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Tax Policy and CO_2 Emissions

An Econometric Analysis of the German Automobile Market

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Colin Vance and Markus Mehlin*

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Abstract
In addition to efficiency standards and consumer information, car-related taxes constitute one of three pillars of the European Commission's strategy to reduce CO_2 emissions from passenger cars. A longstanding question concerns the effectiveness of such taxes in determining the car-purchasing behavior of households. Several recent studies suggest that purchases are primarily determined by retail costs rather than by taxes, the latter of which are typically incurred over the lifetime of the car. Using panel data on new-car registrations in Germany, Europe's largest car market, the present paper addresses this issue with an econometric analysis of the impact of fuel costs and circulation taxes on car market shares. By employing a nested logit model that explicitly recognizes the segmented structure of the car market, the analysis takes account of correlation in unobserved shocks among cars belonging to the same market segment. Moreover, given the panel structure of the data, a fixed effects estimator is employed to control for the influence of unobservable, time-invariant automobile attributes that could otherwise induce biases in the estimated coefficients. Contrasting with much of the evidence garnered to date, the results suggest that circulation taxes and fuel costs significantly determine car market shares, and hence may serve as effective instruments in influencing the composition of the car fleet and associated CO_2 emissions.

JEL Classification: C51, L91, Q48

Keywords: Fuel tax, circulation tax, car market, Germany, panel data, nested logit model

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1. INTRODUCTION

The formulation of policies that balance economic development against environmental stewardship is one of the most pressing challenges confronting transportation planners worldwide. In the European Union (EU), where the transport sector currently accounts for 28% of total CO_2 emissions (EC, 2008), a series of policy measures have been implemented to decrease the transport intensity of the economy. These interventions have focused largely on increasing the energy efficiency of passenger cars, which alone represent nearly half of transport's emissions burden (COM, 2005). The European Commission (hereafter Commission) deems car-related taxes to be an especially critical instrument in reducing the average emissions of the new car fleet, having set a target level of 120g CO_2/km by 2012. Nevertheless, with European automobile manufacturers struggling to achieve the intermediate target of 140g CO_2/km set for 2008, progress toward this goal remains elusive.

At the individual country-level, EU-Member States have relied to varying degrees on a combination of fuel-, registration-, and annual circulation taxes (i.e. annual motor vehicle taxes paid over the lifetime of the car) as both a source of revenue and as a mechanism for influencing driver behavior. While the Commission is currently advocating the gradual abolition of the registration tax to improve the competitiveness of the European car industry, there remains uncertainty surrounding the likely economic and environmental impacts of compensatory increases in circulation- and/or fuel taxes. In contrast to registration taxes, the costs from these taxes accrue incrementally over the life of the car, raising the question of the extent to which they bear on household car-purchasing behavior. In this regard, two types of hypothetical consumers can be distinguished: those who are rational or far-sighted, basing their purchase decision on the lifetime costs of the car, and those who, for various reasons, take mainly account of retail prices when purchasing a car (COM, 2005).

The prevalence of far-sighted consumers would have immediate relevance for policy, as it would afford greater fiscal scope for influencing the composition of the new car fleet toward the achievement of the emissions targets. To date, however, empirical evidence on the responsiveness of automobile purchases to various forms of taxation is sparse. The view expressed in a Commission working document is that car purchases are more affected by retail prices than by lifetime costs (COM, 2005), a conclusion based on a study that finds no impact of circulation or fuel taxes on new car demand when the influence of retail prices is controlled for (TiS, 2002). This finding partially confirms an earlier study widely cited in Commission communications, which concludes that fuel taxes provide only small reductions in the average CO_2 of new cars compared to vehicle taxes (COWI, 2002). A more recent report on the European car market also concurs with this view, asserting that buyers of new cars do not consider the longer-term costs of owning a vehicle, and that measures such as circulation taxes will consequently have only a muted effect in determining purchasing decisions (Kågeson, 2005). A dissenting perspective is given by Goodwin, Dargay, and Hanly (2004), who find evidence to conclude that car ownership is, to some extent, determined by fuel prices, and that the linkage should therefore not be dismissed.

The present paper aims to build on this small body of evidence with an analysis of new car registrations in Germany. The German experience with vehicle taxation is of particular interest because, as Europe's largest car market, the country is a major source of transport emissions, accounting for some 19% of the EU-15 total in 2005 (Balint *et al.*, 2007). Moreover, Germany's fiscal policy is heavily reliant on fuel and circulation taxes: its fuel taxation rate is in Europe second only to the United Kingdom's, and it is one of the few countries to completely eschew registration taxes. Against this backdrop, there is currently a heated policy debate within Germany regarding the structure of the circulation tax scheme, which, in contrast with most other European countries, is currently based on the cubic capacity of the car. Several attempts to make the tax dependent on CO_2 emissions, as advocated by the Commission, have failed, largely as a result of disputes between the state- and federal governments over the distribution of revenues.

The paper begins by developing an econometric model to estimate the effect of individual automobile attributes, including taxes and technical traits, in determining market shares in Germany based on product-level car market data. The following section describes the data sources and their assembly for the quantitative analysis, and includes documentation of the evolution of the German car market for different vehicle segments over the 1995-2005 interval. Finally, model results are presented and elasticity estimates are derived therefrom to analyze the relative effectiveness of fuel and circulation taxes in influencing car-purchasing behavior.

The econometric model has two features distinguishing it from the previous studies in this area. First, by employing a nested logit model that explicitly recognizes the segmented structure of the car market, the analysis takes account of correlation in the unobserved shocks among cars belonging to the same market segment. Second, given the panel structure of the data, a fixed effects estimator is employed to control for the influence of unobservable, time-invariant automobile attributes that could otherwise induce biases in the estimated coefficients. Contrasting with much of the evidence garnered to date, the results suggest that circulation taxes and fuel costs significantly determine market shares, and hence may serve as effective instruments in influencing the composition of the car fleet and associated CO_2 emissions.

2. THE ECONOMETRIC MODEL

The automobile market is a textbook example of an interdependent market structure in which individual manufacturers each face a demand for their product that is both a function of price-awareness as well as product loyalty (Frondel, Schmidt and Vance, 2008). An important implication is that the demand for automobiles in each individual market segment is likely to be considerably more elastic than for the automobile market as a whole. Moreover, to the extent that market interdependence within segments is high, there will be correlation in the shocks among brands (i.e. car models) belonging to the same market segment.

The econometric model employed in this paper attempts to empirically accommodate these features by drawing on a method for estimating differentiated-product models using aggregate data (Berry, 1994). The method proceeds by deriving a market-level share expression from a random utility model of discrete choice at the individual consumer level. The utility consumer *i* receives from brand *j* is given by the mean quality of brand *j* plus idiosyncratic tastes for the product:

$$U_{ij} = x_j'\beta + \xi_j + \varepsilon_{ij} \qquad (1)$$

where x_j is a vector of observed product characteristics, β is a vector of parameters to be estimated, ξ_j is the average value of products *j*'s unobserved characteristics, and ε_{ij} is the distribution of consumer preferences around this mean. Different models emerge from (1) depending on the assumed distribution of the error term, among the most popular of which is the conditional logit model, which assumes an identically and independently (iid) distributed Type I extreme value error.

One drawback of the logit model is its imposition of the independence of irrelevant alternatives (IIA) assumption, requiring that when one alternative is removed from the choice set, the choice probabilities of the remaining alternatives rise by the same proportion. This assumption is, in particular, violated when the error terms are not independent, as is the case when there are subsets of alternatives for which unobserved shocks have concomitant effects. Following McFadden (1978), one can relax the IIA assumption and account for groupings of similar sets of alternatives (e.g cars belonging to the same market segment) via the nested logit model, which allows for correlations in the error terms for products within G + 1 , g = 0, . . . , G, exogenously specified groups. An additional segment is reserved for an outside good, segment 0, thereby accounting for the possibility that consumers may decide not to purchase any of the brands. The utility of consumer *i* for product *j* in the nested logit model is thus given by:

$$U_{ij} = x_j'\beta + \xi_j + \zeta_{ig} + (1-\sigma)\varepsilon_{ij} \tag{2}$$

where individual heterogeneity enters the model through the random disturbance $\zeta_{ig}+(1-\sigma)\varepsilon_{ij}$, which is assumed to have an extreme value Weibull distribution. For consumer *i*, ζ_{ig} is utility common to all products within a group *g* and has a distribution that depends on σ, which measures the degree of substitution within the segments or groups. The corresponding market share equation is:

$$s_j = \frac{e^{(\delta_j/(1-\sigma))}}{(D_g^{\sigma}\sum_g D_g^{(1-\sigma)})} \tag{3}$$

where $D_g = \sum_{j\in G_g} e^{\delta_j/(1-\sigma)}$, G_g denotes the set of automobiles of type g, and $\delta_j = x_j'\beta + \xi_j$ is the mean utility for product j.

Assuming that the mean utility from the outside good is equal to zero, Berry (1994) shows that Equation (3) can be inverted to yield the following demand equation (time subscripts are included to account for the panel structure of the data):

$$\ln(s_{jt}) - \ln(s_{0t}) = x_{jt}'\beta + \sigma\ln(s_{jgt}) + \xi_{jt} \tag{4}$$

where s_{jt} is the market share for car model *j* at time *t*, s_{0t} is the market share for the outside option (i.e. the proportion of consumers that choose not to purchase a new car), s_{jgt} is the market share of car model *j* in segment *g*, and σ is the corresponding similarity coefficient. The nested logit model is consistent with utility maximization if $0 \leq \sigma \leq 1$for any set of values in the data (McFadden, 1978). When σ equals zero, the model collapses to the standard logit; as this parameter increases, there is a higher degree of substitution among cars that belong to the same segment than among cars from different segments.

Because the share s_{jgt} is, by construction, endogenous, it must be estimated using instrumental variables. The analysis consequently follows Berry, Levinsohn, and Pakes (1995), who exploit competition within the market by using the sums of characteristics of other car models as instruments. Specifically, three sets of instruments are employed. Two of these are the sum of characteristics for other cars belonging to the same market segment, and the sum of characteristics for other cars produced by the same manufacturer. The third comprises counts of the number of car models produced by a given manufacture, the number of car models produced within a given market segment, and the number of car models produced by a manufacturer within a market segment.

To exploit both the cross-sectional and time dimensions of the data, the model in Equation (4) is estimated using the fixed-effects variant of the two-stage least squares estimator for panel data, with fixed effects dummies specified at the level of the car model. The inclusion of the dummies captures the influence of time-invariant, unobserved characteristics and thereby obviates the need to instrument for correlation between other explanatory variables and the fixed component of unobserved product quality (Nevo, 2000).

3. DATA

The primary data source used in this research is drawn from R. L. Polk Europe, a private data vendor providing comprehensive coverage of new car registrations in Europe. For the German market, the data distinguishes over 6000 car models annually based on a range of attributes, including the engine version, the number of doors, and the body-type (e.g. hatchback/sedan/station wagon). Starting from this highly detailed breakdown, we aggregated the versions based on transmission and fuel type, without discarding the other attributes that distinguish the models. This aggregation was necessary to develop a data set of cars that could be tracked over time; without it, the data would include relatively few car models observed more than one year. In this regard, it bears noting that marketing imperatives dictate that manufacturers regularly develop new names for models, often on an annual basis. Hence, the name or model number does not necessarily serve as an appropriate indicator for what is essentially the same car from one year to the next, requiring us instead to employ some degree of expert discretion in defining a model.

Given that the focus of the analysis is on the car-purchasing behavior of households, an additional feature complicating the assembly of the data is the existence of other consumer-types such as companies and government agencies, who comprise roughly 50% of the market for new cars. To the extent that cars purchased by these entities may result from different incentives than those of households, their inclusion in the data may induce biases. Drawing on company-car share estimates from the German Federal Motor Transport Authority (KBA by the German acronym), we therefore netted out these cars from the data. In doing so, we treated the company registrations of car dealers and rental agencies as private registrations, because both types of firms typically sell the cars to private customers shortly after receiving them. Consequently, roughly 18% of the registrations were designated as company cars and removed from the data. We also explored (but do not present) models in which all cars were included in the data to test for robustness. While this was found to have only a negligible bearing on the estimates, the behavior of company purchasers is an area warranting further investigation.

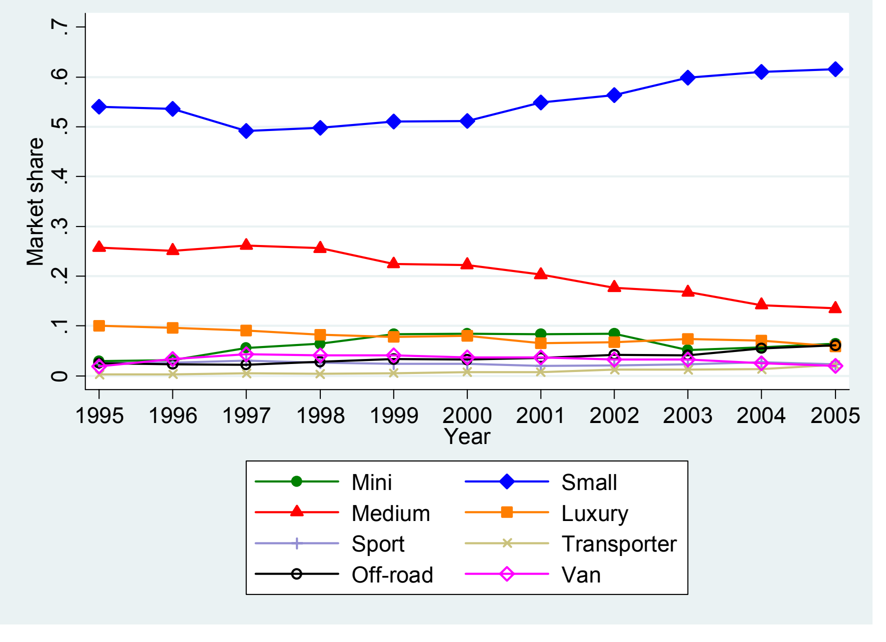
The resulting data set used for estimation comprises 681 individual models. Temporal coverage spans the 1995 to 2005 interval, with each model observed an average of 7.35 years. The data set thus comprises a total of 5007 observations. Where feasible, cross checks of the data with the official monitoring data of the European Commission were undertaken, which indicated a tight correspondence. Missing values and evident data errors were imputed using the expectation-maximization algorithm recommended by King et al. (2001).

While the calculation of the market share of each individual model j in time t, s_{jt}, can be directly derived from the data, the calculation of the outside good, s_{0t}, is complicated by the fact that the share of consumers choosing not to purchase a new automobile cannot be directly observed. To circumvent this difficulty, the analysis assumes that the annual total number of households in Germany, h_t, represents the market size for new cars, where each household is assumed to purchase one or zero cars. Denoting the total number of registrations for model j in time t as c_{jt}, the share of the outside good is given by: $s_{0t} = 1 - \sum_j \frac{c_{jt}}{h_t}$.

The evolution in the composition of the inside market is presented in Figure 1, which is generated by summing the s_{jt} over eight market segments: mini, small, medium, luxury, sport, transporter, off-road and van. The segmentation follows closely that of the KBA, which designates cars according to their size and the market position. Members of these segments include, for example, a Volkswagen Polo (4 cylinders, 75 hp) in the Small segment or a Mercedes E-Class (6 cylinders, 200 hp) in the Luxury segment. SUVs are included in the Off-Road segment and MPVs are indicated as Van. The transporter segment incorporates light commercial vehicles that are registered as passenger cars.

On the basis of the segments, two alternative nesting variables were created to explore the implications of different correlation patterns on the model results. The first variant defines the nest as the share of model *j* within its market segment *G*, s_{jgt}. The second distinguishes further by car origin, where the nest is defined by the share of model *j* within either the sub-group of foreign or domestic cars belonging to segment *G*, s_{jgft}. As a comparison, a model is also presented that constrains the nesting coefficient to be zero, corresponding to the case of the standard logit model.

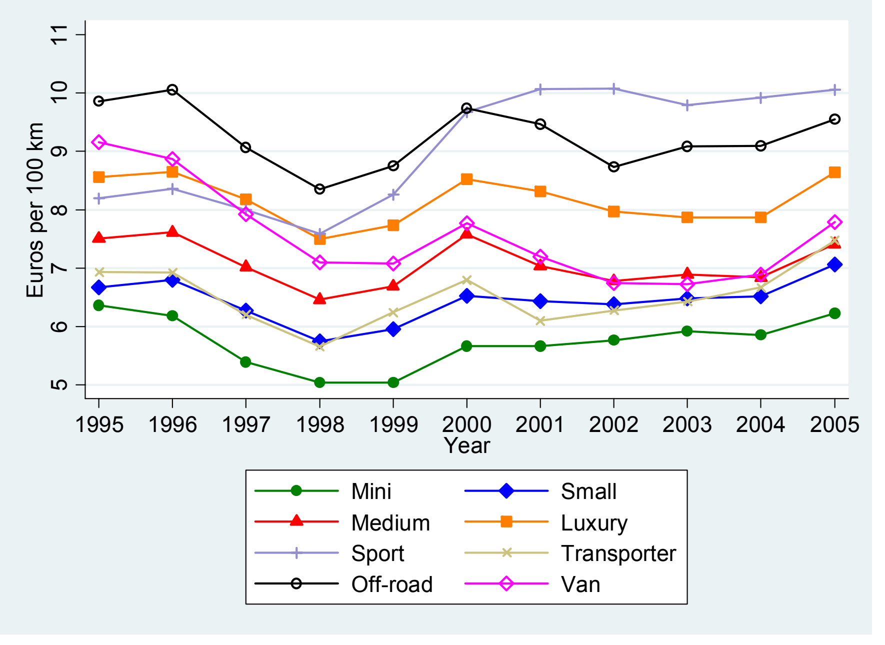
FIGURE 1: Market shares of automobile segments



The amount of the circulation tax paid for each model was entered into the data using tax documentation provided by the Federal Ministry of Finance. The figures were subsequently deflated using a consumer price index obtained from the German Federal Statistical Office (2008). Taxes are set as a function of engine capacity, measured in cubic centimeters, with different rates prevailing for petrol and diesel engines. The rates have been reduced periodically over time in order to promote the new European exhaust emissions standards (known as Euro 3 and 4). In 1995, the rate for petrol cars was set by multiplying every 100 cm^3 of the engine capacity with 6.75 €. This factor was reduced to 6.14 € in 1997 and again to 5.11 € in 1999, where it remained until 2005. Diesel cars were subject to the same temporal sequence of reductions, beginning with a factor of 18.97 € per 100 cm^3 in 1995, dropping to 14.83 € in 1997 and finally to 13.8 € in 1999. The range in tax burden has been particularly pronounced among diesel cars. In 2005, the tax level for diesel cars spanned 110 € to 676 €, with an average level of 282 €. The petrol tax burden in this year ranged between 31 € and 347 €, averaging 106 €.

The effect on market shares of an increase in the cost of driving is identified by using time-series variation in the price of fuel and time series/cross-sectional variation in the fuel efficiency of the individual car model. Information on fuel prices was obtained from the Association of the German Petroleum Industry (2008), which publishes annual figures of petrol and diesel prices in Germany. After deflating these figures using the consumer price index, they were merged by fuel type and year with the data set. Fuel efficiency, which is recorded by car model in the Polk data, is measured as liters consumed per 100 kilometers, and is based on the fuel consumption data of the "New European Drive Cycle" (93/116/EC). Although the actual fuel consumption tends to be higher than the test cycle consumption data, the latter is appropriate in modeling purchases as it serves as a standardized measure that consumers reference when comparing cars. To construct the measure of fuel-costs used in the model, fuel efficiency was multiplied by fuel price per liter, yielding a measure of fuel costs per 100 kilometers. Despite monotonic increases in fuel efficiency for most segments since 1995, Figure 2 illustrates that these costs have fluctuated substantially. By 2005, fuel driving costs reached an average level of 8 €/100 km, which, due to steadily increasing fuel prices since 2000, were slightly higher than the average of 7.9 €/100 km in 1995.

FIGURE 2: Real fuel cost of driving by segment, sales weighted



Four other control variables are included in the model that vary over both time and car models: the deflated retail price of the car divided by the national disposable income level (also in real terms), engine power (measured in kilowatts), size (length times width), and curb weight. As with circulation taxes and fuel costs, the price variable is expected to have a negative effect on market shares. Power, size, and weight, by contrast, are all expected to have a positive impact on market shares, as these attributes are typically coveted by consumers when holding fixed the costs of acquisition and operation. The model additionally includes annual year dummies to control for the effects of autonomous changes in the macroeconomic environment. Several other important determinants, including whether the car is domestic or foreign, its maintenance costs, and its reliability, are omitted from the model, many of which must be acknowledged as a potential source of bias. Nevertheless, to the extent that these factors remain fairly stable over the time period under observation, if they vary at all, their influence will be captured by the fixed effects dummies.

4. RESULTS

Table 1 shows the results from three specifications of the two-stage least squares panel models, distinguished by the inclusion and definition of the nesting variables. Model I is a standard logit model while Models II and III incorporate the nests defined by $\ln(s_{jgt})$ and $\ln(s_{jgft})$. All three models tell a consistent story. With the exception of curb weight, the automobile attributes are all statistically significant at the 1% level and have the expected signs. Circulation taxes, the fuel cost of driving, and the income-weighted price of the car have negative effects on market shares, while power and size both have positive effects. The insignificance of curb weight is undoubtedly a consequence of its strong correlation with size, which is 0.84. We also explored a model that omitted curb weight, and found that the remaining results changed only negligibly.

Referring to the similarity coefficients on $\ln(s_{jgt})$ and $\ln(s_{jgft})$, the demand estimation results from both nested models are consistent with the conditions for utility maximization, with the point estimates satisfying the condition that $0 \leq \sigma \leq 1$. Whether the model defines nests by group membership or additionally distinguishes by foreign manufacturers appears to have little bearing on the results. Both models uncover evidence for within group correlation, suggesting a higher degree of substitution among products belonging to the same group or sub-group. Moreover, as judging from the uniformly higher estimates of Models I, the implications of omitting the nesting variables are upwardly biased coefficients.

TABLE 1: **Fixed effects logit and nested-logit models of market shares**

	Logit	Nested logit	
	Model I	Model II	Model III
Circulation tax	-0.850	-0.544	-0.506
	(0.074)	(0.058)	(0.055)
Fuel driving costs per km	-0.293	-0.197	-0.186
	(0.023)	(0.018)	(0.017)
Car price/income	-0.432	-0.272	-0.255
	(0.081)	(0.055)	(0.052)
Engine power (KW)	0.014	0.008	0.007
	(0.002)	(0.001)	(0.001)
Size (length*width)	0.021	0.014	0.013
	(0.008)	(0.005)	(0.005)
Curb weight	0.315	0.154	0.102
	(0.309)	(0.200)	(0.188)
$\ln(s_{jgt})$		0.377	
		(0.040)	
$\ln(s_{jgft})$			0.431
			(0.040)
F(10, 4310) time dummies	14.41		
Chi sq (10) time dummies		87.7	81.42
R^2	0.11	0.66	0.65
Number of observations	5007	5007	5007

Standard errors in parentheses

Turning to the extent to which circulation taxes and fuel costs affect market shares, Table 2 presents own-elasticity estimates and associated standard errors for the individual market segments. Drawing specifically on the coefficients from Model III (and noting that those from Model II yield very similar estimates), the elasticities are calculated by:

$$\eta = \frac{\beta_x}{1-\sigma} x_{jt} (1 - \sigma s_{jgt} - (1-\sigma) s_{jt}) \tag{5}$$

As Equation (5) is comprised of multiple parameters that preclude analytical computation of the variance, the Delta method is used to calculate the standard errors.

TABLE 2: Elasticity estimates by market segment

	Circulation tax	Fuel cost
Mini	-0.586	-1.752
	(0.052)	(0.135)
Small	-1.230	-2.102
	(0.109)	(0.163)
Medium	-1.587	-2.422
	(0.140)	(0.188)
Luxury	-2.100	-2.971
	(0.186)	(0.230)
Sport	-1.408	-3.346
	(0.124)	(0.258)
Transporter	-1.475	-1.934
	(0.130)	(0.149)
Off-road	-2.185	-3.307
	(0.193)	(0.256)
Van	-1.742	-2.818
	(0.154)	(0.218)

Standard errors in parentheses

Three principle observations can be drawn from the table. First, the low standard errors indicate that the precision of the estimates is high, with statistical significance at the one-percent level in all cases. Second, with the exception of the mini segment, the responsiveness of market shares to changes in circulation taxes and fuel costs is elastic: a one-percent increase in either cost factor induces a greater than one-percent decrease in the market share. Finally, the estimates are uniformly higher for fuel costs, reaching as high as 3.35% in the case of the sport segment. To the extent that motorists pay the circulation tax once a year while they are regularly confronted with fuel costs, the greater responsiveness to the latter is plausible.

To glean some insight into the implications of these results for CO_2 emissions, the coefficient estimates from Model III were used to implement a simple simulation for the year 2005. Two sets of predicted market shares were generated: under the actual tax regime and after setting the tax level to zero for all car models, holding the other variables in the model at their observed levels. These shares were then multiplied by the average CO_2 emissions by segment and summed over segments to obtain a market level average for the two scenarios. The resulting difference in CO_2 emissions between the actual and simulated scenarios amounted to 6.55g CO_2/km, an increase of about 3.8% over the observed level of 170.49g CO_2/km in 2005. This estimated difference can, of course, only be interpreted as indicative. As circulation taxes in Germany are based on cubic capacity, the estimate may be subject to downward bias relative to that obtained under a CO_2-based tax regime, particularly given recent technological developments that have weakened the correlation between engine power and emissions. On the other hand, it also bears noting that the *ceteris paribus* assumption underpinning the calculation precludes general equilibrium adjustments in car prices, which is likely to impart upward bias on the estimate.

5. CONCLUSION

Despite significant efforts to reduce the transport sector's environmental burden, CO_2 emissions from road transport in the EU-15 continue to increase unabated, rising by 26% between 1990 and 2005 (Balint *et al.*, 2007). The European Commission's strategy to combat this trend currently relies on a combination of mandated efficiency standards, consumer information, and car-related taxes, whereby the largest CO_2 abatement opportunities are seen in initiatives that target improved energy efficiency as the primary goal (ECMT, 2007). To this end, the most recent regulation on CO_2 from cars, adopted by the Commission at the close of 2008, obliges automakers to achieve disproportionally higher emissions reductions from heavy vehicles than lights ones, such that a fleet wide average of 130g CO_2/km by 2012 is achieved. A key policy question emerging from this goal is the extent to which tax incentives, including differentiated vehicle taxes based on CO_2, constitute an additional means for effectively promoting the purchase of more efficient vehicles.

The evidence presented in this study, based on a nested logit model of new car registrations from Germany over the 1995-2005 interval, suggests that annual circulation taxes and fuel costs (and, by extension, fuel taxes) significantly impact the composition of the new car fleet. Returning to the question posed at the outset, the conclusion follows that consumers are not myopic in their car-purchasing behavior, but instead take into account the incremental costs that accrue over their ownership of the car. Fuel costs, in particular, elicit a strong response, as evidenced by the segment-level elasticity estimates that are uniformly greater than one.

Taken together, these findings call into question the Commission's expressed reservations with reliance on fuel excise taxes (COM, 2007), along with the corresponding emphasis on per kilometer emissions reductions as the key instrument for reducing total emissions from transport (Balint *et al.*, 2007). While such mandated efficiency standards generate economic benefits in their own right, they obfuscate the true costs of emissions reductions through their reliance on technological innovations, and hence are a blunt instrument if the primary goal is to reduce fuel consumption and associated emissions. In this regard, the gains from increased efficiency may be offset by rebound effects, under which motorists drive more in response to cheaper per kilometer costs (Frondel and Vance, in press; Sorrell, 2007). By contrast, fuel- and vehicle taxes directly confront motorists with increased costs of driving and car ownership, which not only has an immediate influence on driving behavior, but, as shown here, also bears on the car purchasing decision. Ultimately, taxation policy thereby serves to trigger the technological innovations sought via mandates by curbing market demand towards more fuel efficient vehicles.

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