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The effect of dieselization in passenger cars emissions for Spanish regions: 1998–2006

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ABSTRACT

Following the goal of improving on-road fuel efficiency, the Spanish Government engaged in an active policy called the *dieselization* between 1998 and 2006, which was intended primarily for light duty vehicle (mostly passenger cars and SUV's). However, the effect of the dieselization on controlling emissions has been questioned by many authors. At the Spanish national level, we first provide descriptive evidence of the effects of dieselization on passenger cars emissions. Second, we use a panel data set for 16 Spanish regions between 1998 and 2006, and estimate a dynamic panel data model that relates CO_2 emissions generated by passenger cars with a set of variables related to the dieselization process, fuel efficiency and other control variables. Combining both analysis, we find the existence of a significant indirect, negative effect on CO_2 emissions caused by the dieselization, which is more important than the direct, positive technology-efficiency impact.

1. Introduction

The Spanish economy experienced one of its largest expansive economic cycles between 1998 and 2006 resulting in, among other things, a large increase in transport demand. As a consequence, the road transport energy consumption and emissions associated with this sector almost doubled during this period (EC, 2009). Currently, the Spanish transport sector is one of the largest in Europe in terms of its contribution to total emissions, representing about 30% of total CO_2 emissions, with more than 70% coming from road transport (MITYC, 2009). The European Environmental Agency reported that this sector, within which passenger cars constitute a significant fraction of total emissions, presented one of the largest obstacles to meeting upcoming Kyoto Protocol targets. Another major concern is a widening imbalance between the demand for diesel and gasoline fuel (CONCAWE, 2007).[1]

Spain has adapted several EU Directives (70/220/CEE, 88/77/CEE, 70/157/CEE, 1999/94/CE, etc.), i.e., fiscal incentives to embrace less polluting vehicles, for the purpose of reducing emissions in the road sector. Following the purpose of fuel efficiency, between 1998 and 2006, the Spanish Government engaged in an active policy called the *dieselization* process (Clerides and Zachariadis, 2008; Fontaras and Samaras, 2007): policy incentives to replace gasoline vehicles with diesel vehicles.[2] The dieselization policy was intended primarily for light duty vehicle (mostly passenger cars and SUV's), though the success on controlling emissions has been questioned by many authors (Schipper et al., 2002; Schipper and Fulton, 2009; Mendiluce and Schipper, 2011).

In this paper we study the relationship between emissions generated by passenger cars (including SUVs or 4×4s vehicles) and a set of variables related to the dieselization process for the 1998–2006 period at the Spanish regional level. This period coincides with the most intensive part of the dieselization process that occurred in Spain. In order to have a more homogenous behavior, we have not considered light trucks in the sample, because they are more likely to be devoted to freight transport than to a personal travel use. Moreover, it is more likely that regional fuel consumption and emissions would not be distorted by inter-regional trucking, which would skew our regional analysis.

In general terms, dieselization might have different impacts on emissions. On the one hand, there is a favorable impact because diesel fuel is more efficient (i.e., in liters per kilometers) than gasoline. Some research, focusing only on this partial approach,

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[1] European policymakers have responded to these issues in a number of ways, as set out in the White Paper on Transportation, the Green Paper on the Security of Energy Supply, the Green Paper on Energy Efficiency and the Voluntary Agreement with the European automobile manufacturer's association (European Automobile Manufacturer's Association, EAMA, 2008).

[2] There are several factors behind the success of the dieselization process (Monaham and Friedman, 2004): diesel engines are more fuel efficient than gasoline engines; there are fiscal advantages to acquiring and fueling diesel vehicles (Rietveld and Van Woudenber, 2005); and significant technical improvements have been made to diesel vehicles, resulting in better driving performance.

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conclude that increasing the share of diesel vehicles would decrease CO_2 emissions (Sullivan et al., 2004; Zervas, 2006; Zachariadis, 2006; Jeong et al., 2009). However, on the other hand, there might exist important induced indirect channels involving the reaction of economic agents to such changes in efficiency. For example, since the cost per kilometer for diesel cars is lower (and/or diesel provides fiscal advantages), the dieselization process has also incentivized mobility and/or the acquisition of more powerful and larger vehicles. These indirect effects would be reflected in higher diesel consumption by cars and more emissions. Taking this consideration into account, Schipper and Fulton (2009) for eight OECD countries and Mendiluce and Schipper (2011) for Spain, among others, have concluded that, in many cases, these indirect effects of dieselization on emissions have been more significant than the direct impact of higher efficiency. In the same sense, recent paper by Bonilla (2009) and Tovar (2011) conclude that only improvements in vehicle efficiency is not enough to mitigate emissions.

Our analysis complements Mendiluce and Schipper (2011) by analyzing the emissions-dieselization issue at the regional level in Spain, which allows us to consider a panel regression approach and quantify the relationship. More concretely, we use a panel data set for 16 Spanish regions between 1998 and 2006 and estimate a dynamic panel data (DPD) model that relates car CO_2 emissions with alternative measures of the dieselization process (referred to as *dieselization variables* from now on): the diesel to gasoline car (stock) ratio, the diesel to gasoline new car registration ratio, the diesel to gasoline fuel consumption ratio (for cars only) and the diesel to gasoline distance traveled ratio for cars. The main conclusion reached in this paper is that, for Spanish regions from 1998 to 2006, there exists a significant indirect effect on CO_2 emissions caused by dieselization and is more important than the direct one, technology-efficiency impact. This conclusion supports the argument that when energy services become cheaper, it will prompt a rebound effect (among others, see Schipper et al., 2002).

In order to properly implement our quantitative analysis, we note the following. The *dieselization variables* are affected by changes in consumption habits and by aspects directly related to the relative technological state of the different engines (diesel with respect to gasoline). In order to distinguish both effects, we also need to include in the model a variable that only reflects the efficiency advantages of diesel with respect to gasoline, to which end we use the fuel/km series for diesel and gasoline cars, as provided by IDAE (Spanish Energy Conservation Agency) and directly related to the technological state of the engines. Thus, combining this information with the dieselization variables would allow us to distinguish between the efficiency effect and the indirect effects. Finally, in order to obtain accurate and unbiased estimates of the emissions-dieselization relationship, we also need to include additional control variables, such as the real GDP and the overall fuel consumption (measured in per capita terms). We also discuss in the paper the inclusion of real fuel prices and the motorization rate.

An important aspect considered in this article concerns the process of estimating the DPD model. Using these types of models, Marrero (2010), González and Marrero (2012), Pock (2010), Huang et al. (2008) and Baltagi et al. (2003), among others, have shown that estimation results can change significantly depending on the econometric method used. Using these papers as points of reference, we discuss the convenience of using the one-step system GMM estimator (Arellano and Bover, 1995; Blundell and Bond, 1998) to estimate our DPD emissions model. To the best of our knowledge, this paper is the first contribution that considers and properly estimates a DPD model to evaluate the dieselization effects on car emissions.

The paper is structured as follows: Section 2 includes a detailed description, by fuel type, of the car stock, registration, driving distances, consumption, fuel intensity and emissions for Spain between 1998 and 2006 at the national and regional level. This section provides some descriptive evidence of the effects of dieselization on car emissions. Section 3 presents the DPD regional model and discusses the econometric method. In Section 4 we show estimation results and check for robustness under alternative specifications. Finally, Section 5 concludes the paper and discusses policy implications.

2. Data on road transport emissions, fuel consumption and dieselization in Spain

2.1. Data overview at the national level

In this section we summarize statistics related to passenger cars in Spain from 1998 to 2006. We comment on data for CO_2 emissions, fuel consumption, fuel intensity and the change in the stock, new registrations, distance traveled and consumption of diesel compared to gasoline passenger cars (Table 1). Data sources are described in the footnote of the table. The period considered is 1998–2006, as this coincides with the most intensive part of the dieselization process that occurred in Spain. The year 1998 was the first in which diesel passenger car registrations achieved figures similar to those for gasoline cars, before eventually surpassing them every year since then until 2006. In 2006, there was a change in the trend in diesel passenger car registrations, becoming almost constant by 2007. Since 2008, largely motivated by the financial crisis, diesel passenger car registrations have decreased significantly.

First we note (first horizontal panel in Table 1) that CO_2 emissions from road transport increased between 1998 and 2006 at an average annual rate of 3.6%, reaching 95,139 kt of CO_2, in 2006. Over half of these emissions came from passenger cars and exhibited similar growth rates (3.4% annually, and 30% between 1998 and 2006). Clearly, the slow renewal of the Spanish fleet has not helped to improve the trend in emissions.[3] Additionally, according to our analysis, the dieselization process in Spain seems not to have helped to control emissions during this period either. This section shows some statistical evidence supporting this hypothesis, in line with Schipper and Fulton (2009); Mendiluce and Schipper (2011).

The intensity of the dieselization process in Spain between 1998 and 2006 is quite evident (panels 2, 3 and 4 in Table 1). While the stock of diesel passenger cars grew at an average annual rate of 13.5%, that of gasoline decreased by 1.4%. Thus, the ratio of diesel/gasoline cars went from 27.1% in 1998 to 83.5% in 2006. Similar findings are extracted from new passenger car registration data: diesel registrations rose by 8.3% per year, while new gasoline cars fell by 2.7%. Thus, the ratio of diesel to gasoline passenger car registrations rose from 93.6% in 1998 to 220.1% in 2006. Another indicator of the dieselization process is the change in fuel consumption by passenger cars: diesel increased at an annual rate of 14% while gasoline decreased at a 3% annual rate.[4] The rate of diesel to gasoline consumption by cars was 31.8% in 1998 and 116% in 2006.

Data suggest that the process of dieselization has favored the improvement in fuel efficiency (panel 5 in Table 1). According to data from IDAE, the average fuel efficiency for a diesel engine is

[3] The rate of renewal of the car fleet (new cars/stock cars) was only 8.5%, which partly explains the high proportion of cars over 10 years old in the national car fleet, with an average of 34.3% of the total between 1998 and 2006.

[4] The consumption of diesel and gasoline cars is obtained by multiplying the car fleet of each fuel type by unit consumption figures for cars (tep/car) for each year as published by the IDAE (2009). This calculation can compensate for the absence of statistics about fuel consumption of cars by fuel type.

Table 1
Gasoline and diesel Spanish data: 1998–2006.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average values
Emissions										
CO_2 cars (kton)	38,115	39,727	39,722	41,145	43,177	45,112	47,013	48,307	49,610	3.36*
CO_2 road transport (kton)	71,706	74,855	77,055	80,840	83,014	87,095	90,513	92,666	95,140	3.60*
CO_2 cars/CO_2 road transport (%)	53.15	53.07	51.55	50.90	52.01	51.80	51.94	52.13	52.14	52.08
CO_2/km Rel. to gasoline (%)	95.70	95.91	95.86	95.81	95.91	95.98	95.93	96.02	96.09	95.91
Car stock										
Stock diesel cars	3,321,622	3,984,395	4,629,833	5,268,747	5,908,259	6,485,322	7,381,195	8,290,676	9,107,506	13.48*
Stock gasoline cars	12,237,805	12,343,449	12,283,461	12,319,278	12,252,451	11,635,312	11,565,671	11,350,442	10,909,056	−1.41*
Stock diesel/stock gasoline cars (%)	27.1	32.3	37.7	42.8	48.2	55.7	63.8	73.0	83.5	51.58
Stock cars > 10 years (%)	33.1	34.1	35.1	35.4	35.4	35.9	34.5	33.4	31.9	34.31
Registrations										
New diesel cars	620,172	766,733	785,193	779,869	805,226	899,545	1,075,418	1,133,843	1,141,903	8.25*
New gasoline cars	662,761	735,779	681,736	718,907	603,178	592,973	578,340	542,847	518,708	−2.71*
New diesel cars/new gasoline cars (%)	93.6	104.2	115.2	108.5	133.5	151.7	185.9	208.9	220.1	146.84
New 4x4s diesel/new diesel cars (%)	9.2	9.6	8.7	7.5	7.1	7.4	7.6	9.1	10.6	8.53
Average mass of new car	NA	NA	1,137	1,266	1,725	1,317	1,335	1,374	1,395	4.96*
Consumption										
Consumption of diesel car ′000000	3,758	3,670	4,434	5,252	6,280	7,315	8,464	9,507	10,713	14.21*
Consumption of gasoline car ′000000	11,809	12,070	11,710	11,712	10,953	10,717	10,235	9,722	9,232	−2.99*
Consump. Diesel car/gasoline car (%)	31.8	30.4	37.9	44.8	57.3	68.3	82.7	97.8	116.0	63.01
Fuel intensity										
Gasoline car (l/100 km)	8.3	8.2	8.2	8.2	8.2	8.1	8.1	8.1	8.1	8.16
Diesel car (l/100 km)	6.9	6.8	6.8	6.8	6.8	6.8	6.8	6.7	6.7	6.79
l/100 km Rel. To gasoline (%)	83.0	83.2	83.2	83.1	83.2	83.3	83.2	83.3	83.4	83.22
Driving distances										
km/gasoline car/year	11,696	11,896	11,626	11,623	10,956	11,329	10,912	10,588	10,499	−1.30*
km/diesel car/year	16,517	13,468	14,044	14,658	15,654	16,660	16,989	17,014	17,504	1.05*
km diesel car/km gasoline car (%)	141.2	113.2	120.8	126.1	142.9	147.1	155.7	160.7	166.7	141.60

NA: Not Available.

Note: Car stock and registration data are obtained from DGT. SUV's registrations comes from ANFAC. The average mass of new cars are obtained from european comission (2009); . Fuel intensity data (liters/100 km) are published by IDAE. CO_2 cars emissions come from the Inventario Nacional de Emisiones (National Inventory of Emissions), MARM (2008). This Inventory classifies emissions according to SNAP categories, following the CORINAIR approach. Road transport emissions are included in the SNAP 07 category; more concretely, the SNAP 0701 refers to passenger cars emissions. The CO_2/km data are obtained from values reported by the IPCC for the alternative fuels. Fuel consumption data is built from IDAE data on car gasoline and car diesel consumption (tep/veh). The driving distances are obtained in a similar way, from available information in IDAE for the different types of vehicles (gasoline and diesel).

* Average annual growth rates (%).

20% higher than that of a gasoline engine (6.70 l/100 km for diesel cars compared to 8.16 for gasoline cars). Moreover, diesel cars produce 4% lower CO_2 emissions per km. So, in this regard, the dieselization process should have resulted in significant savings in fuel consumption and emissions (Schipper et al., 2002, Sullivan et al., 2004; Zervas, 2006).

However, this evidence ignores the possibility of an indirect effect in fuel consumption. Thus, there exists much evidence to suggest that diesel fuel has caused a shift in vehicle usage patterns that has resulted in increased fuel consumption (Schipper and Fulton, 2009; Mendiluce and Schipper, 2011). On the one hand, technological improvements and incentives to purchase diesel cars have spurred the growth in sales of more powerful and larger vehicles (Schipper and Fulton, 2009). In this sense (see panel 3, Table 1), registrations of diesel SUV's exceeded 10% in 2006, and the average mass of new passenger cars, which are mostly diesel, was 1364 kg in 2006, 20% higher than the 1137 kg of 2000 (we have not found data for 1998 and 1999).

On the other hand, mobility has grown significantly, especially for diesel cars (see panel 6, Table 1). Thus, diesel passenger car usage has increased considerably to an average of 15,834 km/year, as compared to 11,236 km/year used by gasoline cars. That implies that diesel cars are driven significantly more (an average of 42%) than gasoline cars (Schipper and Fulton, 2009; Schipper, 2009). While the average kilometers traveled by gasoline cars per year has fallen 1.3%, average mobility for diesel cars has grown just over 1% per year between 1998 and 2006.

Different arguments have been made to account for the greater mobility of diesel passenger cars. One such explanation is that diesel cars are on average newer and newer cars are always driven more than older ones, as car usage surveys show (see literature cited in Schipper, 2011). Another explanation relies on the different characteristics of diesel vehicle buyers (Cerri and Hivert, 2003). Schipper (2009) points out that it may be a self-selection effect, as those who drive farther switch to diesel, with those who drive less opting for gasoline cars. Moreover, diesel may be used more as a first family car or for touring, since they are larger than their gasoline counterparts. Another factor is the use of diesel cars for business other than taxis, which are driven almost twice as much as private cars according to Dutch data (CBS, 2010) and Swedish data (Bonilla, 2009) for Netherlands and Sweden).[5] Additionally, the increased mobility of diesel cars may be the result of a rebound effect that derives from the higher efficiency of diesel fuel and its lower cost (Hymel et al., 2010).

Whatever the reason, the descriptive analysis conducted in this section shows clear evidence that the dieselization process undertaken in Spain has generated a significant indirect effects (included a rebound effect).

[5] In Spain there are no statistics that distinguish between the energy consumption in passenger cars for commercial activities (like taxi, cars for rental companies) and the private transport of passengers (Mendiluce, 2010).

Table 2
Spanish regional data (car CO_2 emissions, real GDP pc, car fuel consumption pc, real fuel price and vehicle pc): 1998–2006.

	Car CO_2 emissions pc			Real GDP pc			Fuel consumption pc			Real fuel prices			Vehicle per capita		
REGION	**1998**	**2006**	**AV***	**1998**	**2006**	**AV***	**1998**	**2006**	**AV***	1998	2006	AV*	1998	2006	AV*
Andalusia	0.77	1.04	3.90	10.53	13.30	2.97	0.27	0.36	3.86	76.75	103.53	4.13	46.02	61.41	3.68
Aragon	0.98	1.13	1.75	15.12	18.83	2.79	0.28	0.34	2.25	77.61	103.72	4.01	48.58	60.79	2.85
Asturias	0.95	1.17	2.73	12.26	15.51	2.99	0.29	0.36	2.90	75.13	103.32	4.38	44.52	56.75	3.08
Balearic Islands	1.34	1.31	1.25	18.52	18.49	−0.01	0.48	0.46	−0.46	81.84	103.47	3.21	81.50	83.49	0.32
Cantabria	1.16	1.52	1.84	13.37	17.03	3.07	0.29	0.39	3.59	76.42	103.52	4.21	47.27	62.76	3.61
Castile–Leon	1.26	1.59	3.07	13.08	16.91	3.26	0.29	0.37	3.30	76.56	103.56	4.18	47.56	62.45	3.47
Castilla La Mancha	1.17	1.41	2.46	11.59	13.72	2.14	0.27	0.37	4.18	75.11	103.66	4.51	47.81	65.11	3.94
Catalonia	1.00	1.04	0.52	17.57	20.62	2.03	0.34	0.36	0.79	77.91	103.67	3.95	60.48	66.67	1.24
Valence	0.95	1.09	1.75	13.94	15.86	1.64	0.34	0.39	1.69	76.24	103.39	4.22	58.35	67.04	1.76
Extremadura	0.87	1.11	3.30	9.02	12.10	3.75	0.26	0.37	4.52	75.67	103.03	4.25	44.27	62.37	4.38
Galicia	1.02	1.37	3.78	11.40	14.43	2.99	0.33	0.43	3.49	75.84	103.53	4.29	49.44	64.35	3.35
Madrid	0.92	0.98	0.77	19.39	22.93	2.13	0.39	0.42	0.99	80.94	103.54	3.38	60.68	66.91	1.29
Murcia	0.93	1.20	3.24	12.17	14.23	1.98	0.31	0.40	2.95	79.26	103.69	3.78	53.41	66.85	2.86
Navarre	0.99	1.24	2.98	18.13	22.33	2.65	0.33	0.38	1.75	77.16	103.28	4.07	56.57	66.31	2.02
Basque Country	0.89	1.01	1.70	17.46	22.55	3.26	0.30	0.34	1.79	78.18	103.41	3.89	47.33	56.25	2.19
La Rioja	0.96	1.13	2.06	16.49	18.89	1.72	0.28	0.33	1.79	79.63	104.01	3.72	49.82	58.75	2.09
UNITS	kt/thousand people			€/thousand people			Tep/thousand people			Cent. €/liter base 2000			vehicles/hundred persons		

Note: Regional population and real GDP were taken from the National Statistics Institute (INE in Spanish) and are measured in number of persons and in real terms, respectively. Gasoline and diesel fleet cars and car registrations by fuel type were taken from the National Traffic Office (DGT). The regional real fuel price variable can be easily calculated as a Laspeyres index using the regional prices of gasoline and diesel and the weights corresponding to sales of each fuel type. The real prices of gasoline and diesel, measured in Euros, were obtained from the Ministry of Development, while the gasoline and diesel consumed in the road transport sector, measured in tep, we built from IDAE data on car gasoline and car diesel comsumption (tep/veh).

* Annualized variation between 1998–2006 (%).

Table 3
The table lists the alternative dieselization messures.

	Diesel cars/ gasoline cars			Diesel consumption/ gasoline consumption			Diesel car registrat./ gasoline car registrat.			km diesel cars/km gasoline car		
REGION	**1998**	**2006**	**AV***	**1998**	**2006**	**AV***	**1998**	**2006**	**AV***	**1998**	**2006**	**AV***
Andalusia	0.24	0.93	18.37	0.31	1.41	21.26	1.08	2.56	12.14	0.34	1.55	21.20
Aragon	0.24	0.74	15.11	0.31	1.12	18.02	0.85	2.78	16.62	0.34	1.23	17.96
Asturias	0.43	1.05	11.71	0.55	1.59	14.42	1.99	2.26	2.30	0.61	1.74	14.37
Balearic Islands	0.11	0.36	16.36	0.14	0.54	19.13	0.25	1.08	21.12	0.15	0.59	19.08
Cantabria	0.39	1.07	94.06	0.50	1.63	16.23	1.64	2.25	4.49	0.55	1.79	16.18
Castile-Leon	0.29	0.83	16.08	0.37	1.27	17.18	1.34	2.58	12.13	0.40	1.39	17.12
Castilla La Mancha	0.30	1.07	17.18	0.39	1.63	20.12	1.68	4.01	9.33	0.43	1.79	20.06
Catalonia	0.22	0.69	16.44	0.28	1.05	18.27	0.79	2.21	14.19	0.31	1.15	18.21
Valence	0.30	0.83	14.80	0.38	1.26	16.49	0.98	1.55	14.16	0.42	1.38	16.43
Extremadura	0.23	0.86	17.88	0.30	1.31	20.82	1.27	3.49	1.29	0.33	1.44	20.77
Galicia	0.55	1.29	11.22	0.71	1.96	13.94	2.67	2.75	17.96	0.78	2.15	13.88
Madrid	0.24	0.92	18.68	0.31	1.39	21.23	0.87	3.22	9.53	0.34	1.53	21.17
Murcia	0.37	1.13	17.28	0.48	1.72	17.84	1.63	3.21	9.34	0.52	1.89	17.78
Navarre	0.36	0.94	12.87	0.46	1.43	15.63	1.39	2.74	11.57	0.51	1.57	15.57
Basque Country	0.36	0.91	12.13	0.47	1.38	14.90	1.28	2.36	6.33	0.51	1.52	14.84
La Rioja	0.29	0.85	15.45	0.37	1.29	17.42	1.08	2.49	8.99	0.40	1.41	17.36

* Annualized variation between 1998–2006 (%).

2.2. *Spanish regional data*

The sample size of data at a national level is insufficient to carry out a rigorous quantitative analysis. For this reason, we rely on the information available for 16 Spanish regions between 1998 and 2006. The information in this panel data allows us to estimate a dynamic panel model (Section 3) and quantify the relationship between emissions from passenger cars and different measures of dieselization for Spain. Unfortunately, the statistical information available at the regional level is not as rich as for the whole of Spain. Next we briefly describe the data that we used at the regional level.

All data refer to passenger cars (including SUV's). Tables 2 and 3 summarize these data for every Spanish region (excluding the Canary Islands, Ceuta and Melilla).[6] We show 1998 data (start of the period), 2006 data (end of the period) and the annual growth rate between these years. The endogenous variable is CO_2 passenger car emissions, measured in kt and taken from the from MARM (2008). At the regional level, we consider two different sets of variables. On the one hand, we consider aggregate data that might affect overall CO_2 emissions (Table 2). Depending on the model estimated, we will use real GDP, overall stock of cars, aggregate fuel consumption of cars and real fuel prices. With the exception of fuel prices, all other variables will be measured in per capita terms for comparative

[6] We removed Ceuta, Melilla and the Canary Islands from the sample because of their special peculiarities and the incompleteness of some series.

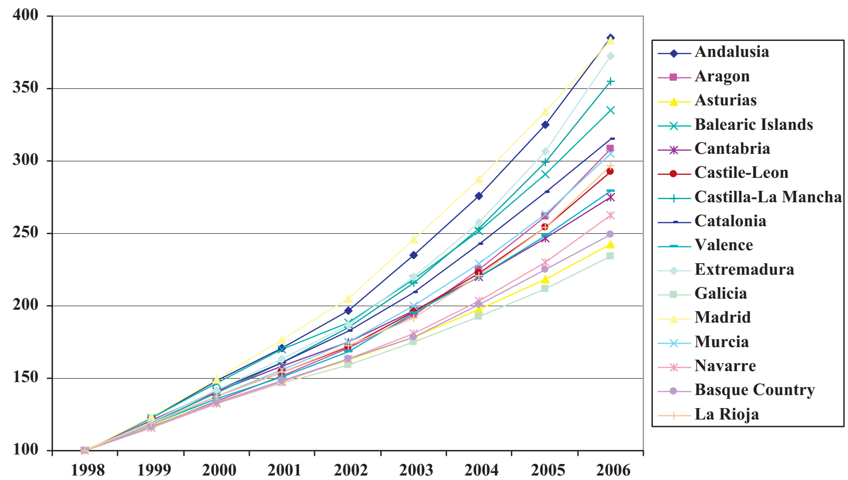

Fig. 1. Diesel to gasoline passenger cars in Spanish regions between 1998 and 2006.

purposes. Further description of the data and data sources are shown in the footnote of Table 2.

On the other hand, we consider alternative variables of dieselization, measured as diesel to gasoline ratios (Table 3): (i) the ratio of diesel to gasoline passenger cars (their stock); (ii) the ratio of new diesel to gasoline car registrations; (iii) the diesel to gasoline car fuel consumption; (iv) the diesel to gasoline distance traveled. Among these dieselization measures, we take the first one as our benchmark measure because most measures for boosting diesel consumption have involved the promotion of diesel cars, although our quantitative analysis will check for robustness for the alternative measures.

Between 1998 and 2006, per capita CO_2 passenger car emissions increased in every Spanish region, although we observe some important differences (see Table 2). With the exception of Aragon, the Balearic Islands, Cantabria, Catalonia, Valencia, Madrid and the Basque Country, which are among the richest regions in Spain in terms of per capita GDP, per capita car emissions increased above 1.9% per year during this period in every region. Of particular note are the cases of Andalusia, Extremadura, Galicia and Murcia, which are among the poorest regions and whose emissions increased more than 3.2% per year. These facts suggest that the recent trend in per capita CO_2 car emissions has, if anything, an inverse relationship with its per capita GDP or regional degree of development.[7] We will test this relationship in the analysis carried out in Section 4.

The comparison between total fuel consumption and emissions data is noteworthy. From Table 2, the Balearic Islands, Galicia and Madrid were the regions with the highest per capita fuel consumption between 1998 and 2006, while Aragon, the Basque Country and La Rioja had the lowest. As concerns growth rates, we find that regions such as Castilla La Mancha, Andalusia and Extremadura, with high rates of growth of per capita fuel consumption (up 3.8% per year), also experienced very significant growth in their emissions (up 2.4%) By contrast, Madrid and Catalonia show low levels of emissions growth (below 0.8%), which also correspond to low levels of fuel consumption growth (below 1.0%). Very briefly, we just note that the motorization rate (stock of vehicles by population) increased in all Spanish regions, with growth rates averaging a maximum of 4.4% in Extremadura and a minimum of 0.3% in the Balearic Islands. Lastly, the real price of fuel increased in all regions at rates of between 3.2% and 4.5%, though, because of the high volatility in fuel prices stemmed from Spain's enormous dependence on foreign oil, notable differences in growth rates are noted over the period analyzed.[8]

Table 3 shows data for the alternative dieselization measures considered in this paper. The overriding trend between 1998 and 2006 in every Spanish region was the significant increase in the amount of stock or new registrations of diesel versus gasoline cars, fuel consumption and mobility. For example, between 1998 and 2006, the ratio of diesel to gasoline passenger cars almost tripled, going from 0.31 to 0.90, with variations over 15% in the majority of regions. To emphasize how widespread this process was among the various Spanish regions, Fig. 1 shows the progression of this ratio for every Spanish region between 1998 and 2006. This ratio tripled in nearly every Spanish region, almost quadrupling in some, as was the case in Andalusia and Madrid. A similar trend is observed if instead of looking at the ratio of passenger cars, we consider new car registrations. The number of diesel cars registered doubled compared to gasoline vehicles registered in the period in question. If we compare these indicators among all Spanish regions, we must highlight the case of Madrid as being most exemplary of the dieselization process, while said process was least significant in Galicia. Similar trends are observed for the fuel consumption and distance traveled ratios.

3. Background, the model and the estimation approach

3.1. Background

A common practice in the literature on modeling CO_2 emissions is to apply an index decomposition technique in order to characterize the driving forces behind such emissions (e.g., Harrison, 1993, Bongaarts, 1992, Martínez-Zarzoso et al., 2007). This approach is based on an identity that relates emissions to structural economic factors. The *IPAT* identity, based on the Kaya decomposition, breaks down the determinants of changes in environmental impacts (I) into population (P), affluence (A) and technology (T). Other authors, such as Dietz and Rosa (1997) and Shi (2003), use the *IPAT* identity to conduct a regression based

[7] Applied to the road transport sector, a negative relationship between per capita GDP and emissions is consistent with the downward part of the inverted U-shape relationship between these two variables, as postulated by the literature on the Environmental Kuznets Curve (EKC) (Selden and Song, 1994; Grossman and Krueger, 1995).

[8] For example, the dollar price of a barrel of Brent crude fell 14% in 2001, while in 2004 and 2005 it went up 33 and 42%, respectively.

analysis. Similar methods have been employed to disentangle the determinants of change in energy consumption or CO_2 emissions in the transport sector. For example, the *ASIF* equation extends the *IPAT* identity (Schipper et al, 2002) to the transport sector.[9] Recently, Mendiluce and Schipper (2011) applied this kind of model to break down the different factors that account for carbon emissions in the Spanish transport sector. These authors find that, in Spain, the dieselization of the fleet has led to an increase in activity due to the rebound effect.

However, when using aggregate data (as in our case), these models reveal two important shortcomings. First, their reduced-form representation is static, which prevents taking into account the dynamic nature of aggregate emissions or fuel consumption. Using aggregate data, the dynamic nature of energy and emissions variables has been shown to be an important aspect to be considered in empirical applications. Since the seminal paper by Houthakker et al. (1974), a dynamic model has been widely used in many fuel demand applications (Baltagi et al., 2003; Sterner, 2007; Pock, 2010, among others). Second, they do not allow for an estimate of partial correlation coefficients, which is an interesting way to measure the causal relationship among variables. The dynamic panel data (DPD) model proposed in this paper addresses these deficiencies and is a good complement to the *IPAT* results. Applied to aggregate CO_2 emissions, a similar model like the one we estimate in this paper can be seen as the reduced form of a neoclassical growth model extended with emissions (Brock and Taylor, 2005; Álvarez et al., 2005). Recently, a DPD model was used by Ryan et al. (2009) for CO_2 road transport emissions in Europe, by Marrero (2010) for aggregate CO_2 emissions in Europe and by González and Marrero (2012) for road mobility in Spain.

3.2. The dynamic model

In this section we present a DPD model for analyzing the effect of dieselization on passenger car emissions for Spanish regions. The specification is in line with the models put forth by Marrero (2010) and González and Marrero (2012). Aggregate variables are measured in per capita terms while the emissions, consumption, fleet, registration, distances traveled, fuel intensity and dieselization variables are associated to cars only. When regional data are unavailable, we use data at the national level, which can be easily included in our DPD model as time variant variables but common to all regions.

Specifically, passenger car emissions in region i at time t, E_{it}, are assumed to be a linear logarithmic function of different sets of variables. We consider aggregate variables commonly used in emissions models, such as real GDP, Y_{it}, and fuel consumption, F_{it}. As an extension of the model, we will also consider real fuel prices and the motorization rate, which will be discussed in Section 4. We also consider variables to capture the effects of fuel-economy improvements on car emissions. We use fuel intensity measured as fuel consumption (in liters) per kilometer. This variable is directly related to the technological state of the engines (see IDAE, 2009), and we consider in the model the diesel to gasoline l/km ratio, denoted by L. The IDAE only provides information for this variable at the national level, but this is not a problem because a reasonable assumption is that technological progress is common to all regions. Finally, we consider the different aggregate measures of dieselization, D, showed in Section 2. When these *dieselization variables* are included together with L, its coefficient captures part of the rebound effect of dieselization. Thus, our DPD model reduces to:

$$\ln(E_{it}) = \alpha_i + \beta \ln(E_{i,t-1}) + \lambda_1 \ln(Y_{it}) + \lambda_2 \ln(F_{it}) + \lambda_3 \cdot L_t + \lambda_4 \cdot D_{it} + \varepsilon_{it}$$
$$t = 1998, \ldots, 2006, \quad i = 1,2,\ldots,16 \qquad (1)$$

where the regional-specific terms α_i capture all of the fixed factors (time-invariant) related to these emissions inherent to each region that are either not considered in the model, such as regional geographical, social and local policy aspects, or not directly observed, such as the initial emissions technology for vehicles in each region. Since L and D are ratios, we do not take logs. Hence, their coefficients reflect quasi-elasticities instead of elasticities. Finally, an error term, ε_{it} is also included, which aggregates all other elements of a random nature that are not considered in the model and are assumed to have the standard error component structure emphasized in Arellano and Bond (1991) and Arellano and Bover (1995). With the remaining factors conditioned, all coefficients reflect a partial short-term impact (elasticity or quasi-elasticities) between passenger car CO_2 emissions and all other explanatory variables. As for the long-term effect, this can be easily obtained by dividing the short-term elasticity by $1-\beta$.[10]

3.3. Estimation procedure

Marrero (2010); González and Marrero (2012) have emphasized the importance of considering an appropriate estimation approach when estimating a dynamic model like (1) for aggregate emissions and the transport sector, respectively. The generalized method of moments (GMM) procedure proposed by Arellano and Bover (1995) and Blundell and Bond, (1998), referred to as GMM-SYS, addresses many of the econometric problems faced when a DPD model is estimated by more traditional methods (pooled-OLS, fixed or random effects, 2SLS, GMM-DIF, etc.). In this section we briefly discuss the advantages of GMM-SYS with respect to these alternatives.[11]

Since the lagged, endogenous term in (1) is not independent of the error term, traditional methods for estimating a panel data model (pooled-OLS, fixed or random effects) are not suited to a dynamic model like (1) (Hsiao, 1986). To solve this endogeneity problem, Holtz-Eakin et al. (1988) and Arellano and Bond (1991) transform the dynamic model into a first-difference model. This transformation allows them to characterize certain orthogonality conditions between the endogenous lagged variable and the residual, which can be used to identify a set of valid instruments, enabling them to build a generalized method of moments (GMM) estimator, which they denote GMM-DIF.

The GMM-DIF approach, however, poses a serious bias problem in small samples when the series used in the model exhibit significant persistence, as is the case with the variables considered in (1). This persistence results in weak instruments in the GMM-DIF approach, meaning that the correlation between the instruments and the variable to be instrumentalized is small. This deficiency also exists for the standard 2SLS estimator. Arellano and Bover (1995) and Blundell and Bond, (1998) offer an

[9] The *ASIF* equation states that emissions from transport are equal to $A^*S_i^*I_i^*F_{ij}$, where A represents transport activity, S the transport structure, I is the modal energy intensity of each mode and F the carbon effect associated with a mix of fuels j for modes i.

[10] The lagged term controls for short-term dynamics but also for conditional convergence. By subtracting E_{it-1} to the left and right hand side of Eq. (1), this dynamic model can be easily expressed as a typical convergence equation (the growth rate as a function of the previous period). Hence $(\beta-1)$ is the conditional convergence parameter. Thus, that $(\beta-1)<0$ (i.e., $\beta<1$) is a symptom of conditional convergence. Moreover, the larger the β, the greater the effect of the inertia as an explanatory factor of its own progression, as well as the slower the convergence speed (Marrero, 2010).

[11] See Blundell et al. (2000) or Marrero (2010) for a detailed discussion of these comparisons. A technical Appendix is available from the authors upon request.

alternative GMM procedure (GMM-SYS) to overcome this weakness. They propose estimating a system of equations by combining the conditions of the first-difference estimator with those of a level estimator. This procedure estimates a system of equations in both first-differences and levels, where the instruments in the level equations are lagged first differences of the variables. We focus exclusively on GMM-SYS estimates in this paper.[12] As is standard practice in GMM-based models, we consider the following tests to validate the assumptions underlying GMM methods: the m1, m2 and the Sargan tests (Arellano and Bond, 1991).

4. Estimation results

In this Section we show the estimation results (Table 4), considering alternative measures of the variable D in (1). In all cases, GMM specification tests (Sargan, m1 and m2) indicate that moment conditions underlying GMM estimates are robustly supported (see the explanatory note in Table 4). An important finding is that the results are quite robust to the alternative dieselization measure considered. For each case, it is highly illustrative to compare results from two alternative models: when including the L variable (first column in each panel) and when L is not included (second column).[13]

We first notice that the estimation of β is clearly lower when L is included in the model than when it is not. This result indicates that part of the inertia in CO_2 car emissions comes from the inertia of the technological evolution of diesel cars with respect to gasoline cars. A second important result is that the relationship between emissions and fuel consumption is always positive and highly significant. However, since fuel consumption is negatively correlated with the l/km variable (L), not including the latter term in the model would bias the fuel consumption coefficient downward (compare the coefficients in both columns).

With respect to real GDP, its estimated coefficient is always significant, at least at the 10% level, and negative, which is consistent with the findings of many authors in the related literature.[14] However, since real GDP is little correlated with the l/km variable, the coefficients associated with Y are now similar whether the variable L is included in the model or not. Focusing on the fully specified model (when L and D are simultaneously included), the coefficients associated with per capita fuel consumption range from 0.29 to 0.43 in the short term, while, for the long term (dividing the short-run elasticity by $1-\beta$), this coefficient ranges from 0.52 to 0.87. For its part, GDP estimated coefficients range between -0.16 and -0.18 in the short term, and between -0.26 and -0.38 in the long term.

The remaining set of results address the primary focus of this paper: the relationship between emissions and the dieselization process. We first notice that the coefficients associated with L are always negative and highly significant when included in the mode. Thus, the efficiency (energy use per km) advantage of diesel compared to gasoline fuel has had a significant beneficial impact on CO_2 emissions from car travel. Given this negative relationship between L and emissions, our more indicative result is the following: the coefficient associated with the variable D is always positive and significant, but it more than tripled and even quadrupled in magnitude when L was not included in the model. The offshoot of this result and its implications are the following. The variables referred to as D in model (1) give a global measure of the relative use of diesel to gasoline cars. Their changes can be affected by variations in consumption habits (more mobility, use of weightier cars, etc.) and/or by changes in consumption directly related to the technological state of the engines. However, the L variable only captures the technological effect. Since both effects have opposite impacts on emissions, the coefficient associated with D must be higher when L is included in the model than when it is not. Moreover, when both variables are included simultaneously in the model, the coefficient associated with D reflects a broad estimation of the induced indirect effect – that include the rebound effect – while the coefficient of L indicates a purely technological impact. Finally, since the coefficient of the variable D remains positive and significant when L is not included in the model, this finding is a clear symptom that the rebound effect had a greater influence on passenger car emissions in Spain between 1998 and 2006 than the technological impact. These results support the evidence exposed in Section 2 and the conclusions of Schipper and Fulton (2009); Mendiluce and Schipper (2011).

4.1. Robustness

We include a sensitivity analysis to examine how robust our results are to alternative model specifications (Table 5). We only show results associated with panel 1 in Table 4, i.e., when the variable D refers to the diesel to gasoline passenger car (stock) ratio.[15] For comparative purposes, the first column of the table repeats the first column of Table 4. We consider the following variants: (i) including regional fuel prices, but keeping the variables in per capita terms (columns 2, 3 and 4); (ii) including, in per capita terms, the stock of passenger cars instead of fuel consumption, (iii) instead of expressing variables in per capita terms, we consider variables in levels and include the logarithm of population as an additional explanatory variable in model (1).[16] The most important finding is that results related to dieselization are strongly robust to these alternative specifications.

For the models including fuel prices, we find the following results. First, fuel price coefficients are negative in every case, as expected. However, they are only significant when prices are considered separately from fuel consumption (columns 2 and 3 in Table 5). This is because the relevant effect of fuel prices on emissions is already captured by fuel consumption. Thus, once fuel consumption is included in the model, fuel prices – and any other variable affecting fuel consumption – should be redundant. Moreover, including both variables simultaneously would lead to collinearity problems. In summary, when fuel prices are not included, fuel consumption is highly significant (column 1); when prices are included, prices are non-significant and fuel consumption becomes less significant (column 2); however, if the stock of cars in per capita terms (the motorization rate) is included in the

[12] In a previous version of the paper (González et al., 2011) and for a slightly different model than (1), we showed results for alternative estimation procedures: pooled-OLS, fixed effects, random effects, GMM-DIF. Following the practical rule proposed by Blundell et al. (2000), we verified that these more traditional procedures did indeed suffer from significant bias problems. We concluded, as in Blundell et al. (2000), that GMM-SYS is a convenient way to overcome the weak instruments problem of GMM-DIF and the endogeneity problem of the other methods.

[13] We estimate a model including information about average mass of new passenger cars and the number of new SUV's registered with respect to total passenger cars. However, these variables were not significant and included important collinearity problems in the model. For that, we have only used a series of fuel intensity (L).

[14] For aggregate data, per capita real GDP measures the region's degree of development, at the difference of personal income when using micro-data. In this respect, Fulton et al. (2000) argue that greater distances are often traveled in rural areas, which generally have lower GDP levels. For the case of diesel demand, Burguillo-Cuesta et al. (2011) find the same result: the coefficient associated with real income is negative, but non-significant.

[15] Results are almost unchanged when considering the other measures of D. Estimation results in these cases are available upon request.

[16] Many authors have considered the population as an explanatory variable in the model (see, among others, Martínez-Zarzoso et al., 2007, and Shi, 2003), instead of including it as part of the dependent variable (per capita emissions).

Table 4
Estimation results DPD model of car emissions for Spanish regions.

	A: Passenger cars on the road (diesel to gasoline tourist ratio) regional data		**B: Total fuel consumption of passenger cars (diesel to gasoline ratio) regional data**		**C: Passenger cars new registrations (diesel to gasoline ratio) regional data**		**D: Distance covered by vehicle type (diesel to gasoline ratio) regional data**	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Estimation results (+)								
Emissions(−1)	0.5434(0.2056)***	0.9117(0.0195)***	0.5228(0.1959)***	0.9077(0.0219)***	0.5120(0.2304)**	0.9145(0.0215)***	0.4153(0.1748)**	0.9216(0.0170)***
GDP	−0.1580(0.0898)*	−0.1574(0.0413)***	−0.1605(0.0914)*	−0.1642(0.0479)***	−0.1852(0.0913)**	−0.1405(0.0306)***	−0.1556(0.0899*)	−0.1460(0.0430)***
Overall fuel consumption of passenger cars	0.3103(0.1649)**	0.1547(0.0473)***	0.2974(0.1519)**	0.1591(0.0479)***	0.4263(0.1594)***	0.1723(0.0751)**	0.3041(0.1700)*	0.1101 (0.0365)***
l/km, passenger cars (diesel/gasoline ratio)	−2.8649(1.487)**	–	−3.0371(1.4478)**	–	−2.8713(1.6674)*	–	−3.5191(1.3895)***	–
Dieselization variable (diesel/gasoline ratio)	0.0865(0.0211)***	0.0308(0.0123)**	0.0582(0.0113)***	0.0187(0.0082)**	0.0224(0.0109)**	0.0049(0.0050)	0.0576(0.0254)**	0.0139(0.0069)**
Specification tests (++)								
Sargan	37.2079(1.000)	47.9261(1.0000)	35.5628(1.0000)	47.9055(1.0000)	35.0742 (1.0000)	48.0243(1.0000)	28.8860(1.0000)	41.5123(1.0000)
m1 test	−6.637(0.000)	−4.4677(0.0000)	−7.2647(0.0000)	−4.2575 (0.0000)	−8.4952(0.0000)	−4.3790 (0.0004)	−6.1606(0.0000)	−2.9766 (0.0029)
m2 test	−1.1062(0.2686)	−1.2022(0.2293)	−1.0913(0.2752)	−1.2088(0.2267)	−1.1044(0.2694)	−1.1911(0.2336)	−1.0935(0.2742)	−1.3047 (0.1920)

(+): Standard deviation in parenthesis
(++): *p*-values in parenthesis
(1): This model includes the relative liters per km variable. Hence, the dieselization variable captures an overall rebound effect.
(2): This model does not include the relative liters per km variable. Hence the dieselization contains both the rebound and the technological progress impact.
Explanatory Note: Standard deviations are computed using the asymptotic standard errors, robust to heteroscedasticity; m1 and m2 are tests for first- and second-order serial correlation in the first-differenced residuals. These tests are asymptotically $N(0,1)$ distributed under the null of no serial correlations. Low *p*-values for the m1 test (below 0.05) and high *p*-values for the m2 test (above 0.05) would be required for the validity of GMM assumptions. The Sargan is an over-identifying restrictions test, which is asymptotically distributed as chi-squared with degrees of freedom equal to the number of instruments minus the number of parameters to be estimated. The *p*-value reported is for the null hypothesis of instruments validity. A high *p*-value is symptom of instruments validity. The instruments used in the first-differenced equation are (for all periods t): $E_{i,t-2}, \ldots, E_{i,1}$; $Y_{i,t-2}, \ldots, Y_{i,1}$; $F_{i,t-2}, \ldots, F_{i,1}$; $L_{i,t-2}, \ldots, L_{i,1}$; $D_{i,t-2}, \ldots, D_{i,1}$. The instruments for the level equations are (for all periods t): $\Delta E_{i,t-1}$; $\Delta Y_{i,t-1}$; ΔF_{it-1}; $\Delta L_{i,t-1}$; $\Delta D_{i,t-1}$.

*** Significance al 1%.
** Significance at 5%.
* Significance at 10%.

Table 5
Estimation results DPD model of car emissions for Spanish regions: robustness analysis.

	Benchmark model (+)	Including fuel prices with fuel consumption (+)	Including fuel prices with passenger cars stock (+)	Including fuel prices only (+)	Benchmark model with variables in levels
Estimation results					
Emissions(−1)	0.5434(0.2056)***	0.5466(0.2074)***	0.5458(0.1756)***	0.6151(0.1163)***	0.5433(0.2046)***
Population	–	–	–	–	0.2410(0.1002)**
GDP	−0.1580(0.0898)*	−0.1529(0.0911)*	−0.1158 (0.0832)	0.0616 (0.1375)	−0.1400(0.0809)*
Overall fuel consumption of passenger cars	0.3103(0.1649)**	0.3103(0.1681)*	–	–	0.3170** (0.1354)
Overall stock of passenger cars	–	–	0.2386(0.1387)*	–	–
Aggregate fuel prices	–	−0.0533 (0.0477)	−0.0971(0.0437)**	−0.0903(0.0517)*	–
l/km, passenger cars (diesel/gasoline ratio)	−2.8649(1.4870)**	−2.5715(1.5480)*	−2.6802(1.3792)**	−2.9583(1.4730)**	−2.2499(1.2920)*
Dieselization variable (diesel/gasoline ratio)	0.0865(0.0211)***	0.0920(0.0233)***	0.1658(0.0288)***	0.1467(0.0269)***	0.0964(0.0288)**
Specification tests (++)					
Sargan	37.2079 (1.0000)	36.9105 (1.0000)	31.4997 (1.0000)	28.7370 (1.0000)	43.1322 (1.0000)
m1 test	−6.637 (0.0000)	−6.5491 (0.0000)	−8.7595 (0.0000)	−5.4053 (0.0000)	−8.7513 (0.0000)
m2 test	−1.1062 (0.2686)	−1.0866 (0.2772)	−1.0649 (0.2869)	−1.0915 (0.2751)	−1.1054 (0.2690)

Standard deviation in parenthesis;
(+): Variables are expressed in per capita terms; (++): p-values in parenthesis.

*** Significance al 1%.
** Significance at 5%.
* Significance at 10%.

model instead of fuel consumption (column 3), both variables (fuel prices and total passenger cars) now become significant and exhibit the appropriate sign (negative and positive, respectively). They are significant because both fuel prices and the passenger car stock are determinants of fuel consumption but collinearity problems are now less important. Lastly, if we only include fuel prices (column 4), its coefficient remains negative and significant, but some other coefficients change substantially (for example, that of GDP and the lagged emissions term), which is a clear symptom of a omission variables problem.

In the last column of Table 5, we include results when using variables in levels. We note that the coefficient associated with regional population is positive and highly significant, as expected. But more importantly, all other estimates are highly robust to this new specification. For example, the estimated coefficients associated with the L and D variables are now -2.25 and 0.09, respectively, while they were -2.86 and 0.09 in Table 4.

5. Final remarks and policy implications

Improving energy efficiency in the road transport sector is a way to support growth while providing environmental benefits. The drive to improve fuel efficiency by replacing gasoline cars with diesel cars was one of the most ambitious programs carried out by the Spanish Government between 1998 and 2006. In this respect, there exists an extensive debate about whether the reduction in emissions as a result of improved fuel efficiency can be more than offset by the induced indirect effects leading to an overall increase in mobility.

After an initial overview of the subject using national data between 1998 and 2006, we have estimated a regional dynamic panel data model to quantify the effect of the dieselization policy on car emissions in Spain. As expected, fuel consumption was found to be an important factor in explaining CO_2 emissions in the sector. With respect to the dieselization policy, our results highlight how the improvement in diesel technology with respect to gasoline has had a beneficial effect on emissions. This technological improvement notwithstanding, we also found a significant offsetting effect on emissions, namely, that the increment in the diesel to gasoline passenger car ratio is positively related to overall car emissions. Our results, based both on a preliminary analysis of data for Spain and on estimates of the dynamic model with regional data, suggest that the overall impact of the dieselization policy has been detrimental to CO_2 emissions, at least for car transport and for the reporting period 1998–2006. Moreover, a very important finding is that results involving dieselization are strongly robust to the alternative specifications and dieselization measures used.

This is not to say that policy makers should abandon policies that promote fuel efficiency, but it does highlight the need to simultaneously introduce measures that mitigate the resultant indirect impact, such as the rebound effect. This policy prescription is in line with Schipper and Fulton (2009), who conclude that the lower taxation of diesel fuel does not seem justified, given that it has led to a greater travel rebound effect and has offset some of the CO_2 and other benefits of its higher fuel efficiency. Therefore, the dieselization process should have been accompanied by a package of measures to mitigate the resulting rebound effect, integrating incentives for energy conservation (Van den Bergh, 2011). Instead, the policy that was implemented has only served to deepen the impact on mobility.

Additionally, it would probably be necessary to improve the modal distribution of demand, reduce the length and number of motorized trips, and gradually introduce mobility plans in cities (Ministry of the Environment, 2007).

We finish the paper with several caveats and promising extensions. It is clear that a partial analysis of technical efficiency is insufficient for predicting total energy and emissions reductions in the transport sector (Schipper et al., 2000). A complete analysis should also consider the response of consumers and producers to such efficiency improvements. Analyses that consider only the efficiency impact could lead to misleading predictions regarding the impact of the dieselization process and of other energy and road traffic policies on emissions. Therefore, we must make progress in building theoretical models that consider the most important reciprocities among economic agents, energy incentives and road traffic policies.

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