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Manuel Frondel and Colin Vance[1]

Future Pain at the Diesel Pump? Potential Effects of the European Commission's Energy Taxation Proposal

Abstract

The Energy Tax Directive recently proposed by the European Commission envisages to tax fuels based on their energy content. By raising prices for diesel to a level higher than that of petrol, this proposal would eliminate the price advantage currently enjoyed by diesel in most EU Member States. To explore the implications of such a tax regime for automobile travel, the present analysis undertakes a comparative analysis of price elasticities for both fuel types. Drawing on household panel data from Germany, we fail to reject the hypothesis that the fuel price elasticities for petrol and diesel are equal. With our uniform fuel price elasticity estimates being on the order of -0.5 to -0.42, the typical finding from the empirical literature that the elasticities gleaned from household-level data are generally larger than those from aggregate time-series data is reconfirmed.

JEL Classification: L98, Y10

Keywords: Fuel taxation; fuel price elasticities; household data; automobile travel; panel

September 2011

1 Manuel Frondel, RWI, RUB; Colin Vance, RWI and Jacobs University Bremen. *– We are grateful for invaluable comments and suggestions by Christoph M. Schmidt. Furthermore, we highly appreciate Michael Simora's research assistance. This work has been supported by the Collaborative Research Center "Statistical Modeling of Nonlinear Dynamic Processes" (SFB 823) of the German Research Foundation (DFG), within the framework of Project A3, "Dynamic Technology Modeling".* *– All correspondence to Colin Vance, Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), Hohenzollernstr. 1-3, 45128 Essen, Germany. E-Mail: vance@rwi-essen.de.*

1 Introduction

A fracas is brewing in Europe over a draft directive from the European Commission that would radically alter how motor and heating fuels are taxed in the European Union. Under the proposed revision of the Energy Taxation Directive, which is facing vigorous opposition from the automobile industry, Member States of the European Union (EU) would be compelled to tax fuels based on both their energy content and on the related carbon dioxide (CO2) emissions, thereby creating an environmentally based approach to taxation that eliminates the price advantage currently enjoyed by diesel. This advantage owes to the fact that current per-liter tax rates appear to be arbitrary, rather than being proportional to the energy content, with most Member States setting substantially lower rates of taxation for diesel than for petrol. In Germany, France, and the Netherlands, for example, the gap between petrol and diesel fuel taxes stands at 18 cents per liter and more, resulting in prices at the pump being on average 15% higher for petrol in Germany (MWV, 2011a).

The timing of the proposal's entry into force, tentatively set for 2013, coincides with the beginning of the third phase of the EU's emissions trading scheme (ETS), and complements the ETS by introducing a tax on carbon for those sectors that have thus far been exempt from carbon emission restraints, such as transport and agriculture. In fact, the draft is intended to amend the current system of fuel-specific minimum tax rates[1] by creating a scheme that would yield a uniform carbon tax of 20 Euro per metric ton of carbon dioxide for all fuels (DIEMER, 2011). By specifically encouraging higher diesel prices, the Commission anticipates that such a revision of the tax regime will not only reduce CO2 emissions, but also improve local air quality. Whether this optimism is well-founded depends crucially on the responsiveness of motorists to increases in prices of different fuel types. To the extent that diesel drivers have a lower elasticity of demand than petrol drivers, as is found by DAHL (2011) in an extensive survey of hundreds of empirical studies, the environmental effectiveness of the policy would be

[1]For example, the minimum tax rate set by the European Commission for EU Member States amounts to 33 cents per liter diesel, whereas it is 35 cents per liter for gasoline.

muted.

Yet, while the literature on fuel price elasticities is vast and has been ably summarized in several review articles (e.g. DAHL, 2011; DAHL and STERNER, 1991; GRAHAM and GLAISTER, 2002; GOODWIN, DARGAY and HANLY, 2004; BASSO and OUM, 2007), the overwhelming majority of demand sensitivity analyses focuses on petrol fuel to the exclusion of diesel (STERNER, 2007:3196). This creates a sizeable void in our understanding of demand responses to fuel price changes, particularly with respect to Europe, where the share of diesel engines in new car registrations reached some 53% in the EU-15 in 2007 (ACEA, 2011a), and has more than doubled since 1994 when the share was about 23%.

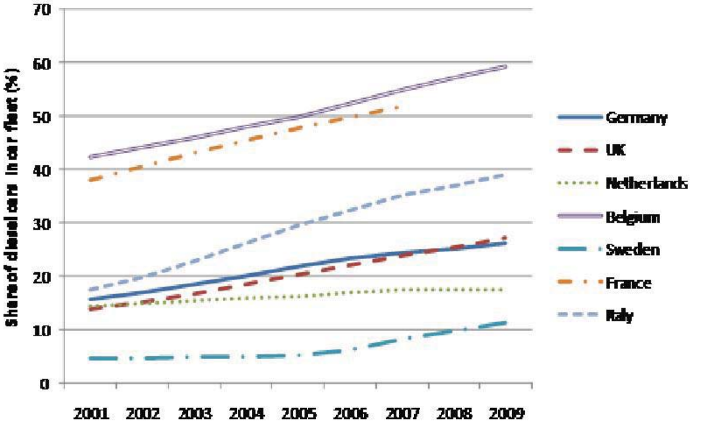
The aim of the present analysis is to fill this void by undertaking a comparative analysis of fuel price elasticities for petrol and diesel in Germany, which is home to some of the EU's biggest car manufacturers and has one of the highest per-capita car ownership rates in Europe. To this end, we begin by drawing on Becker's household production framework to demonstrate why, theoretically, there is reason to expect short-run fuel price elasticities for diesel and petrol to be equal. Subsequently, we test this hypothesis by drawing on household-level data collected between 1997 and 2009, focusing on single-car households that did not change their car within the three-year period they are surveyed at most. Our empirical results obtained from panel models indicate that demand responses do not differ significantly across fuel types. We find uniform, but relatively high fuel price elasticities on the order of -0.5 to -0.42, which substantiates a recent German study by FRONDEL, PETERS, and VANCE (2008). Taken together, these findings support the efficacy of fuel taxation based on energy content as a transport demand management tool.

The following section provides for some descriptive statistics on the usage of diesel versus petrol cars for individual transport purposes in Germany. Using BECKER's household production framework, Section 3 develops a theoretical model on mobility demand and its response to fuel prices. Section 4 describes our modeling approach, which draws on alternative panel estimators. This is followed by a concise description of the panel data set in Section 5. The presentation and interpretation of the results is covered in Section 6, while the last section summarizes and concludes.

2 Diesel versus Petrol Cars in Germany

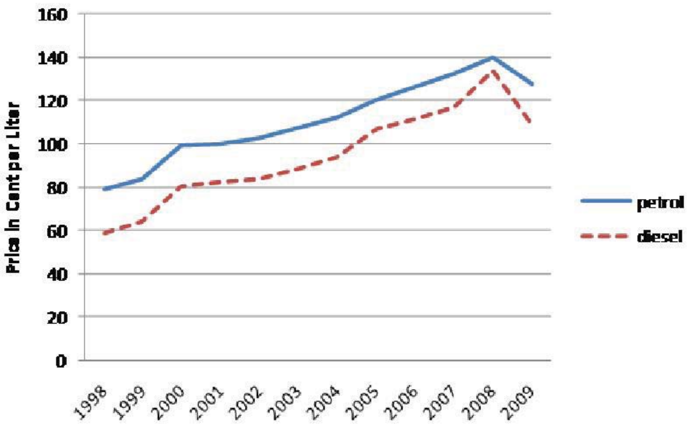
Almost all over Europe, the share of diesel cars in the fleet of private automobiles has increased substantially since the beginning of the millennium (Figure 1). In Germany, this share has grown from 16% in 2001 to 26.2% in 2009, but is still significantly below the EU average, which amounted to 33.7% in 2008 (ACEA, 2011b). In other EU countries, such as Belgium and France, the diesel share in the car fleet is much higher than in Germany. In Belgium, for instance, the diesel share was as high as 60% in 2009, most likely due to the large price advantage of diesel relative to petrol fuel and the fact that, in contrast to other countries, the motor vehicle tax does not differ for diesel and petrol cars.

Figure 1: Share of Diesel Cars in the Fleet of Private Automobiles (EUROSTAT, 2011).



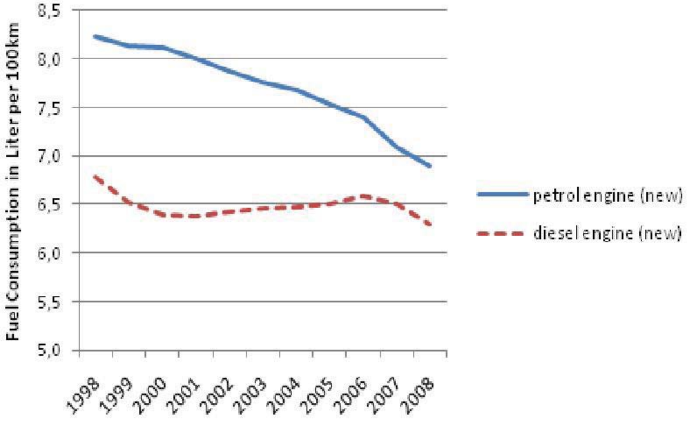
Yet, with a strongly increasing share of diesel engines among the newly registered cars in Germany, the gap between the EU average and the share of diesel cars in the fleet of private automobiles in Germany diminished in recent years. In 2007, the share of diesels among newly registered cars was as high as about 47%, declining thereafter to 41.9% in 2010 (KBA, 2011a). A key reason for this drop may have been the temporarily shrinking difference in the prices of diesel and petrol fuels, with a particularly small price distance to be observed for the year 2008 (Figure 2), a consequence of the surge in global demand for diesel fuel. Since then, the difference between diesel and petrol prices has returned to the long-term average of the price gap of about 18 Euro Cents per liter, precisely reflecting the difference in fuel taxes in Germany: While the fuel tax on diesel amounts to 47 Cents per liter, it is as high as 65 Cents per liter for petrol.

Figure 2: Nominal Prices of Diesel and Petrol Fuels in Germany (MWV, 2011b).



Besides significant price advantages of diesel fuel due to lower fuel taxes, the trend towards diesel engines owes largely to the higher fuel efficiency of diesel cars relative to petrol automobiles. In 2008, the average fuel consumption of newly registered diesel cars in Germany amounted to about 6.3 liters per 100 kilometers, whereas the average fuel consumption of new petrol cars was 6.9 liters per 100 kilometers (Figure 3). Due to technological progress, however, this disadvantage of petrol cars has been substantially reduced and can be expected to diminish further in the future. If the draft directive of the European Commission to tax fuels on the basis of their energy content becomes legislation, the current price advantage of diesel fuel will be eradicated because its energy content is roughly 12% higher than that of petrol fuel.[2] Both potential developments would leave consumers with hardly any incentive to buy diesel cars in the future, unless motor vehicle taxes are abolished for diesel cars in order to compensate for their higher sales prices.

Figure 3: Average Fuel Efficiencies of Newly Registered Diesel and Petrol Cars in Germany (BMWI, 2011).



From an environmental perspective, a decreasing share of diesel cars might be beneficial for several reasons. First, the combustion of diesel fuel leads to higher CO2 emissions than for petrol. As a result of the combustion of one liter diesel, 26.5 grams of CO2 are produced, while the combustion of one liter petrol implies lower emissions of 23.2 grams of CO2 (KBA, 2011b: 6). It was just due to the higher fuel efficiency of diesel cars in the past that, on average, the related CO2 emissions on a per kilometer basis were lower than those of petrol cars. This advantage has disappeared now: Using the 2008 average fuel efficiencies of new petrol and diesel cars of 6.9 and 6.3 liters per

[2]The Commission's proposal would effectively raise the minimum tax rate for diesel from 33 to 41.2 cents per liter by 2023.

100 km, respectively, as well as the above per-liter emission values, the specific CO2 emissions per 100 km amount to about 160 grams for newly registered petrol cars, but about 167 grams for new diesel cars.[3]

Second, while, on average, newly registered diesel cars produce more CO2 emissions on a per-kilometer basis than petrol cars, diesels also cause more harmful emissions of nitrogen oxides (NOx), particulate matter (PM), and noise. All of these gases and exhausts are hazardous to human health, as they can cause serious diseases such as cancer. In fact, the combustion of diesel produces about three times more NOx than that of petrol fuel, and the air pollution due to particulates, also known as "black smoke", is far worse (OECD, 2004: 16, 99, 132). This is the reason why diesel engines must have a particle filter these days. It bears noting, however, that with the application of exhaust after-treatment and filter traps, diesel engines could perform equally well even in terms of NOx and PM emissions (OECD, 2004: 10).

Due to technological progress and stricter environmental laws, the emissions of sulfur dioxide (SO2) originating from diesel cars were substantially reduced, so that today the SO2 emissions levels of both diesel and petrol cars are roughly the same and their exhausts are almost sulfur-free (OECD, 2004: 32, 71, 85). All in all, though, diesel cars appear to have more negative environmental impacts than comparable petrol cars. As these negative impacts are not internalized, today's case for the relatively low fuel taxes for diesel is questionable.

3 Theoretical Considerations

In this section, we provide for a theoretical discussion on why the households' demand responses to the same relative fuel price increases is expected to be equal across fuel types, despite the fact that diesels are generally more fuel-efficient than petrol cars. Along the lines of BECKER's (1965) seminal work on household production, we assume

[3]The ambitious aim of the European Commission is to reduce the average CO2 emissions of newly registered cars to 95 grams per 100 km in 2020 (UBA, 2010).

that households are, ultimately, not interested in the amount of energy required for a certain amount of service, but in the energy service, such as mobility and home heating, itself:

$$s = f(e, t, k, o), \tag{1}$$

where production function f describes how households "produce" the service in the amount of s by using time, t, capital, k, other market goods o, and energy, e. The higher the efficiency μ of a given technology, the less energy $e = s/\mu$ is required for satisfying the service demand s, which reflects the definition of energy efficiency typically employed in the economic literature (see e. g. BINSWANGER, 2001:121):

$$\mu = \frac{s}{e} > 0. \tag{2}$$

This efficiency definition assumes proportionality between service level and energy input regardless of the level – a simplifying assumption that may not be true in general, but provides for a convenient first-order approximation of the relationship of the service level with respect to the energy input. For the specific example of individual conveyance, parameter μ can be measured in terms of vehicle kilometers per liter of fuel input.

Based on efficiency definition (2), it follows that the price p_s per unit of the energy service, given by the ratio of service cost to service amount, is smaller the higher the efficiency is:

$$p_s = \frac{e \cdot p_e}{s} = \frac{e}{s} \cdot p_e = \frac{p_e}{\mu}\,. \tag{3}$$

Taking logs and differentiating $\ln p_s$ with respect to $\ln p_e$ in expression (3), it can be seen that, irrespective of the level of efficiency μ, a relative increase in fuel price $\ln p_e$ translates into an identical relative increase in the price per mobility service:

$$\frac{\partial \ln p_s}{\partial \ln p_e} = \frac{\partial \ln p_e}{\partial \ln p_e} - \frac{\partial \ln \mu}{\partial \ln p_e} = 1\,, \tag{4}$$

if $\frac{\partial \ln \mu}{\partial \ln p_e} = 0$. This assumption may particularly hold true for our short-term analysis for which we deliberately confine ourselves to single-car households that did not change their cars within the three-years period they are surveyed. In this context, one would therefore expect that the fuel price elasticities for petrol and diesel are equal if the level s of the mobility service merely depends on the price p_s of this service.

Using BECKER's household production framework and assuming that any household's utility depends solely on the amounts $s_1, ..., s_n$ of n energy services, such as mobility, home heating, and cooling:

$$U = u(s_1, s_2, ..., s_n) \quad \text{with} \quad \frac{\partial u}{\partial s_i} > 0 \quad \text{and} \quad \frac{\partial^2 u}{\partial s_i^2} < 0 \quad \text{for } i = 1, ..., n, \tag{5}$$

it is now shown that the equality of the the fuel price elasticities for petrol and diesel seems plausible, at least in the short term, if fuel prices decrease service demand s_i, but do not alter the input of time t_i, capital k_i, and other market goods o_i.

To this end, it is assumed that households maximize utility subject to the following budget constraints and time restrictions:

$$T = t_w + \sum_{i=1}^{n} t_i, \tag{6}$$

where any household's available time budget T is split up into the hours t_w spent on working and the time necessary to produce services. With w denoting the wage rate, households face the budget constraint

$$t_w w = \sum_{i=1}^{n} p_{e_i} e_i + p_{k_i} k_i + p_{o_i} o_i, \tag{7}$$

if the non-wage income is assumed to be zero for the sake of simplicity. p_{e_i} and p_{o_i} indicate the prices of energy and other market good inputs, respectively, while p_{k_i} captures the annualized investment cost required for satisfying the demand s_i for service i.

The Lagrangian L for the utility maximization problem subject to budget constraint (7) and time restriction (6) reads:

$$L := u(s_1, s_2, ..., s_n) - \lambda \left[\sum_{i=1}^{n} (p_{e_i} e_i + p_{k_i} k_i + p_{o_i} o_i + w t_i) - wT \right]. \tag{8}$$

If joint production is ruled out, the first-order condition with respect to service j is given by

$$\frac{\partial u}{\partial s_j} = \lambda \left[p_{e_j} \frac{\partial e_j}{\partial s_j} + p_{k_j} \frac{\partial k_j}{\partial s_j} + p_{o_j} \frac{\partial o_j}{\partial s_j} + w \frac{\partial t_j}{\partial s_j} \right]. \tag{9}$$

If price alterations merely change the service demand s_j, but do not alter the input of time t_j, capital k_j, and other market goods o_j, that is, if

$$\frac{\partial t_j}{\partial s_j} = 0, \frac{\partial k_j}{\partial s_j} = 0, \text{and } \frac{\partial o_j}{\partial s_j} = 0, \tag{10}$$

then service demand s_j solely depends on p_{s_j}:

$$\frac{\partial u}{\partial s_j} = \lambda \cdot p_{s_j}, \tag{11}$$

where we have employed price relationship (3), i. e. $p_{s_j} = p_e/\mu_j$, and $\partial e_j/\partial s_j = 1/\mu_j$, thereby exploiting efficiency definition (2).

4 Econometric Model

Along these theoretical lines, the main objective of our empirical analysis is to test the hypothesis that the elasticity of mobility demand with respect to petrol and diesel prices are equal. Two fuel price variables are consequently included in the specification of our econometric model: $\ln(p_g)$ designates the logged price paid for petrol if the car uses petrol fuel and amounts to 0 otherwise, while $\ln(p_d)$ denotes the logged price paid for diesel if the car uses diesel fuel and amounts to 0 otherwise. In addition, the specification includes a dummy variable diesel, indicating diesel cars, and a set of variables designated by the vector $\mathbf{x}$ to control for household attributes and factors that may corrupt assumption (10), such as the density of the public transit system. Denoting the log of monthly kilometers traveled by $\ln(s)$, the model to be estimated is:

$$\ln(s_{kt}) = \alpha_0 + \alpha_{p_g} \cdot \ln(p_{g_{kt}}) + \alpha_{p_d} \cdot \ln(p_{d_{kt}}) + \alpha_d \cdot diesel_{kt} + \boldsymbol{\alpha}_{\mathbf{x}}^T \cdot \mathbf{x}_{kt} + \xi_k + \nu_{kt} \,. \tag{12}$$

Subscripts k and t are used to denote the observation and time period, respectively. ξ_k denotes an unknown individual-specific error term, ν_{kt} is a random component that varies over individuals and time, while the alpha's designate the coefficients to be estimated and the superscript T indicates the transposition of a vector.

The availability of panel data affords three principle approaches for the econometric modeling of transport demand: the fixed-, between-groups, and random-effects estimators. The key advantage of using the fixed-effects estimator is that it captures the influence of time-invariant, unobservable factors ξ_k, such as topography and urban form that are potentially correlated with the explanatory variables, thereby producing consistent estimates. In contrast, random effects treats the ξ_k as part of the disturbances, thereby assuming that their correlation with the regressors is zero. If this assumption is met, the random-effects estimator is a viable alternative, as it confers the advantage of greater efficiency over the fixed-effects estimator. Violation of the assumption, however, implies biased estimates. Likewise, the between-groups effects estimator, which is equivalent to an OLS regression of averages across time, is subject to bias if the error term is correlated with the regressors.

While most analyses neglect between-groups effects, instead focusing on the choice between fixed and random effects, we see merit in applying all three estimators. Doing so allows us to individually distinguish for each variable between fixed and random effects using a test presented by FRONDEL and VANCE (2010) that, in essence, is based on the comparison of the fixed- and between-groups effects. This test is an alternative to the HAUSMAN test commonly employed to test the null hypothesis that the fixed effects are equal to the random effects, which, if not rejected, would suggest adoption of the random-effects estimator due to its higher efficiency. Yet, testing the hypothesis that the fixed- and the random effects are equal is numerically identical to testing that the between-groups and fixed effects are equal – see e. g. BALTAGI (2005:67) – and thus that the inter-temporal within-subject effects are the same as the cross-sectional effects across subjects.

Departing from the standard panel data model (12) and estimating the specification

$$\begin{aligned} \ln(s_{kt}) \;=\; & \alpha_0 + \alpha^b_{p_g} \cdot \overline{\ln(p_{g_k})} + \alpha^w_{p_g} \cdot (\ln(p_{g_{kt}}) - \overline{\ln(p_{g_k})}) \\ & + \alpha^b_{p_d} \cdot \overline{\ln(p_{d_k})} + \alpha^w_{p_d} \cdot (\ln(p_{d_{kt}}) - \overline{\ln(p_{d_k})}) \\ & + \alpha^b_d \cdot \overline{diesel_k} + \alpha^w_d \cdot (diesel_{kt} - \overline{diesel_k}) \\ & + (\boldsymbol{\alpha}^b_{\mathbf{x}})^T \cdot \bar{\mathbf{x}}_k + (\boldsymbol{\alpha}^w_{\mathbf{x}})^T \cdot [\mathbf{x}_{kt} - \bar{\mathbf{x}}_k] + \xi_k + \nu_{kt} \end{aligned} \quad (13)$$

via OLS simultaneously yields estimates of the between-groups- and fixed effects, where the parameters denoted with the superscript w and b are related to the fixed-effects and between-groups effects, respectively, and bars denote means over time. This specification not only allows to test for the equivalence of petrol and diesel price elasticities using either the fixed-, between-groups-, or random-effects estimates, but, by exploiting the equivalence of between-groups and fixed effects under the null, also allows us to examine the equality of the fixed- and between-groups effects for individual variables, as well as that of the whole range of coefficients. For this specification, we can use simple t-tests to determine for which variables the assumption of equivalence holds.

5 Data

The data used in this research is drawn from the German Mobility Panel (MOP, 2011), an ongoing travel survey that was initiated in 1994. The panel is organized in overlapping waves, each comprising a group of households surveyed for a period of six weeks in the spring for three consecutive years. All households that participate in the survey are requested to fill out a questionnaire eliciting general household information, person-related characteristics, and relevant aspects of everyday travel behavior. In addition, respondents record the price paid for fuel, the liters of fuel consumed, and the kilometers driven for every car in the household.

The data used in this paper cover thirteen years, spanning 1997 through 2009, a period during which real fuel prices rose 1.97% per annum on average. We focus on single-car households that did not change their car over the three years of the survey, thereby abstracting from complexities emerging from the substitution effects among households owning multiple cars. The resulting sample includes 674 households, 301 of which appear two years in the data and 373 of which appear three consecutive years. Altogether, we are faced with 1,721 observations. We use the travel survey information, which is recorded at the level of the automobile, to derive the dependent and explanatory variables. The dependent variable, which is converted into monthly figures to adjust for minor variations in the survey duration, is the total monthly distance driven in kilometers. The key explanatory variables for estimating fuel price elasticities are the prices paid for fuel per liter of diesel and petrol. The price series were deflated using a consumer price index for Germany obtained from DESTATIS, 2011.

Table 1: Variable Definitions and Descriptive Statistics

Variable Name	Variable Definition	Mean	Std. Dev.
s	Monthly kilometers driven	1,118.2	681.9
p_d	Real diesel price in € per liter	0.903	0.165
p_g	Real gasoline price in € per liter	1.047	0.136
diesel	Dummy: 1 if fuel type is diesel	0.138	–
children	Dummy: 1 if children younger than 10 live in the household	0.127	–
# employed	Number of employed household members	0.738	0.770
# diploma	Number of household members with a college preparatory diploma	0.552	0.726
income	Net monthly household income in 1,000 €	2.106	0.672
job change	Dummy: 1 if an employed household member changed jobs within the preceding year	0.095	–
work distance	Furthest Distance from home to work in km among employed household members	7.925	12.863
car vacation	Dummy: 1 if household undertook vacation with car during the survey period	0.228	–
population density	People in 1,000 per square km in the county in which the household is situated	0.966	1.065
transit density	Density of public transit service in 1,000,000 services per areal unit in square km	0.038	0.050

In addition to fuel prices, several socio-demographic attributes are specified as control variables in the analysis, the descriptive statistics for which are presented in Table 1. Demographic influences are measured by a dummy indicating the presence of children under 10, the number of employed persons, and the number of persons with a college preparatory degree. Household income is captured by a categorical variable that measures monthly disposable income. Geographic and spatial features are captured by the furthest observed distance in kilometers between home and work among employed people in the household, the population density of the district where the household is located, and a variable measuring the density of the local transit service. The variable *transit density* is constructed by dividing the mileage of transit travel for all modes by the area of the transit zone. Finally, to control for events that may disrupt the normal pattern of travel, dummies are included indicating whether any employed member changed jobs in the preceding year and whether the household undertook a vacation with the car during the survey period. The inclusion of time dummies for each year was also explored, but these were found to be statistically insignificant both individually and jointly.

6 Empirical Results

Table 2 presents the coefficients from the fixed-, between-groups-, and random effects estimators. With respect to the central focus of the analysis on fuel price elasticities, the range in the estimates across the three models is seen to be relatively tight. Diesel price elasticities vary between -0.426 and -0.411, while those for petrol are slightly higher, varying between -0.509 and -0.445. The absence of statistically significant differences between the models is confirmed by the t-tests presented in the final column, which fails to reject the equivalence of the fixed- and between-groups effects estimates of the diesel and petrol price coefficients.

Turning to each model individually, we additionally undertake a test for the equivalence of the price elasticities across the two fuel types, the results from which are presented in the final three rows of the table. These tests also confirm what can be gleaned from casual observation: that the elasticity with respect to fuel price for diesel is not significantly different from that with respect to petrol. We thus find empirical support for our theoretical conjecture that drivers of diesel cars exhibit the same responsiveness to fuel price changes as drivers of petrol cars. As presented in the appendix, other specifications of the model including squared and interaction terms were also explored, none of which call into question the robustness of this finding.

Table 2: Estimation Results for the Determinants of Driving.

	Fixed Effects		Between-Groups Effects		Random Effects		T tests
	Coeff.s	Std. Errors	Coeff.s	Std. Errors	Coeff.s	Std. Errors	$\alpha_b = \alpha_w$
$\ln(p_d)$	*-0.421	(0.183)	**-0.416	(0.300)	** -0.437	(0.163)	0.009
$\ln(p_g)$	** -0.505	(0.158)	**-0.447	(0.173)	** -0.482	(0.112)	0.193
diesel	–	–	0.196	(0.069)	0.240	(0.063)	–
children	0.043	(0.111)	0.025	(0.064)	0.055	(0.049)	0.374
# diploma	0.051	(0.035)	* 0.066	(0.031)	* 0.053	(0.023)	1.301
# employed	0.074	(0.041)	** 0.100	(0.034)	** 0.065	(0.025)	2.334
job change	* 0.111	(0.046)	* 0.210	(0.089)	** 0.147	(0.040)	0.904
income	0.009	(0.028)	0.023	(0.038)	0.015	(0.022)	0.516
work distance	0.001	(0.002)	** 0.013	(0.002)	** 0.007	(0.001)	** 3.575
car vacation	** 0.314	(0.034)	** 0.491	(0.062)	** 0.345	(0.029)	2.490
population density	-0.135	(0.118)	-0.024	(0.040)	-0.026	(0.035)	-0.639
transit density	-0.471	(2.011)	-0.412	(0.857)	-0.237	(0.677)	-0.244
constant	** 6.678	(0.147)	** 6.463	(0.074)	** 6.587	(0.053)	–
$H_0 : \alpha_{\ln(p_d)} = \alpha_{\ln(p_g)}$	F(1; 1,709)=0.120		F(1; 661)=0.010		$\chi^2(1)$=0.050		
Hausman test			$\chi^2(12)$ = 73.81**				

Note: * denotes significance at the 5 %-level and ** at the 1 %-level, respectively.
Observations used: 1,721. Number of households: 674.

With regard to the remaining coefficient estimates, all of those that are statistically significant have signs that are consistent with intuition. It bears noting, however, that the equivalence found for the fuel price elasticities across the fixed- and between effects models does not hold for several of the other coefficient estimates. In particular, statistically significant differences are seen for the variables standing for the number of household members with a high school diploma (# *diploma*), the number of employed persons (# *employed*), the distance to work (*work distance*), and the dummy indicating *car vacation*.

Given these differences, it is not surprising that the classical HAUSMAN test presented in the final row rejects the null hypothesis that the fixed- and random-effects coefficients are jointly equal. On the basis of this test, a conservative interpretation would dictate referencing the fixed-effects model, as it controls for the influence of unobserved, time-invariant variables and thereby ameliorates the threat of endogeneity bias from unobserved variables. Aside from the two fuel price elasticities, the only statistically significant coefficients in this model are on the dummies job change and car vacation. The former variable suggests that a change of jobs in the previous year increases driving by 11.7%, while a car vacation increases driving by 36.9%.

7 Summary and Conclusion

Over the past decade, climate protection policy in the European Union's transport sector has relied heavily on a combination of fuel taxation and fuel efficiency standards to reduce emissions. Emphasis was shifted to efficiency standards when, in April 2009, the European Commission enacted new legislation (Regulation No. 443/2009) requiring automakers to reduce the average per-kilometer CO2 emissions of newly registered automobiles to 130g/km by 2015 (EC, 2009). Because diesel engines have traditionally had lower per kilometer emissions than petrol engines, sales of diesel automobiles – which have been promoted by lower diesel fuel taxes – have helped companies achieve progress toward reaching this target.

It is therefore not surprising that automakers have voiced adamant opposition to the recently proposed draft on a new Energy Tax Directive. By introducing a rate structure based on the per-liter energy content and the related CO2 emissions, both of which are higher for diesel than for petrol, the proposal would reverse the price advantage currently enjoyed by diesel at the pump. *Ceteris paribus*, this shift in relative fuel prices would likely lead to a decreasing share of diesel engines among new car sales, although the empirical substantiation of this conclusion has been outside the scope of this paper.

Criticism of the proposal has focused on this likely market development, and has questioned the logic of a policy change that would increase taxes on more fuel efficient diesel vehicles (ACEA, CLEPA, and FIA, 2011). But this criticism is specious. Because the benefits of higher efficiency are fully internalized by motorists in the form of lower cost per kilometer driven, the higher per kilometer efficiency afforded by diesel vehicles provides no justification for lower taxes on diesel fuel. Indeed, from a climate protection perspective, higher fuel efficiency has the adverse effect of encouraging driving and thereby offsetting the pollution reduction from the efficiency gain, a behavioral response referred to as the rebound effect. To the extent that this effect is large, it calls into question the efficacy of policies such as the CAFE-standards in the U. S. or the EC's more recent Regulation No. 443/2009, both of which aim to increase the efficiency level of the new car fleet (FRONDEL, SCHMIDT, VANCE, 2010).

Because the rebound effect emerges from varied unit costs of an energy service, its magnitude is effectively revealed by fuel price elasticities. This paper has estimated the magnitude of these elasticities by employing panel econometric methods to German household mobility data spanning 1997 to 2009, focusing on single-car households that did not change their car within the three-year survey period. We were particularly interested in testing whether the responsiveness to petrol prices is equal to that of diesel prices, a hypothesis that we failed to reject. Our estimates of fuel price elasticities range between -0.50 and -0.42, suggesting considerable scope for reducing driving through fuel taxation. Put alternatively, these estimates indicate that upwards of 50% of the emission reduction achieved through an efficiency improvement is lost to increased driving, which is in line with the rebound effects estimated by FRONDEL, PETERS, and VANCE (2008).

Based on these findings, we conclude that the Commission's renewed focus on fuel taxation policy is highly warranted. Beyond providing Member States with the opportunity to raise taxes on climate-unfriendly fuels, the proposed Energy Tax Directive would, if enacted, establish a common framework for CO2 taxation before a patchwork of schemes emerges at the member state level. Equally important, it would correct the tax advantage currently enjoyed by diesel at the pump, which has no environmental basis given the higher CO2 emissions per kilometer and more local pollutant emissions relative to petrol fuel due to the burning of diesel on a per-liter basis.

Appendix: Model with Interactions

Alternative specifications were estimated using various combinations of interaction terms to explore the robustness of the results. The following table presents a fixed-effects model that includes a quadratic specification of fuel prices in addition to the interaction of fuel prices with income and distance to work.

Table A1: Model with Quadratic Specification of Fuel Prices and Interactions

	Coefficients	Std. Errors
$\ln(p_d)$	-0.654	(0.496)
$(\ln(p_d))^2$	-0.109	(0.809)
$\ln(p_g)$	-0.422	(0.327)
$(\ln(p_g))^2$	-0.188	(0.227)
# children	-0.061	(0.114)
# diploma	-0.045	(0.037)
# employed	-0.075	(0.041)
job change	* 0.109	(0.045)
income	-0.001	(0.029)
income $\cdot \ln(p_d)$	0.086	(0.195)
income $\cdot \ln(p_g)$	-0.129	(0.165)
work distance	0.0001	(0.003)
work distance $\cdot \ln(p_d)$	0.0004	(0.010)
work distance $\cdot \ln(p_g)$	0.028	(0.019)
car vacation	** 0.317	(0.034)
population density	0.123	(0.120)
transit density	1.695	(2.080)
constant	** 6.675	(0.150)

Note: * denotes significance at the 5 %-level and ** at the 1 %-level, respectively. Observations used: 1,721. Number of households: 674.

As indicated by an F-statistic of F(4; 1,703)= 0.35, this model also fails to reject no statistically significant differences in the effects of diesel and petrol fuel:

$$H_0 : \alpha_{\ln p_d} = \alpha_{\ln p_g}, \alpha_{(\ln p_d)^2} = \alpha_{(\ln p_g)^2}, \alpha_{income \cdot \ln p_d} = \alpha_{income \cdot \ln p_g}, \alpha_{workdistance \cdot \ln p_d} = \alpha_{workdistance \cdot \ln p_g}.$$

Other specifications were also explored that confirmed this finding.

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