

Dieselization and Road Transport CO₂ Emissions: Evidence from Europe*

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ABSTRACT

Road transport carbon dioxide emissions were analyzed, by focusing on a panel of 14 European countries for the time span 1995-2007. We deal with the existence of contemporaneous correlation by using the Panel Corrected Standard Errors estimator. We extend the empirical literature by controlling the effect of new diesel passenger car registrations and the average power of those vehicles. The price of gasoline and income reduce road transport carbon dioxide emissions, while population density and average power of new diesel passenger cars raises those emissions. We deepen the debate about dieselization, concluding that saving emissions by using diesel tend to be surpassed by the increased kilometers driven.

Keywords: Road Transport; CO₂ Emissions; Fuel Prices; Dieselization

1. Introduction

European countries have been expressing deep environmental concerns for some time and now play a leading role worldwide in the fight against pollution. To achieve this purpose, the European Union (EU) has been implementing environmental policies to counteract the degradation of the ozone layer and to bring the green house effect to an end. The EU has established directives for its member states in order to restrain and diminish the emission of greenhouse gases (GHG), namely carbon dioxide (CO₂), chlorofluorocarbons, methane, nitric acid and ozone. Since CO₂ is the major GHG released into the atmosphere (98% in 2007 for the EU15), it is essential to reduce its emissions in order to work against global warming and climate change. Substantial CO₂ emissions originate in the transport sector (25% in 2007 for the EU15, excluding the international traffic departing from the EU) and almost all of this comes from road transportation (93% in 2007 for the EU15). This large contribution makes this sector one of the largest polluters with respect to oil fuel combustion.

The road transport sector includes both motorcycles and automobiles. The latter consist of: 1) passenger cars (PC) (84.4% of the number of automobiles sold in 2007 for the EU15); 2) commercial vehicles (15.2%); and 3)

buses and coaches (0.4%). Since PCs constitute the majority of automobiles on European roads, they play a crucial role in road transport CO₂ emissions. As a consequence, the EU decided to make voluntary agreements with the automobile manufacturers' associations, the ACEA [1] JAMA [2] and KAMA [3], in order to promote the decrease of the average CO₂ emissions per km, by each new PC.

The literature regarding CO₂ emissions from PCs brings to the fore a vast normative perspective, but it suffers from scarce empirical support. This paper contributes to the empirical evidence, focusing on the drivers of road transport CO₂ emissions. Overall, the nature of drivers can be socio-economic, demographic, energetic, manufacturer or market. In particular, we work on the questions: 1) is dieselization actually reducing CO₂ emissions released by PCs? And 2) how does GDP per capita influence CO₂ emissions? The responses may define important policy measures to facilitate a reduction in road transport CO₂ emissions. For this purpose, we use a panel dataset for thirteen years (1995-2007) from the EU15 (except Greece). These countries belong to Europe, which has been in the front line of the reduction of road transport CO₂ emissions, and they are selected to fulfill the criteria of the longest time span with available data for drivers we control. In accordance with the common policies guidance from the EU, the econometric methods take into account the contemporaneous correlation.

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We extend the literature on road transport CO₂ emissions by: 1) showing the relevant role of the drivers of new diesel PC registrations per 1000 inhabitants, and the average power of new diesel PCs registered; 2) shedding light on the debate of the pros and cons of dieselization; 3) discussing the importance of car sharing and the use of public transport in the reduction of CO₂ emissions; and 4) applying panel econometric techniques that cope well in the presence of common political guidance.

The paper is organized as follows: the second section consists of a literature review, the third presents the data and methodology used in this work. Section 4 provides the results obtained, the fifth section discusses those outcomes and section 6 concludes.

2. Literature Review

In a modern society, CO₂ emissions are generated by numerous sectors. Energy industries, manufacturing, construction, transport and other sectors, like commercial/institutional, residences, agriculture/forestry/fishery, all contribute to environmental damage. According to the source of CO₂ emissions, different literature is applied and several methodologies can be found. The literature on road transport CO₂ emissions, particularly from PCs, evolves according to two main perspectives: 1) the normative; and 2) the empirical. The normative focuses on the analysis of CO₂ emissions, considering both characteristics and fleet composition of PCs [4]. The empirical perspective includes several techniques, namely the decomposition analysis of CO₂ emissions [5], and the panel data approach [6]. The influence of the various vehicle characteristics on the changes in CO₂ emissions from PCs was analysed by [5], in Greece and Denmark between 1990 and 2005. In their turn, Ryan *et al.* [6] focused on the relationship among variables like fuel price, vehicle taxes, income and population density.

As noted by Stead [7], PCs using different fuel types release different amounts of CO₂. Indeed, the average diesel PC releases smaller quantities of CO₂ per km in comparison to the average gasoline car [8]. A diesel engine consumes 20% to 30% less fuel per km than a gasoline engine equivalent [9]. Nevertheless, while consuming 20% less, it only releases 9% fewer grams (g) of CO₂ per km than gasoline engines [10]. Apart from the fuel economy of diesel PCs, as Pock [11] pointed out, diesel cars have also been upgraded, namely in comfort and driveability, and their retail price is lower in relation to gasoline cars in most European countries. This has all contributed to the trend known in Europe as dieselization, which consisted of a sustained diesel market growth. On the one hand, authors such as Fontaras and Samaras [12] and Cuenot [13], connect dieselization to a reduction in CO₂ emissions, as a consequence of the increased fuel efficiency of diesel engines. On the other

hand, recent literature minimizes the impact of this trend in reducing CO₂ emissions, because of the higher distance travelled by diesel PCs [14]. This phenomenon of longer trips taken by diesel PCs deserves further analysis.

Diesel PCs release inferior average CO₂ emissions per km than gasoline cars, when travelling the same distance. Nevertheless, as Schipper [14] points out, these type of vehicles in Europe travel 40 to 100% more than their gasoline counterparts, namely since most taxi drivers, salesmen and businessmen use them. For example, in 2005, in France diesel PCs were driven 64% further than gasoline ones and, in Germany, 80% more [15]. Also in Denmark, in 2007, Papagiannaki and Diakoulaki [5] mentioned that diesel cars travelled twice as far as gasoline PCs.

As stated earlier, the increasing demand for diesel is due to its lower retail price compared to gasoline in most European countries. This asymmetry is a consequence of the lower taxation applied to diesel, which results partly from the professional transport sector lobby, as noted by Pock [11]. Moreover, this author points out that, in the short run, higher fuel prices decrease vehicle use, while in the long run, they cause a reorganization of the PC fleet to more efficient gasoline cars and diesel ones. In the former case, this is true since diesel price and diesel PC ownership expenses are reasonably low. Therefore, in the long run, given the correlation between fuel consumption and road transport CO₂ emissions [6], as the former decreases, so CO₂ emissions diminish. Such fuel consumption reduction is directly caused, on the one hand, by fewer kilometers driven in the long run [16,17] and, on the other hand, by lower speeds on roads. In fact, fuel consumption diminishes as more drivers circulate at optimum speeds [18]. All these consequences of high fuel prices arise from its impact on families and individuals' income.

When there are higher incomes, two opposite behaviors can arise. According to Storchmann [19], in the short run, individuals tend to drive more, increasing road transport CO₂ emissions. In contrast, over time buyers have greater opportunity to acquire powerful vehicles, but also better equipped with regard to fuel efficiency and technology [18]. Hamilton and Turton [20], when studying GHG emissions in OECD countries from 1982 to 1997, and Hatzigeorgiou *et al.* [21], when analysing CO₂ emissions in Greece between 1990 and 2002, pointed out GDP as the greatest contributor to CO₂ emissions. Nonetheless, Tapio *et al.* [22] noted that in the EU15 countries, from 1960 to 2000, GDP growth decoupled from energy use and, therefore, from CO₂ emissions. Another socio-economic factor affecting CO₂ emissions is population. Although it makes a positive contribution to road transport CO₂ emissions, its effect is

not very noteworthy due to the small variations in population figures over time [5]. Nonetheless, it is worthwhile mentioning that increasing population density reduces the number of gasoline PC [6], favouring the use of diesel cars.

Another contributor to road transport CO₂ emissions is PC power, which is highly correlated with PC weight. Zervas [4] reported a rise in the average maximum power of both gasoline and diesel cars, from 1995 to 2003, as a result of the improved combustion efficiency. The increase in PC weight and power were in part a result of dieselization [10]. Diesel PCs have experienced a greater growth in power than gasoline ones. Since diesel PCs had to find more torque to increase their power/weight ratio in comparison to gasoline cars, they became more powerful. As a consequence, fuel consumption and CO₂ emissions also increased, counteracting the advance of technological standards in fuel efficiency. Regardless of the technical aspects, the last word about the average power of PCs, as Bonilla [18] points out, belongs to consumers, whose preferences when buying a new PC depend on their income.

The greater demand for diesel in Europe produces, however, a negative outcome in the whole CO₂ emissions, because it generates inefficiency in the entire fuel supply chain. Indeed, the adjustment of European refineries to the production of diesel causes an increase in CO₂ emissions due to higher energy loss. Exportation of gasoline and importation of diesel associated with the lower and higher demand, respectively, of the European PC fleet increases CO₂ emissions due to international transportation [23].

In the EU, most decisions aimed at reducing CO₂ emissions have a common guidance. To the best of our knowledge, the scarce empirical literature on road transport CO₂ emissions has not yet taken into account the possible existence of contemporaneous correlation between the EU countries as a result of the similar policies measures taken in all member states. To that extent, apart from the variables mostly suggested by literature (GDP per capita, population density, and gasoline price), we control for the effect of new diesel PC registrations and average power of new diesel PCs registered on road transport CO₂ emissions. The next section describes the data, method and estimation process.

3. Data and Methods

In order to select the appropriate methodology that will give us a full understanding of the object on which we are focused, we must have a thorough understanding of the available data. In this section we present the data, their sources and main characteristics, as well as pursuing a discussion about the methodological choices.

3.1. Data

Data from the year 1995 to 2007 were used, for a panel of 14 EU member states: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. Greece was excluded for lack of data. Due to the inexistence of data prior to 1995 and subsequent to 2007 for some of the variables, the maximum time span was ascertained (1995-2007). Furthermore, because the remaining countries of EU27 only offer data from 2000 for some variables, we had to limit the study to EU15, except Greece. Otherwise, the actual period of thirteen years (1995-2007) would be only eight years (2000-2007). Although the number of observations is not exactly the same for all countries, missing values are few, isolated, and purely random. Therefore, we can apply the estimators in our unbalanced panel without causing inconsistency in these estimators.

The main goal of this paper is to make an empirical evaluation, for a panel of 14 European countries, of the explanatory power of several variables over the following dependent variable: road transport CO₂ emissions (*CO₂ROAD*). The explanatory variables for understanding the course of *CO₂ROAD* are in accordance with the literature. GDP per capita and population density are important socio-economic drivers of *CO₂ROAD* due to their influence on the PC fleet composition and on the number, frequency, length and speed of journeys. The price of gasoline is highly correlated with the price of diesel, allowing us to control for the impact of energy pricing on *CO₂ROAD*. New diesel PC registrations per 1000 inhabitants enable us to understand the consequences of dieselization on *CO₂ROAD*. New diesel PC average power, as one of the three major vehicle characteristics (power, weight, engine capacity), allows us to control for the influence of manufacturer drivers on *CO₂ROAD*.

GDP per capita (*GDPPC*). Income produces two opposite outcomes in families and individuals' behaviours. On the one hand, a positive signal is observed when higher incomes lead both to increasing the propensity to drive more [19] and to buying powerful vehicles, contributing towards raising *CO₂ROAD*. On the other hand, a negative signal is identified when higher incomes allow individuals to acquire PCs with more advanced fuel efficiency technologies [18]. The final signal depends on the dominance of these two opposite effects.

Population density (*POPDENS*). The literature suggests that population influences positively *CO₂ROAD*. The influence is generally low, because over time population does not suffer significant changes [5]. *POPDENS* has an effect on the PC fleet, since the number of gasoline cars diminishes when *POPDENS* increases [6]. This

effect produces an outcome on *CO₂ROAD*. In accordance, we control for this variable, expecting that large *POP-DENS* will contribute to greater *CO₂ROAD*.

Gasoline price (*PRICEG*). Energy prices infer on consumer behaviours and preferences, because:

Their available incomes become affected. As a result of high fuel prices, drivers may decrease their fuel consumption travelling at optimum speeds [18]. Moreover, in the long run, the distances travelled may be reduced [16,17] and car owners tend to replace gasoline cars with more fuel efficient ones or with diesel ones [11]. Most PCs worldwide are propelled through gasoline or diesel combustion. *PRICEG* and diesel price are highly correlated, which prevents their simultaneous use in the estimation, in line with the collinearity concerns. We control for *PRICEG*, given that it is commonly used in the empirical literature [11,16,17]. A negative relationship is expected between this variable and the *CO₂ROAD*.

New Diesel PC registrations per 1000 inhabitants (*DIESCAR*). *DIESCAR* is used to measure the level of dieselization. As discussed before, the literature suggests two opposite effects regarding dieselization. On the one hand, one could expect a negative signal to *CO₂ROAD*, given that, comparatively, diesel PCs emit lower average CO₂ emissions per km [12,13]. On the other hand, a positive signal could be expected due to the larger distances travelled by diesel PCs [14] and thus, dieselization may induce the increase of *CO₂ROAD*. This divergence in the contribution of *DIESCAR* to *CO₂ROAD*, makes it relevant to identify whether the predominant effect is negative or positive.

New Diesel PC Average Power (*AVPOWERD*). *AVPOWERD* corresponds to the average power of new diesel PCs registered in one country for a year. A strong

increase in *AVPOWERD* was observed from 1995 to 2007 [3,24]. Following the literature, we control for *AVPOWERD*. Since more power requires more fuel consumption ceteris paribus, a positive signal for *AVPOWERD* is expected in explaining *CO₂ROAD*.

Table 1 shows the variables, their sources and descriptive statistics.

3.2. Methods

With regard to *CO₂ROAD*, within the EU several policy measures have been taken, which impact on all member countries. One example is the mandatory agreement with the automobile manufacturers' associations to achieve the average emission released by new PCs of 120g of CO₂ per km by 2012 [24]. As noted by De Filippis and Scarano [25], a genuine cultural orientation in Europe has led to a continuous fight against GHG emissions.

Both this common guidance for the automobile manufacturers' associations from the EU and the strong connection between the policies of their member countries have led to the belief that there is contemporaneous correlation. Thus, this phenomenon arouses the need to use the adequate estimators.

We proceed to analyse the structure of the panel data, which may incorporate error terms with complex composition. To do so, we make a first visual inspection of the data. After that, we test for the presence of three main phenomena: heteroskedasticity, panel autocorrelation and contemporaneous correlation. We carry out econometric analysis using the Stata 11.

The visual inspection of the correlation matrix suggested that the concurrent use of the variables is far from a concern (**Table 2**).

Indeed, the correlation coefficients signal the absence

Table 1. Variables, sources and descriptive statistics.

Variable	Definition	Source	Obs.	Mean	SD	Min	Max
<i>CO₂ROAD</i>	Road transport CO ₂ emissions (million tonnes)	EC, 2009, "EU energy in figures 2010"	182	53.3338	52.6163	3.4024	175.0016
<i>GDPPC</i>	GDP per capita (constant 2000 US\$)	World Bank, World Development Indicators Database	182	24076.66	8250.636	9197.02	56624.73
<i>POP-DENS</i>	Population density (people/km ²)	World Atlas & World Bank, World Development Indicators Database	182	163.1827	123.1303	16.7701	485.2398
<i>PRICEG</i>	Premium unleaded gasoline 95 total prices (US\$/Unit) (using PPP) (all taxes included)	International Energy Agency Data Services	181	1.0996	0.2277	0.648	1.949
<i>DIESCAR</i>	New diesel passenger car registrations per 1000 inhabitants	Annual reports "Monitoring the CO ₂ emissions from cars in the EU"	177	15.1910	14.8289	0.5	83.2
<i>AVPOWERD</i>	New diesel passenger car average power (cm ³)		177	78.1938	12.4373	53	114

Table 2. Correlation matrix and Variance Inflation Factor (VIF).

	CO ₂ ROAD	GDPPC	POPDENS	PRICEG	DIESCAR	AVPOWERD
CO ₂ ROAD	1					
GDPPC	-0.2833	1				
POPDENS	0.1768	0.0258	1			
PRICEG	0.1879	-0.2720	0.2549	1		
DIESCAR	-0.0657	0.5731	0.1248	0.0365	1	
AVPOWERD	0.0247	0.4572	-0.0782	0.4711	0.1981	1
VIF		4.10	1.33	3.30	1.85	3.46
1/VIF		0.243749	0.754363	0.303109	0.540219	0.288868
Mean VIF				2.81		

of collinearity among variables. Despite this evidence, in order to solve any remaining doubt about collinearity, we also analysed the Variance Inflation Factor (VIF) test for multicollinearity. Both the mean VIF of 2.81 and the low values for the individual VIF reveal that collinearity is, in fact, not a problem.

After this preliminary analysis of the nature of the data, we advance by testing the presence of heteroskedasticity and panel autocorrelation. The existence of groupwise heteroskedasticity is tested through the modified Wald statistic test [26] in the residuals of a fixed effect regression. The presence of serial correlation is appraised by providing the Wooldridge test. Ultimately, the presence of countries' independence is tested by applying both the parametric testing procedure proposed by Pesaran [27], and the semi-parametric test proposed by Frees [28,29], either to random effects or fixed effects. Once the presence of these phenomena has been established, the common panel data estimators, random effects (RE) and fixed effects (FE), lead to inefficiency in coefficient estimation and to bias in the standard errors. As a consequence, the appropriate estimators are the Feasible Generalized Least Squares (FGLS) and the Panel Corrected Standard Errors (PCSE). However, given that the number of periods is smaller than the number of countries, the appropriate estimator to handle panel-level heteroskedasticity and contemporaneous correlation is the PCSE [30].

The general model to estimate is:

$$CO_2ROAD_{ct} = \alpha + \sum_{k=1}^k \beta_k X_{kct} + d_c + d_t + \mu_{ct} \quad (1)$$

with η_{ct} being serially uncorrelated, but correlated over countries, the error term is $\mu_{ct} = \rho_c \mu_{c,t-1} + \eta_{ct}$. Dummy variables d_c and d_t relate to country and time, respectively. As pointed out by Cameron and Triverdi [31], the PCSE estimator permits; 1) first-order autoregressive models for μ_{ct} to be employed over time, 2) μ_{ct} to be correlated over countries; and 3) μ_{ct} to be heteroskedastic. The specification tests and the estimation results are presented in the following section.

4. Results

The specification tests summarized in **Table 3** are crucial to correctly defining the best-suited estimator to proceed to our analysis. The presence of heteroskedasticity, panel autocorrelation and contemporaneous correlation was appraised.

The modified Wald statistic reveals that the errors exhibit groupwise heteroskedasticity, while the Wooldridge test leads to the rejection on the null of no first-order autocorrelation. Regarding the assessment of contemporaneous correlation, both for random and fixed effects, the Frees test strongly suggests the rejection of the null hypothesis of cross-sectional independence. Simultaneously, the evidence from the Pesaran test is not so strong, *i.e.*, the null hypothesis is rejected for the fixed effects regression model only with a 10% significance level. In sum, the specification tests suggest that our panel reveals that there is: 1) heteroskedasticity, probably as a consequence of differences in the countries on CO₂ROAD; 2) autocorrelation of order one; and 3) contemporaneous correlation across the countries, although in the Frees test the null of countries independence is strongly rejected.

In order to cope with the presence of these phenomena, we use the PCSE estimator given that in our panel data

Table 3. Specification tests.

	Pooled	Random effects	Fixed effects
Modified Wald test (X^2)			11926.68***
Wooldridge test $F(N(0,1))$	111.792***		
Pesaran's test		-1.295	-1.756*
Frees' test		3.174***	3.586***

Notes: The Modified Wald Test has X^2 distribution and tests the null hypothesis of: $\sigma_c^2 = \sigma^2$, for $c = 1, \dots, N$; The Wooldridge test is normally distributed $N(0,1)$ and tests the null hypothesis of no serial correlation; Pesaran and Frees' tests test the null hypothesis of cross-section independence; Pesaran's test is a parametric testing procedure and follows a standard normal distribution; Frees' test uses Frees' Q-distribution. *xtcsd* command was used [32]; ***, **, * denote 1% and 10% significance level, respectively.

the number of countries is larger than the number of periods. This estimator turns out to be adequate both in the presence of panel-level heteroskedasticity and contemporaneous correlation, and in finite cases performs better than the asymptotically efficient FGLS [33]. Moreover, in order to check the robustness of the results achieved with the PCSE estimator, we follow two options. The first one is to apply the common panel data estimators, RE and FE. Results accomplished with the PCSE estimator are robust if the other models, such as RE and FE estimators, return different results. In that case, it seems that there is inefficiency in coefficient estimation and biased standard errors, by using the common panel data estimators. The second one is to test various assumptions about the variance across countries and serial correlations. If the results remain in essence unchanged, then the option of using the PCSE estimator is strengthened.

We start by estimating a pooled OLS model (model I) and then we work upon a panel data structure by applying the RE (model II) and FE (model III) estimators. For the models 1 to 3 the error term in Equation (1) is $\varepsilon_{ct} = \eta_c + \mu_{ct}$. We assume that regressors are uncorrelated with μ_{ct} and allow X_{ct} to be correlated with the time-invariant element of the error, η_c . After that, we estimate the model presupposing the various assumptions,

as follows: model IV—correlation over countries and no autocorrelation; model V—country-level heteroskedastic errors and common first-order autoregressive error (AR1); model VI—correlation over countries and autocorrelation AR(1); and model VII—correlation over countries and autocorrelation country-specific AR(1). **Table 4** shows the results.

The results in **Table 4** show that there are no changes in the signal of the estimated coefficients. Overall, we can only observe changes in the level of significance, namely when comparing the common panel data estimators, RE and FE, with the panel data estimator PCSE, which is indeed an expected outcome, given the presence of contemporaneous correlation in our panel. In fact, in line with what was pointed out by Reed and Ye [30], this evidence could come from the inefficiency in coefficient estimation and biased standard errors when we use these common panel data estimators, under the scenario of no cross-sectional independence.

In order to deepen the consequences of unseemly use of inefficient estimators in the presence of contemporaneous correlation, we additionally provide two exclusion tests for the variables that RE and FE estimators suggest as playing a non-relevant role in explaining the CO₂-ROAD, i.e. the variables *DIESCAR* and *AVPOWERD*.

Table 4. Estimation results.

Independent variables	Dependent Variable CO ₂ ROAD						
	OLS (I)	RE (II)	FE (III)	(IV)	(V)	PCSE (VI)	(VII)
<i>GDPPC</i>	-0.0048*** (0.0010)	-0.0013*** (0.0003)	-0.0013*** (0.0003)	-0.0049*** (0.0006)	-0.0028*** (0.0005)	-0.0028*** (0.0003)	-0.0037*** (0.0002)
<i>POPDENS</i>	0.1210*** (0.0386)	0.3873*** (0.0922)	0.5588*** (0.1169)	0.1210*** (0.0161)	0.0938*** (0.0300)	0.0938*** (0.0104)	0.0856*** (0.0140)
<i>PRICEG</i>	-66.0670 (43.7524)	-40.5535*** (5.1730)	-42.4134*** (5.2311)	-66.0670** (29.7979)	-23.5729 (21.9611)	-23.5729* (12.0237)	-19.0828** (8.7162)
<i>DIESCAR</i>	1.0034*** (0.3573)	0.1295* (0.0697)	0.1086 (0.0701)	1.0033*** (0.1424)	0.4723** (0.1908)	0.4723*** (0.1298)	0.7949*** (0.1206)
<i>AVPOWERD</i>	2.67200*** (0.6698)	0.0503 (0.0927)	0.0623 (0.0929)	2.6720*** (0.2741)	0.6333* (0.3233)	0.6333*** (0.1456)	0.4745*** (0.1168)
<i>CONS</i>	17.5121 (53.7478)	44.107* (23.6976)	18.8181 (18.6557)	17.5121 (25.3270)	71.0030** (31.0636)	71.0030*** (15.2196)	87.6974*** (10.1999)
<i>N</i>	176	176	176	176	176	176	176
<i>R²/Pseudo R²</i>	0.21			0.21	0.29	0.29	0.72
<i>F (N(0,1))</i>	2.46***		8.68***				
<i>Wald (X²)</i>		142.32***		1497.74***	56.05***	531.95***	1041.56***
Exclusion tests for <i>DIESCAR</i> and <i>NPCDPW</i>							
<i>JST</i>	8.61***	3.48	1.21	102.87***	7.9**	20.08***	44.50***
<i>LRT</i>	3.6753***	0.1799	0.1709	3.6753***	1.1056***	1.1056***	1.2694***

Notes: OLS—Ordinary Least Squares. RE—Random Effects. FE—Fixed Effects. PCSE—Panel Corrected Standard Errors. The F-test is normally distributed $N(0,1)$ and tests the null hypothesis of non-significance as a whole of the estimated parameters. The Wald test has X^2 distribution and tests the null hypothesis of non-significance of all coefficients of explanatory variables. JST—Joint Significance Test. JST is a Wald (X^2) test with the null hypothesis of $H_0: \beta_i = \beta_j = 0$, with β_i and β_j meaning the coefficient of *DIESCAR* and *NPCDPW*, respectively. LRT—Linear Restriction Test has the null hypothesis of $H_0: \beta_i + \beta_j = 0$. Standard errors are reported in brackets. In models I to III, conventional standard errors option was used for residuals. All estimates were controlled to include the time effects, although not reported for simplicity. ***, **, * denote significance at 1, 5% and 10% significance levels, respectively.

We provide the Joint Significant Test (JST) for all the estimated models. Only for the common panel data estimators do we not reject that null that both coefficients of these variables are equal to zero. In other words, *DIESCAR* and *AVPOWERD* together must be retained as explanatory variables, in contrast to what the inefficient estimators RE and FE suggest. Moreover, the same evidence is achieved when we apply the Linear Restriction Test (LRT) of the coefficients. For all models, except for the RE and FE estimators, we strongly reject that the hypothesis of the sum of the coefficients of *DIESCAR* and *AVPOWERD* is zero.

As shown, the PCSE estimator proves to be appropriate to meet the nature of our panel data, so they are thereafter the reference models, namely model VII. In this model we assume both correlation over countries and country-specific first-order autocorrelation. The results support the negative effect of the *GDPPC* on the *CO₂ROAD*. The effect of *POPDENS* on *CO₂ROAD* is highly statistically significant, and is positive. The larger the *POPDENS*, the larger the *CO₂ROAD* will be. In general, the results show that there is a negative and statistically significant relationship between *PRICEG* and *CO₂ROAD*. Both *DIESCAR* and *AVPOWERD* favour *CO₂ROAD*. That relationship is, in fact, positive and statistically significant.

5. Discussion

It is worthwhile emphasizing that models I to III do not entirely follow the specification tests from **Table 3**. They are estimated as an indicator of robustness of the results achieved from the PCSE estimator (models IV to VII). The former are the reference models for discussion, namely model VII, where we assume both correlation over countries and autocorrelation AR(1) which is country-specific.

The negative and highly statistically significant relationship between *GDPPC* and *CO₂ROAD* suggests that a rise in income does not imply more *CO₂ROAD*. Nevertheless, in the short run, higher income allows greater distances to be driven [19] and powerful vehicles to be bought, increasing *CO₂ROAD*, it also enables consumers to buy PCs with better advanced fuel saving technologies [18]. Moreover, with higher income, the recurrent replacement of PCs is more likely to happen, bringing more fuel efficient PCs to the existing fleet at a faster pace. In this way, there is a double contribution to decreasing *CO₂ROAD*. Our results do not contradict those of Tapio *et al.* [22], who, when addressing the EU15 countries between 1960 and 2000, pointed out that economic growth no longer means increasing energy use and, thus, CO₂ emissions.

Our results show a positive and highly statistically sig-

nificant relationship between *AVPOWERD* and *CO₂ROAD*. This is in line with what was expected. The nature of this relationship is stable, even in the presence of increasing dieselization for the time span and countries analyzed. In other words, dieselization was not enough to overcome the increasing *CO₂ROAD* due to the rise of *AVPOWERD*. This result is in accordance with what was expected, reinforcing the robustness of our results and the adequacy of our option to control for this driver. Regarding the design of eventual policy measures, in order to reduce *CO₂ROAD*, the EU could optimize the advancing fuel saving technologies by restraining the maximum power for automobile manufacturers' associations, according to PC size.

As regards demography, we observed a positive and highly statistically significant contribution of *POPDENS* to *CO₂ROAD*. Concerning general CO₂ emissions, this relationship was also reported by Hamilton and Turton [20], Hatzigeorgiou *et al.* [21], and by Papagiannaki and Diakoulaki [5] relative to *CO₂ROAD*. It follows that since a larger *POPDENS* is associated with higher *CO₂ROAD*, any people movements that increase population densities, such as both external and internal migrations, could cause damage to the environment. In order to mitigate this effect, policies should encourage people to reduce *CO₂ROAD* in their daily routines, namely through car sharing and the use of public transport.

The *CO₂ROAD* is negatively related to *PRICEG*. In fact, there is a negative and statistically significant relationship between these variables. Several reasons can help to explain this relationship. First, higher *PRICEG* can induce lower fuel consumption as a result of PCs being driven at optimum speeds [18]. Second, it can persuade people, in the long run, to reduce kms driven [16,17]. Third, in the long run, high *PRICEG* can influence consumer decisions to opt to buy vehicles with more advanced fuel saving technologies and powered by cheaper fuels [11], or even, to replace the use of PCs with public transport. In order to impact *CO₂ROAD*, the design of public policies could manage taxes penalizing fuel prices. Nevertheless, such policies would imply harmful consequences to economic activities, both directly and indirectly. Thus, it is crucial to achieve the appropriate balance between them.

With regard to dieselization, we shed light on the lack of consensus in the literature. In line with Schipper [14], we find a positive relationship between *DIESCAR* and *CO₂ROAD*. In fact, this relationship is highly statistically significant and is resistant to different assumptions taken gasoline PCs travel the same number of kms per year. However, this assumption seems to us far from real. For within models. This evidence deserves a deep reflection, given that some literature assumes that both diesel and instance, Schipper [14] notes that diesel PCs in Europe

travel 40% to 100% more than gasoline ones. That mis-specification could be the source of the negative sign achieved by this literature, such as Zervas [34]. It follows that public policies promoting the acquisition of diesel PCs maybe be contributing to environmental damage.

6. Conclusions

This paper focuses on a panel of 14 EU countries from 1995 to 2007, to analyze the impact of several drivers on road transport CO₂ emissions. We innovate by using the PCSE estimator, which proves to be appropriate, taking into consideration the existence of contemporaneous correlation among the various countries. We contribute by showing the relevance of new drivers in explaining road transport CO₂ emissions; meanwhile, we extend the debate about the dieselization effect on those emissions. Overall, the results are robust.

Income and the price of gasoline contribute towards mitigating road transport CO₂ emissions. On the other hand, population density and the average power of new diesel PCs registered have the opposite impact, *i.e.*, they contribute to exacerbating those CO₂ emissions. As far as dieselization is concerned, our findings are crucial to fully understanding this trend by showing that saving emissions from using diesel tends to be surpassed by the increased kms driven. Indeed, we show that a large share of new diesel PCs contributes to more road transport CO₂ emissions. This result with a positive signal does not depend on the debatable assumption that diesel and gasoline PCs travel the same number of kms per year.

The designers of public policies should be aware that dieselization and PC power are causing an increase in road transport CO₂ emissions. On the one hand, further research is needed to better understand the real effect of the increasing kms driven by diesel PCs on road transport CO₂ emissions. On the other hand, once a positive relationship between PC power and road transport CO₂ emissions has been verified, then it is advisable that public policy should make powerful PCs more expensive and could, alternatively, promote agreements with automobile manufacturers' associations in order to limit power in new PC models.

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