For EVs we follow Thiel et al. (2010) who estimate CO_2 emissions for electrical vehicles, assuming a certain mix of fuels for the power generation in Europe. Note that while the numerical values of inequality and social welfare of supporting EVs are sensitive to the emissions factors of these vehicles, the conclusion that different in efficiency has also impacts on these metrics still holds.

in fuel prices for environmental purposes in the last 10 years. The revenue is returned via lump-sum transfers in a second stage. In a third step, subsidies for electrical vehicles and for CNG vehicles are introduced and financed using the additional fuel tax obtained in the previous steps. We extend the approach Hausman (1983) using panel data and a linear demand specification.

We find that increases in taxes via conventional fuel prices have a regressive effect which is in line with the findings in the literature. However, returning the additional revenue in equal amounts to each household reduces income inequality and social welfare losses. When introducing subsidies for alternative vehicles we observe reductions of welfare gains for buyers of these vehicles. At the same time, we find that the subsidy policies increase income inequality and social welfare. This empirical evidence supports the argument given by Grösche and Schröder (2014) that subsidies on the purchase of durable goods with environmental purposes have regressive effects. Although we have designed both subsidy schemes in such a way that they yield identical reductions in CO_2 emissions, more CNG vehicles have to be subsidised as compared to electrical vehicles. This is because electrical vehicles are simply much "cleaner" than CNG vehicles. This exemplifies that technologies with larger environmental savings go along with smaller increases in income inequality.

These results show the importance of including inequality measures when evaluating the effect of environmental policies, and call for a redesign of the implementation of taxes and subsidies with environmental purposes. As Skerlos and Winebrake (2010) argue, subsidies have to be designed in consideration of income and regional differences in order to increase their social benefit.

In general, one possible extension to our methodology might be to consider welfare gains or losses from car manufactures under different policies (see Adamou et al., 2014).

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8 Appendix: Tables

Table 1: Summary statistics for car owners

Variable	Mean	Std. Dev.	Min.	Max.	N
km	1117.58	775.4	28.52	8004.59	6259
Price per km	0.11	0.03	0.02	0.51	6259
Non-equivalised income	2901.86	1337.91	282.47	5905.15	6259
Equivalised income	1917.76	841.6	223.91	5905.15	6259
Rural roads	0.14	0.35	0	1	6259
Private car	0.81	0.39	0	1	6259
HH sex	0.66	0.47	0	1	6259
Holidays	0.32	0.47	0	1	6259
Number of cars	1.25	0.53	1	9	6259
Children	0.22	0.41	0	1	6259
HH size 1	0.19	0.39	0	1	6259
HH size 2	0.42	0.49	0	1	6259
HH size 3	0.39	0.49	0	1	6259
Population 1	0.64	0.48	0	1	6259
Population 2	0.22	0.42	0	1	6259
Population 3	0.13	0.34	0	1	6259
Vehicle age 1	0.26	0.44	0	1	6259
Vehicle age 2	0.24	0.43	0	1	6259
Vehicle age 3	0.2	0.4	0	1	6259
Vehicle age 4	0.31	0.46	0	1	6259
Vehicle small	0.18	0.39	0	1	6259
Vehicle medium	0.69	0.46	0	1	6259
Vehicle large	0.12	0.33	0	1	6259
Fuel type	1.55	0.74	1	3	6259

Table 2: Regression Output estimated using Equation (1)

	ols	re	fe
Price per km	-4,016.025***	-3,551.448***	-2,786.938***
	(339.076)	(389.838)	(580.177)
Two vehicles*price per km	-1,080.141***	-1,188.942***	-1,377.823***
	(361.722)	(403.263)	(492.270)
Rural*Price per km	-324.361*	-456.703**	-613.544**
	(185.465)	(199.940)	(276.574)
Income	57.240***	53.855***	36.236*
	(8.678)	(10.325)	(21.195)
Two vehicles*income	-55.264***	-63.275***	-65.597***
	(12.889)	(13.547)	(16.116)
The sex of HH is male	53.785***	63.495***	
	(17.233)	(22.192)	
Private car	-441.348***	-409.861***	-380.150***
	(26.528)	(32.972)	(47.875)
Holidays	184.724***	181.307***	157.169***
	(17.878)	(17.628)	(20.664)
Children	-28.584	-30.009	-49.474
	(29.009)	(30.214)	(45.671)
HH size 1	-228.056***	-225.457***	-226.730***
	(31.999)	(36.978)	(66.639)
HH size 2	-154.948***	-148.314***	-85.577
	(25.729)	(28.844)	(57.698)

Table 2: Regression Output (cont)

	ols	re	fe
Population 1	-85.601***	-120.404***	-182.766*
	(24.826)	(32.237)	(102.787)
Population 2	-2.149	-15.102	6.940
	(28.333)	(35.703)	(97.912)
Vehicle age 1	286.876***	276.917***	269.346***
	(22.826)	(26.534)	(39.640)
Vehicle age 2	116.349***	120.311***	118.390***
	(19.882)	(23.011)	(35.209)
Vehicle age 3	84.887***	77.603***	68.017**
	(20.709)	(22.563)	(32.736)
Vehicle small	-183.658***	-165.644***	-125.567***
	(31.388)	(33.012)	(42.991)
Vehicle medium	-6.245	10.954	58.738*
	(26.882)	(27.746)	(34.887)
Diesel	343.548***	370.052***	435.219***
	(27.386)	(36.120)	(58.409)
Constant	1,727.651***	1,666.245***	1,634.002***
	(64.104)	(71.408)	(128.996)
Observations	6,259	6,259	6,259
R-squared	0.329		0.346
Number of id		2,480	2,480

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: Discrete choice model for technology (Conditional logit) Dependent variable: Technology choice codified from 1 to 7.

Variable	(1) discrete Technology choice		S.E.
Purchase price	-0.037	***	(0.004)
Fuel cost	-0.076	***	(0.003)
Petrol	0.603	***	(0.107)
Hybrid	0.032		(0.117)
Gas	-0.275	**	(0.118)
Bio	-0.715	***	(0.124)
Hydrogen	-0.268	**	(0.114)
Electric	-1.016	***	(0.131)
Small children x petrol	-0.180		(0.132)
Small children x hybrid	0.145		(0.142)
Small children x gas	0.300	**	(0.140)
Small children x bio	0.389	***	(0.144)
Small children x hydrogen	0.077		(0.138)
Small children x electric	0.476	***	(0.153)
Multiple vehicles x petrol	-0.349	**	(0.163)
Multiple vehicles x hybrid	-0.183		(0.176)
Multiple vehicles x gas	-0.351	*	(0.184)
Multiple vehicles x bio	-0.015		(0.178)
Multiple vehicles x hydrogen	0.239		(0.157)
Multiple vehicles x electric	-0.087		(0.196)
Rural x petrol	0.151		(0.116)
Rural x hybrid	0.190		(0.129)
Rural x gas	0.435	***	(0.129)
Rural x bio	0.284	**	(0.135)

Continued on next page

Table 3 – continued from previous page

Variable	Technology choice		
Rural x hydrogen	0.146		(0.124)
Rural x electric	0.109		(0.147)
KM x petrol	-0.013	***	(0.002)
KM x hybrid	-0.007	***	(0.002)
KM x gas	-0.351	*	(0.184)
KM x bio	-0.015		(0.178)
KM x hydrogen	0.239		(0.157)
KM x electric	-0.087		(0.196)
Horse power	0.006	***	(0.001)
Fuel availability	0.012	***	(0.001)
CO_2	-0.003	***	(0.000)
CO_2 x Man	-0.001	*	(0.001)
CO_2 x under 45 year	-0.001	***	(0.000)
CO_2 x Education level	-0.001	**	(0.000)
Observations	25,116		

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

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Table 4: Own Price Elasticities across income quintiles (OPE)

	OPE	SE	OPE	SE	OPE	SE
1st	-0.340	0.071	-0.349	0.073	-0.368	0.068
2nd	-0.304	0.063	-0.304	0.063	-0.372	0.068
3rd	-0.291	0.061	-0.295	0.061	-0.329	0.061
4th	-0.253	0.053	-0.252	0.052	-0.318	0.058
5th	-0.231	0.048	-0.233	0.048	-0.267	0.049

Table 5: Purchase price, CO_2 emissions and fuel cost

Technologies	**% values w.r.t conventional technologies**		
	Mean purchase price (euro)	Δ CO_2 (%)	Δ fuel cost(%)
Conventional	22,353	0	0
EVs	34,475	-70	-14
CNG vehicles	24,056	-20	-22

Table 6: Welfare owners of one vehicle across income quintiles. Estimated using expression (6)

	Welfare All	SE	Welfare Urban	SE	Welfare Rural	SE
1st	-4.498	2.223	-4.649	2.315	-4.553	2.334
2nd	-3.412	1.695	-3.484	1.734	-3.420	1.746
3rd	-2.691	1.355	-2.749	1.392	-2.701	1.400
4th	-2.091	1.018	-2.164	1.060	-2.129	1.066
5th	-1.384	0.671	-1.425	0.698	-1.404	0.702

Table 7: Welfare owners of one vehicle across income quintiles for EV subsidies. Estimated using expression (6)

	Welfare All	SE	Welfare Urban	SE	Welfare Rural	SE
1st	0.289	0.136	0.295	0.133	0.294	0.132
2nd	0.198	0.093	0.198	0.091	0.197	0.090
3rd	0.161	0.070	0.165	0.068	0.164	0.067
4th	0.122	0.054	0.119	0.054	0.118	0.053
5th	0.074	0.034	0.075	0.034	0.074	0.034

Table 8: Welfare owners of one vehicle across income quintiles for CNG subsidies. Estimated using expression (6)

	Welfare All	SE	Welfare Urban	SE	Welfare Rural	SE
1st	0.461	0.125	0.485	0.122	0.479	0.118
2nd	0.355	0.085	0.363	0.083	0.359	0.081
3rd	0.294	0.065	0.310	0.064	0.306	0.062
4th	0.188	0.051	0.191	0.050	0.190	0.049
5th	0.118	0.032	0.124	0.032	0.123	0.031

Table 9: Social Welfare for different policies (Inequity aversion: 1.6). Estimated using expression (11)

	AI	Δ AI	MEI	Social welfare	Δ Social welfare
Before tax	0.170	0.000	1718.971	1426.252	0.000
After tax	0.169	-0.468	1747.094	1450.978	1.734
After tax sub EVs	0.171	0.442	1715.513	1422.091	-0.292
After tax sub CNG	0.173	1.318	1708.792	1413.970	-0.861

Atkinson Index (AI), Mean Equivalent income (MEI)

Table 10: Changes in tax revenue, alternative vehicles and CO2 emissions (%)

	Δ Tax Revenue	Δ alternative vehicles	Δ CO2
After tax	100	0	8.65
After tax sub EVs	-8.02	7.20	1.32
After tax sub CNG	-23.83	27.17	1.32

Δ alternative vehicles w.r.t new vehicles

Additional Appendix: Income imputation based on SOEP data

Income in the main data, i.e. the MOP data, is measured in categories. This is inconvenient because we want to analyse a continuous variable on household income. In order to do so, we impute (continuous) household income based on the German Socio-Economic Panel (SOEP) data. The SOEP contains continuous information on income. In the imputation procedure we also make use of the categorical information from the MOP data. The imputation is carried out in a simple linear regression which accounts for income class, household size, federal state and a dummy for rural area. These are the variables that are relevant and also available in the MOP data. Hence the imputation is calculated as follows:

$$\begin{aligned} \hat{Y}_i = \quad & \hat{\beta}_0 \quad + \sum_{c=1}^{7} \hat{\beta}_c D_i\left(yclass = c\right) + \sum_{h=2}^{6} \hat{\gamma}_h D_i\left(HHsize = h\right) \\ & + \quad \sum_{f=2}^{16} \hat{\delta}_f D_i\left(federalstate = f\right) + \hat{\zeta} D_i\left(rural = 1\right) \end{aligned} \tag{12}$$

where $\hat{\beta}_0$, $\hat{\beta}_c$, $\hat{\gamma}_h$, $\hat{\delta}_f$ and $\hat{\zeta}$ denote the estimated coefficients from the corresponding regression model. The regression model is estimated by OLS based on SOEP data and the coefficients are then taken to the MOP data according to equation (12). The imputation results are not displayed for brevity, but are available from the authors on request.

Choice Experiment

Table 11: Attributes and attribute levels in the choice experiment

Attribute	*Number of levels*	*Levels*
Fuel type	7	Petrol, Diesel, Hybrid, LPG/CNG, Biofuel, Hydrogen, EVS
Purchase price	3	75%, 100%, 125% of reference[a] (in thousands of Euros)
Horse power	3	75%, 100%, 125% of reference[a] (in PS)
Fuel costs per 100km	3	€5, 10, 20
CO_2 emissions per km	5	no emissions[b], 90g, 130g, 170g, 250g
Fuel availability	3	20%[c], 60%, 100% of service station network

[a] average of the lower and upper bounds for the next car indicated by the respondent

[b] only applied to non-fossil fuel types (i.e. biofuel, hydrogen, and electric)

[c] not applied to conventional fuel types (i.e. gasoline and diesel)