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An Estimation of Fuel Demand Elasticities for Spain

An Aggregated Panel Approach Accounting for Diesel Share

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Abstract

In this paper, an econometric analysis of transport fuel demand elasticities is presented for Spain, for the period 2000 to 2007, giving emphasis to the diesel share of the road transport fleet. Estimation results show a significant impact of the share of diesel-powered vehicles, when considering the specific gasoline and diesel demand, but the same does not hold when considering the total fuel demand, where the impact is much lower. In addition, a simple tax reform simulation is carried out, showing that greater savings in CO_2 emissions are achievable only in the long run.

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1.0 Introduction

The demand for transportation and the related energy demand have been, in recent years, at the centre of a large academic and public policy debate. This is basically due to the fact that the increasing private travel demand, in large part served by cars, has resulted in a significant growth in oil demand. This increasing oil demand has its impact on both the dependence from foreign energy sources (common in most developed countries) and on global pollutants, mostly CO_2. In 2007, according to the European Energy Commission report (European Commission, 2010), road transportation was responsible for 20.12 per cent of total CO_2 emissions in Europe, increasing from 704.3 million tonnes in 1990 to 905 in 2007. In Spain, the country considered here, the situation is similar, with road transportation representing 25.3 per cent of total CO_2 emissions, and having increased from 50.4 million tonnes in 1990 to 97.8 in 2007. Dealing with the impact on the environment and on security of supply of the transport sector represents, therefore, an enormous challenge for the decision maker, given its large link with economic and social growth.

To address these environmental and sustainability issues, a government can promote public transport, enhance infrastructures, subsidise more efficient technologies, or act directly on new vehicles' fuel efficiencies by imposing standards. However, one of the most widely proposed tools for influencing private transport has been to act on the taxation level of both fuels and purchases of new cars. According to the previously cited white paper, one of the first steps to take should be to revise the current 'motor fuel taxation with clear identification of the energy and CO_2 component' (European Commission, 2011c, p. 29).

Nevertheless, the intervention on fuel demand through fiscal policy should be done carefully, since tax changes might affect consumers' behaviour and utility.[1] Moreover, as Santos *et al.* (2010a) and Santos *et al.* (2010b) suggest, any change in the tax burden is usually subject to a great pressure from public opinion, since it affects largely the competitiveness of a nation and, even if needed, it must rely on a wide political and public consensus.

Yet cross elasticities, hidden costs, and rebound effects are just some examples of how difficult it is to design or modify a policy on energy and transport. Under this perspective, the need for both the data and the scientific instruments, or models, to interpret them is crucial for refining predictions and estimates of policy effects. Many of them involve econometric techniques, investigating how changes in prices and income (among other aspects) affect changes in consumers' behaviour in the transport sector.

The two main approaches used for estimating the relationship between the demand for fuel and prices/income can be distinguished by the structure of the data. One approach relies on aggregate data, mostly coming from national accounts, while the other is based on disaggregated data like household surveys.[2]

[1] For a study on the redistributive effects of fuel taxes, see Asensio *et al.* (2003).

[2] For a broad review of past works on this topic, see Goodwin (1992), or Graham and Glaister (2002), while the meta-analysis by Espey (1998) and Brons *et al.* (2008) provide a comparison of the determinants in the formulation of the estimation models, and the data that are affecting the different results. Basso and Oum (2007) offer a broad view of methods and conclusions, giving an extensive insight into the pros and cons of using disaggregated data. Among the main issues in using aggregated data just for gasoline, authors identify two main errors: the inclusion of gasoline demand destined to use for other type of vehicles (motorbikes, buses, among others), and the exclusion of other types of fuel such as diesel, biodiesel, and other biofuels.

In Spain, the price elasticity of fuel products has been studied mainly using disaggregated models with data coming from the Spanish Statistics Institute's (INE) Family Budget Survey.[3] Using a seven-equation model, Labandeira *et al.* (2006) studied how price changes in gasoline, electricity, and other energy sources result in changes in demand. For gasoline, findings suggest that there is no substitution effect between this product and other energy sources, mainly because of technological limits.[4] Romero-Jordán *et al.* (2010) use the same survey data, but focus on fuel demand, providing a deep analysis of its state in Spain. The model used in this last case is the so-called AIDS (Almost Ideal Demand System), which is adapted to fuel demand. The suggestion they give is that the low price elasticities they found for fuel are an obstacle for using gasoline tax increases for reducing oil consumption in private transport, at least in the short term. Although similar in the data set used, the results for the two papers differ significantly, especially regarding the price elasticity (−0.1 in Romero-Jordán *et al.* vs. −0.6 in Labandeira *et al.*). Reasons could be the problem formulation, the different period taken into consideration, or, most probably, the estimators' choice — a crucial point, as will be discussed later.

However, these two papers do not distinguish between diesel and gasoline demand (due to the impossibility of separating these two from the INE's data set). This might be a relevant limitation, because of the different evolution in diesel and gasoline shares (both in fuel demand and in car fleet structure). The effects of the increasing diesel share and the related policies are the focus of a large debate in the literature. Sterner (2007), for instance, argues that a large effect on the difference between fuel demand in Europe and the US could be explained by the higher tax levels for oil products in the European Union, and also that the different treatment in taxing diesel and gasoline can play a role in this gap.

The effects of an increased adoption of diesel technology in private vehicles are still under debate. González and Marrero (2012), who extensively review the dieselisation phenomenon and estimate its effect on Spanish CO_2 emission from private vehicles, found that the increasing ratio of the diesel over the gasoline vehicles significantly affect the CO_2 levels in the private transport sector. But how does this change in the fleet composition affect fuel consumption?

Schipper *et al.* (2002) (updated in Schipper and Fulton, 2009) show that the aggregate 'real world' fuel savings coming from the increasing diesel car share are somewhat negligible, or even null, once compared to the potential fuel efficiency gain. Looking for the causes for this (somehow counterintuitive) phenomenon, Schipper *et al.* consider different possibilities. The reasons proposed are all linked to the economic principle of the 'rebound effect', which could affect both the vehicle use and the vehicle purchase. Those effects are a clear example of how the shift from diesel to gasoline has non-linear effects on the demand

[3]According to the vast database used in Dahl (2012), the published country-specific studies dedicated to Spanish road fuel consumption are just Arimany De Pablos (1977), Labeaga and Lopez (1997), and Labandeira *et al.* (2006). This last will be extensively reviewed, along with Romero-Jordán *et al.* (2010). Another recent work, González-Marrero *et al.* (2012), will also be discussed in this paper, for analogies regarding both data set and methodologies. As for other countries worth mentioning: Polemis (2006) for Greece and Crôtte *et al.* (2010) for Mexico.

[4]Future developments and the diffusion of electric vehicles might change the substitution in domestic demand between oil and electricity.

of both gasoline and diesel, and is one of the reasons that moved the authors of this paper to use aggregate instead of disaggregate data.

Indeed, we argue that using an aggregate model is the only way to uncover how the economic setting and the fleet composition affect the gasoline and diesel demand separately, and how each one differs from the other. Although the aggregate data lack some detail — for instance, separating the private and commercial demand — they allow a better insight of the fleet composition and some economic determinants, such as real income and prices. Moreover, using a dynamic panel data, as in this case, allows us to estimate the long-run effects of those economic variables, hence providing insights from a medium- to long-term perspective.

By making explicit the impact of the number of diesel vehicles on the total fleet, the intention of this paper is to capture the effect of an aspect which has been, for a long time, the centre of both political and scientific debate, regarding the increasing adoption of diesel.

We are only aware of one paper that has looked at this issue for Spain, also using aggregated data (indeed, a data set similar to ours): González-Marrero *et al.* (2012) formulate an econometric model to explain aggregate fuel consumption for road transport, doing so separately for gasoline and diesel. However, the model structure and also the estimators used are different, which leads to divergent results and conclusions, as will be shown in the following sections.

The formulation used here is an adaptation of the flow adjustment model, first presented in the seminal paper by Houthakker and Taylor (1966), which takes into account the frictions of the demand in responding to changes in prices and other economic variables. Even if a large part of the literature on fuel consumption does estimate the per-capita consumption (including González-Marrero *et al.*, 2012), here the per-car consumption has been studied instead. Well-known examples of this approach include Baltagi (1983) — who fully developed the model, adapting a previous model by Sweeney (1978) — followed by Baltagi and Griffin (1997), Baltagi *et al.* (2003), and the recent Pock (2010). We share, with the latter, the inclusion of both the gasoline and diesel fleet, although here the ratio diesel over gasoline is used, as shown in the model specification.

Studying the per-vehicle consumption allows us to relate the consumption of a specific fuel to the diffusion and share of the particular technology that uses it, one of the objectives of this paper. This is then corrected by the term of the total fleet, since, *ceteris paribus*, twice the vehicles per household should not lead to twice the usage, resulting in an expected negative effect of the fleet increase with respect to the adult population, as observed in the literature (Pock, 2010; González-Marrero *et al.*, 2012, among others).

The study of these three different demands for fuel (although with some limitations) should provide interesting insights on both the short- and the long-term reactions of consumers to changes in fuel prices and income, as well as changes in the fleet composition.

Moreover, a simulation of two different tax reforms is presented in Section 4. The tax reforms are those proposed by Labandeira (2011), following the suggestions of the European Commission (European Commission, 2011c, 2011b) for fiscal rates in energy products and transportation. The simulation exercise is simply done by applying to the estimation results the relative price changes referring them to a reference year (2007, in this case). This should provide a hint about the effects of a taxation reform from the energy saving point of view, and how it can contribute to lower CO_2 emissions in the transport sector.

2.0 Model and Data Specifications

2.1 The classical approach and the diesel car share

A large part of transport fuel demand depends on fuel prices and on the income of the consumer (larger incomes and cheaper gasoline makes people drive more), but the fleet size, composition, and efficiency also affect the amount of energy demanded in the transport sector.[5]

According to previous papers by Sweeney (1978) and Baltagi (1983), a general specification of the so-called 'ideal demand' of fuel per car (variable $(GAS/CAR)^*$) is a function of the income per capita Y/POP, the price of fuel P, and the number of cars per adult CAR/POP.[6] The formulation is presented in equation (1):

$$(GAS/CAR)^* = \alpha(Y/POP)^{\beta}(P)^{\gamma}(CAR/POP)^{\delta}, \tag{1}$$

where the fleet size per adult CAR/POP has to be considered a correction for the 'per vehicle' demand, allowing for the per vehicle per capita suggested in the introduction.

Consumers need time to adapt their behaviour to changes in economic settings. Most of the decisions that are part of these reactions are taken once every several years. In the case of transport, those decisions are about car purchase, driving habits, and living and working locations — decisions which are not taken more often than every few years, in the vast majority of households.

For this reason, Houthakker and Taylor (1966) came up with the introduction of a different (and not directly observed) demand, called the 'ideal' demand. This essentially represents consumers' decisions in absence of any friction — that is, what they would like to consume, given income or prices, among other aspects, when there are no constraints regarding technology (vehicles, modes) or location (house, work).

The relationship between the 'ideal' (without frictions) and 'actual' (with frictions) demand is described in Houthakker and Taylor (1966), as presented in equation (2), where $(GAS/CAR)^*$ represents the former, while (GAS/CAR) represents the latter. This formulation allows us to distinguish between the effects in the short term and in the long term on the consumption. In equation (2), the term θ should be interpreted as the speed of adjustment or the inverse of the time necessary for the short term to converge to the long term, after a change in the initial conditions:

$$\frac{(GAS/CAR)_t}{(GAS/CAR)_{t-1}} = \left(\frac{(GAS/CAR)^*_t}{(GAS/CAR)_{t-1}}\right)^{\theta}, \quad \text{with } 0 < \theta \leqslant 1. \tag{2}$$

Finally, plugging equation (3) into equation (1) will allow us to get rid of the 'ideal' term, as in equation (4), from which we can take logarithms, leading to the final baseline of the

[5]For a qualitative assessment of the movers of the transportation demand in Spain, see Romero-Jordán *et al.* (2010).

[6]In the original formulation, an efficiency index was included as well, but the lack of data and the difficulty of defining an appropriate proxy for that led to this variable not being included in many models (for example, Baltagi and Griffin, 1997; Baltagi *et al.*, 2003; Pock, 2010). This paper follows the latter, omitting a direct proxy for efficiency.

estimation presented in equation (5) to which has been added the classic error term u_t:

$$(GAS/CAR)_t^* = \left(\frac{(GAS/CAR)_t}{(GAS/CAR)_{t-1}^{1-\theta}}\right)^{1/\theta}, \quad \text{with } 0 < \theta \leqslant 1, \tag{3}$$

$$\left(\frac{(GAS/CAR)_t}{(GAS/CAR)_{t-1}^{1-\theta}}\right)^{1/\theta} = \alpha(Y/POP)^{\beta}(P)^{\gamma}(CAR/POP)^{\delta}, \tag{4}$$

$$\begin{aligned}\log(GAS/CAR)_t = {} & \theta \log(\alpha) + (1-\theta)\log(GAS/CAR)_{t-1} + \theta\beta\log(Y/POP)_t \\ & + \theta\gamma\log(P)_t + \theta\delta\log(CAR/POP)_t + u_t,\end{aligned} \tag{5}$$

where u_t represents the usual error term.

In contrast with the formulation in Pock (2010), in this paper, the diesel car share has been introduced as a single variable (DS, equal to $CARD/CAR$, where $CARD$ represents the quantity of diesel-powered cars circulating and CAR the total number). The total fuel demand will take the form as in equation (6):

$$\begin{aligned}\log(GAS/CAR)_t = {} & \theta\log(\alpha) + (1-\theta)\log(GAS/CAR)_{t-1} + \theta\beta\log(Y/POP)_t \\ & + \theta\gamma\log(P)_t + \theta\delta\log(CAR/POP)_t + \theta\sigma\log(DS)_t + u_t.\end{aligned} \tag{6}$$

The formulation in equation (6) is the baseline that allows the estimation of gasoline, diesel, and total fuel demand, as explained in Section 2.2.

2.2 Gasoline, diesel, and total fuel demand

Although previously cited papers (Baltagi, 1983; Baltagi and Griffin, 1997; Baltagi *et al.*, 2003; Pock, 2010) used similar formulations for estimating just the gasoline demand, avoiding dealing with the diesel demand, here a more general representation of the demand for fuel is provided.[7]

In order to study the particular demands (gasoline and diesel) in different regions, a modification of equation (6) is required. This is done simply through the introduction, along with the region index i, of an index $k = \{G, D, F\}$, which will refer to the fuel type being G (gasoline), D (diesel), and F (total fuel). For instance, $GAS_{G,i,t}$ will be the gasoline demand that take places in region i at time t, and $p_{D,i,t}$ the real price of diesel in region i at time t.

Accordingly, equation (7) represents the more general demand:

$$\begin{aligned}\log(GAS/CAR)_{k,i,t} = {} & \theta_k\log(\alpha_k) + (1-\theta_k)\log(GAS/CAR)_{k,i,t-1} \\ & + \theta_k\beta_k\log(Y/POP)_{i,t} + \theta_k\gamma_k\log(P)_{k,i,t} \\ & + \theta_k\delta_k\log(CAR/POP)_{i,t} + \theta_k\sigma_k\log(DS)_{i,t} + u_{k,i,t}.\end{aligned} \tag{7}$$

[7] It should be noted that diesel figures include commercial demand, which would require a different modelling not considered here, due to the lack of data.

It is worth noting that both the car share CAR/POP and diesel fleet share DS parameters remain untouched in the last formulations. As previously noted, this is because the effects of the total car share (there are fewer people per car when there are more cars per household) should not be related to the particular technology considered. The effects of the different technologies are, in our model, addressed by the technology share variable DS and the associated parameter σ.

As mentioned before, this specification is different from the one in González-Marrero *et al.* (2012) in several aspects: we do not consider the proxy for saturation of roads, we use a different indicator for the dieselisation of the fleet (expressed as a ratio rather than as two different terms), and more importantly, following Pock (2010), the dependent variable is associated to the specific fuel consumption per vehicle, rather than per capita. This allows a formulation closer to the original one in Baltagi (1983), where the gasoline consumption is composed of the utilisation, gasoline efficiency, and stock.

The sign and the magnitude, along with their economic interpretation of our estimates, are crucial. As for price and income elasticities, we would expect a negative value for the first and a positive for the latter, and both values should be below or slightly above 1 in absolute terms, given the well-documented inelastic demand for fuels (Dahl, 2012, for example) and the already high share of private transport in Spain — according to our data, almost a third of the adult population own a vehicle, on average.

Moreover, the variables connected to the fleet composition should provide insights on how the increasing total car fleet and the observed dieselisation could affect consumption patterns. As said before, on the one hand, a larger per-adult car ownership level would negatively affect the consumption per car, as there the usage, even if increased, will be shared among more vehicles. On the other hand, the effect of the DS variable on consumption is not that straightforward, as it does not represent an 'absolute' or 'per capita' value, but rather a 'per-car' ratio, capturing the dieselisation level of the fleet.

Although a larger ratio of diesel over gasoline vehicles will probably lead to lower per-car gasoline use, the effects on diesel consumption are not so obvious. On one side, as more 'low-mileage' users switch to diesel cars, the consumption (per car) of diesel will become lower. On the other side, as Schipper *et al.* (2002) suggest, the cheaper access to this fuel will lead to a higher vehicle use, leaving unchanged (or even increasing) the per vehicle fuel consumption. As data on the driven distances are not available, it is difficult to distinguish these two driving forces.

2.3 Data description

Our data cover fleet composition, fuel demand, fuel prices, and incomes for sixteen regions in Spain for the years 2000 to 2007, with annual frequency. Autonomous cities such as Ceuta and Melilla and the autonomous community of Las Canarias have not been taken into consideration, due mainly to the different fiscal setting. The main source is the Spanish Statistics Institute (INE). Fuel demand data comes from the National Energy Commission (CNE), while the fleet composition source is the Transit General Directorate (DGT). Regarding fuel prices, the source is a yearly bulletin published by the Spanish Ministry of Industry, Commerce and Industry (MITyC), which collects price data from a sample of final resellers.

Both fuel prices and gross domestic products are discounted for each region to the year 2000 by the consumer price index, one of the few available (and reliable) indexes for deflating variables from nominal to real terms.

Table 1
Data Descriptive Statistics

	(GAS/CAR)	(Y/POP)	(P)	(CAR/POP)	(DS)
Min	0.974	0.098	6.426	0.398	0.237
Max	2.806	0.245	7.950	0.923	0.577
Mean	1.792	0.167	7.118	0.653	0.402
Overall variability	0.500	0.046	0.500	0.127	0.115
Within variability	16.9%	24.1%	91.5%	24.0%	60.3%
Between variability	83.1%	75.9%	8.5%	76.0%	39.7%

Table 1 shows the descriptive statistics of the variables used in the model (six). It is interesting to see that while the 'Between variability' explains most of the variability of the fuel demand, the per-capita income, and the car share, the 'Within variability' is the one that explains the diesel share variability, suggesting that the way it changes is homogeneous among the regions. The price variability is, not surprisingly, explained by the 'Within variability', since nominal prices are moved mostly by the national and international oil markets, being almost homogeneous across the regions.

2.4 Estimators

The literature on this topic has devoted many pages to comparing estimators and trying to evaluate which estimation tool could perform better in the specific case of an aggregate demand. Comparing the performance in gasoline demand of eleven homogeneous and thirteen heterogeneous estimators in a 30-year-long data set for thirteen OECD (Organisation for Economic Co-operation and Development) countries, Baltagi and Griffin (1997) found that homogeneous estimators outperform heterogeneous ones in both forecast trials and plausibility, contrasting with the theoretical prediction. These results are confirmed in a later paper by Baltagi *et al.* (2003), using a data set from twenty-one French regions, with evidence leading us not to consider heterogeneous estimators in this work.

Finally, Pock (2010), confirming findings by Baltagi *et al.* (2003) about IV and GMM estimators, suggests the suitability of the fixed effect estimators for the estimation of aggregate fuel demand. Moreover, Pock proposes a corrected version of the Within estimator, affected by well-documented biases (Nickell, 1981). This corrected estimation (called LSDVc), applied to unbalanced data, relies on a procedures developed for statistical software STATA by Bruno (2005) through the adaptation of the methods suggested in Kiviet (1995) and Bun and Kiviet (2003).

The superiority of the estimators proposed is supported by the structure of the panel. The fact of treating the whole population of individuals (the autonomous communities), and a sample of the years, suggests a much better performance of fixed effect estimators, as the same evidence by Baltagi and Griffin (1997) shows.

Since the aim of this paper is not to investigate the goodness of the estimation techniques, but rather to study the characteristics of the different fuel demands and what affects them, only the classic and corrected version of least square dummy variable (LSDVc) estimators will be applied to the formulation presented in Section 2.2. This is another methodological difference from the work of González-Marrero *et al.* (2012), who argue that FD-GMM and sys-GMM perform quite well, although showing high p-values for most of the variables when estimating diesel demand.

Nevertheless, for the sake of completeness, and to compare with these alternative approaches, we conducted the estimation experiments, applying classic OLS, IV, GLS, and GMM estimators with results (not showed here) that were in most cases inconsistent with both expectations and theory (for example, speed of adjustment greater than one).

3.0 Estimation Results

In this section, the results of applying equation (7) to data presented in Section 2.3 are discussed. As mentioned in the previous section, the estimators applied are the classical Within group estimator and a corrected version of it (LSDVc) proposed by Kiviet (1995) and Bun and Kiviet (2003). The estimates using LSDVc will be discussed more broadly throughout this section, using results from Within estimations for comparison.

Table 2 shows the estimation results for gasoline, diesel, and total fuel demands. The dependent variables are divided in short- and long-run estimates. Following equations

Table 2
Fuel Consumption Estimations Including the DS Variable

	Gasoline		*Diesel*		*Total fuel*	
	Within	*LSDVc*	*Within*	*LSDVc*	*Within*	*LSDVc*
Short-run estimates						
$\ln(GAS_{k,t-1})$	0.527^{***}	0.698^{***}	0.724^{***}	0.861^{***}	0.727^{***}	0.889^{***}
	(4.62)	(9.60)	(7.89)	(22.53)	(6.96)	(13.88)
$\ln(y_t)$	0.0576	0.0687^{***}	0.300^{***}	0.217^{***}	0.252^{**}	0.162^{***}
	(0.57)	(3.42)	(3.39)	(7.82)	(2.73)	(4.19)
$\ln(p_{k,t})$	-0.264^{***}	-0.246^{***}	-0.243^{***}	-0.231^{***}	-0.293^{***}	-0.276^{***}
	(−3.31)	(−5.82)	(−6.07)	(−8.54)	(−5.35)	(−8.65)
$\ln(CAR_t)$	−0.142	−0.0832	-0.328^{**}	-0.204^{**}	-0.297^{**}	−0.165
	(−1.38)	(−1.34)	(−3.13)	(−2.96)	(−2.86)	(−1.94)
$\ln(DS_t)$	-0.128^{*}	-0.100^{*}	-0.251^{**}	-0.126^{**}	−0.0926	−0.0655
	(−2.11)	(−2.18)	(−2.76)	(−3.09)	(−1.78)	(−1.77)
Long-run estimates						
$\ln(y_t)$	0.122	0.228^{*}	1.086^{**}	1.564^{***}	0.924^{*}	1.460^{*}
	(0.55)	(2.18)	(2.93)	(3.57)	(2.33)	(2.18)
$\ln(p_{k,t})$	-0.558^{*}	-0.815^{*}	-0.880^{*}	-1.667^{**}	-1.072^{*}	−2.491
	(−2.43)	(−2.51)	(−2.54)	(−2.64)	(−2.16)	(−1.50)
$\ln(CAR_t)$	−0.301	−0.275	-1.187^{**}	-1.472^{***}	-1.088^{*}	-1.492^{**}
	(−1.30)	(−1.41)	(−2.94)	(−3.79)	(−2.26)	(−2.76)
$\ln(DS_t)$	-0.271^{*}	-0.333^{*}	-0.908^{***}	-0.911^{***}	−0.339	−0.590
	(−2.13)	(−2.27)	(−5.33)	(−3.74)	(−1.65)	(−1.22)

Notes: t statistics in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

(2) and (5), the long-run estimates for price, income, car, and diesel share are simply obtained by dividing the respective short-run estimates by $1 - \theta_{SR}$, where θ_{SR} is the estimate associated with the lagged demand $\ln(GAS_{k,t} - 1)$.

At first glance, it seems that most of the estimates are in accordance with the economic theory predictions, showing positive income elasticity and a negative price elasticity. Going into deeper detail, it seems that short-run price elasticities are similar for all the demands, and between −0.23 for diesel and −0.28 for total fuel when considering LSDVc estimators, with gasoline in between, with an elasticity of −0.25. Although a little bit higher, the Within estimator shows similar results, with elasticities of −0.26 for gasoline, −0.24 for diesel, and −0.29 for total fuel. Indeed, our price estimation results appear to be in accordance with both the economic expectation and the literature results for both gasoline and diesel. For instance, our price elasticity results sit just in-between those in Romero-Jordán *et al.* (2010) and Labandeira *et al.* (2006) — which do not differentiate gasoline and gasoil consumption.

Regarding income, estimates for the different fuel demands are far more dispersed. Diesel's short-run elasticity of 0.22 is three times higher than gasoline's estimated elasticity of 0.07. Total fuel shows an intermediate result of 0.16. Estimating income effects with the Within estimator shows higher values for diesel (0.3) and total fuel (0.25), but not for gasoline, as the Within estimate is lower (0.057) than the LSDVc and not significant.

These results seem to be consistent with the ones found in the previously cited works. Even if, in the literature, the income effect appears to be stronger (larger elasticity in absolute terms) than the price effect, as shown in Dahl (2012), similar studies show low-income elasticities. For gasoline, Pock (2010) obtains an income elasticity of just 0.07, while in González-Marrero *et al.* (2012), the result for the same variable was −0.011. Our results are more divergent from this latter work, in the case of diesel. There, both income and price elasticities appear to be around 0 and not significant (−0.027 and 0.044, respectively), and the same can be said for the parameters related to the fleet composition, as opposed to our results showed in Table 2 and presented above. As said in the introduction, the reasons for these differences can lie on the estimator used and, more importantly, on the particular model adopted. As stated in Basso and Oum (2007), the estimator used and the model can affect the results, as the comparison with González-Marrero *et al.*, with whom we share a similar data set, clearly shows.

The car index parameter (share of cars per adult) shows a negative sign, as expected, but it is significant only in the case of diesel demand estimation (−0.20). Finally, regarding the diesel share, the estimates suggest not only that an increase of this variable has a significant negative effect on gasoline demand (−0.10), but also that it has a negative effect on diesel demand (−0.13). Although smaller and not significant, the effect turns out to be negative for the total fuel demand (−0.07) as well. Compared with results by González-Marrero *et al.* (2012), we find yet another divergence. According to their results, an increase of the vehicle fleet (in per capita terms) has a positive effect on diesel consumption for both diesel and gasoline vehicles. Once again, this could arise from the different estimators and, most probably, due to the different structure of the model, as they use consumption per capita.

As seen in the introduction, the more efficient (and increasingly cheaper) diesel technology is leading to a shift from gasoline car users (Mayeres and Proost, 2001). In this experiment, the adoption of the diesel technology by these 'low-mileage' consumers

Table 3
Correlation Matrix of Coefficients of the Total Fuel Estimation Model

	$ln(GAS)_{t-1}$	$ln(Y/POP)$	$ln(P)$	$ln(CAR/POP)$	$ln(DS)$
$\ln(GAS)_{t-1}$	1.0000				
$\ln(Y/POP)$	−0.2792	1.0000			
$\ln(P)$	0.3273	−0.4687	1.0000		
$\ln(CAR/POP)$	0.1257	−0.2257	−0.1586	1.0000	
$\ln(DS)$	0.2143	−0.1032	−0.3677	0.2898	1.0000

is not overtaken by the rebound effect; the significant negative sign of the estimated parameter suggests that the popularity of diesel lowered the consumption per vehicle of this fuel.

One concern could arise regarding the presence of collinearity in the dependent variables, as suggested by Pock (2010). In particular, the relationship between income and vehicle ownership could lead to higher variances in the estimated coefficients — although the consistency of estimation results is still unaffected. Tests for collinearity conducted show how our model is not affected by such issue with the data set use. Table 3 shows the correlation matrix of the coefficients for the total fuel consumption model, demonstrating that all values lie between −0.5 and +0.5, far below the perfect correlation between pairs of variables. Moreover, as suggested in, for example, Belsey *et al*. (1980), Hill and Adkins (2003), or Kennedy (2003), a corrected version of the condition index for the three models (diesel, gasoline, and total fuel consumption) has been computed, showing values always lower than 2.5, thus suggesting that multicollinearity is not affecting the sample.

4.0 Simulating Energy Fiscal Reforms

4.1 Simulation setting

Finally, and to show the potential applicability of our estimates, in this section we present the results from a simulation exercise of the impact of a tax reform. For that, the estimated elasticities will be used to see how changes in the fuel taxation may affect energy use and CO_2 emissions. The tax reform taken into consideration is the one proposed by the European Union (European Commission, 2011c, 2011b). In these two documents, the necessity of linking energy and emissions with taxes has been formalised into a plan for a fiscal reform with deadlines in 2013 and 2018 (these two years will be considered the two steps of the reform).

What would the adoption of these reforms entail for the member states? The case of Spain has been widely discussed by Labandeira (2011), who proposes two different fiscal reforms of the entire energy system, analysing the impacts in 2013 and 2018. The simulation provided in this section uses the very same tax reform scenarios, while assessing how energy and CO_2 emissions change compared to a reference scenario that, in our case, is the year 2007, and not focusing on revenues, as Labandeira does.

Although this simulation exercise does not take into account several factors affecting fuel demand such as the general equilibrium indirect effects, the role of technology

Table 4
Disclosure of the Simulated Tax Reform (in Thousand Euros per GJ) Used in the Simulations

		Nominal tax levels			*Final price*	
		on CO_2	*on Energy*	*Total*	*Absolute*	*Relative change (%)*
Reference year						
2007	gasoline	0.00	14.30	14.30	32.08	
	diesel	0.00	8.39	8.39	25.52	
Reform A						
2013	gasoline	1.38	9.60	12.96	30.74	−4
	diesel	1.48	8.20	11.42	26.79	+5
2018	gasoline	1.38	9.60	12.96	30.74	−5
	diesel	1.48	9.60	13.07	28.44	+11
Reform B						
2013	gasoline	1.38	9.60	12.96	30.74	−4
	diesel	1.48	8.20	11.42	26.79	+5
2018	gasoline	1.38	13.69	17.78	35.56	+11
	diesel	1.48	13.69	17.89	25.27	+27

Note: The price changes are relative to the 2007 levels.

advances, or the many limitations of the policy simulations through econometric results,[8] the results presented in this section should provide a hint about the order of magnitude of the effects of such a reform in the abatement of CO_2 emissions and the reduction in energy use (if any).

The tax reforms (A and B) simulated are essentially the same as those presented in Labandeira (2011) and quantitatively presented in Table 4. Reform A just tries to correct the gap between diesel and gasoline by applying an indirect tax related to the carbon content of the fuel, 1,384 eur/GJ for gasoline and 1,480 eur/GJ for diesel for all the different scenarios, and an increasing energy-related tax, which starts at 9,600 eur/GJ for gasoline and 8,200 eur/GJ for diesel in 2013, rising an equal 9,200 eur/GJ in 2018 for both fuels. Reform B shares with reform A most of the values, although the taxation in 2018 is assumed to include some of the external costs produced by transportation and to move taxation levels closer to the ones adopted by the other European Union member states.[9]

4.2 Simulation results

Table 5 represents the detailed results for the demand of both gasoline and diesel. This is done by simply multiplying the estimated demand elasticities (the corrected LSDV in Table 2) to the relative price changes proposed in Table 4. Those results are then processed for calculating the overall changes in oil consumption in transport and the changes in the entire energy sector and the related CO_2 emissions, as in Table 6.

[8]Lucas (1976) clearly shows how the econometric models cannot forecast the effects of monetary policy due to construction limitations.

[9]According to the data from the European Commission, the tax share for oil products in Spain is almost 20 per cent lower than the European average (European Commission, 2011a).

Table 5
Simulation Results for the Gasoline and Diesel Consumption and Related Emissions Under the Two Considered Reforms

			Energy cons. change		*CO_2 emission change*	
Year	*Fuel type*	*Elasticity*	*Abs. (GJ)*	*Relative (%)*	*Abs. (tonnes)*	*Relative (%)*
Short-run results						
Reform A						
2013	gasoline	−0.25	+2,760,693.12	+1.03	+145,848.73	+1.03
	diesel	−0.23	−12,055,084.08	−1.19	−730,959.76	−1.19
2018	gasoline	−0.25	+2,760,693.12	+1.03	+145,848.73	+1.03
	diesel	−0.23	−25,121,720.24	−2.47	−1,523,254.96	−2.47
Reform B						
2013	gasoline	−0.25	+2,760,693.12	+1.03	+145,848.73	+1.03
	diesel	−0.23	−12,055,084.08	−1.19	−730,959.76	−1.19
2018	gasoline	−0.25	−7,136,258.73	−2.67	−377,011.95	−2.67
	diesel	−0.23	−63,248,297.90	−6.22	−3,835,059.18	−6.22
Long-run results						
Reform A						
2013	gasoline	−0.81	+9,138,768.84	+3.42	+482,805.51	+3.42
	diesel	−1.67	−86,994,914.09	−8.56	−5,274,934.74	−8.56
2018	gasoline	−0.81	+9,138,768.84	+3.42	+482,805.51	+3.42
	diesel	−1.67	−181,289,643.50	−17.84	−10,992,493.61	−17.84
Reform B						
2013	gasoline	−0.81	+9,138,768.84	+3.42	+482,805.51	+3.42
	diesel	−1.67	−86,994,914.09	−8.56	−5,274,934.74	−8.56
2018	gasoline	−0.81	−23,623,277.26	−8.83	−1,248,028.99	−8.83
	diesel	−1.67	−456,428,193.10	−44.92	−27,675,513.63	−44.92

Regarding gasoline and diesel demand, results appear to be mixed. Applying reform A will result in a small but positive increase of gasoline demand (+1.0 per cent in the short term and +3.4 per cent in the long run), given the lower taxation compared to the reference case (year 2007). Diesel, on the other hand, will always experience a decrease in demand, given that retail prices will always be higher when adopting the reforms. Compared to the first step of the reform (year 2013), the decrease in both demand and CO_2 emissions is estimated to be around 1.2 per cent in the short run and 8.5 per cent in the long run (given the large (−1.6) long-run elasticity estimated). These figures are even more prominent when we consider the second step of the potential reform A (year 2018): estimated energy reductions in diesel demand are then 2.5 per cent in the short term and 17.8 per cent in the long term.

Similarly, the adoption of reform B suggests a strong decrease in diesel demand. Moreover, the second reform step (the one that differs from reform A) shows a decrease in both fuel demands, which is estimated to drop by almost 45 per cent for long-run diesel demand. The 'true' value should be probably included in the estimated 95 per cent interval of the reduction, which is between −75 per cent and −11 per cent, an interval too wide to provide

Table 6
Simulation Results for the Total Fuel Consumption and Related Emissions and Impact on the Overall Energy Demand and Carbon Emission

	Energy cons. change		CO_2 emission change		Overall relative change	
Year	Abs. (GJ)	Relative (%)	Abs. (tonnes)	Relative (%)	Energy (%)	CO_2 (%)
Short-run results						
Reform A						
2013	−9,294,390.96	−0.72	−585,111.03	−0.77	−0.15	−0.16
2018	−22,361,027.12	−1.74	−1,377,406.23	−1.82	−0.37	−0.37
Reform B						
2013	−9,294,390.96	−0.72	−585,111.03	−0.77	−0.15	−0.16
2018	−70,384,556.63	−5.48	−4,212,071.12	−5.56	−1.17	−1.14
Long-run results						
Reform A						
2013	−77,856,145.25	−6.07	−4,792,129.23	−6.33	−1.29	−1.29
2018	−172,150,874.60	−13.41	−10,509,688.10	−13.88	−2.86	−2.83
Reform B						
2013	−77,856,145.25	−6.07	−4,792,129.23	−6.33	−1.29	−1.29
2018	−480,051,470.40	−37.40	−28,923,542.61	−38.19	−7.97	−7.80

a reliable figure. Nevertheless, the short-run estimate can be considered a better instrument for determining the reduction of the demand since, as for diesel, it should be included (−0.077, −0.048) in the interval (at 0.95 level), but the effect in the longer term, interesting though it may be, is hard to predict.

5.0 Summary and Concluding Remarks

The overall estimated savings were presented in Table 6. It is worth noting that in all cases, the proposed reforms produce savings in the overall energy use, mainly given the greater share of diesel in the total fuel demand (this can be easily observed by comparing gasoline and diesel absolute figures in Table 5).

The impact of adapting just reform A is rather small, resulting in a reduction of 0.4 per cent in the short term for both overall energy demand and CO_2 emissions in 2018, while the long-term estimate suggests a decrease, on average, of less than 3 per cent, although in this case the reduction of energy from overall oil products in transportation is around 13.5 per cent.

Reform B should have larger impacts once compared to the just assessed reform A, given the much higher tax levels for both gasoline and diesel. In this case, results suggest a greater impact on the overall energy use and CO_2 emissions from fossil fuels for transport, which, although just around −1.2 per cent, could reach −8 per cent in the long run. Yet, it is worth remembering that this last result should be associated with its confidence interval that suggests, at the 95 per cent level, a decrease of between −2 per cent and −13 per cent in the total energy consumption coming from fossil fuels (not just oil, but coal and natural gas as well).

In a nutshell, given the low short-run price elasticities estimated in Section 3, the taxation reform for gasoline and diesel seems to be having little effect on the overall energy use and the related CO_2 emissions. Results for the long-run impact of reforms suggest much higher savings in energy use and lower emissions. However, the high variance of those estimates does not help in identifying a clear value for this estimate, but rather a broad interval.

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