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by

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FUEL CONSUMPTION, ECONOMIC DETERMINANTS AND POLICY IMPLICATIONS FOR ROAD TRANSPORT IN SPAIN

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ABSTRACT:

Road transport is one of the most polluting sectors in Spain, generating almost one fourth of total CO_2 emissions. Moreover, the consumption of fuel is the main source of these emissions. In this paper we estimate several fixed-effect models to study the economic factors that explain the short-term variations in fuel usage per vehicle, distinguishing between gasoline and diesel, using data from the 17 regions in Spain between 2000 and 2006. Price variations in fuel, modernization of vehicles, improved infrastructures and the dieselization process have proved ineffective in reducing energy usage per-vehicle in Spain, which would indicate the need to implement several measures simultaneously to control the increasing use of road transport.

KEY WORDS: Fuel consumption, road transport, fixed-effect model.

JEL: R41, O13, O56

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1. INTRODUCTION

The Spanish economy has grown strongly over the past decade, resulting in, among other things, a large increase in the demand for transportation. Between 1995 and 2005, the transportation of passengers and freight grew by 43% and 55%, respectively, outpacing the 38% of the real GDP. In that decade, CO_2 emissions from the transportation industry grew by 43%, versus the 13% increase recorded by the EU-15, with road transport contributing the most to this increase.[3] Overall, emissions from road transport represented 25% of total emissions in Spain in 2005, a ratio that is only exceeded by the energy industry, whose share is 34% of total emissions. Clearly, the trend in road transportation in Spain poses a serious roadblock to reaching the goals set by the 1997 Kyoto Protocol (ratified by Spain in 2002), which for Spain limits the increase in emissions in 2008-2012 to 15% of their 1990 levels.[4]

CO_2 emissions from road transport stem primarily from the consumption of energy in the form of fossil fuels, which in 2005 represented almost 99% of all fuel used in Spain. As a result, any short-medium term measures intended to reduce CO_2 emissions must inevitably rely on controlling and making more efficient use of the fuel consumed by vehicles.

The consumption of energy in the transportation sector has been studied in depth in the empirical literature for various countries. See, for example, Schipper et al. (1992) and Johansson and Schipper (1997) for OECD countries, Mazzarino (2000) for Italy, Kwon (2005) for the United Kingdom, Polemis (2006) for Greece, Tapio et al. (2007) for the EU-15, Zervas (2006) for Ireland, Alvaes and Bueno (2003) for Brazil, Samimi (1995) for Australia, Nicol (2003) for Canada and the United States, Ramanathan (1999) for India, Koshal et al. (2007) for Japan, and Belhaj (2002) for Morocco, among others. And yet, despite the increasing demand for energy consumption in Spain and its active dieselization process, few empirical studies have been done on the Spanish case, which is unique situation in the European context. Some exceptions are the works of Labeaga and López-Nicolás (1997) and Labandeira and López-Nicolás (2002), which estimate the demand for automotive fuel, though they mainly focus on analyzing the effects of taxes on overall consumption, and Asensio et al. (2002), which estimates a petrol expenditure function for Spain and evaluate the redistributive effects of petrol taxation, using micro data from the Spanish Household Budget Survey.[5]

In this paper we examine which are the factors that explain the increasing energy consumption by road transport in Spain. The results obtained allow for an evaluation of the effectiveness of different transportation and energy policies applied in Spain to reduce short-term energy use in road transport. This inevitably implies managing how existing vehicles consume fuel, which is the way of controlling energy intensity that we propose in this work. Explanatory factors considered include those which would affect energy consumption in

[3] In its report, *Environmental Profile in Spain for 2006*t, the Spanish Ministry for the Environment notes that emissions from road transport account for over 90% of the Spanish transportation industry's total emissions.

[4] At the European level, concerns over the pollution generated by transportation have resulted in relevant policies being drafted, as set out in the *White Paper on Transportation*, the *Green Paper on the Security of Energy Supply* and the *Green Paper on Energy Efficiency*. At the Spanish level, we note the E4 strategy for 2004-2012, which sets a series of energy savings and efficiency goals for this industry.

[5] For the Spanish case, most studies reference emissions due to transportation. We note here some recent works: Pérez Martínez and Monzón de Cáceres (2006) developed a model for the regions which explains the relationship between greenhouse gas emissions from transportation and the per capita growth in the GDP; Burón (2005) forecast emissions from road transport in Spain for 2000-2010; Lumbreras et al. (2008) advanced projections for energy consumption and emissions for the region of Madrid until 2012.

transportation from both a supply and demand perspective. On the demand side, we examine aspects involving technology and infrastructure, while on the supply side we endeavor to analyze factors involving income, price and mobility.

We limit our analysis to a short-term perspective, due to two reasons. The first concerns the difficulties and uncertainties involved in empirically analyzing long-term factors. At present, long-term strategies inevitably imply a greater dependence on and development of renewable energies in transportation and on continuing technological improvements in vehicles, both of which involve enormous economic costs. Furthermore, there are no long-term data on renewable energies[6], which limits the significance of empirical results derived from any cointegration analysis. The second reason involves the current debate on climate change and the urgent need to take immediate short-term actions to reduce CO_2 emissions.

The methodology used in this paper is based on the research by Barro and Sala-i-Martín (1992, 1995) and Mankiw et al. (1992), who studied the convergence and the determinants of economic development using models based on the neoclassical growth theory. De la Fuente (2002) applied this type of models to analyze Spanish economic growth from a regional perspective. Brock and Taylor (2004, 2006) and Álvarez et al. (2005) did the same for the case of emissions of different pollutants at international level, while Markandya et al. (2006) applied it to the overall energy intensity in emerging European countries. In this paper we use a specification consistent with this methodology and apply it in an innovative way for the case of energy use in road transport, distinguishing by fuel type in the different Spanish regions for the period 2000-2006.

In addition to the breakdown by region and the methodology used, another relevant aspect of this work is the distinction made between gasoline and diesel consumption.[7] This analysis is very important for the case of Spain, since it is probably, along with France, one of the countries in which the dieselization process has been the most significant in the last decade. This has led to a very uneven distribution in the consumption of gasoline and diesel, implying that the conclusions derived from an analysis of overall energy consumption could be misleading.

The results obtained in this work allow the following conclusions to be drawn: first, given the reduced estimated short-term fuel price elasticities (which are insignificant even for diesel), we can conclude that taxation policies are largely ineffective in reducing per-vehicle energy usage, at least at the current fuel price levels; second, the measures adopted, such as dieselization, the modernization of vehicles, the improvement of road infrastructures and the promotion of public transportation have not had the desired effect on energy consumption. These measures have resulted in greater mobility due to the better performance of the new vehicles, the lower cost per kilometer of diesel automobiles and the enlargement and improvement of the road network which, as theory suggests, generates a higher demand for transportation. The results, then, hint at the short-term need to jointly apply different measures for road transport, such as restricting and regulating the mobility of private vehicles, rewarding efficient use and promoting the use of public and non-motorized transportation.

[6] In road transport in Spain, biofuel usage was 0.83% that of petroleum derivatives, while in the EU-15 it was 1.21%. Before 2000, the use of biofuels was negligible.

[7] See Polemis (2006) for Greece and Zervas (2006) for Ireland and Labandeira and López-Nicolás (2002) for Spain.

This paper is structured as follows. In section 2 we analyze CO_2 emissions in Spain, along with energy consumption indicators, for the 1998-2006 period. Section 3 presents the methodology used, while section 4 discusses the results obtained from a fixed-effect model to characterize the factors explaining changes in energy consumption per vehicle, distinguishing by type of fuel. Finally, section 5 summarizes the main conclusions and offers some policy recommendations in light of the results obtained in this paper.

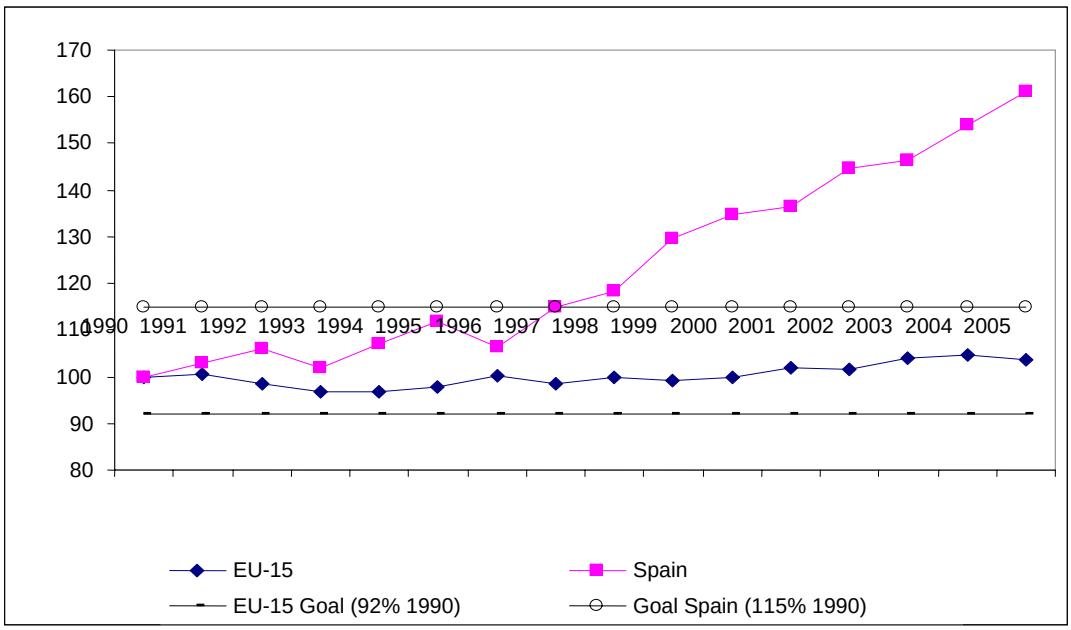
2. CO_2 EMISSIONS AND ENERGY USE IN ROAD TRANSPORT IN SPAIN

In this section we first present the trend in CO_2 emissions in the road transportation sector in Spain as compared to Europe, and we note its direct relationship to the energy consumption in the sector. Additionally, we present the trends in energy consumption and the different indicators for road transport in Spain by region.

The effect of greenhouse gas emissions (of which CO_2 is the most important) has led the EU to adopt a commitment to reduce emissions by 8% below 1990 levels for the 2008-2012 period, while Spain, which has experienced considerably higher emission rates, has committed itself to reducing them to at most 15% above 1990 levels.

Graph 1 shows the total CO_2 trends for the EU-15 and Spain, along with the Kyoto Protocol objectives agreed to in both regions. Note that between 1997 and 2005, Spain was well above its Kyoto target (+15% with respect to 1990), while in the EU-15, although emissions are still above its global target (-8%), the gap between actual emissions and the objective is much smaller that in the case of Spain.[8]

Graph 1: CO_2 emissions in the EU-15 and Spain: 1990-2005. Index1990=100

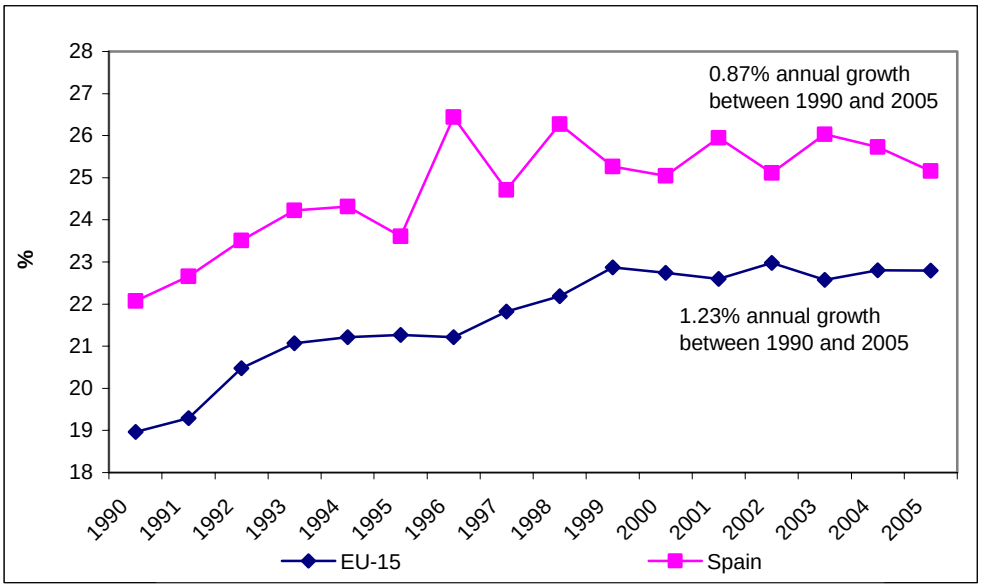


Source: Eurostat and Ministry for the Environment. Compiled by authors

[8] In view of the emissions data available to date, the Spanish government [Ministry of the Environment Report (2007)] has set an objective for 2008-2012 of not exceeding the base year emissions by 37%. Most of the difference with respect to the 15% will be offset through the purchase of carbon credits.

Road transport is the sector that contributes the most to CO_2 emissions (after the energy industry). Additionally, in the case of Spain, this contribution is considerably higher than in the EU-15. Graph 2 shows the trend for the ratio of CO_2 road transport emissions with respect to total emissions, for Spain and EU-15 between 1990 and 2005. This difference is explained by the ratio between road transport final energy consumption and total energy consumption, which is around 32% in Spain and only 25% in EU-15. Note also how the difference between the Spanish and EU-15 ratios remains constant throughout the period.

Graph 2: Ratio road transport CO_2 emissions / total CO_2 emissions EU-15 and Spain, 1990-2005



Source: Eurostat. Compiled by authors

One of the main measures adopted in Spain to control CO_2 emissions from road transport has been to promote the use of diesel, a process commonly known as 'dieselization'. This entails encouraging the use of diesel vehicles over gasoline vehicles through lower taxes on diesel. To assess the effectiveness of this measure in controlling emissions, we show in Graph 3 the ratio of gasoline versus diesel vehicles,[9] and the CO_2 emissions from road transport per capita and per vehicle for the 1997-2006 period.

This graph reveals a sharp drop in the ratio of gasoline to diesel vehicles. In 1997 gasoline vehicles outnumbered diesel by almost three to one, while by 2006 the ratio has dropped approximately to one. And yet this dieselization process, along with technical improvements introduced in vehicles and the commitment by manufacturers to reduce emissions[10], has done little to reduce per capita CO_2 emissions, which actually increased during the period analyzed. Nor did emissions decrease with respect to the total number of vehicles, as was initially the hope with dieselization.[11] This is because during the time period in question the

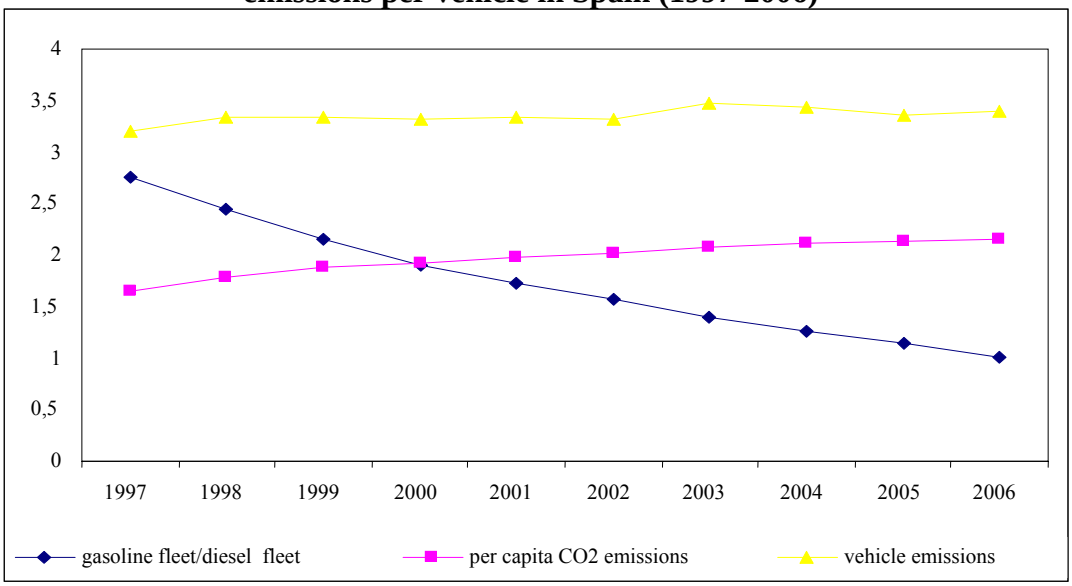
[9] The number of vehicles includes passenger cars, buses, tractors, vans and motorcycles. For 2006, the statistics on the total number of vehicles differentiate not only between gasoline and diesel vehicles, but also between other vehicles not included in this study and which account for a very small percentage of the total.

[10] In 1995 the European Union signed an agreement with the European Automobile Manufacturers' Association (ACEA) to reduce emissions to 120 grs/km for vehicles registered in the EU after 2005.

[11] This is in contrast to the predictions made by some authors simulating different diesel penetration scenarios in some European countries [Zerva and Lazarou (2007) for Switzerland and Zerva et al. (2006) for Greece] and with the results of other studies [Sullivan et al. (2004)].

number of vehicles increased more than the population, as evidenced by greater rates of vehicle ownership, and also mobility has increased.

Graph 3: Ratio of gasoline to diesel vehicles, CO_2 overall emissions per capita and CO_2 emissions per vehicle in Spain (1997-2006)



Source: Office for Traffic (DGT), Ministry for the Environment (MMA), INE

The dieselization process is related to another observed fact: an increase in diesel consumption (by over 6% per year) and a lower gasoline use (by slightly over 4% per year) between 1998 and 2006. Graph 4 shows the change in overall energy, gasoline and diesel consumption for this period.[12] The uneven trends display how total consumption increased by around 30%, gasoline use fell some 20% and diesel use went up by almost 70%.

The difference in the trends of gasoline and diesel consumption prompted us to perform an analysis differentiated by fuel type, as presented in the next section. Our objective is to identify which are the factors determining gasoline and diesel use in Spain, from a regional perspective. We focus on a measure of energy intensity in road transport, defined as the ratio between fuel consumption and the number of vehicles. This measure is consistent with the definition of energy efficiency given by Velthuijsen and Worrell (2002), which states it as "reducing the use of energy per unit of activity without affecting the level of this activity."[13]

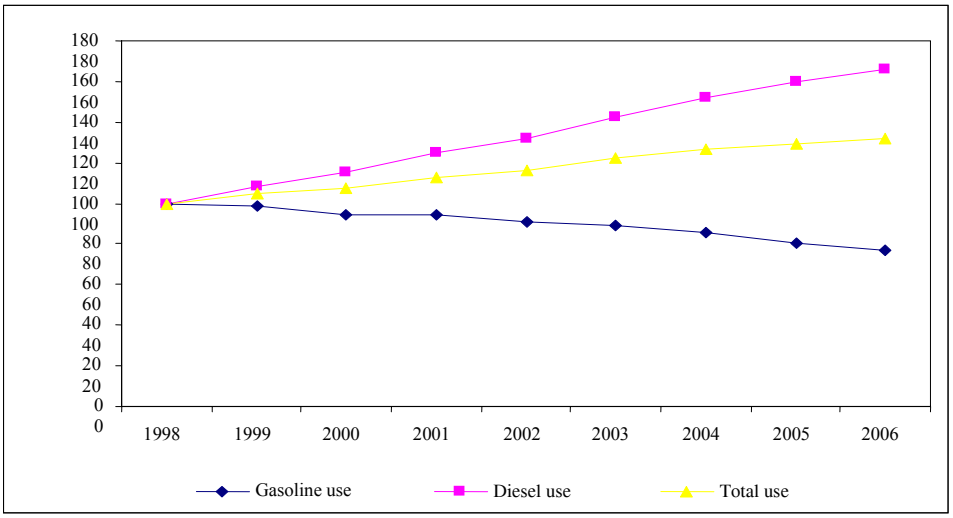
In order to compute the proposed energy intensity measure, we use the number of vehicles, i.e. mobility, as a proxy for production in the sector. This is a good approximation given the

[12] Gasoline and diesel consumption is measured in kilotons. In addition, the data on diesel only consider the type A diesel used exclusively in automobiles. Moreover, given the non-availability of separate data for diesel types for the years 1998, 1999 and 2006, we determined diesel type A consumption by using the average of diesel A usage to total diesel usage (A+B) for the years 2000, 2001, 2002, 2003, 2004 and 2005.

[13] The definition for fuel efficiency in transport is normally expressed in liters per kilometer [see Kirby et al. (2000)]. Since the official statistics for Spanish regions do not differentiate between kms traveled by gasoline and kms traveled by diesel vehicles, we cannot use this measure. The ideal measure for our purposes would differentiate between passenger and freight transport, given the multi-output nature of transportation activities. However, separate statistics at this level by fuel and by Spanish regions are not available either.

existence of a high degree of correlation between the increase in mobility by road and the growth in the number of cars.

Graph 4: Gasoline, diesel and overall consumption in Spain, 1998-2006
Index 1998=100



Source: Statistics Bulletin on Hydrocarbons. CORES, Ministry for Industry, Tourism and Commerce.

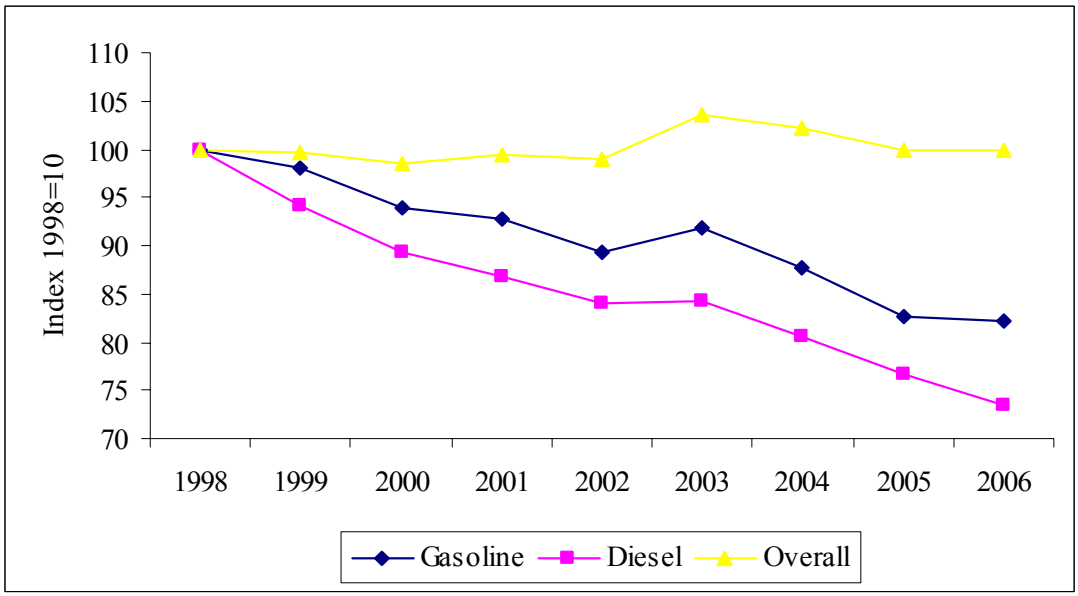
Graph 5 shows the change in the energy usage ratios per vehicle for both gasoline and diesel for road transport. Note the clear drop in these ratios for both cases, though the decrease is more pronounced for diesel. Between 1998 and 2006 the amount of gasoline used per vehicle dropped by 17%, while diesel consumption per vehicle fell by 26%. The drop in this ratio for gasoline is explained by the fact that the decrease in consumption is greater than the reduction in the number of vehicles, while the drop in the ratio for diesel results from an increase in usage that is below that of the number of vehicles. These trends on energy consumption and number of vehicles by fuel type offset when we consider the overall picture which reveals, as shown in the graph, that energy consumption with respect to the total number of automobiles remained practically constant throughout the period on question. This is consistent with the road transport CO_2 emission trends per vehicle shown above (see Graph 3).

The variables considered in this paper as determinants of energy consumption per vehicle are: i) ratio total number of vehicles/road network length, as a measure of saturation of the network; ii) ratio vehicle registrations/total number of vehicles, as a measure of modernization of the vehicle fleet; iii) growth rate of real Gross Domestic Product (GDP) per capita as a measure of purchasing power; and, iv) real fuel prices (gasoline and diesel), as a key variable affecting the demand of fuel consumption.[14] Table 1 lists the average annual

[14] Data on the road network, vehicle registration and real gasoline and diesel prices were obtained from the Ministry of Transport and Public Works. GDP data per capita for the different regions were taken from the National Institute for Statistics (INE). Petrol prices are measured in real terms and are retail prices. See Perdiguero (2006) for more details about how petrol prices are determined in Spain.

variation rates for all these variables for the period 1998-2006 for each Spanish region (excluding Ceuta and Melilla).

Graph 5: Energy consumption per vehicle in Spain: overall, gasoline and diesel 1998-2006



Source: Statistics Bulletin on Hydrocarbons. CORES. Ministry for Industry, Tourism and Commerce. DGT

TABLE 1: VARIABLES USED PER REGION

Average annual growth rate 1998-2006

REGION	Consumption/ Gasoline vehicle*	Consumption/ Diesel vehicle*	No. of vehicles/ road network	Registrations/ No. of vehicles**	Per capita GDP
Andalusia	-1.98	-4.71	4.76	0.25	3.01
Aragón	-2.15	-3.06	2.11	0.04	2.73
Asturias	-2.08	-2.50	2.23	-1.02	3.12
Balearic Isl.	-2.03	-3.80	3.72	-3.61	0.11
Canary Isl.	-4.12	-6.16	4.37	-0.71	1.64
Cantabria	-2.48	-2.56	4.13	-2.14	3.24
Castilla y León	-2.20	-4.34	4.55	1.09	3.18
Castilla La Mancha	-3.09	-4.12	3.34	-1.30	2.30
Catalonia	-2.68	-3.88	2.81	-0.58	2.17
Valencia	-2.01	-2.49	3.73	0.08	2.02
Extremadura	-2.07	-4.49	3.94	-0.59	3.72
Galicia	-1.95	-3.89	3.13	-2.00	2.95
Madrid	-2.59	-3.71	3.32	3.12	2.62
Murcia	-2.23	-2.15	4.82	0.13	2.27
Navarre	-0.67	-1.22	2.56	-3.77	2.82
Basque Country	-1.99	-1.22	2.86	-2.17	3.53
La Rioja	-1.51	-3.72	3.18	-2.55	1.90
SPAIN	**-2.22**	**-3.41**	**3.46**	**-0.04**	**2.55**

* Average annual growth rate 1999-2006

** Average annual growth rate 2000-2006

The table shows how the ratio of both gasoline and diesel consumption per vehicle fell between 1999 and 2006 in every Spanish region. Likewise, with the exception of Murcia and the Basque Country, the decrease in this ratio was greater for diesel than for gasoline.

According to the trend in the number of vehicles versus the road network, the saturation level of roads increased in every region, with the maximum average annual growth rate in Murcia (4.8%) and the minimum in Aragon (2.1%). Still, if we consider year-to-year numbers, the rate of increase in this saturation measure tend to moderate over time. As for the degree of modernization of the vehicle fleet, this varies greatly by region. Vehicle registration per total number of vehicles fell in eleven regions, while it increased in six. The highest registration rate was in Madrid, with an average annual growth rate of +3.1%, while the lowest was in Navarre, where the rate changed by -3.7%.

Real gasoline and diesel prices increased by 4.9% and 6.5%, respectively, between 1998 and 2006. Significant differences were noted in their growth rates during this period. The large volatility in fuel prices resulted from Spain's enormous dependence on foreign oil, on the important fluctuations on fuel prices in dollars between 1999 and 2006,[15] and on changes in fuel taxes and their repercussions on the final price. Lastly, the data on per-capita GDP growth rate showed an average increase of 2.6% nationally, varying between 0.11% in the Balearic Islands and 3.7% in Extremadura. Overall, the per-capita GDP figures showed a notable regularity among the various regions, as evidenced by the generalized slowdown between 2001 and 2003-2004 and the later recovery until 2006 for most of the regions.

3. METHODOLOGY

In this section we first present the model specification proposed to study the short-term influence of economic factors on energy consumption in road transport. The endogenous variable is a measure of energy intensity, defined as the ratio of energy consumption to the total number of automobiles, differentiating between gasoline and diesel. The explanatory variables used are among those traditionally considered as indicators for characterizing the behavior of the road transportation sector.

Fuel demand is dynamic by nature and therefore, as pointed out by Johansson and Schipper (1997), changes in the explanatory variables do not lead to simultaneous changes in energy usage, which instead lags behind those changes. This may be due, for example, to a persistence in fuel usage habits, requiring that a dynamic model be specified. Some authors use the so-called endogenous-lag model, where the endogenous variable is estimated as a function of the lagging endogenous variable. In this paper we opted to account for this effect by considering the growth rate of the endogenous variable, since we want to focus specially on short-term fluctuations.

Specifically, the methodology used in this paper is based on the convergence and growth approach of Barro and Sala-i-Martin (1992, 1995), applying it to energy consumption. This methodology presents at least three advantages: first, it allows for an easy and useful interpretation of the estimated parameters in terms of elasticities and as evidence of convergence between the regions; second, it permits working with the entire data panel and to specify fixed-effect models to estimate its parameters [Hsiao (1986)]; and third, it takes into account any possible heterogeneity between the various regions.

The fixed-effect model based on this methodology is as follows:

[15] For example, in 2001 the price in dollars of a barrel of Brent crude fell 14%, while in 2004 and 2005 it rose by 33 and 42%, respectively.

$$\Delta \ln(y_{i,t}) = \alpha_i + \beta \ln(y_{i,t-1}) + \lambda' X_{i,t} + \phi' S_t + \varepsilon_{i,t}, \qquad (1)$$

where Δ is the first difference operator, meaning $\Delta ln(y_{i,t})$ is a measure of the annual logarithmic variation of the endogenous variable for each region i at time t; $ln(y_{i,t-1})$ is the level of energy use per vehicle of region i in the previous period; S_t is a group of time-dependent explanatory variables which are common to all the regions (for example, trends in national energy prices[16]); $X_{i,t}$ is a set of time-dependent variables which are dependent on each region, and which can affect energy usage per vehicle (for example, degree of saturation of the road network, registrations, etc.); α_i considers those fixed factors inherent to each region and which are not included in $X_{i,t}$ (such as geographical, social or local policy aspects). Finally, $\varepsilon_{i,t}$ encompasses effects of a random nature which are not considered in the model.

In this fixed-effect model, a negative coefficient for the parameter associated with $ln(y_{i,t-1})$ indicates the presence of conditional convergence in the per vehicle energy use variable among the different Spanish regions during the period in question. In other words, conditioned to its long-term equilibrium, the percentage of fuel consumption per vehicle in a region tends to increase more rapidly (or to decrease more slowly) for a smaller initial value of this ratio.[17]

The fixed-effect model is based on the available panel data (119 observations for 17 regions over seven years), as specified in Hsiao (1986). This model considers the possible heterogeneity present among the Spanish regions as reflected in the series of residuals and the estimated constants (the fixed effects) for each region. The variables considered are as follows: GASO is the energy consumption divided by the number of gasoline vehicles; DISL is the consumption of diesel divided by the number of diesel vehicles; GDPpc is the per capita Gross Domestic Product; P.GASO is the real price of gasoline throughout Spain; P.DISL is the real price of diesel in Spain; SAT is the saturation of the road network, measured as the total number of vehicles divided by the kilometers of road; REG is the modernization of the vehicle fleet, measured as the ratio between new registrations and the total stock of existing vehicles.

The model also assumes a linear tendency [as in Kirby et al. (2000) and Polemis (2006)], denoted by TEND, and which aims to account for possible technological or regulatory changes common to all regions and which undergo stable changes in time.[18]

[16] Since annual changes in petrol prices in Spain are mainly determined by the evolution of international energy prices, we assume in this work a common price series for all Spanish regions.

[17] Specification (1) assumes that the endogenous variable in the model (fuel consumption per vehicle) has its own equilibrium level in each Spanish region. This variable depends on factors such as geographical, institutional, technological, social, and other aspects. The contrast in conditional convergence signals the existence of a correlation between the rate of change of the endogenous variable and its initial level, conditioned by the long-term equilibrium of the variable in each region. See, among others, Barro and Sala-i-Martin (1995) for more details on this point.

[18] The number of passengers on both public transportation and road traffic were also considered as explanatory variables. Data on public transport passengers per region for both urban and interurban travel were obtained from INE information on a data set of 750 companies. This information was not available for all the regions, however, hence it i not suitable for our purposes. The traffic variable was obtained from statistics published by the Ministry of Transport and Public Works and is measured in terms of vehicles-km. This variable was not only no significant in the model, but its trend revealed very strong changes in some regions which lacked a reasonable explanation. For this reason, this variable was not included in the proposed model either.

Taking specification (1) and the variables defined above as our starting point, we can estimate the following models, the first for gasoline and the second for diesel:

$$\Delta\ln(GASO_{i,t}) = \alpha_i + \beta\ln(GASO_{i,t-1}) + \lambda_1\Delta\ln(GDPpc_{i,t}) + \lambda_2\Delta\ln(SAT_{i,t}) + \lambda_3\Delta\ln(REG_{i,t}) + \phi_1\Delta\ln(P.GASO_t) + \phi_2 TEND_t + \varepsilon_{i,t}, \quad (2)$$

$$\Delta\ln(DISL_{i,t}) = \alpha_i + \beta\ln(DISL_{i,t-1}) + \lambda_1\Delta\ln(GDPpc_{i,t}) + \lambda_2\Delta\ln(SAT_{i,t}) + \lambda_3\Delta\ln(REG_{i,t}) + \phi_1\Delta\ln(P.DISL_t) + \phi_2 TEND_t + \varepsilon_{i,t}, \quad (3)$$

4. RESULTS

The results for these two models are shown in Table 2. For each model we give the estimates of the parameters associated with the explanatory variables considered, the *t*-statistic and the p-value of the test.

The results obtained allow us to conclude that the explanatory variables considered are globally significant in explaining the behavior of the endogenous variable. In addition, the adjustment of the gasoline model is, on average, better than that for diesel. This agrees with the fact that the estimates of the coefficients associated with the explanatory variables are less significant than in the diesel model. The worse adjustment of this model could be due to the dieselization process that has taken place in Spain over the last decade, and which has resulted in diesel consumption being exposed to factors which are not of a strictly economic nature. What is more, note that in the diesel model, the coefficients associated with the explanatory variables are lower in magnitude, which allows us to conclude that the relationship between gasoline consumption and vehicle type is less sensitive to changes in the economic variables used.

The parameters estimated for the $DISL_{t-1}$ variable (specific to the diesel model) and the $GASO_{t-1}$ (specific to the gasoline model) are negative and significantly different from zero at the 1% level of significance. The estimate is -0.45 for the diesel model and -0.88 for the gasoline model. The evidence for conditional convergence is significant in both cases, though it is greater for the gasoline case. The estimates indicate that the rate of convergence for the fuel consumption per vehicle ratio, conditioned to its long-term equilibrium levels in each region, is 45% for diesel and 88% for gasoline. These values are very high in comparison to those typical in the literature on growth, though this is partly due to the short time scale used in our sample.

The main difference between the two models is that for the diesel case, changes in the price of fuel and GDPpc do not result in significant changes to the consumption per vehicle ratio. The insensitivity of this ratio to the price of diesel could be because diesel prices during the period in question were very low and below those of gasoline. For its part, the numerous incentives for diesel vehicles along with higher fuel efficiency could have boosted sales of this type of vehicle, and therefore of diesel, independently of changes in income. The income

elasticity in the gasoline model is significant, though, with a value of 0.73. This is somewhat higher than values found in empirical data at an international level.[19]

Table 2: Estimates of the consumption models per vehicle (gasoline and diesel)

	Diesel model			Gasoline model		
	Estimate	t-statistic	P-value	Estimate	t-statistic	P-value
DISL(t-1)	-0.45	-4.76	0.00	--	--	--
GASO(t-1)	--	--	--	-0.88	-8.71	0.00
GDPpc(t)	-0.06	-0.16	0.87	0.73	1.82	0.07
P.DISL(t)	-0.04	-0.71	0.48	--	--	--
P.GASO(t)	--	--	--	-0.12	1.72	0.09
SAT(t)	-0.34	-2.15	0.03	-0.39	-2.50	0.01
REG(t)	0.10	2.12	0.04	0.18	3.63	0.00
TEND	-0.02	-5.01	0.00	-0.02	-6.49	0.00
R2	0.38			0.57		

Regarding the real price of fuel, the estimate of its elasticity is negative and significant for the case of gasoline, though its magnitude is well below one (-0.12). This result confirms the evidence that the elasticity of the demand price for gasoline is low in the short term, as verified by, among others, Kayser (2000) with data for the United States. Results at the international level place the price elasticities at around -0.2 and -0.3 (Dahl and Sterner, 1991). The lower sensitivities of Spanish consumers could be explained by the low price of fuel in Spain.[20] This indicates that fuel demand is inelastic, at least at current price levels and in the short term. Moreover, it supports a result commonly seen in the literature: although increasing fuel taxes is a policy that helps to increase public revenues, it is not effective to lower fuel consumption [Kirby et al. (2002)].

For its part, the price of the alternative fuel is not significant in explaining the short-term changes in consumption of the other fuel, which is why P.DISL was not included in the gasoline model and P.GASO in the diesel model. This last result is also consistent with the literature on transportation due to the strictness that exists in substituting types of vehicles in the short term. Still, we must note that during the period in our study, there was a significant substitution process between gasoline and diesel vehicles, though the main reason was the dieselization process itself, and not so much variations in the price of fuel.

The remaining variables are specific to the road transport sector and include relevant aspects that can affect energy usage in the sector. Thus, for example the variable SAT (our measure of the degree of saturation of the road network in each region) is significant in both models. Its estimate is negative and very similar in both models (-0.34 for diesel and -0.39 for gasoline). This may be interpreted in several ways. It could imply that an improvement of the

[19] Dahl and Sterner (1991) showed that short-term income elasticity on gasoline demand varied between 0.30 and 0.52 in the different studies they considered. Studies such as that by Koshal et al. (2007) gave values of 0.29. For a detailed review, see Graham and Glaister (2002) and Goodwin et al. (2004).

[20] Labandeira and López-Nicolás (2002) obtained a fuel price elasticity value similar to ours, though they used a different methodology.

road infrastructure, and the resulting reduction in saturation, promotes higher vehicle mobility[21] and therefore increases energy usage.

Another possible implication of this result is that any measure which favors the use of public transport (train, subway, tram, etc.) would initially lead to a reduction in the use of private vehicles and thus to a reduction in the saturation of the road network. But according to our results, this could result in an indirect incentive to use vehicles (and even to purchase new ones), which would increase energy consumption and could more than offset the initial effect. This result must not lead us to believe that the way to reduce energy consumption for transportation is to abandon road investments to saturate them artificially, which would result in lower productivity and less jobs. The solution involves increasing the usage of the more sustainable modes of transportation (public and non-motorized transport), improving and enlarging the road network while at the same time restricting and penalizing the use of cars, as well as promoting a more efficient use of cars, through other measures (e.g. car-pooling).

Another relevant result which complements those mentioned above is obtained by interpreting the results associated with the REG and TEND variables together. The estimated coefficients of these two variables in both models are very significant and have a similar magnitude.

Since new vehicles are more fuel-efficient than old ones, the modernization of the vehicle fleet could lead to a reduction in fuel usage [as suggested by Sprei et al. (2008)],[22] which would imply a negative coefficient for the REG variable. And yet the results of our research indicate that this variable has a positive effect on energy use. This result implies that improvements in fuel efficiency have not been sufficient to offset the increase in mobility resulting from the lower marginal cost of transportation (the so-called rebound effect) [see Schipper et al. (2002)].

Furthermore, the modernization of the vehicle fleet has resulted in larger and safer vehicles (all-terrain vehicles, or SUVs)[23], which had a negative effect on reducing fuel consumption because the higher weight and power of these vehicles. As noted by Koopman (1995), vehicle weight and engine displacement are also instruments for environmental policy and must be taken into account when modernizing the vehicle fleet.

For its part, the negative coefficient associated with the linear tendency does indicate that there have been certain improvements in fuel efficiency. Moreover, the fact that the estimated coefficient is practically identical in both models suggests the existence of a legislative framework and/or technological change common to all regions and vehicle types which has had a similar effect in reducing per-vehicle fuel consumption

[21] As noted by Goodwin (1996), improving infrastructures has an induced effect on the demand for transport. Moreover, Cervero and Hansen (2002) provided empirical evidence of the existence of an inverse relationship between investing in roads and the demand for transport, namely that an expansion of infrastructures generates demand for transport, which in turn induces the creation of infrastructures.

[22] Baltas and Xepapadeas (1999) concluded that the modernization of a country's vehicle fleet favored lower emissions.

[23] In Spain, a vehicle renovation incentive-scheme (Plan PREVER) funded by the national government has been in effect since 1997. During the period 1997-2006, a total of 3.3 million vehicles were registered as a result of this incentive scheme. This program has contributed to a large extent to the modernization of the country's vehicle fleet. Another result was the increase in the number of SUVs representing 12.6% of total fleet in 2006 (ANFAC, 2006).

5. CONCLUSIONS

One of the main problems involving road transport is its great energy dependence and the associated emissions. The fact that the growth in the demand for transport in Spain over the last decade has exceeded that of GDP suggests that there must be other factors besides income to explain mobility and fuel consumption.

In this paper, we use a model whose endogenous variable is the annual rate of change in fuel consumption per vehicle and per fuel type (gasoline or diesel) for the period 2000-2006. We consider a set of explanatory variables of an economic nature, some of them unique to the transportation industry, such as per-capita GDP, the real price of fuel, the ratio between the number of vehicles and road network length, and new vehicle registrations versus the existing number of vehicles. Finally, we also considered a linear trend which would account for legislative and/or possible technical advances which would affect all the regions equally.

Obtained results show that the gasoline model provides a better overall fit than the diesel model. This could be because for the case of diesel, there are other non-economic factors, which may affect its consumption. The estimated coefficients for the diesel model are also smaller in magnitude and less significant than those for gasoline. This indicates that their behavior is less sensitive to modifications in the economic variables. In this sense, the lack of significance of GDP per-capita and fuel price in the diesel model is notable. The low sensitivity shown by the variation in per-vehicle fuel consumption to fuel price has been widely verified at an empirical level, and serves to highlight that the unresponsiveness of consumers in Spain to fuel prices could be due to the low levels of the latter.

The variable used in our study as a proxy for the saturation of the road network and, to some extent, of mobility, was the ratio between the number of vehicles and the length of the road network. This variable turned out to be highly significant in both models and with parameters with relatively high absolute values. This result would indicate that any measure intended to reduce congestion on the roads, such as the promotion of guided transport (train, tram) and/or the introduction of BUS-HOV lanes could indirectly result in greater private vehicle use due to short-term improved mobility conditions on roads. In short, travel would be encouraged (particularly long-distance travel) and the final outcome would be a higher energy use.

As concerns the vehicle modernization variable, it has a positive and very significant effect on fuel consumption. This clearly shows that the modernization of the vehicle fleet has had the opposite effect on fuel consumption compared to what was initially intended for. We also find several factors, which are common to all regions, and that affect gasoline and diesel consumption equally, possibly due to technical improvements or to legal considerations, as reflected by the negative estimated linear tendency coefficient introduced in both models.

The net result is that, in order to reduce short-term energy use by road transport, along with CO_2 emissions, without a concomitant loss in productivity, it is critical that measures be implemented which not only favor public and non-motorized transport and efficient energy use, but which, at the same time, manage mobility and penalize the indiscriminate use of private vehicles. A combination of measures along these lines has been proposed at the state level as part of the Action Plan for Energy Savings and Efficiency in Spain (PAE4), which includes traffic control policies, promotes non-motorized forms of transport, and proposes improvements to and greater development of public transport. As such, measures adopted at

the regional and local level take on added significance, meaning it is critically important for the various regions to have a common and coordinated approach.

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