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Assessment of CO_2-Oriented Vehicle Tax Reforms: A Case Study of Greece

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ABSTRACT

Vehicle taxation based on a car's CO_2 emission levels is increasingly adopted in countries around the world. This paper describes a model of oligopolistic competition in markets with differentiated products, simulating automobile demand and supply under alternative tax regimes. The objective is to perform simulations in order to evaluate policies that could shift consumer purchases towards low-CO_2 cars and thus lead to the reduction of fuel use and CO_2 emissions. Focusing on an analysis of the car market of Greece, we assess the environmental and economic implications of alternative carbon-based tax schemes. Our findings, which are relevant for other European countries as well, illustrate that careful policy design, supported by an appropriate model, can bring about substantial environmental benefits without losing control of economic parameters such as public finances or firm profits. In some cases vehicle taxation can have adverse (though unintended) environmental consequences.

Key words: CO_2 emissions, automobile market, feebates, carbon taxation.

1. Introduction

Transportation is a major contributor to global energy consumption and greenhouse gas (GHG) emissions, accounting for about one fourth of total energy-related carbon dioxide (CO_2) emissions worldwide, with increasing trends for the future decades as a result of sharp growth in mobility projected for non-OECD countries. It is widely accepted that – irrespective of emission reductions in other economic sectors – global transport emissions should decrease greatly if the world is to meet the objective to contain average global temperature increase to two degrees Celsius (compared to pre-industrial standards) by the year 2050 (IEA, 2009). It is therefore crucial to implement more aggressive policy measures if they are to ensure progress in limiting fuel consumption and CO_2 emissions.

During the last decades, fuel economy (or CO_2 emission) standards and fuel taxes have been the most widely implemented policy instruments – the former aiming to induce supply of more fuel efficient automobiles and the latter intending to discourage consumers from using gas-guzzling cars. A third policy option that receives increasing attention around the world is the change in the taxation system of motor vehicles so that, among several available car models, consumers are encouraged to purchase those models with the lowest CO_2 emissions. This may be a promising policy option since it is technology-neutral and involves a market-based instrument that can affect consumer behavior, in contrast to command-and-control regulations that may be economically inefficient. Unlike politically unattractive fuel tax increases, the shift to CO_2-based taxation can be designed to be revenue-neutral. Moreover, if the tax levied per unit of carbon emitted is fixed (i.e. if the tax is a linear function of a car's carbon emissions) this equates marginal compliance costs across car models and automakers, thus leading to an efficient outcome (Anderson et al., 2012).

Most European Union countries have put in place a CO_2-based component in their calculation of vehicle taxes – either as a part of registration taxes, paid when a car is purchased, or of circulation taxes paid annually by each vehicle owner. ACEA (2011) and OECD (2009) provide an overview of the CO_2-based taxation schemes implemented by individual countries. In some cases these schemes apply a feebate system, paying a rebate to consumers who purchase a fuel-efficient vehicle and imposing a penalty on those who purchase gas-guzzlers. The feebate option has been discussed and analyzed in North America for several years (Bunch et al., 2011; Fischer, 2008; Greene et al., 1995) but, despite the increased use of such schemes in Europe, there is little research regarding their appropriate design and impact at European level. Studies carried out on behalf of the European Commission, the EU's executive body, have dealt with this issue in an aggregate manner and with simple statistical/econometric methods (COWI, 2002; TIS et al., 2002). Other studies have made descriptive ex-post assessments of taxation schemes implemented in specific countries, such as Rogan et al. (2011) for Ireland or Bastard (2010) for France. Recently we have explored the environmental and economic implications of feebate schemes in Germany in an ex ante analysis, which was probably the first one of this kind in Europe (Adamou et al., 2012)[1]. We have estimated a discrete choice model of automobile demand and supply in the German market and simulated the impact of alternative feebate settings on emissions, consumer welfare, public revenues and auto manufacturer profits.

In this paper we extend our analysis to Greece, a European country that differs from Germany in several aspects but whose automobile market shares many common features with other European countries. Greece has no automobile industry; it imposes substantial taxes on the purchase of new cars; vehicle taxation rises sharply with engine size; and use of diesel-powered private cars has not been allowed in urban areas for many decades, out of environmental considerations. We specify a nested multinomial logit model in line with Berry (1994) and estimate it econometrically with the aid of detailed data from the Greek car market of the period 1998-2008. This model is simpler than the one we used for Germany because Greek consumers have fewer options than German consumers due to the above mentioned ban of diesel cars. On the other hand, the Greek vehicle tax system allows us to study a greater variety of tax regime changes than in Germany. We thus simulate not only the adoption of a feebate scheme but also the partial replacement of the current registration tax, which imposes a tax on a new car purchases as a function of engine size, with an alternative system that calculates tax levels as a function of a car's CO_2 emissions. There are a

[1] In a related study, Vance and Mehlin (2009) examined whether tax incentives promote the purchase of more efficient vehicles in Germany. However, they estimated a variant of the nested logit equation that departs somewhat from the underlying theoretical utility framework.

large number of European countries that, like Greece, impose a 'registration tax' on newly purchased automobiles[2]; hence the policy implications we derive from the Greek case study are relevant for these countries as well.

Section 2 of this paper describes the theoretical specification of our automobile demand and supply model and outlines how it is used to perform policy simulations. We describe our dataset in Section 3 and present our empirical application of the model in Section 4. Two different tax policy changes are simulated with the aid of the model and are presented in Section 5, and Section 6 concludes.

2. The model

2.1. Automobile demand and supply

We employ the nested logit model proposed by Berry (1994) to estimate demand for automobiles. The utility of buying an automobile depends on its price, its observed characteristics (such as engine size) and an unobserved characteristic. The nested logit model has been widely used because it produces sensible substitution patterns depending on predetermined classes of products and is much easier to implement than the more general random coefficient model.

The nested logit model assumes that products are grouped in different categories within one or more nests. In our data the nest comprises automobile models grouped on the basis of body type and engine size (e.g. sedan cars with engine size ranging from 1.4 to 1.8 liters). Consumers are identical (up to an idiosyncratic taste shock) within each group but different across groups. Berry (1994) has shown that utility-maximizing behavior by consumers leads to the following demand equation:

$$\ln(S_j) - \ln(S_0) = x_j\beta - \alpha P_j + \sigma \ln(S_{j/g}) + \xi_j, \qquad (1)$$

where S_j is the market share of product *j* (sales divided by M consumers), S_0 is the outside good share, P_j is the observed price of product *j*, x_j is a *k*-dimensional vector of observed attributes of product *j* (such as horsepower, engine size, emission levels

[2] Austria, Belgium, Cyprus, Denmark, Finland, Hungary, Ireland, Malta, Netherlands, Norway, Portugal, Romania, Slovenia and Spain. See ACEA (2011) and Braathen (2012).

etc.), ξ_j is a disturbance summarizing unobserved characteristics of product *j*, $S_{j/g}$ is the share of the model within its group and *β, α, σ* are the demand parameters to be estimated.

On the supply side the basic equation is derived by profit maximization of the firm. Profits from sales of product *j* are given by

$$\pi_j = \left(\frac{P_j}{1+v} - mc_j \right) S_j , \tag{2}$$

where mc_j is the marginal cost of product *j* and *v* is a sales tax or a value-added tax. Following Berry (1994), the first order condition under the assumption of Bertrand-Nash equilibrium in prices is given by the following relationship:

$$\frac{P_j}{(1+v)} = mc_j + \frac{1-\sigma}{\alpha(1+v)[1-\sigma S_{j/g} - (1-\sigma)S_j]} . \tag{3}$$

Pre-tax price is therefore equal to marginal cost plus a markup term depending on *α* and *σ,* the parameters appearing in demand equation (1). Equation (3) holds for the case that every firm is a single-product firm. A multi-product firm will choose prices to maximize joint profits from all its products. The corresponding FOC is

$$\frac{P_j}{(1+v)} = mc_j + \frac{1-\sigma}{\alpha(1+v)[1-\sigma S_{f/g} - (1-\sigma)S_{f,g}]} , \tag{4}$$

where $S_{f/g} = \sum_f S_{j/g}$ denotes the share of firm *f*'s products within group *g* and $S_{f,g} = \sum_f S_j$ represents the firm's group *g* sales as a percentage of the potential market (Verboven, 1996).

In order to estimate the demand equation (1) it is necessary to address the endogeneity of prices and within shares. The demand error term ξ_j is correlated both with price and the within-group share. If firms observe unobserved quality ξ_j they will take it into account when they set prices. This will induce a positive correlation between price and the error term, thus leading to an upward bias (lower *α* in absolute terms) in the estimated coefficient in an OLS regression. The other endogenous variable, the within-group share, is also positively correlated with unobserved quality and the coefficient σ will also be biased upwards in the OLS case. For this reason, general method of moments (GMM) or instrumental variable (IV) methods should be used. Additionally, it is possible to allow the parameter σ to vary across groups. The σ_g 's can be estimated by interacting $\ln(S_{j/g})$ with a set of group-specific dummy variables G_{jg} that take the value of 1 if product *j* belongs to group *g* and 0 otherwise.

2.2. Public Revenues, Firm Profits and Consumer Welfare

Using the estimated parameters $\tilde{\beta}$, $\tilde{\alpha}$ and $\tilde{\sigma}$, it is possible to compute consumer welfare (*W*), firm profits (from the markup term) and public revenues. The exact formulas for these can be derived if one knows details of the taxation system applying in the country under examination.

The automobile taxation system in Greece for years 1998-2008 had two main components. One was an *ad valorem* tax imposed on the import price (marginal cost). The second was the value added tax (VAT), which was applied to the final price less the amount of the *ad valorem* tax. Let P_j denote the final consumer price, which is the sum of marginal cost C_j, the *ad valorem* tax tC_j, the markup MU_j, and the VAT amount $v(C_j + MU_j)$. Solving for the markup gives

$$MU_j = \frac{P_j - C_j(1 + t + v)}{(1 + v)}$$

Plugging this into (4) leads to the following expression:

$$P_j = C_j\ (1 + v + t_j) + \frac{1 - \sigma_g}{\alpha[1 - \sigma_g S_{f/g} - (1 - \sigma_g) S_{f,g}]} \qquad (5)$$

After a personal communication with several representatives of major car retailers in Greece, we concluded that auto manufacturing firms – and not retailers on their own – determine their markups. Therefore, it is the decisions of the car manufacturer that are indeed modeled on the supply side.

Under this taxation system, public revenues from sales of product *j* become $\frac{vP_j + t\widetilde{C}_j}{(1+v)}$

and firm profits from product *j* are $\frac{1-\tilde{\sigma}_g}{\tilde{\alpha}[1-\tilde{\sigma}_g S_{f/g} - (1-\tilde{\sigma}_g)S_{f,g}]}$.

Finally, if one defines $D_g = \sum_{j \in J_g} e^{(\delta_j)/(1-\sigma_g)}$, where $\delta_j = x_j\beta - \alpha P_j + \xi_j$, then consumer welfare is (Trajtenberg, 1989):

$$W = \frac{1}{\alpha} \ln\left[\sum_g D_g^{(1-\sigma_g)}\right] + C,$$

where C is the constant of integration and can be ignored because only the change in welfare ($W_{simul} - W_{actual}$) is of interest.

2.3. Simulations

The objective is to use an alternative tax regime based on each car's CO_2 emission levels in order to compute simulated shares, prices, public revenues, firm profits, CO_2 emissions and consumer welfare. Then it is possible to compare simulated variables with the actual ones. First one has to compute the simulated prices and shares.

Assume that a feebate is introduced, in which consumers receive a rebate when purchasing low-CO_2 cars or incur an additional fee when purchasing a high-CO_2 car. Then a tax A_j enters linearly in the FOC (equation (4)), where A_j is positive for high-CO_2 car and negative for low-CO_2 cars. Similarly to the feebate, the introduction of an emissions-based car registration tax can be simulated.

As a benchmark, we will first consider the case where firms do not change their mark-ups, meaning that there will be 100% pass-through of the new tax to final prices. In this case new prices are simply the actual prices plus A_j, and new market shares can be easily computed using the expressions in Berry (1994). Our main scenario will follow economic theory, which suggests that imposition of the feebate or tax will cause firms to adjust prices in line with their goal of profit maximization; that is, firms will adjust prices so that the FOC in (4) holds. Computing these prices requires solving the system of N first order conditions (4). We solved this system using *Matlab*'s nonlinear equation solver. We also solved the system using contraction mapping techniques, which produced the same result.[3]

3. Data

For the empirical implementation of the model described in section 2, a large dataset is necessary that should include, for each model sold in a country in a given year, several vehicle attributes as explanatory variables of consumer decisions as well as sales numbers and retail automobile prices. For this purpose, data were obtained from a private vendor (JATO Dynamics) specializing in the collection of automotive data worldwide. For each one of a few thousand models or model versions every year, the dataset contains 17 distinct vehicle attributes such as vehicle weight, engine size etc., sales volume and sales price. Table 1 summarizes the data that were available to the authors.

[3] See Adamou et al. (2012) for more details on the contraction mapping method.

Table 1: Description of the Greek automobile market data.

Years: 1998-2008

Vehicle attributes:

Variable	*Unit*
Make	
Model	
Vehicle length	Meters
Vehicle width	Meters
Engine size	Liters
Max. engine power	HP
Max. torque	Newton-meters
Fuel type	(petrol, diesel etc.)
Transmission type	(manual, auto)
Body type	(hatchback, convertible etc.)
Max. speed	kilometers per hour
Acceleration 0-100 km/h	Seconds
Fuel consumption, combined cycle	liters per 100 kilometers
CO_2 emissions, combined cycle	grams per kilometer
Airbag for driver seat offered as standard	Yes/No
Airbag for passenger seat offered as standard	Yes/No
Air conditioning system offered as standard	Yes/No
Climate control offered as standard	Yes/No
Segment type	(small, lower medium etc.)
Retail price	Euros
Sales volume	

The dataset of the Greek car market initially consisted of 50,701 observations for market years 1998-2008, containing data about sales, prices and characteristics as shown in Table 1. The database records two car models with the same engine size, fuel and transmission type but differing in a minor characteristic (e.g. the availability or not of climate control) as different observations. We merged such models in one, by summing up their sales and calculating a sales-weighted average price. We then removed from the dataset a few outliers such as models with a sales volume less than 10, models with a sales price of over 100,000 Euros and models with engine capacity more than 5 liters; these can be considered to belong to a very special market, oriented only to very high income consumers. This process of model aggregation and removal led to a dataset of 3,909 observations in total. Out of these, 546 observations involve Sport Utility Vehicles, 442 Multi-Purpose Vehicles, 171 luxury cars and 318 sports cars; the rest, or 62% of the sample, comprise 'regular' cars. Some summary statistics for key variables are provided in Table 2 below.

Table 2: Descriptive statistics of the Greek dataset (obs: 3909)

Stats	Sales	Prices (thousand Euros'2005)	Engine Capacity (liters)	CO_2 emissions (grams per kilometer)	Horsepower (kilowatts)	Torque (Newton-meters)
Minimum	11	6.735	0.599	103	39	53
Percentile 5%	15	10.155	1.108	139	61	93
Percentile 25%	52	14.766	1.390	161	90	126
Percentile 50%	198	21.289	1.598	184	113	150
Percentile 75%	811	32.757	1.995	212	150	203
Percentile 95%	3272	61.815	3.192	286	240	320
Maximum	12844	120.866	4.966	405	420	483
Mean	726	26.697	1.801	192	127	175
Std. Dev.	1312	17.077	0.638	45	54	71

Table 3 shows the average prices, sales, engine capacity and CO_2 emissions by vehicle class. The 'small' class contains automobiles with engine capacity between 0.6 and 1.4 liters, the 'medium' class contains cars with engine capacity from 1.4 to 1.8 liters and the rest are considered as large automobiles. As expected, larger cars have higher CO_2 emissions and prices but lower sales. This classification is the one we use in the demand estimation below.

Table 3: Descriptive statistics of the Greek dataset by vehicle class (obs: 3909)

Class	observations	Prices (thousand Euros'2005)	Sales	Engine Capacity (liters)	CO_2 emissions (grams per kilometer)
Small	1196	13.349	1470	1.164	153.69
Medium	1437	22.368	591	1.652	183.77
Large	1276	44.084	181	2.472	237.92

One of the most interesting features of these data is the variability of CO_2 emissions of relatively similar cars. If one observes the CO_2 performance of vehicles within the same segment, it becomes evident that, other vehicle attributes being equal, CO_2 emissions vary by up to a factor of two. This indicates that appropriate incentives, e.g. through vehicle taxation, can encourage consumers to buy low-CO_2 cars even without changing radically their preferences. In the United Kingdom it has been assessed that choosing the lowest CO_2 emitters in any car market segment can make a difference of about 25% to fuel efficiency and CO_2 emissions (King, 2007). The same observation has recently been made for Germany (Zachariadis, 2012).

Figures 1 and 2 illustrate this aspect by showing the distribution of engine size and CO_2 emissions of cars in two of the most popular market segments for automobiles sold in Greece in the year 2008. It is evident that, while most car models fall within a relatively narrow range of engine size (as well as engine power, not shown here), their CO_2 emission levels are more dispersed. This is also demonstrated in Table 4, which shows a further analysis of the data shown in Figure 2. Out of the models with the smallest engine size in that specific segment (less than 1.8 liters), 83% emit more than 160 g/km CO_2 and 25% emit even more than 180 g/km; at the same time cars with somewhat larger engine size (between 1.8 and 2.0 liters) have a high share (41%) of models emitting less than 160 g/km.

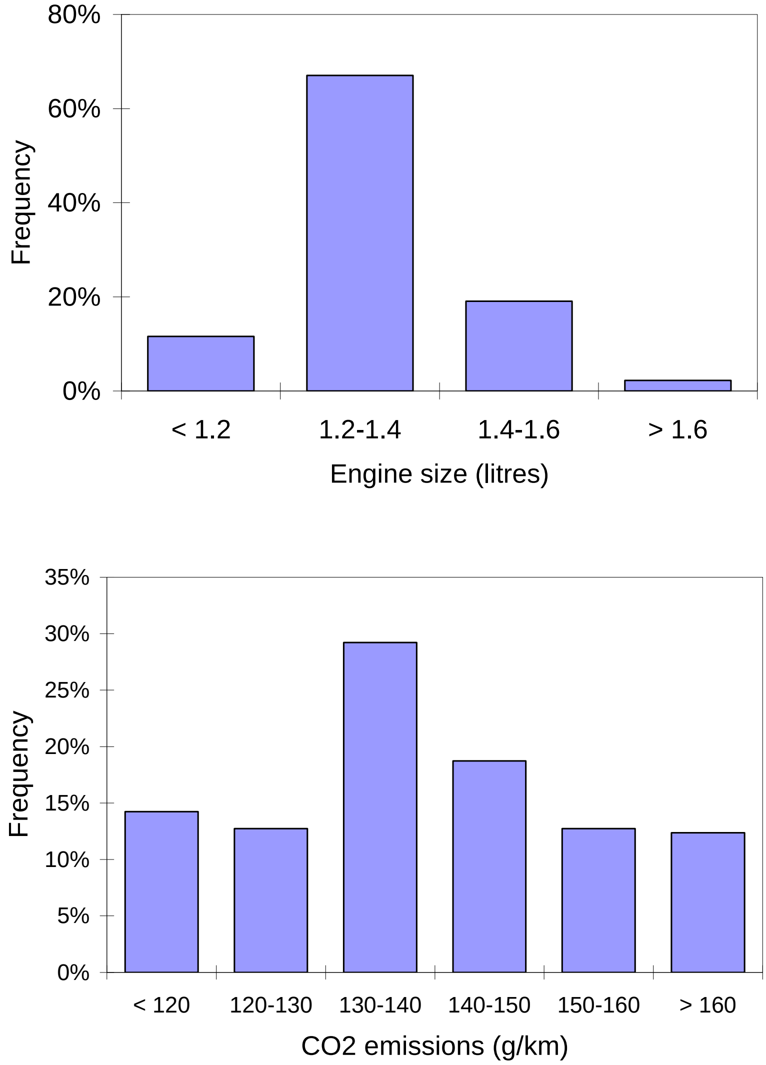
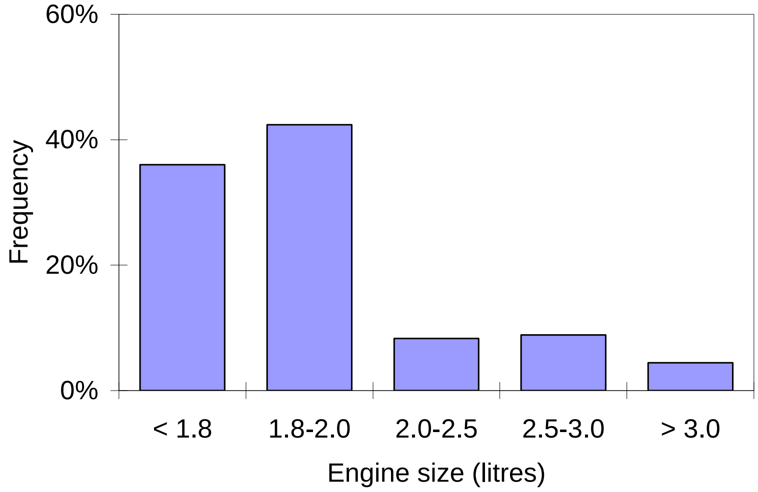


Figure 1: Distribution of engine size *(top)* and CO_2 emissions *(bottom)* for cars of market segment ‘B–small cars’ sold in Greece in the year 2008.

Notes: CO_2 emission levels are those of the composite (urban and extra-urban) legislated driving cycle used in Europe. Classification of cars into specific segments follows the categorization of the automotive data provider.



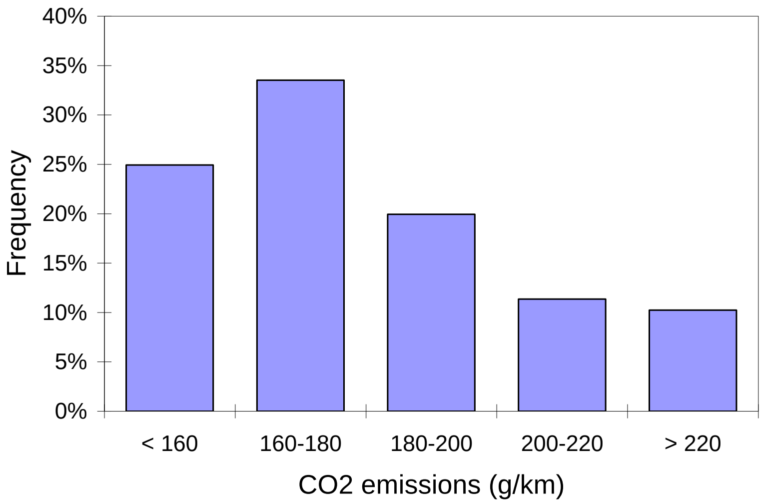


Figure 2: Distribution of engine size *(top)* and CO_2 emissions *(bottom)* for cars of market segments 'D1+D2–Upper medium-sized cars' sold in Greece in the year 2008.

See explanatory notes in Figure 1.

This means that even if consumers do not shift away from their preferred market segment, it is still possible to reduce new car CO_2 emissions by a considerable amount through e.g. a higher tax on high-CO_2 cars of that segment. To what extent, however, such a shift is possible depends on all other vehicle attributes that affect consumer decisions, and hence only the detailed empirical analysis according to the model described in section 2 might provide robust evidence for or against such policies.

Table 4: Distribution of CO_2 emissions of car models belonging to two sub-segments of market segment 'D1+D2–Upper medium-sized cars' sold in Greece in the year 2008. Percentages refer to the fraction of models in each sub-segment that belong to each emissions category.

	Engine size	
CO_2 emissions (g/km)	*1.8-2.0 litres*	*> 2.0 litres*
< 160	17%	41%
161-180	58%	24%
> 180	25%	36%
Total:	100%	100%
Average CO_2 emissions:	172	173

4. Estimation

Table 5 presents the estimation results. The choice of instruments in this model specification (number of models in the group, CO_2 emission of own models and CO_2 emission of own models squared) was guided by the appropriate tests for instrument relevance and overidentification. The Anderson canonical correlation LM statistic – a test of the null hypothesis that the model is under-identified – was rejected. The Sargan statistic – a test of the null hypothesis that the instruments are valid – could not be rejected. It is worth noting that tax rates did not prove to be useful instruments. We estimated demand only and not demand and supply jointly. Therefore, the marginal cost is obtained by equation (5) given that the markups are obtained using the demand estimates.

Engine capacity, horsepower, torque, climate control and airbags are important car attributes for the demand side. CO_2 emissions turned out to be statistically insignificant; this supports the statement made by Greene (2010) that consumers substantially undervalue fuel economy relative to its expected present value. SUVs, sports and luxury cars have a positive and significant coefficient but MPVs have a negative and significant coefficient. The average own price elasticities are -6.08 (-1.66 for small, -3.78 for medium and -12.84 for large cars). Average markups per model are 5.881 (8.171 for small, 6.050 for medium and 3.545 for large cars). On the cost side, car characteristics are all statistically significant and positive.

Public revenues for year 2008 are found to be 1,089 million Euros (at 2005 prices) or 4,372 Euros per car; these represent the total revenues from both the *ad valorem* tax and the VAT. Average CO_2 emissions are 167.5 grams per kilometer per car. Retailer profits are found to be 20,490 million Euros'2005 throughout thw 1998-2008 period, or 7,219 Euros per car; for year 2008 the corresponding profits are 1,765 million Euros'2005 or 7,086 Euros per car. Finally, welfare (without the constant term C) is about 728 Euros per car in year 1998, increases to 1069 Euros for 1999 and 1199 Euros for 2000, and then gradually declines to 882 Euros for year 2008.

Table 5(a): Estimation results. Standard errors are given in parentheses. *, ** and *** denote significance at 1%, 5% and 10% level respectively. Year fixed effects are included but not reported for brevity.

Variables	Demand side parameters	Cost side parameters
Price (000 Euros'2005)	-0.077***	
	(0.0062)	
$\ln(S_{j/g})*G_{j,small}$	0.383***	
	(0.065)	
$\ln(S_{j/g})*G_{j,medium}$	0.544***	
	(0.066)	
$\ln(S_{j/g})*G_{j,large}$	0.736***	
	(0.070)	
Engine Capacity	0.561***	3.52***
	(0.104)	(0.24)
CO_2 Emissions	0.0013	0.034***
	(0.00096)	(0.0030)
Horsepower	0.0061***	0.064***
	(0.0011)	(0.0036)
Torque	0.0025***	0.011***
	(0.00087)	(0.0031)
Climate Control	0.280***	1.340***
	(0.038)	(0.123)
Airbags	0.167***	1.320***
	(0.057)	(0.173)
SUV	0.547***	1.676***
	(0.092)	(0.217)
MPV	-0.439***	0.806***
	(0.080)	(0.162)
LUXURY	0.822***	7.168***
	(0.110)	(0.258)
SPORT	0.151*	3.973***
	(0.081)	(0.195)
Constant	-7.109***	-9.956***
	(0.275)	(0.386)
F-test	189.69***	1206.3***
Underidentification test	79.42, P-value: 0.000	
Overidentification test	1.81, P-value: 0.178	

Table 5(b): Estimation results (continued). Variables shown here denote the country of origin of each car model. See further explanations in Table 5(a).

Variables	Demand side parameters	Cost side parameters
China	-1.163**	-2.739
	(0.471)	(1.724)
Czech Rep.	0.140	-1.197***
	(0.102)	(0.351)
England	-0.030	0.381**
	(0.052)	(0.192)
France	0.017	-0.674***
	(0.045)	(0.166)
Germany	0.506***	2.55***
	(0.050)	(0.149)
Italy	-0.176***	-0.869***
	(0.055)	(0.198)
Korea	0.00028	-2.944***
	(0.078)	(0.210)
Romania	-1.219**	-1.892
	(0.568)	(2.108)
Russia	-0.885***	-3.746***
	(0.150)	(0.508)
Spain	-0.092	-1.347***
	(0.072)	(0.269)
Sweden	0.221***	2.696***
	(0.084)	(0.286)
Switzerland	-0.132	-1.487***
	(0.131)	(0.492)
USA	-0.278**	-3.692***
	(0.132)	(0.409)

5. Policy simulations

Having estimated the parameters of our model as described above, we have then simulated the effects of two different vehicle taxation policies on automobile sales, prices, public revenues, firm profits, consumer welfare and sales-weighted CO_2 emissions. Results for each one of the two policies are reported in Sections 5.1 and 5.2. We first compute (but do not report here for the sake of brevity) the effects assuming that changes in taxation are fully passed through by firms to consumers, and then calculate the effects of a (probably more realistic) scenario which assumes that, after changes in the tax system, retailers maximize their profit and set different markups for different models. All results that will be presented in this Section show the effect of taxation on the most recent car models, i.e. those available in year 2008; this provides a better indication about the eventual changes in car sales in the near future (e.g. in year 2011 or 2012). Although our database does not contain more recent sales data, this is probably an advantage because automobile demand in the Greek market may have changed considerably post-2008 due to the fiscal problems faced by the country; years 2009-2011 have certainly not been representative of long run demand patterns.

5.1. Simulation of the effect of a CO_2 feebate

Our first policy exercise assumes that a feebate A_j is introduced, while all other taxes remain the same as before. As sales-weighted average CO_2 emissions of cars sold in Greece in the year 2008 are found to be 159.5 grams per kilometer (g/km) per automobile, a linear tax is introduced in such a way that it is positive for cars with CO_2 emissions over 159.5 g/km and negative for cars with emissions lower than this pivot point:

$A_j = \mu \ (CO2 - 159.5)$, where $CO2$ is the CO_2 emissions level of model j.

In this exercise, coefficient μ is equal to 31 Euros, which implies that retail prices may decline by up to 20% for individual low-CO_2 car models, while they can rise by more than 10% for big models with very high CO_2 emissions. The value of μ has been set at such a level that the government cannot subsidize any car model with a rebate higher than the average tax imposed on all models; this ensures that the government does not risk losing too many public revenues due to the new taxation system.

We first assumed that the feebate passes fully through to retail prices. As a next step, we relaxed the assumption of 100% pass-through of taxes to prices; by doing so, we allow retailers to maximize their profit and set different markups for each car. Demand and supply equations are solved simultaneously to find the simulated prices and simulated shares. As the results of the two cases are very similar, we report here only the outcome of the (more realistic) simulation that allows for different markups per car.

Tables 6 and 7 report the changes in prices and market shares resulting from the introduction of this feebate. Total automobile sales remain essentially unchanged; they increase by only 0.4% in the feebate scenario. Low-CO_2 cars experience a decline in their prices and a consequent increase in their sales, which is stronger for the group of cars with emission levels below 130 g/km.

Table 6: Effect of a feebate on prices and sales volumes of cars by CO_2 emissions class.

CO_2 emissions class (g/km)	Prices without feebate	Simulated prices with feebate	Difference	Sales without feebate	Simulated sales with feebate	Difference
< 130	10609	9362	-11.8%	29283	33553	14.6%
130-160	13849	13646	-1.5%	123059	127858	3.9%
160-180	18640	19063	2.3%	53499	52286	-2.3%
180-200	25052	26376	5.3%	22643	20839	-8.0%
> 200	40969	43427	6.0%	20522	15376	-25.1%
Total:	17751	17098	-3.7%	249006	249912	0.4%

Table 7: Effect of a feebate on average prices and average sales volumes of cars by engine size class.

Engine size class	Prices without feebate	Simulated prices with feebate	Difference	Sales without feebate	Simulated sales with feebate	Difference
Small	12655	12050	-4.8%	148987	154820	3.9%
Medium	19959	20161	1.0%	72720	70944	-2.4%
Large	39682	40467	2.0%	27299	24148	-11.5%
Total	17751	17098	-3.7%	249006	249912	0.4%

Table 8 presents the effect of the feebate within engine size classes. It is evident that the CO_2-based tax not only shifts sales towards smaller cars, but also provides an incentive for consumers, out of the models within their preferred vehicle class, to purchase those with lower CO_2 emission levels. The shift is particularly pronounced in the cases of cars with very high and very low CO_2 emissions; especially in medium and large cars the feebate affects very high-CO_2 vehicles substantially, reducing their sales by more than 20%, so that even models with relatively high emissions (of the group 180-200 g/km) gain sales shares despite the increase in their retail prices.

Table 8: Effect of a feebate on prices and sales volumes of cars by engine size and CO_2 emissions class – percentage differences from the current taxation regime.

	Change in sales price by engine size class			Change in sales volume by engine size class		
CO_2 emissions class	Small	Medium	Large	Small	Medium	Large
< 130	-11.8%	-	-	14.6%	-	-
130-160	-3.2%	-0.8%	-0.6%	2.8%	5.7%	49.9%
160-180	1.5%	1.8%	1.4%	-4.8%	-2.1%	26.7%
180-200	4.7%	3.9%	3.3%	-15.4%	-12.3%	3.5%
> 200	-	6.3%	6.3%	-	-21.5%	-25.7%
Total:	-4.8%	1.0%	2.0%	3.9%	-2.4%	-11.5%

Table 9 shows the resulting pass-through of taxes to retail prices by engine size and CO_2 emissions class. The pass-through varies from 99.95% to 100.39% for individual models, and declines gradually for higher CO_2 classes. This means that firms absorb some of the tax increase for high-CO_2 cars in an attempt to mitigate some of the decrease in their sales. In any case, all pass-through values are very close to unity (or 100%), which explains why the results differ very little in comparison to those of the 100% pass-through case.

Table 9: Average pass-through of taxes to prices by car engine size and CO_2 emissions class in the feebate case (in %).

	Change in sales price by engine size class		
CO_2 emissions class	Small	Medium	Large
< 130	100.05	-	-
130-160	99.99	100.02	100.39
160-180	99.97	99.99	100.10
180-200	99.95	99.99	100.04
> 200		99.97	100.01

Under the simulated market, as a result of the changes in prices and sales shown above, sales-weighted CO_2 emissions are reduced to 156.3 g/km per automobile, a 2% decline compared to observed emission levels in year 2008. Public revenues decrease by 339 Euros per car or 81 million Euros in total, which represent a decrease of government revenues in year 2008 by 7.4% due to a significant drop in sales of large cars, which will generally experience an increase in their taxation under the feebate system because most large car models emit more than 159.5 g/km. Retailer profits are found to be 7170 Euros per car, which corresponds to an increase in retailer markups by 84 Euros per car or 1.2%; this is due to the shift of sales towards smaller cars which, as shown in section 4.1, have higher markup levels. Finally, consumer welfare rises from 882.1 Euros per car in the actual sales of year 2008 to 885.4 Euros per car in the feebate scenario because of the slightly increased car sales in the feebate case.

In summary, the feebate policy simulated here leads to modest results because of the selected values for the implied carbon tax rate μ and the pivot point. As we have shown in the case of Germany (Adamou et al., 2012), different values of these two parameters can crucially influence the results. A lower pivot point, in particular, can lead to greater environmental benefits without being detrimental to public finances.

It is necessary to note at this point that we have not accounted for any rebound effects in these simulations. In theory, when consumers purchase a more fuel efficient (and low-carbon) car it is possible that they drive more with it because fuel costs are cheaper or that they drive more with it and drive less with a second, less fuel efficient car that they own. Such an effect might partly offset the environmental benefit of a low-carbon car. We have implicitly assumed here that each consumer chooses the mileage to drive with a car before purchasing a specific car model, regardless of its size. In any case, Small and Van Dender (2007) have found the rebound effect to diminish in recent years in the US, which probably indicates a similar trend in other high-income countries.

5.2. Partial abolition of existing automobile taxes and introduction of a CO_2-based tax

The second policy exercise assumes that a part of the existing *ad valorem* tax on cars is abolished and replaced by a tax based on a car's CO_2 emission levels. This is in line with policies currently implemented in many EU countries, where a part of a car's registration tax is calculated on the basis of emissions and another part on another vehicle attribute such as engine size. We chose to impose a tax equal to 15 Euros (at 2008 prices) for each gram of CO_2 emitted per kilometer above a threshold of 100 g/km; it is straightforward to show that such a tax, for a lifetime of 150 000 kilometers, corresponds to a carbon price of 20-30 Euros per ton of CO_2. At the same time we reduced the *ad valorem* tax rates by 43% so that, if sales volumes did not change in comparison to actual sales of year 2008, government revenues would remain equal to the actual 2008 revenues. Although it is obvious that such a taxation change will shift sales among different engine size classes, this assumption intends to ensure that public revenues do not deviate too much from those observed in year 2008.

Like in the previous section, we only report results of the case where the assumption of 100% pass-through of taxes to prices has been relaxed because, as in the case of the feebate presented above, pass-through rates are very close to unity – ranging from 99.99% to 100.87%. Tables 10 and 11 report (by engine size and emissions class respectively) the changes in prices and market shares as a result of the introduction of this tax. Since the CO_2-related portion of the new tax is a linear function of emission levels above 100 g/km, whereas the current taxes are strongly non-linear as they grow rapidly with increasing engine size, the change in taxation system is beneficial for large cars: their engine size-related tax decreases by a large amount, so that their retail prices decline substantially (by 5.8%). As a result, their sales shares increase by more than 19% compared to actual shares observed in the Greek market in 2008. Conversely, small cars experience an increase in their prices and a subsequent fall in their sales volume.

Table 10: Effect of a CO_2-based registration tax on prices and sales volumes of cars by CO_2 emissions class.

CO_2 emissions class (g/km)	Prices without CO_2 tax	Simulated prices with CO_2 tax	Difference	Sales without CO_2 tax	Simulated sales with CO_2 tax	Difference
< 130	10609	10781	1.6%	29283	29207	-0.3%
130-160	13849	14328	3.5%	123059	120370	-2.2%
160-180	18640	18864	1.2%	53499	53054	-0.8%
180-200	25052	24503	-2.2%	22643	23073	1.9%
> 200	40969	38917	-5.0%	20522	24530	19.5%
Total:	17751	18224	2.7%	249006	250234	0.5%

Table 11: Effect of a CO_2-based registration tax on average prices and average sales volumes of cars by engine size class.

Engine size class	Prices without CO_2 tax	Simulated prices with CO_2 tax	Difference	Sales without CO_2 tax	Simulated sales with CO_2 tax	Difference
Small	12655	13053	3.1%	148987	144221	-3.2%
Medium	19959	19902	-0.3%	72720	73497	1.1%
Large	39682	37366	-5.8%	27299	32516	19.1%
Total	17751	18224	2.7%	249006	250234	0.5%

Table 12 displays the effect of this tax within a combination of engine size and emissions classes.

Table 12: Effect of a CO_2 tax on prices and sales volumes of cars by engine size and CO_2 emissions class – percentage differences from the current taxation regime.

	Change in sales price by engine size class			Change in sales volume by engine size class		
CO_2 emissions class	Small	Medium	Large	Small	Medium	Large
< 130	1.6%	-	-	-0.3%	-	-
130-160	3.6%	-0.4%	-7.1%	-3.6%	1.6%	37.8%
160-180	4.3%	-0.2%	-6.6%	-5.6%	0.1%	32.3%
180-200	3.4%	-0.3%	-6.1%	-6.3%	5.5%	0.2%
> 200	-	-0.3%	-6.8%	-	-7.5%	24.0%
Total:	3.1%	-0.3%	-5.8%	-3.2%	1.1%	19.1%

It is interesting to observe the results of this policy to emissions as well as public and private finances. Although the existence of a CO_2-based tax mitigates a little the increase in sales of high-CO_2 cars, still the overall decline in the tax burden of large automobiles dominates and leads to significantly higher sales of large cars, even of those emitting more than 200 grams CO_2 per kilometer. As a result, average emission levels rise by 2 g/km per car, a 1.3% increase compared to actual emission levels in year 2008; combined with a slight increase in total car sales, total CO_2 emissions rise by 1.8%. Public revenues rise considerably, by 598 Euros per car or by 155 million Euros (14.2%) in total, because of the increased sales of bigger cars as well as the increased taxes imposed on smaller cars. As a result of the slight increase in total automobile sales, consumer welfare also rises by 4.5 Euros per car or 1% in total. Finally, firm profits decline by 82 Euros per car, or by -0.7% in total, because consumers increasingly purchase larger cars, whose markups are lower as their demand is more elastic.

Overall, results of this policy simulation show that it is environmentally ineffective because of the current taxation system, which puts a heavy tax burden on large cars irrespective of their emission levels; a partial abolition of this system may have negative environmental repercussions, although it could be beneficial for public revenues. This finding is not relevant for Greece only but for several European countries with similarly increasing registration taxes, such as Denmark, Ireland, the Netherlands and Norway (Kunert and Kuhfeld, 2006).

To summarize the above results, Figures 3 and 4 illustrate simulated sales shares by emissions class and engine size respectively according to the two scenarios described in this Section, and compare them with the actual sales shares observed in the Greek market in year 2008.

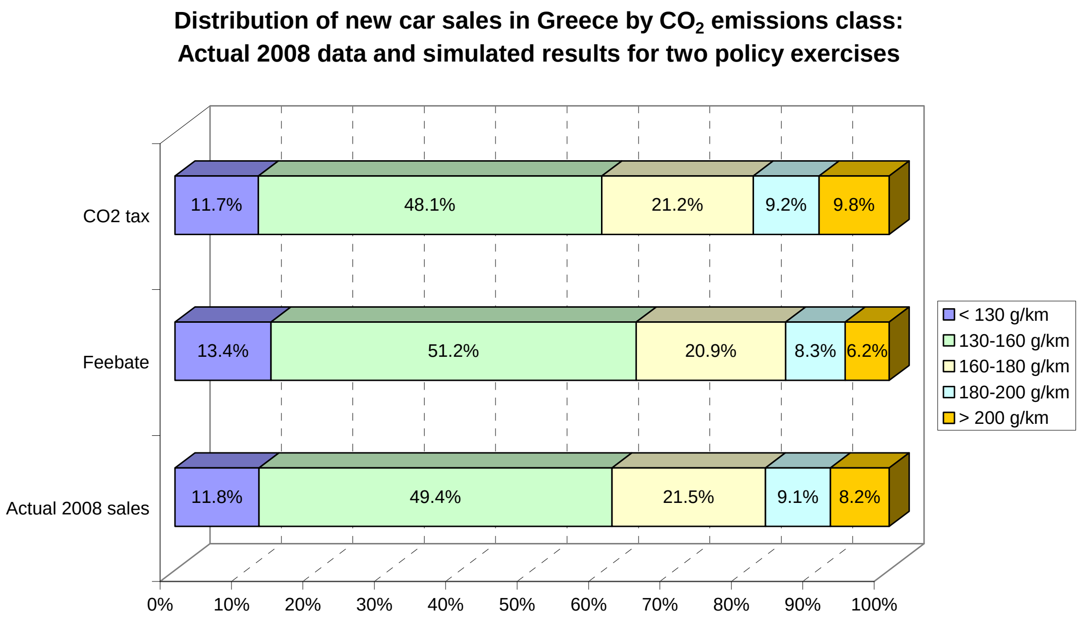


Figure 3: Comparison of actual and simulated automobile sales shares in Greece by emissions class. Note that sales-weighted average CO_2 emissions are 159.5 g/km for actual sales of year 2008, 156.3 g/km in the feebate case and 161.5 g/km in the 'CO_2 tax' case.

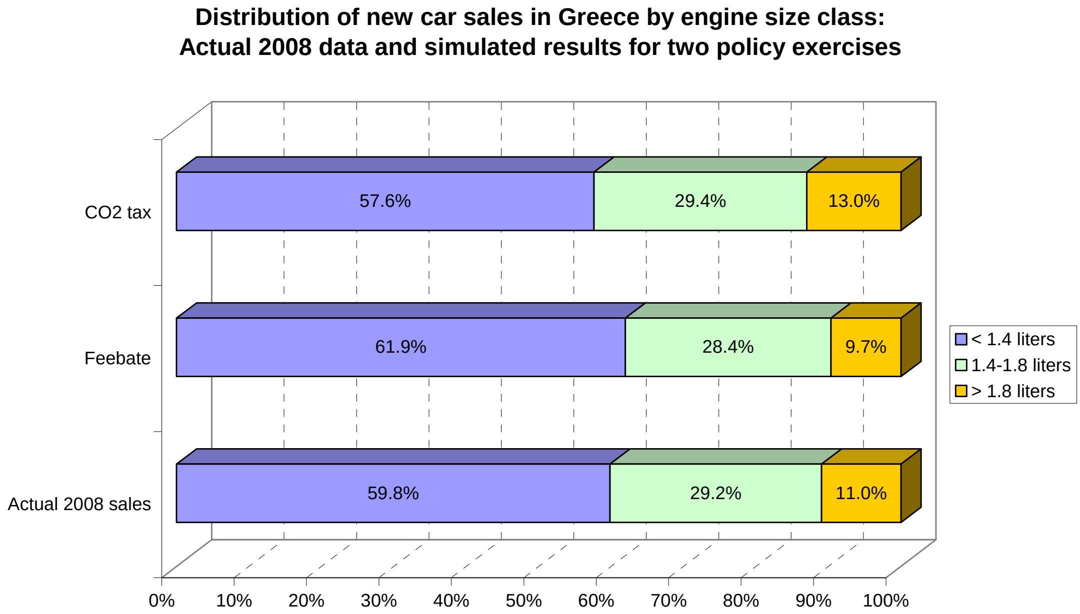


Figure 4: Comparison of actual and simulated automobile sales shares in Greece by engine size class.

6. Concluding remarks

This paper has described a model of oligopolistic competition in markets with differentiated products, simulating demand and supply under alternative tax regimes in the car market. It is applied using detailed car sales data from Greece for the period 1998-2008. The objective is to evaluate policies that could shift consumer purchases towards low-CO_2 cars and thus lead to the reduction of fuel use and CO_2 emissions. We presented the econometric analysis and the results from two policy simulations exploring the changes in the country's car market due to the introduction of carbon-based vehicle taxes.

At a time when several countries increasingly adopt a CO_2-based element in the calculation of their vehicle taxes, the model described in this paper constitutes a useful tool for the evaluation of real-world policy options. The model can simulate changes in absolute sales levels as well as shifts in market shares as a result of different taxation regimes. This is important because recent experience has shown that environmental reforms in car taxation have been designed in many cases without a sound analysis of consumer response to these policies. As a result, the effect on public revenues has often been assessed by governments in a very rough manner, which has probably led to significant errors. If consumer response is overestimated then a specific policy does not have the effect it was initially assumed to have; on the other hand, if consumer response is underestimated then the policy may prove to be more successful than initially thought, which in turn may lead to a significant loss of public revenues – this was indeed so in at least three cases we are aware of: the CO_2 rebate system in the Netherlands in year 2002, the French feebate system ('bonus-malus') that was launched in 2008 (Bastard, 2010) and a CO_2-based car taxation scheme introduced in Ireland in 2008 (Rogan et al., 2011).

We experimented with two carbon taxation schemes: a feebate system, in which consumers receive a rebate when purchasing low-CO_2 cars or incur an additional fee when purchasing a high-CO_2 car, and a partial replacement of the existing Greek registration tax (which is calculated as a function of engine size) with an emissions-based tax. The feebate simulation shows that a reduction of new car CO_2 emissions is possible without adverse effects on the economy, provided that crucial policy settings are selected carefully. Conversely, the CO_2-based registration tax simulation illustrated that, if such a tax is adopted in countries that already impose a registration tax which increases sharply with vehicle size, this measure can have negative unintended consequences, thereby deteriorating average carbon emissions of new cars. This conclusion is relevant not only for Greece but also for many other countries across Europe which apply strongly increasing registration taxes.

Overall, our simulations have shown that careful policy design can lead to realistic measures that bring about substantial environmental benefits without losing control of public finances and private welfare. For low-carbon transportation policies to be effective, the support of a theoretically appropriate and empirically robust modeling framework, like the one described in this paper, is essential.

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