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Does Dieselization Favour a Cleaner Transport? Evidence from EU-15

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ABSTRACT *In the 1990s, purchases of diesel passenger cars in the EU had intensively grown, with the subsequent increase of diesel oil demand. One of the main factors explaining this change on consumer preferences was the improvement in combustion technology of diesel engines. In this context, just because diesel cars use less energy per kilometre than petrol ones, EU authorities have considered dieselization as a phenomenon harmonic with transport policy objectives enhancing the change in consumer preferences for diesel cars with fiscal and technical policies. The process of dieselization was consolidated; European consumers have maintained their preferences for diesel cars over time. The economic literature lacks in the study of dieselization and in the study of dieselization environmental consequences. However, this work tries to shed some light onto this issue analysing, through the estimation of a two-simultaneous-equations model, EU's new diesel passenger car demand and diesel oil demand in the last two decades. The results will permit to characterize the main factors behind the change to dieselization. After this, we will discuss about the environmental implications of the European social option for dieselization.*

1. Introduction

The early 1990s was the starting point of an intense process of dieselization that has taken place in the EU-15 during the last two decades. The percentage of diesel passenger cars registered in 1990 represented 13.3% of the total number of registrations (see Table A1 in the Appendix). This percentage increased by more than 40 points in 18 years, reaching 52.9% in the year 2008. This process was pronounced (with different intensities) in all of EU-15 countries with the exception of Greece where diesel car registrations represented only 3.6% in 2008. At the same time, the phenomenon of dieselization had a direct impact on the relative weight of diesel oil in the total amount of automotive fuel consumption. At the

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beginning of the 1970s, in the EU-15 diesel oil consumption represented on average one-third of the total consumption of automotive fuels (see Table A2 in the Appendix). That figure reached 35.5% in 1980, 44.1% in 1990, 53% in 2000 and 66.27% in 2008. In short, the primary automotive fuel in the EU-15 from the end of the 1990s has been diesel oil.

Hence, European dieselization is a socio-economic phenomenon that deserves to be analysed. In fact, since the 1970s economists have paid a great deal of attention to the analysis of energy demand in the transport sector. One of the primary foci of attention was the study of the economic consequences of petroleum scarcity and the necessity of fuel economy. During the last two decades, economists have enlarged their interests towards fuel consumption effects on the environment. Undoubtedly, a key factor is the role played by the transport sector in fulfilling Kyoto objectives. For diesel engines and diesel oil characteristics, dieselization is a transport feature involved in that challenge.

Nevertheless, the available literature on the transport sector's energy demand has paid little attention to the great increase of both diesel passenger cars and diesel oil demand in the EU. As a result, the environmental implications of this phenomenon have not been enough examined. This study attempts to fill this gap, providing a better understanding of European dieselization process in order to extract lessons for transport environmental policy.

Thus, we analyse first the role of technological and socio-economic factors that are on the basis of the process of dieselization that started in the 1990s in the EU-15. To this end, a two-simultaneous-equations model—the demand for new diesel passenger cars (number of registrations per 1000 inhabitants) and the demand for diesel oil (tonnes per capita)—is estimated. Then, we use the model's results to discuss the environmental possible consequences of the choice of European society for diesel cars.

The study is structured as follows: in the second section, a review of the existing literature on diesel oil and diesel cars consumption is presented. The third section presents an historical background of the phenomenon analysed. The specification of the model is presented in the fourth section, and the estimation and discussion of the results are presented in the fifth. To bring the discussion to a close, the conclusions are presented, and their implications for transport policies in the EU are analysed.

2. Previous Literature

The main economic interest on dieselization has to do with its influence on fuel economy and its environmental impacts. The link between dieselization and atmospheric pollution is fuel consumption. In fact, economic works focused on energy economy of transport are based on fuel demand estimations. Our study will follow this approach which is usual in the abundant economic literature aiming to provide a better understanding of the behaviour of drivers in order to improve transport policies (see Basso and Oum, 2007). Notwithstanding, there are other works tackling dieselization that follow methods of analysis different from the usual economic ones. This is the case of Mayeres and Proost (2001), Schipper *et al*. (2002), Kavalov and Peteves (2004), Zervas (2006), Zervas *et al*. (2006), Al-Hinti *et al*. (2007), Schipper and Fulton (2009), Jeong *et al*. (2009) and Lee and Cho (2009).

Most studies tackling fuel vehicle demand issues analyse either the demand for gasoline or the demand for fuel as a whole (see the reviews of Espey, 1998;

Graham and Glaister, 2002; Basso and Oum, 2007; Brons *et al.*, 2008). In fact, there are very few papers that analyse explicitly the demand for diesel oil. Birol and Guerer (1993), Banaszak *et al.* (1999), Dahl and Kurtubi (2001), Belhaj (2002), Chandarisi (2006), Bonilla (2009), and Bonilla and Foxon (2009) are a few exceptions. Basically, from a macro and microeconomic standpoint there are two alternatives to analyse the demand of fuel. The first option consists of using an equation of fuel demand where some measure of the stock of vehicles is explicitly included (Puller and Greening, 1999; Kayser, 2000; Banfi *et al.*, 2005 among others). In this case, fuel demand can be obtained directly or indirectly (in this case, the dependent variable is fuel economy, and fuel demand is indirectly derived) even if the former is the more used approach (Basso and Oum, 2007). An alternative procedure is to employ a system of simultaneous equations in which the demand for vehicles and the demand for fuel are analysed jointly (i.e. Train, 1986, Belhaj, 2002; Chandarisi, 2006). We believe that to study dieselization, the second method is better, because this process is a direct consequence of the choice of a specific type of car. Moreover, it is the result of a joint decision, these two commodities are complementary, and therefore the demand for diesel fuel is dependent of the demand for diesel passenger automobiles (Chandarisi, 2006). So, in this case, as Train (1986) pointed out, it seems reasonable to use a simultaneous econometric approach that takes into account the interdependence among both choices.

One of the essential results of the model studying fuel demand is price and income elasticity, in the short and long terms. These figures permit to guide public policy towards obtaining efficiency gains in energy conservation.

Nevertheless, as can be expected, the price elasticity for fuel demand is very heterogeneous, depending on the geographic location, as well as on the methodology and the type of data used. Even though many studies analyse the case of single developed countries, some of them are focused on world regional areas for example Baltagi and Griffin (1983, 1997), Prosser (1985) and Sterner (1990) for OCDE countries and Drollas (1984), Koopman (1995) and Pock (2010) for Europe. The latter is the first study that analyses gasoline demand in Europe considering that in that region there is a great share of diesel in total passenger cars, so indirectly it approaches some aspects of European dieselization.

Taking into account the results of the meta-analysis carried out by Espey (1998) and Brons *et al*. (2008) and the survey by Graham and Glaister (2002), we can conclude that the demand for fuels is much more inelastic in the short term than in the long term. In the short term, price elasticity is ranged between –0.2 and –0.3 and in the long term it is located between –0.6 and –0.8. The few studies carried out on diesel oil show price elasticity that is even lower; ranged in the short term between –0.08 and –0.15 and in the long term between –0.57 and –0.67. As pointed out by Birol and Guerer (1993, p. 1170), these differences are the result of the better fiscal treatment of diesel oil.

With respect to income elasticity, the results of the surveys mentioned above find it ranged from 0.35 to 0.55 in the short term and between 1.2 and 1.3 in the long term. "The finding that income elasticities are higher than price elasticities implies that fuel prices must rise faster than the rate of income growth even just to keep the fuel consumption at the existing level. This poses a serious dilemma in all growth-oriented economies" (Basso and Oum, 2007, p. 458).

In the case of diesel oil, the studies find an income elasticity higher than those of gasoline, but this must be taken carefully because the available literature is

Table 1. Studies on diesel oil and diesel cars consumption

Authors	Focus of analysis	Method	Consequences on the environment	Geographical area
Birol and Guerer (1994)	Impact of transport gasoline and diesel oil demand in total energy demand; vehicles	Model of demand estimations using a direct equation	Not analysed	Turkey, Thailand, Pakistan, Morocco, Tunisia and Malaysia
Banaszak *et al*. (1999)	To account for fiscal purposes the gasoline and diesel oil substitutability; vehicles	Model of Multi-equations demand system based on direct demand equation estimations of gasoline and of diesel oil	Not analysed	South Korea and Taiwan
Dahl and Kurtubi 2001	Impact of different oil product (where diesel oil) in total energy demand for security purposes; vehicles	Model of demand estimations using a direct equation	Not analysed	Indonesia
Mayeres and Proost (2001)	Rationality of different tax treatment of diesel oil and gasoline	Model of optimal taxation considering externalities	Positive for CO_2 negative for air pollutants	A selection of 10 European countries
Belhaj (2002)	Energy demand of transport sector, distinguishing diesel oil and gasoline demand; vehicles	Model of simultaneous equations of vehicle and diesel oil demand	Not analysed	Morocco
Schipper *et al*. (2002)	Impact of dieselization on energy saving; light duty vehicles	Descriptive analysis of findings.	Not positive	A selection of five European countries
Kavalov and Peteves (2004)	Impact of dieselization on energy saving; vehicles	Descriptive analysis of findings	Not positive	EU-15
Chandarisi (2006)	To capture substitutability between diesel oil and gasoline; vehicles	Model of simultaneous equations of diesel oil, gasoline and vehicle demand	Not analysed	Sri Lanka
Zervas (2006)	Benefits on CO_2 reduction of increasing diesel passenger car sales	Construction of scenarios measuring diesel car sales and its associated fuel consumption	Positive	Ireland
Zervas *et. al*. (2006)	Benefits on CO_2 reduction of increasing diesel passenger car sales	Construction of scenarios measuring diesel car sales and its associated fuel consumption	Positive	Greece

Table 1. Studies on diesel oil and diesel cars consumption

Authors	Focus of analysis	Method	Consequences on the environment	Geographical area
Al Hinti *et al*. (2007)	Potential benefits of diesel passenger car sales	Forecasting model with 3 scenarios	Positive for CO_2	Jordan
Schipper and Fulton (2009)	Impact of dieselization on energy saving; light duty vehicles	Descriptive analysis of findings	Not positive	A selection of eight European countries
Jeong *et al*. (2009)	Impact of diesel passenger car sales on the environment	System dynamics to measure pollutant emissions of cars	Positive for CO_2 negative for air pollutants	South Korea
Lee and Cho (2009)	Forecast demand of diesel passenger cars to provide policymakers of benchmark usual information	Micro-simulated demand forecasting	Not analysed	South Korea
Bonilla (2009)	To investigate the drivers of fuel economy demand in short and long term for diesel oil; passenger cars	Model of indirect diesel demand estimation (the dependent variable is fuel economy)	Positive in the long run for CO_2 but possible rebound effect and probably negative for air pollutants	United Kingdom
Bonilla and Foxon (2009)	To investigate the drivers of fuel economy demand in short- and long-run separating data for gasoline and diesel oil; passenger cars	Model of indirect diesel demand estimation (the dependent variable is fuel economy)	Better in the long run than in the short run (where negative)	United Kingdom

mostly focused on vehicles in general.[1] And as Birol and Guerer (1993) pointed out "gasoline is (almost) exclusively consumed by cars, and diesel is basically consumed for freight and public transport. These are more closely correlated to economic growth process" (pp. 1169–1170).

To summarize Table 1 presents a review of literature tackling diesel issues. They use different methodological approaches, have different focus of analysis and are applied to different countries or group of countries. As can be observed any of these works analyse dieselization of passenger cars in Europe as a whole (the part of the world where this phenomenon has been more remarkable) using a fuel demand approach, a method permitting to provide a better understanding of this process—through price and income demand elasticities—in order to improve transport policies. Our study covers all these lacks.

3. Historical Background

There is a broad consensus on the three principal socio-economic factors that influence at the micro-economic level on the decision of buying a diesel vehicle as opposed to a gasoline one (ACEA, 2005): (1) the efficiency of diesel engines, (2) the price of diesel automobiles, and (3) the price of diesel oil. So these factors were on the basis of consumer preference changes to diesel cars in the 1990s.

- As for efficiency, since the 1980s there was important technological improvements made by European producers on diesel engines. In fact European car manufactures were, and still are, more advanced in the *Compressed-Ignited Internal Combustion Engine Technology* compared to car manufactures of the rest of the World. The technological boom occurred in 1993 as a consequence of the introduction in the passenger car market of the direct injection turbo-diesel engines.[2] As a result, the sales of new diesel cars started to grow fast at the expense of the sales of gasoline cars (Kavalov and Peteves, 2004). Driving diesel car became more attractive because, in comparative terms, vehicles equipped with this technology consume less and have similar, sometimes even better, performance than gasoline vehicles in terms of, for example, top speed and acceleration. In fact, since the introduction of this new technology, diesel automobiles consume on average 26% less fuel per kilometre than gasoline ones, especially, in urban traffic (Sterner, 2007, p. 3199). This gain in consumption efficiency was in fact the key factor on consumer preference changes to diesel cars in the decade of the 1990s
- As for the automobiles price, even though diesel cars have traditionally been more expensive than gasoline cars, these differences have been decreasing throughout the last two decades. If we take as reference the Spanish case, the difference in price between the diesel and gasoline versions of the basic Volkswagen Golf was of 2600 Euros in 1996 and of 1330 Euros in 2008. So changes in relative prices boosted the substitution of gasoline cars for diesel cars.
- Finally, in the majority of EU-15 countries, the price of automotive diesel oil has traditionally been lower than that of gasoline.[3] In fact, it is the tax burden which is on the basis of that difference in prices. Historically, passenger cars ran on gasoline and commercial cars on diesel oil, so fiscal policy has traditionally taxed gasoline higher than diesel oil in order to favour commercial transport instead of private. In the period analysed, the gap between gasoline and diesel oil prices was maintained—the difference was almost constant along the years, being the mean for UE-15 of 0.19 Euros per litre (constant base 2005)—even if the demand of diesel oil has enormously increased (see Table A2 in the Appendix). So the better relative price of diesel oil in face of gasoline's was the third socio-economic factor influencing the change in European consumer preferences to buy a diesel car instead of a gasoline one.

Therefore, institutional factors have accompanied and enhanced the changes on socio-economic circumstances leading to the consumer's option for diesel cars. The first of these factors has to do with European fiscal policy on hydrocarbons.[4] In January 1993, Directive 92/82/EC entered into force being one of its objectives the harmonization of the types of taxation schedules of excise duties imposed on hydrocarbons. This norm resulted in the implementation of a minimum excise duty for diesel five cents (euro) lower than that of unleaded gas and 9.2 cents less than leaded gas. However, these differences have been decreasing over time in the case of diesel oil and unleaded gasoline. In the second place, Directive 92/82/EC brought about an important dispersion in the indirect taxes applied in the EU countries.

In 2003, Directive 2003/96/EC was passed, whose objective among others was an increase in the minimum excise duty applicable to all hydrocarbons with the aim of reducing the differences in price favouring diesel oil. In this way, the minimum excise duty in force as of January 2004 is 0.359 Euros for unleaded gasoline and 0.302 Euros for diesel. By 2010, the excise duty on diesel oil has increased to 0.330 Euros per litre, whereas the minimum excise duty on gasoline did not undergo any changes. In other words, the EU is going to maintain in the upcoming years a fiscal treatment that is favourable to diesel oil, although the difference between the minimum excise duty has been reduced as much as 2.9 Euro-cents.

The second institutional factor accompanying and reinforcing in time the European consumers' option for diesel cars in the 1990s was the signature in 1998 of a voluntary commitment of the ACEA with the European Community on reducing the average CO_2 emissions from new cars (European Commission, 1999). A target emission for the average ACEA vehicle of 140 g CO_2/km (this represents a cut off of 25% on 1995 levels in 2008) was agreed, with an intermediate target of 165–170 g CO_2/km for 2003. In 2009 (European Commission, 2009), a regulation proposing a mandatory new car fuel efficiency target of 130 g CO_2/km by 2012 and 95 g CO_2/km by 2020 was published. In fact this commitment is an incentive to reinforce the technological efficiency advance in diesel engines instead of advances on its gasoline counterparts (Kavalov and Peteves, 2004). It is easier to reach the targets of the CO_2 emission reduction with diesel engines than with gasoline. So this commitment has enhanced in the 2000s the social option for diesel cars undertaken in the EU countries in the 1990s (Fontaras and Samaras, 2007).

In short, the EU authorities have accompanied the consumers in their option for diesel cars as part of its transport policy, using for this end specific taxes on hydrocarbon consumption and establishing standards of CO_2 emissions. As it is known, on average and with existing technology, diesel vehicles consume less fuel and emit less green house gases to the atmosphere than gasoline vehicles. For this reason, the community authorities have implicitly assumed that dieselization is a phenomenon in harmony with the environmental objectives of the EU. However, other relevant circumstances are present—both technological as well as those having to do with the impact of the diesel cars on the environment and health—that place the supposed above-mentioned harmony between dieselization and the transport policy environmental objectives into doubt.

In the first place, diesel vehicles emit a greater amount of suspension particles and nitrogen oxide into the atmosphere than gasoline automobiles. This is still like that even if since 1992 the EU has applied a policy to preserve air quality from road transport pollution: cars must meet certain standards for exhaust emissions before they can be approved for sale. As we can see in Table 2, the limits of car air pollutant emissions have been defined through the successive 'Euro' emission standards for passenger cars. These measures have already helped to achieve considerable reduction in air pollution from cars, for example by forcing carmakers to fit catalyst filters to exhaust pipes. The standard emissions policy has reduced the disadvantages of diesel vehicles instead of gasoline ones in terms of local pollution, but for this kind of pollution diesel vehicles still have a worse performance than its gasoline counterparts.

Moreover, when applying the standard emissions measures to diesel engines, there is a NO_x/PM trade-off. The reduction of nitrogen oxide emissions is

Table 2. EU Emissions standards for passenger cars

Standard	CO (mg/km)		Particulate matters (PM) (mg/km)		Oxides of nitrogen (NOx) (mg/km)		Hydrocarbons (HC) (mg/km)	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
Euro 1 07/1992[a]	2.720	2.720	140	—	—	—	—	—
Euro 2 01/1996[a]	1.000	2.200	80–100	—	—	—	—	—
Euro 3 01/2000[a]	640	2.300	50	—	500	150	—	200
Euro 4 01/2005[a]	500	1.000	25	—	250	80	—	100
Euro 5 09/2009[a]	500	1.000	5	5	180	70	—	100
Euro 6 09/2014[a]	500	1.000	5	5	80	70	—	100

[a]This is the date in which each Euro came into force.
Source: European Commission: http://www.euractiv.com/en/transport/euro-5-emissions-standards-cars/article-133325

normally accompanied by an increase on particulate matter (PM) emissions and of fuel consumption because some after-treatment technologies might be needed (Kavalov and Peteves, 2004). The automotive industry believes that the recent improvement in diesel technology will allow the new passenger cars to meet the EURO 5 and EURO 6 limits for NO_x and PM without additional equipment (CONCAWE, 2008a, 2008b). But if this cannot be achieved, the new emission standards will continue narrowing the fuel efficiency advantages, and CO_2 emissions better performance, of diesel cars compared to gasoline, as they have done since 1993.

In the second place, the better performance of diesel vehicles to achieve Kyoto Protocol objectives is not as clear as it seems. First, as has been explained in the paragraph above, the implementation of the EU standards emission of air pollutants has narrowed the advantages of diesel cars in fuel efficiency compared to gasoline. Second, a diesel car produces more carbon per energy unit than gasoline vehicles—there are more carbon atoms in diesel in relation with hydrogen atoms—(Schipper *et al.*, 2002; Sterner, 2007), so when this is considered, "much of the difference in fuel intensity on new or on-road vehicles disappears" (Schipper and Fulton, 2009, p. 8).

Third, the greater efficiency of diesel passenger cars could be an incentive for their owners to drive more kilometres per year than they would do with a gasoline vehicle (Bonilla, 2009; Schipper and Fulton 2009). In other words, the technological improvements introduced into diesel engines such as turbo injectors are potential creators of rebound effects.[5] Finally, if we analyse differences in CO_2 emissions between gasoline and diesel fuels from an upstream perspective, we can say that the continuous increasing of diesel demand has expanded diesel yield while petrol production has declined further.[6] As a result, diesel oil will progressively become more energy- and green house gas-intensive than petrol in the refinery phase of production (Kavalov and Peteves, 2004).

4. Model

In this section, we define our econometric model of simultaneous equations where (1) and (2) are respectively diesel passenger cars demand and diesel oil demand (where subscripts *i* and *t* are country and year, respectively). The model is estimated using a panel data of EU-15 countries for the period 1990–2008. Variables are expressed in natural logarithms (Ln) and parameters of the model are interpreted as long-term elasticities.

(1) Diesel passenger car demand:

$$\text{Ln}V_{it} = \alpha_0 + \alpha_1 \text{Ln}V_{it-1} + \alpha_2 \text{Ln}Y_{it} + \alpha_3 \text{Ln}\,\text{Pr}\,F_{it} + \alpha_4 \text{Ln}\,\text{Pr}\,V_{it} + \alpha_5 \text{Ln}Ef_{it} + \alpha_6 \text{Ln}Den_{it} + \alpha_7 country_i + \varepsilon_{it}$$

(2) Diesel oil demand:

$$\text{Ln}Q_{it} = \beta_0 + \beta_1 \text{Ln}Q_{it-1} + \beta_2 \text{Ln}Y_{it} + \beta_3 \text{Ln}V_{it} + \beta_4 \text{Ln}Tax_{it} + \beta_5 \text{Ln}\,\text{Pr}\,P_{it} + \beta_6 \text{Ln}Den_{it} + \beta_7 country_i + u_{it}$$

A brief description of the variables used in both equations is shown in Table 3. Otherwise, the estimated coefficients are α_1 to α_7 in Equation 1 and β_1 to β_7 in Equation 2. Likewise ε_{it} and u_{it} are the error terms in both equations, respectively.

Table 3. List of variables of the model

Variables		Comments	Units	Period (Observations)	Mean[c] (Std)	Source
V	New passenger cars registrations	—	Number per 1000 inhabitants	1990–2008 (277)	12.43 (14.15)	ACEA[d]
Q	Diesel oil per capita consumption	—	Tonnes	1990–2008 (285)	0.49 (0.56)	AEAT[e]
Y	Income per capita	In real terms[a]	Thousand of Euros	1990–2008 (285)	26.78 (10.10)	EUROSTAT[f]
PrF	Relative price of fuel	Price of diesel oil/price of gasoline (Euros per litre)	—	1990–2008 (269)	0.82 (0.11)	EUROSTAT[g]
PrV	Relative price of cars	Price of diesel cars/gasoline cars	—	1990–2008 (285)	1.14 (0.08)	Autopista and Instituto de Estudios de Automoción[h]
Ef	Economic Efficiency of diesel cars	Amount of Euros saved by 100 km resulting from driving a diesel car instead of a gasoline[b]	Euros/100 km	1990–2008 (269)	2.29 (0.91)	EUROSTAT, Autopista and Instituto de Estudios de Automoción[i]

Table 3. (*Continued*)

Variables		Comments	Units	Period (Observations)	Mean[c] (Std)	Source
Den	Density	Population/ inhabitants	Inhabitants per km^2	1990–2008 (285)	154.38 (118.51)	EUROSTAT[j]
Tax	Excise duty	Euros per litre in real terms	Euros	1990–2008 (269)	0.44 (0.12)	AEAT[k]
PrP	Price of petrol per barrel	In real terms	Euros	1990–2008 (285)	28.96 (13.37)	CORES[l]

[a]Base year for all real variables is 2005.
[b]This results from subtracting to gasoline cars technical efficiency (L/100 km) multiplied by gasoline price (Euros/L) the same items for diesels.
[c]Values for the whole period and EU-15 as a whole.
[d]www.acea.be/index.php/collection/statisctics/ Document "ACEA Diesel historical series by country in Western Europe.
[e]Own elaboration using data from Agencia Estatal de Administración Tributaria: Impuestos especiales estudio relativo años 1970–2008, capitulo 4 impuesto sobre hidrocarburos cuadro 4.10.5. These documents from 2003 to 2008 are available at http://www.aeat.es/AEAT/Contenidos_Comunes/Aduanas/Impuestos_especiales/Estudio_relativo_2003/hidrocar.pdf
[f]Own elaboration using data from Data Base Statistics, National Accounts, GDP and main components current prices; and from Data Base Statistics, Harmonized Indices of Consumer Prices (annual data, average, base 2005).
[g]Own elaboration from data from the Data Base Statistics Energy, Main Indicators, Energy Statistics, Euro indicators, Energy prices.
[h]Own elaboration using data requested to the following Spanish institutions: Autopista (1990–1995) and Instituto de Estudios de Automoción (1996–2008). We use as proxy an index of the relative price of Diesel VW Golf (basic version) instead of its gasoline counterpart in Spain.
[i]Own elaboration from data of technical efficiency (L/100 km) of new diesel cars instead of new gasoline ones (Autopista (1990–1995) and Instituto de Estudios de Automoción (1996–2008)) and from the prices of diesel oil and gasoline (from the source of Note 10). The economicic efficiency is measured as the amount of Euros saved by 100 km resulting from driving a diesel car. We obtain technical efficiency of cars using a proxy with data of VW Golf matches.
[j]Main Tables Statistics, Population, Main Demographic Indicators.
[k]Own elaboration using data from Agencia Estatal de Admnistración Tributaria: Impuestos especiales estudio relativo años 1995–2008, capítulo 4 impuesto sobre hidrocarburos cuadro 4.3.2. The documents from 2003 to 2008 are available at http://www.aeat.es/AEAT/Contenidos_Comunes/Aduanas/Impuestos_especiales/Estudio_relativo_2003/hidrocar.pdft.
[l]Resumen Anual del boletín Estadístico de hidrocarburos (issues from 1991 to 2009). http://www.cores.es/esp/boletines/anuales.html

Equations (1) and (2) include a lag of the dependent variable—the null hypothesis of no first-order correlation is rejected in both equations.[7] This is the process usually used in the literature to capture the habit (see Deaton and Muellbauer, 1980; Pollak and Wales, 1981; Dynan, 2000 among others). Habit is considered as the resistance of drivers to modify their fuel consumption patterns, even in the presence of changes in prices or income (Goodwin, 1976). There are many reasons that justify consumer habit in private transport consumptions i.e. all reasons linked to people's preferences for using private cars instead of using public transportation. Otherwise, it is well known that drivers' preferences are not directly observable, and they are associated with specific socio-economic and institutional characteristics. In order to control this heterogeneity, we have included a dummy variable in both equations (for discussion see Hsiao, 1986; Wooldridge, 2002). In addition, we have used a variable that includes population density because evidence shows that the impact of dieselization is more important in countries with a greater predominance of rural areas where the public transport network is less developed (see Storchman, 2007; Karathodorou *et al.*, 2010).

Figures 1–3 show how independent variables—diesel oil consumption, income per capita, diesel passenger car registrations, relative price of passenger cars, relative price of diesel oil, economic efficiency, price of crude oil, excise duties on diesel oil and diesel oil consumption—have varied for the EU-15 average during the period 1990–2008.

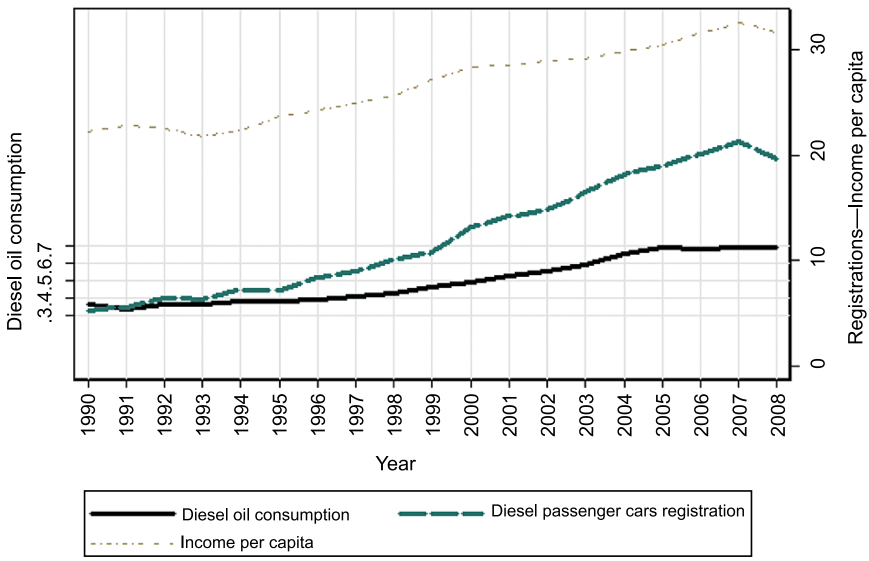

Figure 1. Diesel oil consumption—registrations—income per capita

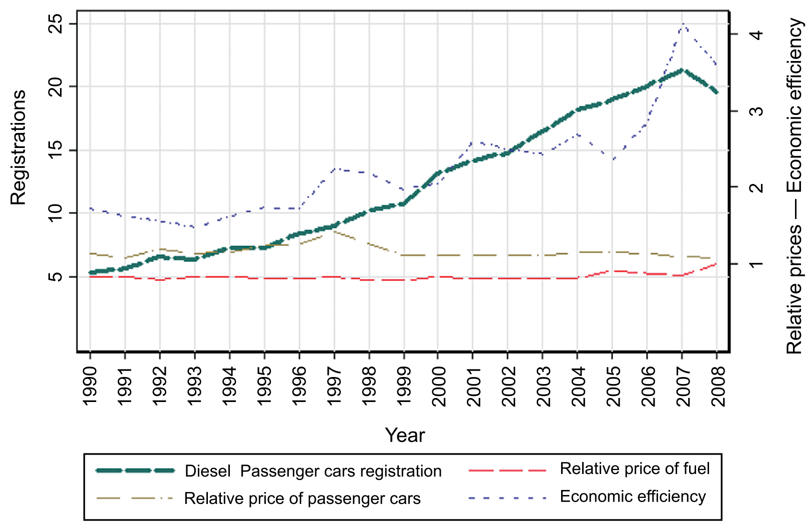

Figure 2. Registrations—relative prices—economic efficiency

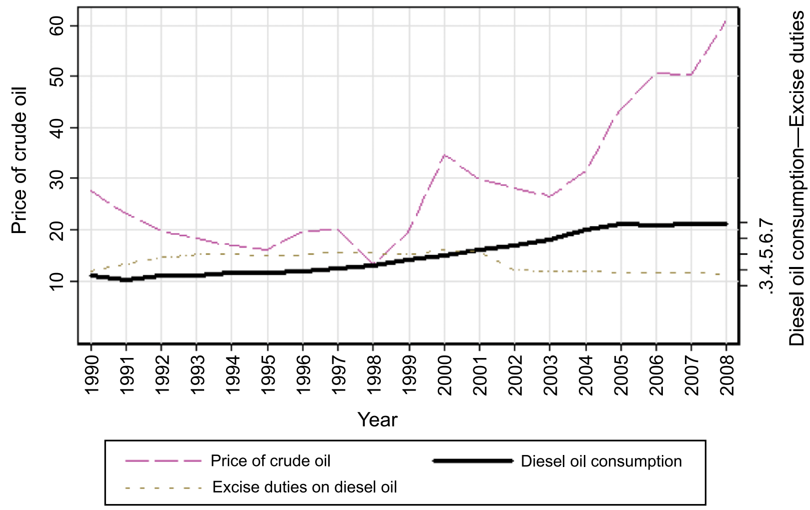

Figure 3. Diesel oil consumption—price of crude oil—excise duties

5. Results

To estimate the model, we have used the Iterative Seemingly Unrelated Regression (*ISUR*) available in Stata since it accounts for the contemporaneous correlation of the error terms (Wooldrige, 2002; Baltagi, 2005; Cameron and Trivedi, 2009; StataCorp, 2009). In order to test the residual cross-sectional independence, we have conducted the Breusch–Pagan statistics (Breusch and Pagan, 1980). Under the null hypothesis of cross-sectional independence, the test yields $\chi^2(1) = 4.737$ and its *p*-value is 0.0295. Consequently, the null-hypothesis is rejected and thus *ISUR* procedure should be used on each equation rather than OLS. Otherwise, adjusted R^2 is very high in both equations so the fit of the model is good.

The estimation results are shown in Table 4. In Equation 1, parameters α_1, α_2 and α_3 are significant and have the expected sign. Therefore, the habit, the income and the economic efficiency are the variables that explain the decision of buying a diesel car. To be more precise, an increase of 1% in the registration of diesel cars in the period $t-1$ generates an increase in diesel car demand by 0.39% in the period t. An increase of 1% in real income per capita increases diesel car demand by 1.06%, and finally 1% improvement in the economic efficiency of diesel cars would increase the demand for this type of automobile by 0.568%. These results are in accordance with diesel car demand variables behaviour: registrations of diesel passenger cars, economic efficiency and real income per capita presented an increasing trend during this period (as shown in Figures 1 and 2). Neither the relative price of diesel nor the relative price of diesel cars is significant in the decision of buying a diesel car. Population density and country dummies are also not significant.

In Equation 2, parameters β_1, β_2, β_3 and β_4 are significant and present the expected sign. Therefore, habit, real income per capita, diesel cars registrations and real excise duties on diesel oil are the variables that determine diesel oil demand. In fact, an increase of 1% in diesel consumption in period $t-1$ generates an increase in diesel oil demand by 0.16 in period t. Thus, habit has great rele-

Table 4. Results of the ISUR estimation

	Demand for diesel passenger cars (Equation 1)		Demand for diesel fuel (Equation 2)	
Variables	Parameters	SE	Parameters	SE
Ln Lag V	0.39962[a]	(0.042)	—	—
Ln Income	1.06765 [a]	(0.230)	—	—
Ln Efficiency	0.56894[a]	(0.110)	—	—
Ln Relative price fuel	0.44850	(0.333)	—	—
Ln Relative price cars	0.28641	(0.357)	—	—
Ln Density	–0.53943	(0.633)	—	—
Ln Lag Q	—	—	0.16548[a]	(0.024)
Ln Income	—	—	0.70176[a]	(0.056)
Ln Registrations	—	—	0.09541[a]	(0.013)
Ln Excise duty	—	—	–0.27875[a]	(0.035)
Ln Relative price oil	—	—	0.00343	0.020
Ln Density			0.19912	0.154
Austria	–0.22017	(0.620)	0.45087[a]	(0.152
Belgium	0.53120[b]	(0.248)	0.12784[b]	(0.059)
Denmark	–1.79337[a]	(0.489)	0.28387[b]	(0.123)
Finland	–2.15902	(1.721)	0.58334	(0.418)
France	–0.28443	(0.587)	0.35795[a]	(0.139)
Germany	–0.15434	(0.159)	–0.01769	(0.035)
Greece	–2.01961[a]	(0.673)	0.41024[a]	(0.168)
Ireland	–1.16882	(0.949)	0.36732	(0.233)
Italy	–0.20096	(0.215)	0.18315[a]	(0.046)
Luxembourg	–0.03984	(0.384)	0.93374[a]	(0.102)
Portugal	–0.29611	(0.552)	0.62947[a]	(0.126)
Spain	–0.06068	(0.701)	0.50913[a]	(0.170)
Sweden	–2.38207	(1.564)	0.54574	(0.383)
Netherlands	–0.31778	(0.416)	–0.18106	(0.100)
Intercept	0.56628	(3.261)	–4.75032[a]	(0.801)
Adjusted R^2	0.9012		0.9732	
Observations	259		259	
Joint significance test *F* (all parameters)	F(20,476)=61.14		F(20,476)=513.3	
	Prob > *F*= 0.000		Prob > *F* = 0.000	
Joint significance test *F* (country dummies)	*F*(14,476) = 46.80 Prob > *F* = 0.0000			
Breusch–Pagan test	χ^2 = 4.737			

[a]Coefficient significant at the 1% level of significance.
[b]Coefficient significant at the 5% level of significance.

vance with respect to the consumption of diesel oil in that it is conditioned to the ownership of a durable good, the cost of which has to be paid for by means of its use (see Baker *et al.*, 1989). In that sense, habit links diesel oil demand to the stock of diesel passenger cars. Moreover, an increase of 1% in new diesel registrations generates an increase of diesel oil demand by 0.09. Hence, diesel oil demand is more likely to be influenced by the stock of diesel cars (through habit) than by new diesel car registrations. Finally, an increase of 1% in real income per capita increases diesel oil consumption by 0.70. And, an increase in real excise duties (Euros/litre) on diesel oil by 1% decreases its demand by 0.27. Therefore, income elasticity is higher than excise duty elasticity. As is known, excise duty is a relevant component of the final price of fuels, and a key element in the differences of gasoline and diesel oil prices. Thus, excise duty on diesel oil elasticity can be considered as a proxy of diesel oil price elasticity. Our results are consistent with the ones of the literature where, as we explained in Section 2, income elasticity of fuel demand is higher than price elasticity. Moreover, the value of this proxy of price elasticity is low, so it is in accordance with the existing empirical evidence[8] (i.e. Greene *et al.*, 2005; Romero-Jordán *et al.*, 2010). All that results as those of the literature on fuel demand demonstrate that an increase in taxes imposed on fuels would have little effect on its demand both in the short and long term, and that policies based on taxes are difficult to apply because taxes must rise faster than the rate of income growth. Most country dummies of this equation are significant. Notwithstanding, the joint significance test of the country is rejected at the 1% level of significance. Moreover, real price of petrol and population density are not significant variables in the consumption of diesel oil.

6. Conclusions and Implications for EU Environmental Policy

In this paper, we have analysed the factors determining the dieselization of EU-15 passenger car fleet during the last two decades. To do so, a model of two equations has been estimated. These equations explain the demand for diesel cars and the demand for diesel oil. In relation with the demand for automobiles, the economic efficiency of diesel cars is one of the main variables that explain its growth. Thus, the variables explaining this economic efficiency—fuel economy of diesel engines and the difference between diesel oil price and gasoline price—have played an important role in the process of dieselization.

Therefore, diesel car choice in Europe is mainly the consequence of technological improvements, reinforced by institutional factors, as a favourable diesel oil fiscal treatment, and standard emissions policies encouraging technical diesel engine development. However, as we commented in Section 3, European authorities are nowadays narrowing fiscal advantages of diesel oil: the difference of diesel oil price compared to gasoline price, which under the period of analysis was almost constant, diminish drastically in 2008, passing from 0.19 Euros to 0.03 Euros. In fact, the better relative price of diesel oil has influenced the decision of buying a car through its impact on economic efficiency gains, but it, by itself, is not significant. So, whereas relative diesel oil price increases did not undermine economic efficiency gains of diesel cars, the process of dieselization will continue, also reinforced by the importance of habit in diesel car demand.

The results of the estimation of the demand for diesel oil, confirmed the importance of habit in the process of dieselization, and remarked also the low political feasibility of fiscal measures to change drivers' behaviour. To sum up, technological factors, habit and supply policies (standard emissions policies) are the key variables explaining dieselization, whereas the influence of fiscal policies seems limited.

As we have already mentioned, community authorities believe that the process of dieselization is in harmony with the environmental objectives of the European Community Transport Policy.[9] But empirical evidence does not confirm this point of view. Our study results show that the situation is worse than what it could, a priori, appear to be for two reasons. First, fiscal instruments are not especially effective in reducing the consumption of diesel oil or discourage diesel cars purchases. Second, because the consumption of diesel oil and diesel cars both now and in the future are heavily influenced by the stock of vehicles. And obviously, any significant change in this stock will only take place over the long term. As Kageson (2005) points out it takes between 15 and 20 years to replace the entire car fleet of a country. In fact, in 2002, 32.5% of existing automobiles in the EU were more than 10 years old. In some countries, this percentage is greater than the community average: Finland (53.4%), Sweden (45.8%), Greece (43.5%), Italy (38.3%), Denmark (36.4%) and Spain (35.4%).

The negative effects generated by dieselization appear in a context where greenhouse gases from the transport sector have increased heavily (for a discussion see Tarancón Morán and Del Río González, 2007). The transport sector is the only economic sector in the EU-15 where greenhouse gas emissions have increased between 1990 and 2006 (European Environment Agency, 2007). In relation with this problem, the European Environment Agency (EEA) has identified a set of possible causes. Probably, the most important one is that "previous and current EU policies have mainly focused on improving vehicle technology and fuel quality to reduce pressures on the environment" (European Environment Agency, 2008, p. 4). In other words, they suggest that the environmental policies implemented in the transport sector lack on focusing demand factors.

In this sense and paradoxically, the EEA affirms in this report that the process of dieselization—which is to a great extent a result of consumer choices—is positive from the standpoint of the environment. In particular, the report emphasizes that "the average European passenger car is gradually becoming more efficient, due to technology improvements and a growing share of diesel-driven vehicles" (European Environment Agency, 2008, p. 16). In fact, there is a certain consensus that diesel vehicles are better than gasoline vehicles in order to confront the problem of climate change due to the fact that they emit less CO_2 per kilometre (Zervas, 2006; Zervas *et al.*, 2006; Al Hinti *et al.*, 2007; Bonilla, 2009; Jeong *et al.*, 2009; Lee and Cho, 2009). However, these papers have not taken into account other studies that measure CO_2 emissions per energy unit, or those other studies that maintain the possible existence of a rebound effect, or the larger size of diesel cars, neither the consequences upstream of the increasing demand of diesel oil for passenger cars. Those studies, as for example Schipper and Fulton (2009), present results that explain why, in a context of heavy dieselization, the Co_2 emissions of passenger cars have not stopped increasing. The report by the EEA associates the increase of emissions to an increase in the use of cars. Surprisingly, however, it does not identify any type of link in relation with the growth of atmospheric pollution and the phenomenon of dieselization.

Otherwise, the greater efficiency of diesel vehicles also makes reference to local pollution emissions. Although in this case, it is emphasized that the transport sector as a whole has improved its environmental performance.[10] Indeed, the policies that limited emissions of local contaminants[11] and the underlying technological improvements that the automobile industry has developed to reach those objectives have been successful, both in the case of diesel as well as gasoline engines.[12] Since in this case the result of public policies has been positive, the EEA is not proposing any change. Still, in that same report, it is stated that "air quality in cities has not yet met the limit values set by European regulations and still has a major negative impact on human health" (European Environment Agency, 2008, p. 18). Therefore, the EEA recognizes that the results have been positive but not effective. Nevertheless, this sidesteps the threat that dieselization currently poses for achieving the thresholds of local pollution established in community norms and regulations. Certainly, from the standpoint of supply, diesel engines present greater potential for eco-efficiency than gasoline engines, and probably in the near future their disadvantages in local air pollution will be reduced when compared to these vehicles (Schipper *et al.*, 2002). However, as the present paper has highlighted, the problems that dieselization poses for the local environment are linked to demand: they are generated by the impact of the stock of diesel passenger cars on diesel oil and diesel cars demand, and by the inability of fiscal policy to reduce the consumption of that fuel.

To sum up, EU policy-makers have indicated that in the case of the transport sector, public environmental policies have not been successful because they have only been applied to supply factors. And, obviously, in a diffuse sector such as transport, where most effects depend on demand, demand policies should also be applied. In this sense, this paper is suggesting that the development of demand policies linked to transport that sidestep environmental criteria can have harmful effects on the environment. The above-mentioned EEA report identifies the lack of demand focus as a main cause of the bad environmental behaviour of the transport sector. Therefore, European public authorities have been accurate in their diagnosis. Nevertheless, it is worrying that these authorities consider dieselization as environmentally recommendable for technological reasons, so looking only at the supply aspect of diesel cars, when above all dieselization is a phenomenon linked to demand, and as Schipper and Fulton (2009) highlighted, the social environmental consequences of dieselization are mainly linked to drivers' behaviour and not to technical features of diesel engines.

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Notes

1. Moreover, most studies analysing diesel oil demand are focused on developing countries; this study also biases the results with respect to the average cases. Notwithstanding, the recent works of Bonilla (2009) and Bonilla and Foxon (2009) are focused on passenger cars in the UK, but although they study the effects of diesel oil demand on CO_2 emissions, they did it using an indirect model where the dependent variable is fuel economy; then they did not calculate price and income elasticities of diesel oil demand, but price and income elasticities of fuel economy demand.
2. A good example is the famous *TDI* engines of the Volkswagen group introduced in the Golf since 1993.
3. The same phenomenon occurs in other parts of the world.
4. There are other taxes that influence the decision of using cars. Basically, these taxes are related with cars purchase and ownership, for example, registrations taxes and circulation taxes. Their tax base is normally linked with the weight of the car or the engine power, so they have nothing to do with the choice of the car fuel and by extension with dieselization. Moreover, for these taxes there

is not, as it is the case for taxes on hydrocarbons, a general European frame establishing minimum patterns of taxation for all EU members.

5. Schipper and Fulton (2009) find that diesel cars in Europe are driven 60–70% more than gasoline ones and are larger on average. This is for them the cause of the rebound effect.
6. The additional increase of diesel fraction from oil refining beyond its optimum balance with petrol yield will result in higher production costs for diesel compared to gasoline. The new fuel quality standards will enlarge the gap between diesel and gasoline production costs, because the refinery cost of meeting these standards is higher for diesel than for gasoline.
7. Results of the test for serial correlation proposed by Wooldridge (2002) are respectively $F(1,14)$ = 27.12 and $F(1,14)$ = 9.12.
8. The influence of the fuel tax on the behaviour of individual users depends on the price elasticity of fuel demand. A low elasticity means that fuel taxes have to be substantial to significantly reduce fuel demand, but the social acceptability and, thus, the political feasibility of high tax rates are generally low. In fact, strong public opposition has made this option politically unacceptable in the USA and elsewhere (see Greene *et al.*, 2005).
9. As did policy-makers of other parts of the World. For example in South Korea, environmental policy-makers think that dieselization is a good strategy to reach Kyoto Protocol objectives (see Jeong *et al.*, 2009).
10. Between 1990 and 2005 in the EU vehicle, emissions of acidifying substances were reduced by 35%; ozone precursors were reduced by 45% and particles by 33% (European Environment Agency, 2008).
11. For example, the directive 1999/30/EC on new emission limits of sulphur dioxide, nitrogen oxides, particles and lead restrict the seven annual limit of PM $particles_{10}$ at 40$\mu g/m^3$ and those of $PM_{2.5}$ at 25 $\mu g/m^3$, and has proposed a 20% reduction of the same for the period between 2010 and 2020.
12. There have been improvements in the quality of fuel, and three-way catalytic converters have been developed and particulate filters have been improved (European Environment Agency, 2008).

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Appendix

Table A1. Percentage of registration over total number of registrations in the EU-15 1990–2008

Countries	1990	2000	2008
Austria	22.1	65.7	54.6
Belgium	30.8	62.6	79.0
Denmark	2.6	17.8	45.9
Finland	4.9	15.6	46.2
France	38.4	56.2	77.3
Germany	11.8	34.5	44.1
Greece	–	0.70	3.60
Ireland	15.5	12.9	33.5
Italy	5.7	36.6	50.7
Luxembourg	16.7	58.2	77.0
Netherlands	11.0	22.9	25.1
Portugal	7.0	28.4	68.4
Spain	12.8	52.5	69.3
Sweden	0.9	5.6	36.2
United Kingdom	6.4	14.1	43.6
Mean	13.3	34.5	52.9

Source: 'ACEA Diesel historical series by country in Western Europe' http://www.acea.be/index.php/collection/statisctics/

Table A2. Relative weight of diesel consumption in the EU-15 (%)

Countries	1970	1980	1990	2000	2008
Austria	34.6	36.6	43.8	65.0	77.0
Belgium	29.4	38.0	55.4	69.2	82.8
Denmark	25.0	30.4	46.9	44.7	62.2
Finland	44.4	44.0	43.2	50.0	56.0
France	25.1	33.5	47.8	66.1	78.2
Germany	32.0	30.3	35.4	46.6	59.2
Greece	36.4	39.1	35.9	36.4	41.1
Ireland	22.2	26.7	40.0	50.0	59.8
Italy	29.6	42.6	53.7	49.9	70.3
Luxembourg	0.0	25.0	50.0	60.0	81.1
Netherlands	23.8	33.9	48.6	53.3	61.7
Portugal	54.5	57.9	51.6	59.6	76.7
Spain	42.3	44.8	51.7	65.7	79.7
Sweden	26.8	26.9	27.4	37.7	55.1
United Kingdom	25.5	22.9	29.7	41.4	56.0
Mean	30.1	35.5	44.1	53.0	66.2

Source: Own elaboration using data from 'Agencia Estatal de Administración Tributaria: Impuestos especiales estudio relativo años 1970–2008'. http://www.aeat.es/AEAT/Contenidos_Comunes/Aduanas/Impuestos_especiales/Estudio_relativo_2003/hidrocar.pdf

Table A3. Indirect tax on leaded gasoline over indirect tax on diesel oil in the EU-15

Countries	1995	1996	1997	1998	1999	2000	2001	2002
Belgium	1.62	1.76	1.90	1.90	1.90	1.90	1.90	1.90
Denmark	1.56	1.62	1.66	1.75	1.74	1.57	1.51	1.54
Germany	1.74	1.74	1.74	1.74	1.68	1.62	1.58	1.57
Greece	1.65	1.65	1.65	1.65	1.37	1.34	1.38	1.38
Spain	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.46
France	1.79	1.79	1.73	1.71	1.71	1.61	1.68	1.64
Ireland	1.28	1.26	1.26	1.41	1.41	1.41	1.84	1.69
Italy	1.51	1.49	1.49	1.49	1.43	1.43	1.46	–
Luxembourg	1.59	1.58	1.58	1.58	1.58	1.68	1.68	1.68
Netherlands	1.87	1.92	1.92	1.94	1.94	1.94	1.94	2.00
Austria	1.67	1.70	1.70	1.70	1.70	1.69	1.70	1.70
Portugal	1.52	1.52	1.52	1.89	1.85	1.98	2.23	2.02
Finland	1.78	2.01	2.01	1.96	1.96	1.96	1.96	1.96
Sweden	1.65	1.88	1.76	1.77	1.77	1.63	1.58	1.58
United Kingdom	1.15	1.14	1.13	1.09	1.05	1.06	1.06	1.06
Mean	1.59	1.64	1.64	1.67	1.64	1.62	1.67	1.65
Std deviation	0.19	0.24	0.24	0.23	0.25	0.26	0.28	0.26

Source: Own elaboration using data from 'Agencia Estatal de Admnistración Tributaria: Impuestos especiales estudio relativo años 1995–2008'

Table A4. Indirect tax on unleaded gas over indirect tax on diesel in the EU-15

Countries	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Belgium	1.38	1.56	1.70	1.70	1.70	1.70	1.70	1.70	1.75	1.61	1.61	1.81	1.79	1.86
Denmark	1.27	1.33	1.38	1.47	1.48	1.34	1.30	1.33	1.33	1.33	1.26	1.26	1.48	1.50
Germany	1.58	1.58	1.58	1.58	1.53	1.49	1.45	1.42	1.39	1.39	1.39	1.39	1.39	1.39
Greece	1.58	1.44	1.44	1.44	1.18	1.22	1.22	1.21	1.21	1.21	1.21	1.20	1.13	1.19
Spain	1.38	1.38	1.38	1.38	1.38	1.38	1.38	1.35	1.35	1.35	1.35	1.35	1.31	1.31
France	1.67	1.67	1.62	1.60	1.60	1.51	1.53	1.51	1.51	1.41	1.41	1.41	1.42	1.42
Ireland	1.17	1.16	1.16	1.15	1.15	1.15	1.40	1.33	1.20	1.20	1.20	1.20	1.20	1.20
Italy	1.22	1.37	1.37	1.37	1.34	1.34	1.36	1.34	1.40	1.40	1.37	1.37	1.33	1.33
Luxembourg	1.33	1.37	1.37	1.37	1.37	1.47	1.47	1.47	1.47	1.75	1.75	1.75	1.52	1.46
Netherlands	1.66	1.70	1.70	1.74	1.74	1.74	1.74	1.79	1.87	1.83	1.83	1.83	1.83	1.70
Austria	1.37	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.38	1.38	1.28	1.19	1.18
Portugal	1.41	1.40	1.40	1.76	1.75	1.42	1.18	1.76	1.69	1.70	1.70	1.64	1.60	1.60
Finland	1.53	1.76	1.76	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.70	1.70	1.61
Sweden	1.65	1.64	1.53	1.54	1.54	1.42	1.38	1.38	1.31	1.34	1.28	1.28	1.27	1.20
United Kingdom	1.00	1.00	1.00	0.98	0.94	0.94	0.88	0.88	0.88	0.88	0.88	0.87	0.88	1.00
Mean	1.41	1.45	1.46	1.48	1.46	1.42	1.41	1.44	1.44	1.43	1.42	1.42	1.40	1.40
SD	0.20	0.21	0.20	0.22	0.24	0.21	0.22	0.24	0.24	0.24	0.25	0.26	0.25	0.22

Source: Own elaboration using data from 'Agencia Estatal de Admnistración Tributaria: Impuestos especiales estudio relativo años 1995–2008' http://www.aeat.es/AEAT/Contenidos_Comunes/Aduanas/Impuestos_especiales/Estudio_relativo_2003/hidrocar.pdft