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Modifying the Rebound: It depends! Explaining Mobility Behaviour on the Basis of the German Socio-Economic Panel

Wenzel Matiaske, Roland Menges and Martin Spiess

Abstract— **We address the empirical question to which extent higher fuel efficiency of cars affects additional travel and how this behavioural aspect is modified by additional variables. The data set used to estimate a theoretical model of the rebound effect covers two panel waves, 1998 and 2003, taken from the German Socio-Economic Panel (SOEP). To take full advantage of the information in the data available, and to avoid problems due to possible selection effects, we estimated an unbalanced two-wave random effects panel model. Our results suggest that in line with the rebound hypothesis, there is a negative effect of car efficiency on the kilometers driven. That is, the lower the fuel consumption, the larger the driven distance. However, contrasting recent empirical literature about the rebound effect in the transportation sector, this seems to be true only for cars with a consumption of more than roughly eight liters per hundred kilometers. In addition, we find a positive diesel effect, which implies that owning a diesel engined car, has a positive effect on the driven distance. Both effects can be interpreted as support for the rebound hypothesis, although not in a simple linear way. Moreover, it can be shown that some "soft" variables such as certain attitudes towards the environment tend to amplify this non-linear rebound effect. Our results support the general direction of the rebound effect on households travel activities. But because of the remaining political relevance of the rebound effect, they also highlight the importance of accounting for additional behavioural variables which tend to influence individual mobility behaviour. Hence, the classical interpretation of the rebound as a linear effect of advances in fuel economy on individual travel has to be questioned.**

Index Terms—**energy demand, rebound effect, panel data analysis**

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I. INTRODUCTION

Just recently the German government decided to introduce a so-called scrapping bonus as part of its second economic stimulus package in order to address the challenge of the global financial crisis. The package foresees granting €2,500 to households which choose to junk their current automobile, provided that it is at least nine years old, and buy a new or slightly used car. It seems that interest of private households is tremendous. The idea to promote the junking of old cars was advertised as one that could not only improve the economic position of the automotive industry, but would also help the environment. This measure is well in line with several rules and regulations governing greenhouse gas emissions, which have been strengthened in recent years. Increasing the fuel efficiency of cars is seen as a proper instrument to reduce energy consumption as well as CO2 emissions in the automotive sector. The central idea is that increasing the fuel efficiency of new cars and replacing older cars with newer ones, would help to reduce energy consumption and CO2-emissions in the mobility sector, which contributes about 33% to worldwide CO2 emissions. One of the first and most prominent measures in this field was the introduction of the Corporate Average Fuel Economy (CAFE) Standards in the US in 1975. The European Commission, for instance, negotiated a voluntary agreement with the major automotive trade organizations which agreed that their member companies meet certain environmental and emission targets across all passenger vehicles sold. One central result of these negotiations was that European Automobile Manufacturers Associations agreed to reduce average emissions to a target level of 140g CO2/km by 2008. Moreover, by the end of 2008 EU member states agreed to introduce new emission standards reducing CO2 emissions to a level of 120g for 65% of new cars in 2012. Between 2012 and 2015 all new cars sold to European consumers should obey this standard.

On the opposite, theoretical and empirical literature about the so-called rebound effect raises a lot of doubts concerning the effectiveness of such technology oriented policies. The rebound effect refers to the behavioral responses of end-consumers to the introduction of new technologies taken to reduce resource use. These responses – driven by price and income effects – tend to offset the beneficial environmental effects of the increased efficiency. In particular, these counterproductive effects are estimated to be prominent in the case of mobility behavior. Some recent studies estimate that more than half of the efficiency improvements of cars are off set by an increase in travel [1]. This is the reason why critics of the scrapping bonus believe that environmental effects will be minimal at best and suggest that a bonus should be also given to those who decide to junk their car and switch to public transportation.

In this paper we address the empirical question to which extent higher fuel efficiency of cars induces travel activities and how this behavioral aspect is modified by additional variables, such as subjective environmental attitudes. Because this question addresses mid- and long-run changes in the pattern of mobility behavior of private households, data cannot easily be obtained from surveys or other statistical sources. The data we used for the purpose of this paper is taken from the German Socio-Economic Panel (SOEP), covering two panel waves, 1998 and 2003. As a major advantage of this data source a lot of topics are covered by the questionnaires including household composition, occupational biographies, employment, earnings, health, environmental behavior and satisfaction indicators among many others. The paper is organized as follows: In the second section we give a brief description of the theory and literature concerning the rebound effect, in order to derive our research hypothesis. In the third section we figure out the data basis taken from the SOEP and define the variables used for our investigation. In section 4 the major empirical results of the panel models used are presented. The paper ends with some conclusion and a short summary in section 5.

II. The Rebound Effect

A. The Rebound

The empirical results of several studies reveal that gains in the efficiency of energy consumption lead to an effective reduction in the per-unit price of energy services and thereby at least partially offset the impact of increased efficiency in fuel use [2]. Khazzoom [3] was among the first, showing that the direct increase in demand for an energy service may be a result of improvements in technical efficiency of energy use. However, the rebound effect of increased efficiency is not restricted to the direct increase in demand because of a price effect. Among others, Brookes [4] highlighted wider economic effects of increased energy efficiency such as an increase in gross output and fuel consumption due to an effective decrease in the price of energy. In the literature (cf. Frondel et al. [1] or Greening et al. [2] for the typology of rebound effects) three types of the rebound have to be considered:

- Th3e direct rebound effect addresses an increased demand for energy due to increased efficiency.
- The indirect rebound effect is based on some kind of income effect, because lower per-unit costs of energy services increase the real income of households. Due to the increased real income households may consume more energy services.
- Whereas the former effects are based on the application of economic theory in a static micro-context, on the macro-level a general equilibrium effect may occur, when individual behavior is aggregated to total consumption and investment Effects on the composite price of energy services may become significant, thereby leading to adjustments in fuel supply markets. However, Greening and Khrusch [5] show that the size of this kind of rebound on the macro-level is highly uncertain because potential paths of technological change are rather stochastic.

Because the research focus of this paper is restricted to households mobility behavior we concentrate on the direct rebound effect as suggested by Khazzoom [3].

B. The Rebound and Transportation

The transportation sector contributes about 1/4 to global energy consumption. In Germany, the fuel consumption due to private car use contributes about 50% to energy consumption of the whole transportation sector. According to Greening et al. [2] the direct rebound effect for transportation, i.e. an increase in households car use in response to an increase in technical efficiency of cars, basically can be decomposed into the following three elements:

- An increase in the number of vehicles,
- an increase in fuel consumption of the given number of cars
- and an increase in km travelled.

Increasing the technical efficiency of vehicles is equivalent to a reduction of the effective price of transportation services. Behavioral changes of car users belong to the trade-off between the fuel economy of cars and other attributes of the car such as size, volume, acceleration or security, perceived by car users and car owners. Hence, a “pure” technological change such as an improvement of fuel economy due to innovations in the combustion process of cars could lead to a change in this trade-off and induce behavioral changes.

Standard literature on the rebound (e.g. Greene et al. [6]) in the transportation sector suggests that measures of the direct rebound from fuel consumption can be obtained from the own-price elasticity of fuel consumption with respect to changes in fuel price or from the negative of the elasticity of kilometer (km) travelled with respect to the fuel cost per km. Hence, the more elastic vehicle km travelled with respect to changes in costs per km, the greater will be the direct rebound. Assuming given values of

- the cars fuel consumption in liter per km driven (*fuel*)
- total fuel consumption of car use (*F*)
- travel activities in km per year (*Km*)
- the price of fuel (*P*)

and a given elasticity of travel consumption *Km* with respect to *P*, one could measure the effect of an exogenous change in fuel economy of the car (*fuel*) by using the identity *F* = *Km*fuel* as follows:

$$\frac{dF}{dfuel} = fuel \frac{dKm}{d(fuel \cdot P)} P + Km \quad (1)$$

Hence, the rebound effect, which is equivalent to the elasticity of *Km* with respect to *fuel,* is given by the following formula:

$$\beta_{F,fuel} = \frac{dF}{dfuel} \cdot \frac{fuel}{F} = \frac{dKm}{d(fuel \cdot P)} \cdot \frac{fuel \cdot P}{Km} + \frac{fuel \,.\, Km}{F} \quad (2).$$
$$= \beta_{Km,fuel \cdot P} + 1.$$

Equation (2) may be interpreted in the following sense: The product (*fuel*P*) represents the per-km costs of driving the car. Only if the elasticity of driven km with respect to per-km costs ($\beta_{Km,fuel*P}$) becomes Zero, the 100% of the potential savings in total fuel consumption due to an improvement of fuel economy will be realized (i.e. $\beta_{F,\,fuel}$ =1).

Greening et al. [2] give an overview about the results of econometric analyses of the demand for gasoline and travel acitivities in the US based on time series of national or state-level data.

Aggregate Studies indicate a relatively small direct rebound effect of about 10% for the short run (i.e. variations within one year) increasing to 20% to 30% as longer periods are observed. Other studies, such as Dahl [7], cite even larger estimates of the direct rebound effect in the transportation sector, ranging from 21 to 50%. More recent surveys from Goodwin et al. [8] indicate rebound effects in the transportation sector between 4% and 89%. An investigation of German households mobility behavior with respect to the rebound is presented by Frondel et al. [1]. The data is drawn from a German Mobility Panel covering information about relevant aspects of households everyday travel activities. Their results suggest that about 58% of the potential energy savings from an improvement in fuel economy is compensated by an increase in driving. Moreover, panel estimations show that travel activities of households (km driven) can be explained by the direct rebound effect (i.e. by the effect of an increase in fuel efficiency of the car), the price of fuel, the level of education and the status of employment of private households.

C. The case of diesel-engined cars

In the discussion about automobile manufactures contribution to lowering the CO2 emissions in the transportation sector, industry brings forward the argument that diesel vehicles have higher fuel economy and lower CO2 emissions than their counterparts. Hence, increased market penetration of diesel powered vehicles seems to be a reasonable strategy towards a more sustainable transportation system. Based on European diesel and gasoline certification data, Sullivan et al. [9] point out and quantify the possible reductions in energy consumption and CO2 emissions.

However, it turns out that such kind of technical comparison of fuel economies will fall short because of neglecting behavioral effects. Among others, Schipper et al. [10] found that diesel drivers use more fuel and emit more greenhouse gases than do drivers of gasoline cars. Average annual driving distances of diesel cars exceed driving distances of gasoline cars by a range between 42% and 113%.[1] To only a minor extent this behavior can be explained by the rebound effect, perhaps a larger portion can be attributed to lower diesel prices - some because long distance drivers self-select for diesel, and some other because people with two

[1] However, leaving behavioural aspects aside, it should be mentioned, that the technical details of comparing energy efficiency of diesel cars with gasoline cars are far from easy. In general diesel vehicles have higher production costs than their gasoline counterparts, because they have to be built in order to withstand higher compression ratios, adding to both, weioght and material costs. Sullivan et al. [9] object that Schipper et al. [10] did not correct for the effect of different weights of cars and underestimate the fuel economy of diesel cars by 29%.

or more vehicles will use the cheapest for long distance trips. Hence, the rebound effect may be two-fold:

- buying a more or less fuel efficient car as fuel prices change
- and driving more or fewer miles after buying the new car.

Similar results are obtained by Verhoeven [11], who found that gasoline vehicles are driven substantially less than their diesel counterparts. However, it seems to be unclear, to which extent this difference can be attributed to a rebound effect. Chen and Sperling [12] conclude that the rebound does not account for the entire difference in travel because of a self-selection effect. Self-selection may become responsible for a large difference in mileage, because those drivers who anticipate driving greater distances will consider the operating cost of their vehicle more carefully than drivers of gasoline cars. Moreover, in cases of a household fleet mileage may be redistributed to favor the more efficient diesel cars. Diesel cars also may be favored because on average diesel cars are newer than conventional gasoline cars and in general newer cars are driven more often than older ones. In general, Chen and Sperling [12] conclude that the economic incentives to buy and to use a diesel instead of a gasoline car is driven more by private cost consideration. Nearly half of European motorists rank the criterion “fuel costs” as one of the top concerns regarding road transportation, whereas only 15% of them are affected by environmental considerations.

D. Research questions

Explaining the (probably unintended) changes of mobility behavior due to a change in fuel economy of cars by the rebound effect delivers an important argument in the economic discussion about the pros and cons of different approaches in energy and climate policies. Far from ideological arguments it becomes obvious that price-oriented instruments are superior to policy interventions targeting technological standards such as fuel economy of cars (cf. Wirl [13] for a comprehensive analysis of the economics of energy savings). However, the standard notion of the rebound effect factors out other possible influencing variables and attracts the focus of econometric research on a linear relationship between fuel efficiency of the car and car use. Frondel et al. [1], for instance, deliver a strong support for the rebound hypothesis, but at the same time they eliminate the influence of using a diesel car, when they are to explain travel activities. Moreover, other soft factors, such as different attitudes towards the environment or towards using the car, such as mentioned in [12] are totally excluded. Given our data set, which will be presented in the next section, we will provide a panel model, which allows us to test for the influence of other variables, such as subjective attitudes on households car use.

III. THE GERMAN SOCIO-ECONOMIC PANEL

A. Data

The data set used to estimate a theoretical model of the rebound effect covers two panel waves, 1998 and 2003, taken from the German Socio-Economic Panel (SOEP). The SOEP is a household panel with annually interviews of about 12 000 households and approximately 24 000 individuals in 2008. In 1998 it consists of five sub-samples which started in 1984, 1990, 1994/1995 and 1998, respectively, covering approximately 8000 households and 16 000 individuals. Individuals within these households are surveyed if they are at least 16 years of age. The topics covered by the questionnaires include household composition, occupational biographies, employment, earnings, health, environmental behavior and satisfaction indicators among many others. The units considered in our study are households holding one car.

B. Variables

According to the identity *fuel* = *F*/*Km*, expressed in logarithms log(*fuel*) = log (*F*) – log(*Km*) and given equation (2), it becomes obvious that the rebound is investigated by regressing log(*Km*), which constitutes the dependent variable, on the variable log(*fuel*), representing the fuel economy of the car as explanatory variable. Hence, we are interested in the effect of the following covariates of independent variables on the dependent variable *kmyear* as log(kilometers driven last year):

- fuel consumption per 100 kilometers of the car (*fuel*),
- price of fuel per liter in Cent of the Euro (*price*),
- whether the car runs with diesel (*diesel*, "`yes"': 1, "`no"': 0),
- OECD household income (*income*),
- number of household members (*nomemb*),
- a dummy for children living in the household (*kids*, ”yes”: 1, “no”: 0),
- the years of schooling of the head of the household (*school*),
- a dummy variable indicating whether the household head is employed or not (*employed*, ”yes”: 1, “no”: 0),

- the time of travel to the workplace in minutes (*traveltime*),
- a dummy for owning a seasonal ticket for the public transport (*ticket*, ”yes”: 1, “no”: 0),
- a dummy variable if the household head enjoys car driving (*fan*, ”yes”: 1, “no”: 0)
- and worries about the environment (*worries*, ”yes”: 1, “no”: 0)

According to our data the variable price can take four different values: The average of prices of regular and premium fuel in 1998 and 2003, and the price of diesel in 1998 and 2003. Because of the limited variation of the price, we abstain from expressing the price in logarithm.

The full set of variables is only available in the SOEP waves 1998 and 2003. In order to take full advantage of the information in the data available, and to avoid problems due to possible selection effects, we use an unbalanced panel data set. Thus, the analysis is based on n=1840 households in 1998 and n=2683 households in 2003. Out of these households, only 708 were observed in 1998 and 2003, 1132 were observed in 1998 only, and 1975 were observed only in 2003.

IV. Empirical Results

A. Descriptive Statistics

Given the rebound hypothesis, it turns out that our main interest is concentrated on the possible influence of the variables *fuel* and *price* on *kmyear*. Table 1 gives an overview of the means and standard deviations of these variables in the data set in 1998 and 2003.

Table 1: Descriptive Statistics of Selected Variables

Wave	Mean (Standard Deviation)			
	kmyear	*fuel*	*Average Price of Regualar and Premium Fuel*	*Price of Diesel*
1998	9.50	8.58	79.95	58.7
	(0.612)	(1.694)	(-)	(-)
2003	9.45	8.34	108.45	88.8
	(0.690)	(1.724)	(-)	(-)

Table 1 shows that the mean number of kilometers driven in our sample slightly decreased by 3% from 1998 to 2003 in our sample, but at the same time the variation increased. In absolute figures the mean of travel activities decreased from 15,788 km per year in 1998 (standard deviation: 9,380) to 15,318 km (10,388) in 2003. Similarly, in the same period, the mean fuel consumption of cars decreased, but again, the variation increased. On the other hand, the prices of regular/premium fuel increased from 1998 to 2003 as well as the price of diesel.

These descriptive results imply that, at least in our sample, there is a reduction of the mean fuel consumption of cars but at the same time, there is only a slight decrease in the number of kilometers driven per year. This may be interpreted as a slight indicator for a possible rebound effect. However, it seems to be clear that households travel activities are largely affected by the sharp increase in fuel prices of about 35.6% (and even more for diesel) between 1998 and 2003. In order to draw inferences about a more general population and to disentangle these effects as well as to isolate possible additional effects of subjective variables, we need to estimate the effects of the different variables simultaneously in a model.

B. Model

We model the effect of the covariates on the dependent variable *kmyear* via a linear regression model which, besides covariates, includes the intercept. We further assume that unobserved individual effects which are invariant over time have an effect on the dependent variable. Thus we adopt a linear regression model and assume that the units are independent of each other. In addition, assuming the individual

unobserved effects as random, leads to a linear random effects model (e.g., Baltagi [14]).

According to the rebound hyothesis, *kmyear* is treated as dependent variable to be explained by the covariates of the dependent variables as listed above. Moreover, in order to test for possible non-linear effects of the efficiency variable *fuel*, we also included log(fuel) in the set of dependent variables.

C. Results

The overall F-test rejects the null hypothesis of "no effect of the covariates" at the 0.1%-level, R^2 is 0.53 for this model. The estimated variance of the unobserved individual effects is 0.160 and 0.247 for the error variance, leading to an estimated correlation of about 0.39 of the combined individual effects and the error terms. Estimation results with respect to the effects of individual covariates based on this model are given in Table 2.

Table 2: Estimation Results of RE-Model

Variable	Coefficient	Std-Error	T-Value
Constant	7.8420	0.3831	20.47***
Fuel	-0.1437	0.0362	-3.96***
log(fuel)	1.2574	0.3135	4.01***
Price	-0.0035	0.0006	-5.39***
Diesel	0.2417	0.0334	7.23***
income/100	0.0003	0.0001	2.11*
Nomemb	0.0100	0.0118	0.85·
Kids	-0.0018	0.0302	-0.06
School	0.0149	0.0040	3.75***
Employed	0.0394	0.0824	0.48·
Traveltime	0.0062	0.0006	10.78***
Ticket	-0.2121	0.0314	-6.75***
Fan	0.1295	0.0212	6.11***
Worries	-0.0602	0.0218	-2.76**
$p(F)<0.01$, $R^2=0.53$			

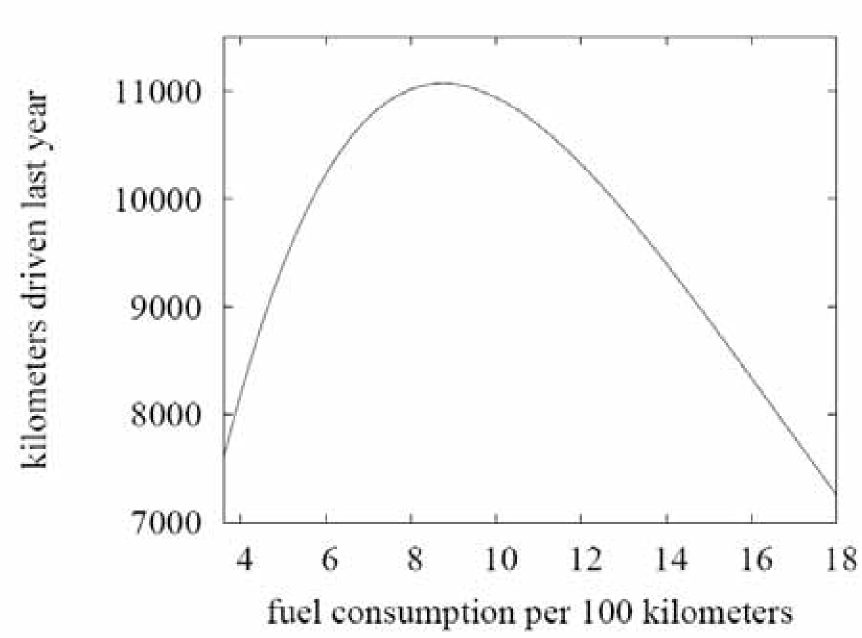
Table notes. Dependent variable: kmyear.

Significance codes: '***'`: 0.001; '**': 0.01; '*': 0.05; '.': 0.1.

The results shown in table 2 imply that there is a significant negative effect of the price of fuel per liter on travel activity at the 0.1% level. Mobility behavior is price sensitive; car use is reduced as the fuel price increases. Contradicting Frondel et al. [1] we identify a significant positive effect of the diesel dummy on the kilometers driven at the 0.1% level. Owning and using a diesel engined car has a positive effect on the driven distance.

The effect of the efficiency variable fuel consumption log(*fuel*) on travel activities is significant at the 0.1% level. However, the standard rebound hypothesis has to be rejected, because of the positive sign of the coefficient stating that an increase in fuel consumption of the car induces additional travel. But note, that there is a non-linear effect, driven by the negative coefficient of the linear value of *fuel*. The different signs of the coefficients show that the dependent variable is positive influenced by log(*fuel*), but because of the positive sign of the linear variable the effect becomes non-linear. Technically speaking, because of the simultaneous influence of both, the linear and the logarithm of fuel consumption on the logarithm of kilometers driven last year, the rebound effect cannot be interpreted in the traditional, linear perspective. The following figure 1 gives an impression of the estimated effect of fuel consumption per 100 kilometers on kilometers driven last year.

Figure 1: A Non-Linear Rebound Effect



For simplicity, we restricted the values of all other covariates to zero in order to interpret this non-linear effect. According to the estimated effect the kilometers driven increases with increasing fuel consumption from 3.6 to around 8 liters, holding all other influencing factors constant. This effect may be due to a preference for larger, more comfortable cars to cover longer distances. However, for a consumption of more than around 8 liters, the kilometers driven decrease with increasing consumption. This effect may be interpreted as rebound effect, which seems to operate in addition to the diesel and the price effect in the segment of cars that need more than 8 liters per 100 kilometers.

In addition, the results in Table 2 reveal positive effects of income and the years of schooling at least at a 5% level. Thus the kilometers driven increase with income, the number of years in school of the household head and with the time of travel to the workplace. As one might expect, owning a seasonal ticket for the public transport has a negative effect on private car use. Interestingly, the subjective variables are significant at least at the 1% level, with a positive effect of the dummy variable "household head enjoys car driving" and a negative effect of "worries about the environment".

V. SUMMARY AND CONCLUSION

Our results suggest that in line with the rebound hypothesis, there is a negative effect of efficiency on the kilometers driven. That is, the lower the fuel consumption, the larger the driven distance. However, contrasting recent empirical literature about the rebound effect in the transportation sector such as Frondel et al. [1], this seems to be true only for cars with a consumption of more than roughly eight liters per hundred kilometers. In addition, we find a positive diesel effect, which implies that owning a diesel engined car, has a positive effect on the driven distance. Both effects can be interpreted as support for the rebound hypotheses, although not in a simple linear way. Further, a negative effect of price of fuel suggests that the efficiency effect operates beyond the price for fuel. Beside positive effects of income, education and travel time to the workplace, households private car use is also affected by the use of public transport as owning a seasonal ticket for the public transport reduces private car use. Interestingly, our results show that some “soft” variables have significant influence on private car use. Travel activities are significantly affected by general emotional attitudes towards car driving und subjective attitudes towards the environment. Enjoying car driving and being not worried about the status of the environment increases the number of kilometers driven by the household.

Summarizing, our results support the general direction of the rebound effect on households travel activities. But because of the remaining political relevance of the rebound effect, they also highlight the importance of accounting for additional behavioural variables which tend to influence individual mobility behaviour. Hence, the classical interpretation of the rebound as a linear effect of advances in fuel economy on individual travel has to be questioned.

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