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Gasoline and diesel demand elasticities: A consistent estimate across the EU-28

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Abstract

Several studies have examined gasoline and diesel demand elasticities. These studies usually cover a single country or a group of countries that belong to a specific economic alliance such as the OECD. Even though consistent elasticities are necessary to analyze and forecast the effects of EU-level fuel policy, there has not yet been a study that provides consistent gasoline and diesel demand elasticity across the EU-28. This study set out to address this literature gap by estimating price and income elasticities for gasoline and diesel. For this purpose, an ARDL Bounds testing approach is used to test the existence of a long-run relationship and estimate the elasticities. The estimation provides short and long-run price and income elasticities of gasoline and diesel demand for the EU-28 countries and shows the countries in which a long-run equilibrium relationship is confirmed. The results show that there is a high variation in elasticity estimates between the EU-28 countries. The estimated long-run elasticities are higher than their short-run counterparts, which is in line with expectations based on the existing literature. The short and long-run income elasticities of gasoline and diesel demand are found to be more elastic than their price equivalents. This implies that if a charge on fuel is designed to decrease emissions by increasing the price, the charge needs to rise at a higher rate than income. An analysis of the EU's long-term emission and fuel consumption reduction targets shows that, with the current tax scheme, it cannot be guaranteed that emission targets will be achieved and thus a more stringent fuel tax policy is essential.

Key words: gasoline demand, diesel demand, price elasticity, income elasticity, ARDL Bounds testing, EU 2030 emissions targets

1. Introduction

Gasoline and diesel demands have been closely examined by academics and politicians in the last few decades. In the past the main concern was economic security, because several countries depended on the import of fuel from a few countries. However, in the last decade the concern has mainly come from the environmental consequences of emissions from fuel consumption. The shift in the origin of concern came from an increasing awareness of the environmental consequences of emissions and several international dialogues and agreements, such as the Kyoto Protocol of 1997 (Sterner, 2007; Basso and Oum, 2007).

With the aim of controlling emissions, many countries have been implementing policies to reduce carbon emissions, such as energy and carbon taxation and subsidies for renewable energy. One of the most widely used policies is fuel tax (Kayser, 2000; Sterner, 2007; Brons *et al.*, 2008). The effectiveness and welfare impacts of a fuel tax depend on how the fuel-consuming sectors of an economy react and adjust to the measure. This responsiveness is measured by the elasticity of fuel demand. Elasticities can signal important information about the development of fuel consumption as income and prices change (Goodwin *et al.*, 2004).

There is a relatively large body of literature on gasoline and diesel demand elasticity estimates, and several reviews have been carried out (Espey, 1998; Graham and Glaister, 2002; Ajanovic *et al.*, 2012; Dahl, 2012). Most studies estimate gasoline or diesel demand elasticities for an individual country. Only a few studies, such as Baltagi & Griffin (1983) and Sterner *et al.* (1992), use the same methodology for a group of countries, and they cover at most 20 OECD countries. Other studies, such as Espey (1998) and Brons *et al.* (2008), estimate aggregate demand elasticities for regions covering several countries, and in some cases the world. The applicability of such an elasticity to a specific country is limited because it ignores differences between countries, such as habit formation, productivity, social structure and environmental awareness (Goodwin *et al.*, 2004; Basso and Oum, 2007; Hunt & Evans, 2011).

Dahl (2012) has reviewed the results of gasoline and diesel demand studies and developed elasticities for more than 124 countries, including the EU-28 countries. To the best of the author's knowledge, this has been the only study that provides gasoline and diesel demand elasticities covering the EU-28 countries. However, Dahl (2012) does not estimate these elasticities, but rather compiles them from several fuel demand studies. For countries not covered by gasoline and diesel demand studies, Dahl (2012) identifies systematic patterns between elasticities and other factors in the existing studies and then guesstimates. However, as Graham and Glaister (2002) and Ajanovic *et al.* (2012) show, elasticity estimates for individual countries from different studies are not comparable because the estimated elasticities vary depending on the estimation methods, underlying theoretical models and data. Thus, existing elasticity estimates do not allow for a consistent comparison of fuel policy effectiveness and welfare impact analysis across several countries such as the EU-28.

The aim of this study is to provide a consistent estimate of short-run and long-run price and income elasticities of gasoline and diesel demand across the EU-28. The estimate is consistent in that the same

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econometric approach, type of data, types of variables and units of measurement are used to estimate each country's elasticity. The elimination of methodological differences means that the estimated elasticities are comparable across these countries. The elasticities are estimated using the ARDL Bounds testing approach of Pesaran & Shin (1999), which enables the existence of a long-run cointegration relationship in gasoline and diesel demands to be tested while estimating short and long-run elasticities. In addition, the applicability of the estimated elasticities for EU-28 policy analysis is demonstrated by analyzing whether the current existing EU fuel tax policy is sufficient to achieve the 2030 transport emissions target.

The paper is organized as follows. Section 2 provides a literature review of gasoline and diesel demand studies. The dataset used for estimation is then discussed in Section 3. Section 4 presents the econometric approach used for estimation. Gasoline and diesel demand elasticities are estimated and the results are discussed in Section 5. In Section 6, the estimation results are applied to examine the fuel charges required to achieve the EU's 2030 transport emissions goal. The final section provides concluding remarks.

2. Literature review

Estimation of demand for gasoline and diesel has a long tradition in economics and there have been several studies on this. Surveys of the literature are found in Espey (1998), Graham & Glaister (2002, 2004), Goodwin *et al.* (2004), Basso & Oum (2007), Brons *et al.* (2008) and Dahl (2012). In total, these seven studies review and analyze more than 600 studies that include over 1000 estimated gasoline and diesel demand-related elasticities covering a wide geographical area for the years 1929 to 2010. Most of the reviews examine gasoline. For instance, among the studies reviewed by Dahl (2012), 240 are gasoline-demand studies for 70 countries, 60 are diesel-demand studies for 55 countries, and 23 consider other fuel types such as natural gas and biofuels. Goodwin *et al.* (2004) analyze and present the main findings of 69 studies conducted since 1990 in the UK and 26 other countries that are comparable to the UK. Among the 69 studies, 43 consider both gasoline and diesel demand. The remaining five literature review studies focus mainly on gasoline. A brief summary of the literature surveys is provided in Table 1 and discussed in this section.

Table 1: Brief summary of the main literature review studies

Study	Number of studies reviewed	Years covered	Method	Fuel type	Price elasticity		Income elasticity		Comment
					Short-run	Long-run	Short-run	Long-run	
Espey (1998)	101	1929 to 1993	Meta-analysis	Gasoline	0 to -1.36 (avg. -0.26)	0 to -2.72 (avg. -0.58)	0 to 2.92 (avg. 0.47)	0.05 to 2.73 (avg. 0.88)	Focuses on gasoline
Graham & Glaister (2002)	50	1950 to 2000	Review	Gasoline	-0.2 to -0.3	-0.6 to -0.8	0.35 to 0.55	1.1 to 1.3	Automobile fuel
Goodwin *et al.* (2004)	69	1929 to 1991	Review	Gasoline/ Diesel	-0.01 to -0.57 (avg. -	0 to -1.81 (avg. -	0 to 0.89 (avg. 0.39)	0.27 to 1.71 (avg.	Focuses on the UK and UK-comparable

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Study	N	Period	Method	Fuel	Short-run price	Long-run price	Short-run income	Long-run income	Notes
					0.25)	0.64)		1.08)	countries. Road fuel
Graham & Glaister (2004)	113	1966 to 2000	Review	Gasoline	-2.13 to 0.59 (avg. –0.25)	-22.00 to 0.85 (avg. –0.77)	0.0 to 1.71 (avg. 0.47)	0.0 to 2.68 (avg. 0.93)	Fuel demand
Basso & Oum (2007)	100s	1980s to 2000s	Critical assessment	Gasoline	-0.2 to -0.3	-0.6 to -0.8	0.3 to 0.5	0.9 to 1.3	Automobile gasoline. Companion to the above studies. Comparison of non-popular models (cointegration). Diesel estimate for Indonesia
				Diesel	-0.13	-0.67	0.57 to 2.14	2.16	
Brons et al. (2008)	43	1970s to 2000	Meta-analysis	Gasoline	−1.36 to 0.37 (avg. −0.34)	−2.04 to −0.12 (avg. −0.84)	-	-	Meta-analysis. Gasoline demand. A SUR approach
Dahl (2012)	300	1929 to 2006	Review and systematic deduction	Gasoline	-1.65 to 0.63 (avg. -0.18)	-61.11 to 5.89 (avg. -1.61)	-2.63 to 3.00 (avg. 0.28)	-40.00 to 38.89 (avg. 1.57)	Gasoline and diesel price elasticities are developed for 124 countries
	60			Diesel	Average -0.16		Average 1.23		
Ajanovic et al. (2012)			Survey	Gasoline	-0.20 to -0.30	-0.60 to -0.85	0.30 to 0.50	0.90 to 1.40	
				Diesel	-0.10	-0.31	0.39	1.36	

Graham & Glaister (2004), which constitutes an update of Graham & Glaister (2002), covers a wide range of road traffic-related elasticity estimates, such as car travel, car ownership, freight traffic and fuel demand. Their analysis of car trips and kilometers travelled by car (car-km) shows that in the short run households respond to price change by adjusting car trips, but in the long run they respond by considerably adjusting kilometers travelled. This is explained by adaptations in terms of mode choice, destination choice, relocation of population, and retail and service activities. Graham & Glaister (2002) find that, in absolute values, income elasticity is greater than price elasticity. This implies that price needs to rise more quickly than income for fuel consumption to remain the same. This is supported by the findings of Basso and Oum (2007) and Brons et al. (2008) who show that gasoline demand responds more to an income change than to a price change.

Goodwin et al. (2004) adopt the same methodology as Espey (1998) and run a meta-analysis to investigate sources of variation in elasticities. The results do not indicate any systematic pattern that explains the variations. Total fuel consumption and total vehicle fleet are more responsive to a price change of gasoline than diesel, and private cars are more sensitive than freight vehicles. However, for an income change the responsiveness of private cars and freight vehicles are not found to be significantly

different from one other. Goodwin *et al.* (2004) show that in the UK and countries that are comparable to the UK, a fuel demand adjustment to a 10 % increase in price is divided between a decrease of about 2.5 % in the first year and a gradual long-run adjustment, which sums up to 6 % in the long run. The fleet of vehicles also gradually adjusts to the change in price. A 10 % price increase leads to an approximate 1 % fall in traffic volume within a year, and a total 3 % reduction in the long run. A price fall also has implications for fuel efficiency and the total number of vehicles owned. A price decrease of 10 % leads to a 1.5 % increase in fuel efficiency and a 1 % decrease in the total number of vehicles owned in the short run, and a 4 % increase in fuel efficiency and 2.5 % decrease in the total number of vehicles owned in the long run. Likewise, a 10 % increase in real income leads to a 4 % increase in the short run and a 10 % increase in the long run of both total fuel consumption and number of vehicles owned. However traffic volume shows a lower increase: 2 % within a year and about 5 % in the longer run. The reason why fuel consumption responds more than traffic volume to a given price change might be that it is easier to adjust driving habits than change vehicles. Moreover, a price increase leads to higher utilization of relatively fuel-efficient vehicles and a technical improvement to existing vehicles.

Brons *et al.* (2008) review 158 price elasticities of total gasoline demand from 43 primary studies using a SUR model with cross-equation restrictions, which enables them to combine and perform a meta-analysis of different estimations. The results show that price elasticity is lower when consumers rely on automobiles for transport services. In the short and long run, gasoline demand responds to a price change mainly by adjusting fuel efficiency and mileage per car and with a relatively small adjustment in car ownership. Gasoline demand is more price elastic in the long run than in the short run. Their result suggests that gasoline demand is not very responsive to a price change.

A comparison of gasoline and diesel demand studies by Dahl (2012) shows that countries with lower gasoline and diesel prices and lower income have less elastic demand. Price elasticities tend to increase as both price and income increase. Dahl's study does not find a significant change in price elasticity of diesel demand for countries that have introduced diesel-favoring policies. However, the higher income elasticity of diesel demand for OECD-member European countries might indicate the impact of favorable policies for diesel. The study finds that after the introduction of turbo engines in the 1990s, diesel demand became 50 % more elastic in comparison to studies conducted based on prior data. Models that do not include the stock of vehicles report higher income elasticity than models that include the stock of vehicles, and 10 % of the income elasticities reviewed are negative. In addition, Dahl (2012) analyzes the effect of diesel price on gasoline consumption using a simple static demand model and finds no viable link between diesel price and gasoline consumption or price elasticity of gasoline demand.

Dahl (2012) uses these findings to provide elasticities for 124 countries, including the EU-28. These elasticities are developed based on gasoline demand studies of 70 countries and diesel demand studies of 60 countries. For the remaining countries for which a fuel demand study is missing, elasticities are developed based on the author's intuition and using the identified patterns between the existing estimates. The identified patterns are also used to correct some of the reviewed estimates. The intuitively developed elasticities do not capture a specific country's gasoline and diesel consumption behavior, which would have been revealed from an estimation based on actual data. In addition, as Graham & Glaister (2002) show, elasticity estimates for individual countries by different studies are not

comparable because the elasticities vary based on the estimation methods, theoretical models, assumptions, exogenous variables, data types and measurements used in the studies.

Dahl (2012) argues that the developed elasticities do not clearly consider the impacts of policies that encourage a shift from gasoline to diesel or generally from fossil fuels to alternative fuels. If these policies are aimed at raising the individual fuel price or if the substitution of other fuels has been relatively small, then the bias in the constructed elasticities will be smaller and they can still be considered useful. However if the policies are aimed at raising substitute fuel prices, then the estimated elasticities might suffer from omitted variable bias of cross-price elasticities. In such cases the developed elasticities are biased and do not properly capture the correct responsiveness, and therefore need to be adjusted.

The survey of the studies summarized in Table 1 shows that there is a high variation between estimated elasticities. The highest variation is reported in Dahl (2012) for the long-run price elasticity of gasoline ranging from -61.11 to 5.89 and long-run income elasticity of gasoline from -40.00 to 38.89. One of the main determinants of this variation is the models employed by the studies (Basso and Oum, 2007). The models can be classified into two broad categories: static and dynamic models. Espey (1998) and Brons *et al.* (2008) show that the choice of a static or dynamic model is a significant determinant of variations in elasticity estimates.

A large number of studies base their analysis on static models, and assume that the observed demand is in a long-run equilibrium. These static models overlook the fact that impacts of price and income shocks linger for more than one period and there are adjustment lags in demands. Basso and Oum (2007) and Dahl (2012) show that static models capture the price elasticity of an intermediate run, which falls somewhere between short run and long run unless a long-run cointegration relationship exists. When there is a long-run equilibrium relationship, the estimates from static models are close to the long-run estimates from dynamic models. Static models have been shown to deliver the same income elasticity as long-run income elasticity from more sophisticated models.

Studies that use dynamic models report separate results of short-run and long-run elasticities accounting for adjustment lags. A common approach of accounting for adjustment lags in dynamic models is to include a lagged dependent variable in the estimated model, and the first lag is most common. Espey (1998) and Basso and Oum (2007) suggest that this is too restrictive because it assumes a constant geometric adjustment process over time. Distributed lag and inverted-v lag models can be more flexible approaches of capturing adjustment lags. However, Basso and Oum (2007) show that these models do not perform any better, they require many parameters to be estimated and lead to a multicollinearity problem. Thus, using the first lag of a dependent variable to capture the dynamic property of demand has remained a dominant practice.

Basso and Oum (2007) show that dynamic models of cointegration and error correction models, which take into consideration the possible non-stationarity of time series data used in fuel demand studies, provide robust estimates of short-run and long-run elasticities. Studies that use these models report relatively inelastic long-run gasoline and diesel demand elasticities compared to studies that use other

dynamic models (Espey, 1998; Goodwin *et al.*, 2004; Basso and Oum, 2007). Studies that use cointegration techniques argue that this is because of a correct handling of time series data. Goodwin *et al.* (2004) compare error correction models, partial adjustment models and inverted-v lag models and show that model choice has a significant effect on the difference in estimated elasticities. In addition, the choice of estimation methods, such as ordinary least squares and instrumental variables, is found to be a significant determinant of elasticity variations between studies by Goodwin *et al.* (2004).

Results of gasoline and diesel demand estimates also vary because of different functional forms used for the estimation (Graham & Glaister (2002, 2004)). The log-linear functional form has been popular in the literature. Basso and Oum (2007) suggest that more flexible functional forms, such as trans-log and non-parametric approaches, could provide a better estimation when household data are used. Goodwin *et al.* (2004) compare different functional forms (linear, log-linear, semilog, Box-Cox, and other non-linear) and show that the functional form has no significant effect on the elasticity estimate. In contrast, Espey (1998) finds that functional forms are important and that the log-linear form is the most appropriate for gasoline demand estimation.

Studies also differ with respect to the data types used for the estimation. Goodwin *et al.* (2004) show that the data type (time series, cross-sectional or panel data) and the interval of data (monthly, quarterly or annual) introduces a significant variation between estimated elasticities. A comparison of elasticities estimated from time series data and cross-sectional data by Basso and Oum (2007) and Brons *et al.* (2008) highlights mixed findings regarding the magnitude of the differences. However, cross-sectional data usually result in higher short-run and long-run price elasticities in absolute values and lower short-run income elasticity than estimates from time series data, while no significant difference is found for long-run income elasticity. Dahl (2012) also finds higher price elasticities in absolute values from cross-sectional data than from time series and panel data. Espey (1998) finds a higher short-run price elasticity from cross-sectional data and a lower short-run price elasticity from panel data compared to time series data. Long-run estimates from cross-sectional, panel and time series data are not found to be significantly different from one other by Espey (1998). Furthermore, it is not clear whether to classify the elasticities estimated from cross-sectional data as short run, long run or intermediate run. As cross-sectional data are a one-time observation across several entities, they do not have the time components of dynamic models. In addition, cross-sectional data do not take into account the time lag in consumer response to a change in price and income, and can therefore lead to specification bias. It is shown that unbiased estimation of elasticities requires dynamic models that include the time component of consumer behavior (Basso and Oum, 2007).

Another common practice in the literature is to use panel data for pooled estimation that assumes common elasticities across countries (Basso and Oum, 2007). Goodwin *et al.* (2004) show that pooled estimation tends to result in a lower elasticity estimate in absolute values. However, Espey (1998) shows that panel data estimation results in more elastic short-run price elasticity and less elastic long-run price elasticity, while no significant difference is observed between panel data and time series for income elasticity. Pooled panel data estimation, just like cross-sectional data, does not enable a country or region-specific estimation of elasticities. It has been shown by Basso and Oum (2007) that the assumption of common elasticities of fuel demand across countries is implausible. The problems with

pooled panel estimation can be mitigated using dummy variables and allowing the intercept in the estimation to vary across countries or regions (fixed effect estimation). However, the reviewed studies have shown that this does not lead to fully capturing regional or country-specific characteristics. The review by Basso and Oum (2007) of findings of dynamic and cointegration estimation results shows that individual time series estimation is preferred and more likely to capture country-specific characteristics.

Another source of variation in diesel and gasoline demand elasticity estimates is the periodicity of the data. There are mixed results on how the frequency of data affects estimated elasticities. Dahl (2012) shows that elasticities estimates on monthly and quarterly data are significantly different from estimates on annual data, but their mean values are not significantly different from one other. The comparison of elasticities by Basso and Oum (2007) estimated on yearly and seasonal data shows that there is no clear pattern in the reviewed studies. However Goodwin *et al.* (2004) show that lower price elasticity and higher income elasticity are reported from annual data. Espey (1998) argues that data periodicity does not have an impact on long-run elasticity, but short-run elasticities from monthly data are higher because fuel demand responses occur within a month. This is better captured by seasonal data, leading to higher estimates in absolute values. Espey (1998) argues that as long as due caution is exercised, seasonal data are just as appropriate for estimating long-run adjustments as annual data.

Data aggregation is an additional source of variation in gasoline and diesel demand elasticity estimates. The data can be household data, aggregated at a regional or country level, which can have significant effects on the estimated elasticities of fuel demand (Graham & Glaister, 2004). Basso and Oum (2007) show that elasticities are usually estimated from aggregate country-level data, mainly because of the relative availability of data and ease in interpreting results. However, it is argued that gasoline demand should be analyzed using disaggregated household data because gasoline consumption decisions are made at household level (Basso and Oum, 2007). Studies that use household data report the same price elasticities, but lower income elasticities as studies that use aggregate data. Goodwin *et al. (*2004) compare results from aggregate, per capita and per household data and show that per capita data gives lower price elasticities and higher income elasticities than the others. In contrast, Espey (1998) shows that the estimation of elasticities based on aggregate, per household, per capita or per vehicle bases does not produce a significant difference.

Basso and Oum (2007) show that the use of disaggregated household data highlights important determinants that would otherwise not be detected, such as household income level, location, demographic characteristics such as the age of the household head, gender, race, education and the number of licensed drivers in the household. Graham & Glaister (2002) report that the use of disaggregated household data can provide insights into the time dependency of consumers' fuel-demand response. In addition disaggregated data allow for more flexibility of exogenous variables included in the estimated models than aggregate data. However it has been shown that it is difficult to determine income effects from disaggregated data as income effect is found to be insignificant in the studies reviewed by Graham & Glaister (2002). Basso and Oum (2007) point out that among the studies surveyed by Espey (1998), only 5 % use disaggregated household data. Aggregated data have remained the main input to elasticity estimation.

In conclusion, despite data time length and cross-sectional width and methodological differences, there is a consensus among the studies that long-run elasticities are higher than short-run elasticities for both price and income by a factor of 2 to 3 on average. The income elasticity of gasoline demand is slightly higher than price elasticity by a factor of 1.5 to 3 (Goodwin, 2004). In the short run, households react to price change by adjusting vehicle utilization and in the long run by adjusting vehicle stock. The main determinants of gasoline and diesel demand are the respective prices, income, number of vehicles and population. However, several other factors are shown to affect gasoline and diesel demand, such as vehicle efficiency, urbanization, female labor force participation, industrial production, seasons, weather, family demographics, price of transit, price volatility, price or availability of public transit, and speed limits. It is also shown that, generally, elasticities vary considerably depending on the underlying model, estimation technique, data type, study area and the number of exogenous factors considered in the study.

3. Data

The literature review in the previous section shows that even though gasoline and diesel demand studies cover a wide variety of factors, the main determinants of gasoline and diesel demand are price, income, number of vehicles and demographic pressure. Therefore the data for the elasticity estimation in this study includes the prices of gasoline and diesel, the quantity of gasoline and diesel consumed, the total number of vehicles and population.

Gasoline and diesel consumption data cover the transport sector of the EU-28 countries. The transport sector consumes the largest percentage of the two fuels in each of the 28 EU countries. From 1960 to 2013, the average annual consumption by the transport sector in the EU was 98.86 % of gasoline and 51 % of diesel (IEA, 2014). Gasoline is mainly consumed by passenger vehicles and diesel is consumed by passenger vehicles and heavy vehicles such as buses, lorries and tractors. Based on the behavioral differences of consumers of the two fuels, the regression results of gasoline and diesel demand may behave differently.

The quantity of gasoline and diesel consumed is measured by total final consumption in the transport sector from the IEA (2016c) for OECD countries and from the IEA (2016d) for non-OECD countries. The quantity consumed per driver in kiloliters is calculated using data on population between the ages of 15 and 69 from the United Nations (2015) as an approximation for the number of drivers. Gasoline and diesel consumption is divided by the number of drivers instead of total population, following Pock (2010), because, as Schmalensee & Stoker (1999) show, using total population instead of the number of drivers leads to an overestimation of elasticities as it does not properly take demographic effects into account (Basso and Oum, 2007; Pock, 2010). Pock (2010) argues that a household owning a second vehicle does not necessarily double fuel consumption or kilometers driven. It also holds true that doubling the members of a household does not necessarily double vehicle utilization or fuel consumption because the number of drivers in the household is not likely to double. This effect is better captured by estimating fuel demand on a per driver basis instead of on a per capita basis.

Data on the prices of gasoline and diesel are obtained from the IEA (2016a) for OECD countries and the IEA (2016b) for non-OECD countries. For Bulgaria, Estonia, Croatia, Latvia, Lithuania, Malta, Romania and Slovenia, additional data from the World Bank world development indicators are used. The prices are tax-inclusive end-user prices in US dollars per liter. Real prices are calculated using CPI from the World Bank world development indicators, except for the United Kingdom for which the data are from its national statistics website listed on the "United Nations Information on National Statistical Systems" (2016).

Illustrations of the data in Figure 1 and Figure 2 show that the prices of gasoline and diesel have been steadily increasing, with a sharp decline after 2008 and 2013, which coincides with the 2008 economic crisis and the 2013 global oil price fall. This suggests that there can be a structural break in the dataset that affects estimation results if not properly taken into account. Gasoline consumption per driver has been more or less constant from 1978 to 2003 and then fallen slightly. There could be multiple reasons for this, such as the rise in prices, emission control policies and an increase in vehicle efficiency. In contrast, diesel consumption per driver fell until 1984 and then remained constant until 1995. It increased from 1995 to 2005 and has then been falling again. The average increase in diesel consumption per driver from the 1990s to the 2000s could be explained by diesel-favoring policies and an efficiency gain by diesel vehicles for long-distance drivers (Dahl, 2012). The fall starting from the mid-2000s could be explained by the combination of several factors such as more stringent fuel consumption policies, environmental awareness and increasing prices. On the other hand, average per capita income across the EU-28 has been steadily rising, except for the fall between 1988 and 1993 and after 2008.
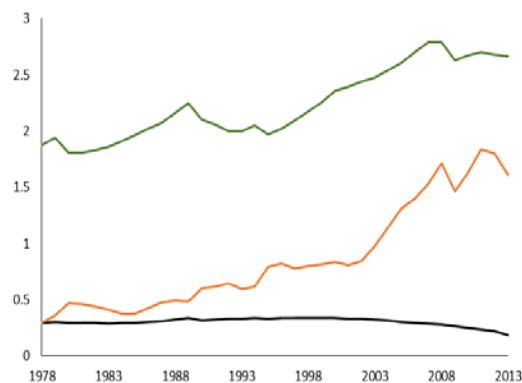

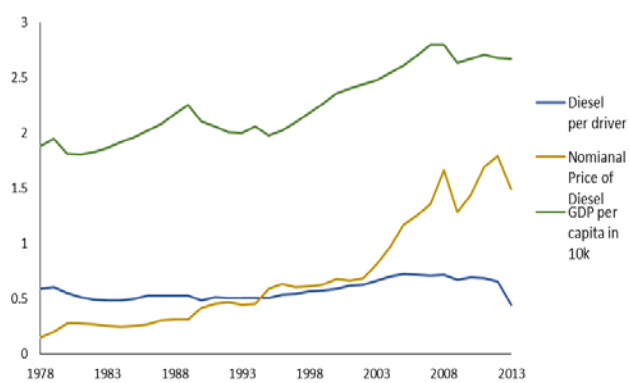**Figure 1:** EU average annual gasoline price and consumption per driver

Figure 2: EU average annual diesel price and consumption per driver

Per capita income used in the estimation is real GDP per capita in US dollars obtained from the World Bank world development indicators. Data on the number of vehicles are collected from EUROSTAT and the individual countries' national statistics websites listed on the "United Nations Information on National Statistical Systems" (2016). It was impossible to obtain sufficient data on the number of vehicles disaggregated into diesel and gasoline-powered vehicles across the 28 EU countries. Therefore only the total number of vehicles is used in the estimation. The total number of vehicles is sufficient for a consistent estimation, but it is not possible to infer substitution between gasoline and diesel engine-powered vehicles and utilization behaviors from the estimated coefficients (Pock, 2010).

Data are collected for each country from 1978 to 2013, but data availability varies between countries. As shown in the summary statistics in Table 2, complete data of the quantity of gasoline and diesel consumed are available for 23 countries, and for Estonia, Latvia, Lithuania, and Slovenia it is available from 1990 to 2013. Long-term data series of prices of gasoline and diesel are available for all countries except Estonia, Latvia, Lithuania, Malta and Slovenia, where price data is available from 1995 to 2013. GDP data from 1978 to 2013 is available for most countries except Estonia and Slovenia, where GDP data were available from 1995 to 2013. The number of vehicles for nine countries is available from 1990 to 2013. Number of vehicles is not included in the gasoline demand estimation for Bulgaria, the Czech Republic and Latvia or the diesel demand estimation for Slovenia because the available data are not sufficient for optimal choice of lag length in the estimated models. For the remaining countries, a higher number of observations is available, as shown in the summary statistics in Table 2.

The summary statistics on Table 2 shows that average gasoline and diesel consumption per driver varied slightly between countries, with an exceptionally high level in Luxembourg. Gasoline consumption per driver varied from 0.0023 kiloliters in Romania to 1.38 kiloliters in Luxembourg. Furthermore, Romania had the lowest and Luxembourg the highest variation in gasoline consumption per driver during the sample period. Diesel consumption per driver varied from 0.0041 kiloliters in Romania to 3.13 kiloliters in Luxembourg. Luxembourg also had the highest mean GDP per capita and number of vehicles per driver, as well has the highest variation in GDP per capita. The highest variation in the number of vehicles per driver for the sample years was in Cyprus. The lowest mean GDP per capita was in Bulgaria, and Romania had the lowest variation in GDP per capita during the sample period. The lowest mean number of vehicles per driver was also in Romania, and the lowest variation was in Denmark. Low mean consumption of gasoline and diesel in Romania coincided with a high level in the mean real price of gasoline and diesel, at 543.1 USD/liter and 659.5 USD/liter respectively, and with high variation during the sample period. The high real prices are a result of the high inflation rise from 1990 to 2013 measured by the CPI. Even though the highest mean consumption of gasoline and diesel per driver was in Luxembourg, the lowest mean real price of gasoline was in Lithuania and the lowest mean real price of diesel was in Cyprus. Malta and Slovenia had the lowest variation in real prices of gasoline and diesel respectively.

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Table 2: Data summary statistics.

Country	Gasoline consumption per driver in kiloliters					Diesel consumption per driver in kiloliters					Real price of diesel in USD per liter					Real price of gasoline in USD per liter					Real GDP per capita in USD					Number of vehicles per driver				
	max	min	mean	sd	N	max	min	mean	sd	N	max	min	mean	sd	N	max	min	mean	sd	N	max	min	mean	sd	N	max	min	mean	sd	N
Austria	0.49	0.28	0.39	0.06	35	1.18	0.37	0.74	0.29	35	1.85	0.79	1.15	0.29	36	1.90	0.98	1.31	0.26	36	41366.5	22034.2	32203.6	6347.7	36	0.75	0.52	0.66	0.07	24
Belgium	0.43	0.15	0.32	0.09	35	1.35	0.82	1.14	0.15	35	1.93	0.53	1.06	0.41	36	2.19	0.94	1.47	0.37	36	38556.3	22148.7	30962.3	5530.8	36	0.70	0.45	0.59	0.09	36
Bulgaria	0.01	0.002	0.003	0.001	35	0.01	0.003	0.01	0.002	35	15.98	0.85	2.47	4.07	18	28.26	0.90	3.50	7.04	18	4807.7	2214.1	3187.5	846.7	34	0.52	0.13	0.33	0.11	25
Croatia	0.24	0.15	0.20	0.03	24	0.50	0.23	0.38	0.10	24	1.61	0.79	1.23	0.28	20	1.67	0.96	1.33	0.24	20	11516	6604	9475.7	1499.8	20	0.50	0.19	0.35	0.11	23
Cyprus	0.01	0.01	0.01	0.00	35	0.01	0.01	0.01	0.003	35	1.28	0.23	0.78	0.35	15	2.21	0.78	1.22	0.34	34	24312.9	9068	17724.4	4674.5	36	0.85	0.30	0.64	0.14	25
Czech Republic	0.28	0.13	0.20	0.05	35	0.49	0.29	0.40	0.06	35	1.91	0.73	1.23	0.40	21	1.94	0.90	1.35	0.34	21	15170.1	9094.6	11981.3	2208.5	24	0.60	0.25	0.46	0.09	23
Denmark	0.51	0.33	0.44	0.05	35	1.54	0.75	0.96	0.20	35	1.93	0.40	0.99	0.48	36	2.18	1.06	1.57	0.33	36	50695	29306.9	40882.4	6863.2	36	0.56	0.38	0.46	0.05	33
Estonia	0.45	0.20	0.29	0.05	23	0.59	0.27	0.42	0.11	23	1.57	0.58	1.01	0.31	19	1.56	0.68	1.13	0.36	19	12443.5	4995.3	9055.3	2461.8	19	0.64	0.12	0.43	0.13	24
Finland	0.54	0.38	0.46	0.05	35	1.20	0.88	0.95	0.08	35	1.87	0.80	1.16	0.33	36	2.14	1.07	1.51	0.34	36	42414	19640.6	30966.9	7001.2	36	0.79	0.52	0.61	0.09	24
France	0.44	0.16	0.33	0.11	36	0.92	0.69	0.80	0.16	36	1.89	0.77	1.13	0.36	36	2.07	1.02	1.47	0.33	36	36074.7	22402	29985.1	4637.3	36	0.75	0.50	0.63	0.08	34
Germany	0.53	0.31	0.45	0.07	35	1.04	0.66	0.83	0.08	35	1.98	0.77	1.23	0.42	23	2.16	1.06	1.50	0.39	23	39273.4	22015.6	30768.5	5288.6	36	0.79	0.41	0.62	0.13	34
Greece	0.50	0.19	0.35	0.10	35	0.79	0.35	0.56	0.13	35	6.57	0.75	1.93	1.44	36	17.29	0.93	3.64	4.43	36	24307	14668	17930.4	3070.5	36	0.68	0.13	0.33	0.17	33
Hungary	0.23	0.16	0.19	0.02	35	0.46	0.19	0.33	0.08	35	6.78	1.15	2.85	1.65	34	12.24	1.26	4.54	3.69	34	11749.8	7254.8	9572.8	1698.1	23	0.43	0.11	0.29	0.10	37
Ireland	0.59	0.32	0.43	0.09	35	1.06	0.40	0.70	0.22	35	1.92	0.85	1.35	0.27	36	2.26	0.94	1.52	0.30	36	52923.5	16552.9	33101.6	13396	36	0.59	0.34	0.49	0.09	23
Italy	0.45	0.21	0.33	0.07	35	0.65	0.49	0.56	0.05	35	2.07	0.89	1.32	0.33	36	3.66	1.16	1.95	0.64	36	32829.9	19248.5	27408.2	4141.4	36	0.88	0.44	0.70	0.14	34
Latvia	0.01	0.004	0.01	0.001	23	0.01	0.004	0.01	0.003	23	1.60	0.62	1.08	0.32	18	1.69	0.89	1.24	0.28	18	8999	3166.1	5502.7	1732.6	36	0.59	0.14	0.34	0.14	23
Lithuania	0.01	0.002	0.004	0.002	23	0.01	0.004	0.01	0.002	23	1.24	0.46	0.86	0.26	18	1.32	0.62	0.96	0.21	18	10549.2	3818.5	6779.7	2220.5	24	0.77	0.09	0.44	0.21	24
Luxembourg	1.83	0.89	1.38	0.33	35	5.41	1.58	3.14	1.29	35	1.66	0.54	0.91	0.32	35	1.78	0.78	1.17	0.30	35	86127.2	32111.2	59390.7	18640.5	36	1.03	0.47	0.80	0.19	36
Malta	0.01	0.002	0.01	0.001	35	0.01	0.002	0.01	0.003	35	1.30	0.40	0.85	0.27	15	1.34	0.48	1.02	0.18	15	16735.9	6343.2	11805.7	3501	36	0.82	0.44	0.68	0.10	23
Netherlands	0.38	0.31	0.34	0.02	35	0.60	0.37	0.49	0.06	35	1.93	0.57	1.08	0.38	36	2.37	0.92	1.52	0.39	36	45147.8	25450.1	34798.1	6846.5	36	0.68	0.45	0.54	0.07	33
Poland	0.19	0.11	0.14	0.02	35	0.41	0.14	0.22	0.08	35	148.8	0.65	13.09	34.38	28	223.3	0.85	18.52	50.18	28	10781.7	4411.4	7299.5	2108.6	24	0.65	0.20	0.40	0.13	23
Portugal	0.28	0.10	0.19	0.06	35	0.63	0.17	0.40	0.17	35	3.27	0.72	1.48	0.64	36	8.66	1.00	2.58	2.10	36	19488.8	9778.8	15375.9	3414.5	36	0.77	0.19	0.50	0.21	34
Romania	0.004	0.001	0.002	0.0004	35	0.01	0.003	0.004	0.001	35	543.1	0.91	37.10	122.5	20	659.5	1.18	45.70	149.2	20	6072.8	3087.5	4241.2	922.1	34	0.31	0.04	0.15	0.09	33
Slovak Republic	0.19	0.10	0.14	0.03	35	0.35	0.18	0.26	0.05	35	2	0.86	1.41	0.30	21	1.94	0.94	1.47	0.31	21	15369.3	6781.5	10917.6	2991.7	22	0.64	0.39	0.47	0.07	22
Slovenia	0.63	0.34	0.47	0.08	23	1.14	0.40	0.77	0.20	23	1.72	0.87	1.18	0.24	19	1.87	0.95	1.25	0.25	19	20987	12422.6	17015.7	2626.4		0.70	0.33	0.50	0.14	33
Spain	0.32	0.14	0.24	0.05	35	0.92	0.31	0.57	0.21	35	1.75	0.79	1.20	0.30	36	3.54	0.95	1.63	0.63	36	27660.4	14654	21084.4	4576.4	36	0.66	0.28	0.50	0.13	34
Sweden	0.70	0.41	0.60	0.06	35	1.33	0.57	0.76	0.19	35	2.15	0.60	1.15	0.44	36	2.17	1.05	1.49	0.34	36	46036.9	25481	35436.8	6815.1	36	0.66	0.50	0.60	0.06	34
United Kingdom	0.57	0.29	0.47	0.08	35	0.53	0.34	0.43	0.06	35	2.27	1.02	1.48	0.38	36	2.13	1.07	1.51	0.34	36	41567.4	21774.1	31823.3	6774.5	36	0.67	0.39	0.55	0.09	33

4. Econometric approach

Following the literature, gasoline demand is defined as a function of gasoline price, GDP per capita and number of vehicles per driver for each member country of the EU-28. Likewise, diesel demand is defined as a function of diesel price, GDP per capita and number of vehicles for each member country of the EU-28.

Gasoline and diesel demands are estimated using the ARDL Bounds testing approach, which was first proposed by Pesaran & Shin (1999) and later extended by Pesaran *et al.* (2001). The ARDL Bounds testing approach fit the purposes of this study well because it enables the existence of a long-run relationship to be tested while estimating long-run and short-run elasticities. The method has several advantages. It is unbiased in the presence of endogenous regressors and it performs well in small samples (Haug, 2002). It enables the existence of a long run-relationship among the dependent and independent variables to be tested, even if they are not integrated of the same order. Other cointegration tests, such as the Engle-Granger and Johansen tests, require regressors to be integrated of the same order, specifically order one, and do not perform well when the variables are not integrated of the same order. In the ARDL Bounds setup, the variables can be I(0) and/or I(1), however the method is not applicable if any of the variables are I(2).

The ARDL Bounds test of long-run cointegration based on the estimation of the unrestricted error correction model (ECM) is given as (see Pesaran *et al.*, 2001):

$$\Delta D_{e,j,t} = c_{0,e,j} + c_{1,e,j}d_{e,j} + c_{2,e,j}t_e + \gamma_{e,j,0}D_{e,j,t-1} + \alpha_{1,e,j}P_{e,j,t-1} + \alpha_{2,e,j}GDP_{e,t-1} + \alpha_{3,e,j}V_{e,t-1}$$

$$+ \sum_{i=0}^{n_{e,j}^*} \beta_{1,e,j,i}\Delta P_{e,j,t-i} + \sum_{i=0}^{n_{e,j}^*} \beta_{2,e,j,i}\Delta GDP_{e,t-i} + \sum_{i=0}^{n_{e,j}^*} \beta_{3,e,j,i}\Delta V_{e,t-i} + \sum_{i=1}^{n_{e,j}^*} \gamma_{e,j,i}\Delta D_{e,t-i}$$

$$+ \varepsilon_{e,j,t} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (1)$$

where $D_{e,j,t}$ is fuel demand at time t with j=1,2 (1 for gasoline and 2 for diesel) and $e = 1,2,\dots,28$ represents the 28 EU countries. d represents impulse dummies of structural breaks, t is trend variable, $P_{e,j}$, j=1, 2, P_1 is the price of gasoline and P_2 is the price of diesel for the 28 EU countries, GDP_e is GDP per capita, V_e is the total number of vehicles per driver and ε is the error term. Δ denotes difference.

The upper bounds of the summations of the differenced explanatory variables and dependent variable ($n_{e,j}^*$), which are the optimal lag lengths, are determined using Akaike information criterion (AIC) and Schwarz criterion (SC). The Bounds test tests $H_0: \gamma_{e,j,0} = 0, \alpha_{1,e,j} = \alpha_{2,e,j} = \alpha_{3,e,j} = 0, \forall e, j$, no long-run relationship against $H_1: \gamma_{e,j,0} \neq 0, \alpha_{1,e,j} \neq 0, \alpha_{2,e,j} \neq 0, \alpha_{3,e,j} \neq 0$. The computed F-statistic has a non-standard distribution for which Pesaran *et al.* (2001) provide lower and higher bound critical values for the case when all regressors are I(0) and I(1), respectively, and Narayan (2005) provides the small sample equivalent of the critical values. Equation (1) is estimated with or without constant, trend and

dummies, and then the F-statistic is compared to the critical values. If the test statistic is above the critical value then it shows the existence of cointegration and a long-run equilibrium relationship. If the test statistic falls within the bounds of the critical values, the test is inconclusive. If the test statistic falls below the critical values, then the test shows that there is no long-run relationship.

The variables are estimated in log form and the estimated $\beta_{1,e,j,0}$ gives the short-run price elasticity and $\beta_{2,e,j,0}$ gives the short-run income elasticities (see Pesaran & Shin, 1999). The long-run price and income elasticities, respectively, are

$$\beta_{1,e,j,i}{}^{*} = \frac{\sum_{i=0}^{n_{e,j}^{*}} \beta_{1,e,j,i}}{1 - \sum_{i=0}^{n_{e,j}^{*}} \gamma_{e,j,i}}, \qquad \beta_{2,e,j,i}{}^{*} = \frac{\sum_{i=0}^{n_{e,j}^{*}} \beta_{2,e,j,i}}{1 - \sum_{i=0}^{n_{e,j}^{*}} \gamma_{e,j,i}}$$

The standard errors for the long-run elasticities can be calculated from the standard errors of the original regression using the delta method.

Before proceeding to the estimation of an ARDL model and Bounds testing, the variables are tested for unit root in order to ensure that none of the variables are I(2). Usually economic variables are susceptible to external shocks that occur outside the economic framework, such as natural disasters and unforeseen political measures. These kinds of exogenous shocks induce structural breaks in the flow of the observed data of variables. Thus the unit root tests are conducted using Augmented Dickey-Fuller and Phillips-Perron unit root tests that do not consider structural breaks and the Zivot-Andrews unit root test, which allows for an endogenous structural break in the test. The test results are shown in Tables 3, 4 and 5. The test results of the variables considered in the estimation of individual countries show that they are a mixture of I(0) and I(1), but none of them are I(2).

Table 3: Results of Augmented Dickey-Fuller unit root test

	lg			ld			lpg			lpd			lgdp			lvt		
Country	Level	1st D.	Dec.	Level	1st D.	Dec.	Level	1st D.	Dec.	Level	1st D.	Dec.	Level	1st D.	Dec.	Level	1st D.	Dec.
Austria	0.693	-5.089*	I(1)	-0.531	-5.363*	I(1)	-1.209	-5.312*	I(1)	-1.182	-5.288*	I(1)	-1.865	-5.059*	I(1)	-3.344**	-3.003**	I(0)
Belgium	1.663	-4.135*	I(1)	-1.294	-5.079*	I(1)	-0.830	-4.197*	I(1)	-0.844	-4.840*	I(1)	-2.093	-4.382*	I(1)	-2.778*	-2.255**	I(0)
Bulgaria	-1.618	-6.349*	I(1)	-1.961	-6.533*	I(1)	-4.626*	-3.173**	I(0)	-4.169*	-3.526*	I(0)	0.148	-3.183*	I(1)	-0.987	-5.320*	I(1)
Croatia	-1.180	-3.319**	I(1)	-0.538	-4.891*	I(1)	-0.655	-2.398**	I(1)	-0.458	-1.942**	I(1)	-2.994**	-3.220**	I(0)	-0.544	-2.366**	I(1)
Cyprus	-0.377	-2.208**	I(1)	-2.649*	-5.472*	I(1)	-1.057	-3.883*	I(1)	-0.866	-3.203**	I(1)	-4.397*	-3.077**	I(0)	-0.846	-2.637*	I(1)
Czech Republic	-1.138	-8.365*	I(1)	-0.802	-4.271*	I(1)	-0.598	-3.536*	I(1)	-0.496	-4.042*	I(1)	-0.092	-4.930*	I(1)	-1.220	-2.436**	I(1)
Denmark	0.711	-1.984**	I(1)	-2.393	-5.038*	I(1)	-1.241	-4.175*	I(1)	-0.370	-4.939*	I(1)	-2.281	-4.044*	I(1)	0.659	-3.296**	I(1)
Estonia	-3.770*	-4.337*	I(0)	-1.035	-4.235*	I(1)	-0.775	-3.626*	I(1)	-0.374	-3.880*	I(1)	-2.009	-2.497**	I(1)	-2.496	-3.276**	I(1)
Finland	-1.112	-3.531***	I(1)	-3.682*	-4.483*	I(0)	-1.165	-4.461*	I(1)	-1.072	-4.912*	I(1)	-1.856	-3.589*	I(1)	2.573	-2.644*	I(1)
France	3.840	-2.577*	I(1)	-1.315	-3.816*	I(1)	-1.218	-4.284*	I(1)	-0.854	-4.638*	I(1)	-2.084	-3.898*	I(1)	-1.861	-2.955**	I(1)
Germany	1.848	-3.800*	I(1)	-2.999**	-6.691*	I(0)	-0.532	-3.597*	I(1)	-0.389	-4.055*	I(1)	-1.271	-5.209*	I(1)	-1.781	-4.191*	I(1)
Greece	-2.357	-3.431*	I(1)	-1.424	-4.270*	I(1)	-3.535*	-3.639*	I(0)	-1.962	-4.331*	I(1)	-0.920	-2.323**	I(1)	-0.282	-5.228*	I(1)
Hungary	-1.716	-3.844*	I(1)	-1.447	-4.506*	I(1)	-1.115	-5.601*	I(1)	-1.530	-6.787*	I(1)	-0.662	-3.194**	I(1)	-6.225*	-4.271*	I(0)
Ireland	-0.658	-2.428**	I(1)	-0.941	-3.494*	I(1)	-1.237	-4.574*	I(1)	-1.224	-5.328*	I(1)	-1.217	-2.392**	I(1)	-2.288	-2.863**	I(1)
Italy	0.460	-2.328**	I(1)	-1.606	-4.465*	I(1)	-2.410	-4.237*	I(1)	-0.978	-5.011*	I(1)	-3.744*	-3.377**	I(0)	-5.073*	-3.287**	I(0)
Latvia	-1.659	-3.100**	I(1)	-0.808	-2.908**	I(1)	-1.485	-4.215*	I(1)	-1.047	-4.043*	I(1)	-0.226	-3.276**	I(1)	-1.229	-4.452**	I(1)
Lithuania	-1.626	-3.562*	I(1)	-1.326	-2.681***	I(1)	-0.491	-3.709*	I(1)	-0.593	-3.925*	I(1)	0.173	-2.235**	I(1)	-2.262	-2.685*	I(1)
Luxembourg	-0.734	-3.332**	I(1)	-0.371	-3.223**	I(1)	-0.759	-4.761*	I(1)	-0.505	-5.949*	I(1)	-1.857	-3.879*	I(1)	-4.624*	-2.616*	I(0)
Malta	-3.027**	-8.526*	I(0)	-2.952**	-9.075*	I(0)	-2.751	-5.160*	I(1)	-1.061	-4.698*	I(1)	-1.993	-4.440*	I(1)	-3.005**	-4.951*	I(0)
Netherlands	-2.350	-4.980*	I(1)	-2.198	-5.957*	I(1)	-1.086	-4.976*	I(1)	-1.100	-5.652*	I(1)	-0.892	-2.967**	I(1)	1.121	-5.318*	I(1)
Poland	-1.175	-5.451*	I(1)	0.791	-3.406*	I(1)	-4.702*	-2.775*	I(0)	-4.431*	-2.631*	I(0)	0.224	-6.235*	I(1)	-1.248	-5.749*	I(1)
Portugal	-1.480	-1.392*	I(1)	-2.379	-2.142*	I(1)	-3.176**	-3.291**	I(1)	-1.458	-4.110*	I(1)	-2.481	-2.666***	I(1)	-3.444*	-0.933	I(0)
Romania	-3.388**	-6.660*	I(1)	-1.747	-6.178*	I(1)	-9.411*	-2.244	I(0)	-10.443*	-2.351	I(0)	0.291	-2.729***	I(1)	-0.982	-3.424**	I(1)
Slovak Republic	-2.131	-6.216*	I(1)	-0.915	-5.506*	I(1)	-1.017	-3.093*	I(1)	-1.218	-3.554*	I(1)	-0.927	-3.209**	I(1)	0.413	-4.795*	I(1)
Slovenia	-0.567	-2.711***	I(1)	-1.563	-5.950*	I(1)	-0.147	-3.132**	I(1)	-0.514	-4.118*	I(1)	-2.531	-2.578**	I(1)	-0.496	-4.088*	I(1)
Spain	1.102	-3.357**	I(1)	-1.290	-3.489*	I(1)	-2.169	-3.914*	I(1)	-1.120	-4.623*	I(1)	-1.578	-2.354**	I(1)	-4.535*	-3.056**	I(0)
Sweden	2.895	-2.784***	I(1)	-2.985**	-4.993*	I(0)	-1.079	-4.502*	I(1)	-1.088	-5.746*	I(1)	-0.850	-4.344 *	I(1)	-2.320	-2.105**	I(1)
United Kingdom	2.998	-2.690***	I(1)	-0.453	-4.410*	I(1)	-1.199	-4.750*	I(1)	-0.852	-4.935*	I(1)	-1.461	-3.509*	I(1)	-3.206**	-2.909**	I(0)

Note: lg is log of gasoline consumption per driver, ld is log of diesel consumption per driver, lpg is log of real price of gasoline, lpd is log of real price of diesel, lgdp is log of real GDP per capita, lvt is log of number of vehicles per driver, 1st D. is first difference of the variables and Dec. is decision of the level of integration. *, ** and *** denote the significance of the test statistic at 1 %, 5 % and 10 % respectively

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Table 4: Results of Phillips–Perron unit root test

Country	lg Level	lg 1st D.	lg Dec.	ld Level	ld 1st D.	ld Dec.	lpg Level	lpg 1st D.	lpg Dec.	lpd Level	lpd 1st D.	lpd Dec.	lgdp Level	lgdp 1st D.	lgdp Dec.	Lvt Level	Lvt 1st D.	Lvt Dec.
Austria	0.553	-5.083*	I(1)	-0.600	-5.485*	I(1)	-1.398	-5.296*	I(1)	-1.324	-5.273*	I(1)	-1.998	-5.044*	I(1)	-3.158**	-2.990**	I(0)
Belgium	1.472	-4.139*	I(1)	-1.460	-5.123*	I(1)	-1.217	-4.174*	I(1)	-1.065	-4.818*	I(1)	-1.902	-4.401*	I(1)	-6.580*	-2.343	I(0)
Bulgaria	-1.296	-7.115*	I(1)	-1.942	-6.499*	I(1)	-6.893*	-3.103**	I(0)	-5.596*	-3.500*	I(0)	-0.278	-3.214**	I(1)	-0.868	-5.506*	I(1)
Croatia	-1.661	-3.316**	I(1)	-0.695	-4.926*	I(1)	-0.991	-2.397**	I(1)	-0.812	-1.990**	I(1)	-2.772***	-3.210**	I(0)	-0.658	-2.308***	I(1)
Cyprus	-0.548	-2.182**	I(1)	-2.634***	-5.587*	I(1)	-1.411	-3.816*	I(1)	-0.865	-3.199*	I(1)	-3.721*	-3.146**	I(0)	-0.829	-2.079**	I(1)
Czech Republic	-1.029	-8.034*	I(1)	-1.196	-4.434*	I(1)	-0.786	-3.517*	I(1)	-0.573	-4.037*	I(1)	-0.276	-4.826*	I(1)	-5.443*	-2.484	I(0)
Denmark	-0.615	-2.122**	I(1)	-2.401	-5.148*	I(1)	-1.523	-4.099*	I(1)	-0.537	-4.929*	I(1)	-2.084	-4.079*	I(1)	0.219	-3.325**	I(1)
Estonia	-3.777*	-4.364*	I(0)	-1.173	-4.223*	I(1)	-0.804	-3.605*	I(1)	-0.377	-3.926*	I(1)	-1.907	-2.000**	I(1)	-2.312	-3.288**	I(1)
Finland	-1.487	-3.729*	I(1)	-3.639*	-4.626*	I(0)	-1.393	-4.360*	I(1)	-1.260	-4.851*	I(1)	-1.664	-3.530*	I(1)	2.023	-4.102*	I(1)
France	2.935	-3.565 **	I(1)	-1.640	-3.783*	I(1)	-1.566	-4.307*	I(1)	-1.109	-4.627*	I(1)	-1.851	-3.893*	I(1)	-1.453	-2.949**	I(1)
Germany	0.973	-3.949*	I(1)	-2.968**	-6.710*	I(0)	-0.613	-3.550*	I(1)	-0.356	-4.021*	I(1)	-1.419	-5.202*	I(1)	-1.682	-4.167*	I(1)
Greece	-1.883	-3.443*	I(1)	-1.467	-4.921*	I(1)	-3.083**	-3.775*	I(0)	-1.940	-4.310*	I(1)	-1.176	-2.460**	I(1)	-0.277	-5.212*	I(1)
Hungary	-2.119	-3.769*	I(1)	-1.585	-4.740*	I(1)	-1.114	-5.617*	I(1)	-1.524	-6.691*	I(1)	-0.699	-3.185**	I(1)	-6.131*	-4.258*	I(0)
Ireland	-1.190	-2.447**	I(1)	-1.011	-3.629*	I(1)	-1.506	-4.527*	I(1)	-1.460	-5.311*	I(1)	-1.005	-1.758***	I(1)	-2.086	-2.891**	I(1)
Italy	-0.495	-2.252**	I(1)	-1.820	-4.671*	I(1)	-2.381	-4.176*	I(1)	-1.213	-4.974*	I(1)	-3.210**	-3.341**	I(0)	-5.476*	-3.264**	I(0)
Latvia	-1.820	-3.126**	I(1)	-1.169	-3.065**	I(1)	-1.390	-4.292*	I(1)	-0.957	-4.119*	I(1)	-0.769	-3.262**	I(1)	-1.226	-4.452*	I(1)
Lithuania	-1.707	-3.668*	I(1)	-1.610	-2.589***	I(1)	-0.473	-3.707*	I(1)	-0.590	-4.016*	I(1)	-0.360	-2.142**	I(1)	-6.623*	-2.665***	I(0)
Luxembourg	-1.236	-3.367**	I(1)	-0.546	-3.170**	I(1)	-1.080	-4.858*	I(1)	-0.630	-5.931*	I(1)	-1.580	-3.957*	I(1)	-3.317**	-2.508	I(0)
Malta	-2.953**	-9.718*	I(0)	-3.033**	-9.819*	I(0)	-2.735***	-5.866*	I(1)	-0.786	-5.172*	I(1)	-1.672	-4.502*	I(1)	-3.234**	-4.928*	I(0)
Netherlands	-2.417	-5.127*	I(1)	-2.348	-5.954*	I(1)	-1.185	-4.932*	I(1)	-1.219	-5.653*	I(1)	-0.831	-2.925**	I(1)	1.441	-5.313*	I(1)
Poland	-1.390	-5.580*	I(1)	0.354	-3.337**	I(1)	-4.560*	-2.671***	I(0)	-4.129*	-2.552	I(0)	0.101	-5.716*	I(1)	-1.206	-5.747*	I(1)
Portugal	-1.427	-3.782**	I(1)	-3.485*	-2.032**	I(0)	-2.800***	-3.268**	I(1)	-1.589	-4.071*	I(1)	-1.929	-2.809***	I(1)	-3.562*	-0.175	I(0)
Romania	-3.338**	-6.835*	I(1)	-1.590	-6.277*	I(1)	-10.895*	-2.381	I(0)	-10.297*	-2.667***	I(0)	-0.434	-2.809***	I(1)	-0.887	-3.345**	I(1)
Slovak Republic	-2.140	-6.284*	I(1)	-1.082	-5.521*	I(1)	-1.245	-3.009**	I(1)	-1.424	-3.537*	I(1)	-0.889	-3.215**	I(1)	0.580	-4.785*	I(1)
Slovenia	-0.990	-2.796**	I(1)	-1.568	-5.853*	I(1)	-0.468	-3.108**	I(1)	-0.580	-4.118*	I(1)	-2.381	-3.607**	I(1)	-0.500	-4.034*	I(1)
Spain	0.018	-3.479*	I(1)	-1.182	-3.654*	I(1)	-2.140	-3.910**	I(1)	-1.361	-4.559*	I(1)	-1.257	-1.848***	I(1)	-3.627*	-3.079**	I(0)
Sweden	1.553	-2.851***	I(1)	-3.122**	-5.120*	I(0)	-1.434	-4.450*	I(1)	-1.114	-5.807*	I(1)	-0.842	-4.307*	I(1)	-2.953*	-2.330	I(0)
United Kingdom	1.472	-2.611***	I(1)	-0.652	-4.526*	I(1)	-1.423	-4.732*	I(1)	-1.029	-4.917*	I(1)	-1.284	-3.547*	I(1)	-2.565	-2.917**	I(1)

Note: lg is log of gasoline consumption per driver, ld is log of diesel consumption per driver, lpg is log of real price of gasoline, lpd is log of real price of diesel, lgdp is log of real GDP per capita, lvt is log of number of vehicles per driver, 1st D. is first difference of the variables and Dec. is decision of the level of integration. *, ** and *** denote the significance of the test statistic at 1 %, 5 % and 10 % respectively

Table 5: Results of Zivot-Andrews endogenous structural break unit root test

Country	lg Level	1st D.	Dec.	ld Level	1st D.	Dec.	Lpg Level	1st D.	Dec.	lpd Level	1st D.	Dec.	lgdp Level	1st D.	Dec.	lvt Level	1st D.	Dec.
Austria	-3.084(0) 1986	-6.095*(0) 1993	I(1)	-3.482(2) 2007	-7.934*(0) 1985	I(1)	-3.279(0) 2004	-5.768*(0) 2003	I(1)	-3.821(0) 2004	-5.796*(0) 2003	I(1)	-2.260(2) 2008	-6.209*(1) 2008	I(1)	-4.840**(0) 2002	-4.775***(0) 2001	I(0)
Belgium	-2.851(0) 1986	-5.183**(0) 1984	I(1)	-4.114(2) 2006	-7.753*(0) 1984	I(1)	-3.751(1) 2003	-4.666***(0) 1986	I(1)	-2.849(0) 1983	-5.144**(0) 1987	I(1)	-2.174(0) 2008	-5.876*(0) 2008	I(1)	-2.514(1) 1998	-4.697**(0) 1986	I(1)
Bulgaria	-4.953**(0) 1991	-6.766*(1) 1991	I(0)	-4.698*(0) 1991	-7.829*(0) 1991	I(1)	-3.504(0) 2003	-15.893*(0) 1999	I(1)	-3.388(0) 2003	-13.757*(0) 1999	I(1)	-4.006(1) 1990	-5.645*(0) 1989	I(1)	-8.383*(0) 2006	-5.948*(0) 2008	I(0)
Croatia	-3.525(2) 2008	-5.190**(0) 1994	I(1)	-1.595(2) 2009	-5.593*(0) 2008	I(1)	-5.277**(1) 2003	-3.148(0) 1999	I(0)	-5.548*(1) 2003	-3.659(0) 2001	I(0)	-3.177(0) 2009	-5.540*(0) 2009	I(1)	-2.548(2) 2009	-4.874**(0) 1994	I(1)
Cyprus	-3.755(1) 1995	-5.710*(0) 2003	I(1)	-2.956(0) 2001	-7.187*(0) 2007	I(1)	-2.725(0) 2004	-4.450(0) 2002	I(1)	-3.499(0) 2002	-5.188*(0) 2001	I(1)	-0.137(0) 2008	-5.436*(0) 2008	I(1)	-3.860(1) 2004	-5.062**(0) 2009	I(1)
Czech Republic	-3.103(1) 1992	-5.374**(2) 1997	I(1)	-3.934(2) 1990	-6.552*(0) 1998	I(1)	-3.190(0) 1997	-5.019**(0) 2009	I(1)	-3.283(0) 2004	-5.932*(0) 2009	I(1)	-2.455(1) 2004	-5.937*(0) 2008	I(1)	-4.912**(1) 2002	-5.237**(1) 2004	I(0)
Denmark	-1.126(1) 1990	-4.646**(0) 1984	I(1)	-3.617(0) 1988	-6.255*(0) 1984	I(1)	-4.116(1) 2003	-6.737*(1) 1986	I(1)	-3.931(0) 1983	-5.955*(0) 1990	I(1)	-2.759(1) 2008	-5.256**(0) 2008	I(1)	-5.602(1) 1990	-5.851*(2) 1995	I(0)
Estonia	-4.142(0) 1997	-9.584*(1) 1996	I(1)	-4.469(0) 2001	-6.188*(0) 1994	I(1)	-6.496*(0) 2005	-4.462(0) 2007	I(0)	-4.281(0) 2005	-4.685***(0) 2007	I(1)	-5.222**(1) 2009	-6.379*(1) 2008	I(0)	-4.549(2) 2001	-5.060**(0) 2003	I(1)
Finland	-2.592(1) 1986	-6.819*(0) 1990	I(1)	-5.817*(2) 2000	-4.046(1) 1985	I(0)	-3.611(1) 2003	-6.372*(1) 1987	I(1)	-3.029(0) 2004	-5.238**(0) 1991	I(1)	-2.778(1) 1998	-4.849*(0) 1994	I(1)	-4.801**(0) 1993	-5.873*(0) 1995	I(0)
France	-3.047(0) 2003	-6.188*(0) 1997	I(1)	-4.766*(1) 1991	-3.117(2) 1989	I(0)	-2.992(0) 2003	-5.547*(0) 1985	I(1)	-3.024(0) 2003	-5.459*(0) 1985	I(1)	-3.362(1) 2008	-4.731***(0) 2008	I(1)	-4.075(1) 1996	-4.884*(0) 2002	I(1)
Germany	-2.644(0) 1986	-5.980*(0) 2000	I(1)	-5.092**(2) 1991	-7.696*(0) 1984	I(0)	-3.128(0) 1997	-5.772*(1) 2002	I(1)	-3.445(0) 2003	-5.225**(0) 2009	I(1)	-3.840(0) 1988	-5.454*(2) 1993	I(1)	-3.132(0) 1992	-4.758***(0) 1992	I(1)
Greece	-0.787(2) 1992	-5.772*(0) 1990	I(1)	0.474(1) 2007	-6.557*(0) 2007	I(1)	-1.908(0) 2003	-6.429*(0) 1986	I(1)	-2.462(0) 2003	-6.269*(1) 1987	I(1)	-2.960(1) 2000	-5.350*(0) 2008	I(1)	-3.391(0) 1991	-5.941**(0) 1998	I(1)
Hungary	-3.571(1) 1986	-5.169**(1) 1990	I(1)	-3.368(2) 1991	-6.145*(0) 1997	I(1)	-2.686(0) 1993	-7.295*(0) 2002	I(1)	-2.813(0) 1994	-7.869*(0) 2002	I(1)	-5.430*(0) 2009	-5.268**(0) 2007	I(0)	-3.964(0) 2008	-7.519*(0) 2000	I(1)
Ireland	-3.326(2) 2007	-5.086**(0) 2007	I(1)	-2.653(2) 2007	-5.363*(0) 1985	I(1)	-2.476(0) 2004	-5.696*(0) 20003	I(1)	-3.142(0) 2004	-6.491*(0) 2003	I(1)	-4.726**(1) 2005	-3.543(0) 2001	I(0)	-3.047(0) 2009	-4.824***(0) 2008	I(1)
Italy	-1.835(2) 1989	-5.649*(0) 1993	I(1)	-2.611(2) 2001	-5.562*(0) 1995	I(1)	-2.854(0) 2003	-5.190*(0) 1986	I(1)	-2.824(0) 2004	-5.468*(0) 1992	I(1)	-0.813(2) 2008	-5.355*(0) 2008	I(1)	-3.366(0) 1985	-6.199*(0) 1993	I(1)
Latvia	-2.192(1) 2003	-5.681*(0) 2008	I(1)	-4.821**(2) 2000	-3.382(2) 1996	I(0)	-4.551(0) 2005	-4.755***(0) 2007	I(1)	-3.988(0) 2009	-4.605***(0) 2007	I(1)	-4.906*(1) 1992	-3.930(0) 1994	I(0)	-2.730(0) 2009	-5.938*(0) 1995	I(1)
Lithuania	-5.788*(2) 2006	-5.319**(2) 2004	I(0)	-3.195(0) 2004	-5.192**(0) 1995	I(1)	-3.692(0) 2007	-5.511**(2) 2007	I(1)	-4.551(0) 2009	-4.944***(0) 2001	I(1)	-7.718*(1) 2009	-4.664***(0) 1995	I(0)	-1.665(0) 1996	-6.670*(0) 2001	I(1)
Luxembourg	-2.548(1) 1989	-5.237**(0) 1989	I(1)	-5.010***(1) 2003	-4.197(0) 2006	I(0)	-5.053**(1) 2003	-6.086*(0) 1986	I(0)	-2.931(0) 2003	-7.006*(0) 1987	I(1)	-1.934(0) 2008	-5.379*(0) 1984	I(1)	0.155(0) 2008	-7.569*(2) 1999	I(1)
Malta	-5.680*(0) 1986	-9.653*(0) 1986	I(0)	-7.435*(0) 1986	-5.468*(2) 1986	I(0)	-6.089*(0) 2003	-5.628*(0) 2004	I(0)	-4.481(0) 2005	-5.918*(0) 2004	I(1)	-2.364(1) 1988	-6.061***(0) 2001	I(1)	-6.992*(2) 1997	-8.570*(0) 1996	I(0)
Netherlands	-4.102(0)	-7.003*(1)	I(1)	-3.821(0)	-7.283*(0)	I(1)	-3.539(1)	-5.315**(0)	I(1)	-2.841(0)	-5.989*(0)	I(1)	-3.323(1)	-4.983*(1)	I(1)	-3.405(0)	-6.479*(0)	I(1)

	1993	1989		1999	1984		1997	1986		1983	1997		2008	2001		1991	1993	
Poland	-3.174(2) 1991	-4.863**(2) 2000	I(1)	-4.907**(1) 1989	-4.055(0) 1995	I(0)	-6.208(2) 2000	-5.524*(0) 1991	I(1)	-6.344*(2) 2000	-5.168**(0) 1991	I(0)	-2.233(1) 1995	-6.764*(0) 2004	I(1)	-7.613*(0) 2007	-6.457*(0) 2006	I(0)
Portugal	-0.877(1) 1987	-5.499*(0) 1985	I(1)	-0.546(1) 2006	-4.510**(0) 1987	I(1)	-3.396(1) 2003	-5.348**(0) 1985	I(1)	-3.171(0) 2003	-4.848**(0) 2003	I(1)	-2.716(1) 2008	-4.799**(0) 1995	I(1)	-0.742(2) 2007	-4.473**(0) 1999	I(1)
Romania	-4.298(0) 2001	-7.050*(0) 1987	I(1)	-3.057(0) 2006	-6.237*(2) 2003	I(1)	-3.674(2) 1999	-4.696**(2) 2006	I(1)	-6.248*(0) 2004	-4.098(0) 1995	I(0)	-3.470(1) 1989	-4.413***(2) 2007	I(1)	-3.496(1) 2002	-4.834**(0) 2007	I(1)
Slovak Republic	-5.201**(0) 1983	-6.556*(0) 1992	I(0)	-3.272(0) 1991	-6.538*(0) 1991	I(1)	-3.018(0) 2004	-4.918**(0) 2003	I(1)	-3.239(0) 1999	-5.224**(0) 2003	I(1)	-3.169(1) 2006	-4.653***(0) 2009	I(1)	-2.601(0) 2008	-6.250*(0) 2006	I(1)
Slovenia	-4.003(0) 1993	-6.156*(0) 1997	I(1)	-3.688(2) 2009	-6.540*(0) 1998	I(1)	-2.321(0) 1999	-5.279**(0) 2007	I(1)	-2.642(0) 2000	-5.264**(0) 2007	I(1)	-3.126(0) 2009	-7.974*(0) 2009	I(1)	-3.286(0) 1995	-4.968**(0) 1990	I(1)
Spain	-2.360(2) 1986	-4.885**(1) 1986	I(1)	-4.874**(1) 2006	-3.829(2) 2006	I(0)	-2.463(0) 2003	-4.915**(0) 1986	I(1)	-2.818(0) 2003	-5.629*(1) 1993	I(1)	-4.982*(1) 2007	-3.866(0) 2008	I(0)	-0.955(0) 1987	-4.859**(0) 1987	I(1)
Sweden	0.324(0) 2007	-4.911**(0) 1984	I(1)	-4.615(2) 1987	-7.927*(0) 1985	I(1)	-2.851(0) 1983	-4.906**(0) 1985	I(1)	-3.557(0) 1983	-5.842*(0) 2003	I(1)	-3.045(1) 1999	-5.397*(0) 1994	I(1)	-4.218***(1) 1989	-3.547(1) 1990	I(0)
United Kingdom	-1.629(0) 1986	-5.810*(0) 1984	I(1)	-5.616(1) 2007	-6.780*(0) 1984	I(1)	-4.361(0) 1983	-5.101**(0) 2008	I(1)	-3.824(0) 1983	-5.603*(0) 2008	I(1)	-4.456(1) 2008	-4.724**(0) 1984	I(1)	-1.332(0) 2006	-4.685***(0) 2006	I(1)

Note: lg is log of gasoline consumption per driver, ld is log of diesel consumption per driver, lpg is log of real price of gasoline, lpd is log of real price of diesel, lgdp is log of real GDP per capita, lvt is log of number of vehicles per driver, 1st D. is first difference of the variables and Dec. is decision of the level of integration. *, ** and *** denote the significance of the test statistic at 1 %, 5 % and 10 % respectively. Lag order is given in parentheses and the break year is given below each test statistic

The actual time of the structural breaks in the data set is determined using the Bai-Perron test (Perron, 2006). The Bai-Perron test provides a flexible approach to determining multiple structural breaks at unknown dates. Once the break points are determined, it is accounted for in the model using impulse dummies. The variant types of the Bai-Perron tests sometimes select several different break points. In this case impulse dummies are included in the initial estimation for all the break points, both individually and in a group, and their significance and their effect on the models properties are compared. Only those that are considered important are included in the final estimation.

The appropriate lag lengths of $n_{e,j}^*$ in the estimation of Eq. (1) are then selected using Akaike information criterion (AIC) and Schwarz criterion (SC), while controlling for serial correlation with the inclusion of dummies, a trend and a constant. The selected model is then estimated on the log of the variables, which allows the estimated coefficients to be interpreted as elasticities. Once an appropriate model is selected and estimated, its stability is checked using the cumulative sum of recursive residuals (CUSUM) and CUSUM of squares (CUSUMSQ) plots. In addition serial correlation in the models is checked using the Breusch-Godfrey Lagrange multiplier test (LM) (Greene, 2003). Details of the estimation results showing the selected model, cointegrating coefficient, Bounds test, LM test, and stability tests are provided in the Appendix.

5. Results and discussion

Table 6 presents the price and income elasticities from the estimation results of gasoline and diesel demand for each of the EU-28 countries. The estimation results of gasoline demand have the expected negative sign for the long-run and short-run price elasticities of all countries. The estimated short-run and long-run income elasticities of gasoline demand also have the expected positive sign, except for the long-run income elasticities of Belgium and Malta. Likewise, the estimated price elasticities of diesel demand have the expected negative sign for both the short-run and long-run estimates of all countries, except for the short-run price elasticity of Poland. The estimated long-run and short-run income elasticities of diesel demand have the expected positive sign, except for the short-run income elasticities of Malta and Slovenia.

As the results in Table 6 show, the estimated short-run price elasticity of gasoline demand is significant for 18 countries and the long-run price elasticity of gasoline demand is significant for 15 countries. The short-run income elasticity of gasoline demand is significant for 16 countries and the long-run income elasticity of gasoline demand is also significant for 16 countries. The estimated short-run price elasticity of diesel demand is significant for 14 countries and the long-run price elasticity of diesel demand is significant for 11 countries. The short-run income elasticity of diesel demand is significant for 18 countries and the long-run income elasticity of diesel demand is significant for 11 countries.

The adjustment factors of both gasoline and diesel demands captured by the cointegrating coefficient from the estimations are between 0 and -1, and significant for all countries except in the diesel demand estimation of Malta. The average adjustment factor of gasoline demand is -0.4, with the smallest being -0.01 in Cyprus and the largest -0.99 in Latvia. For the diesel demand, the average adjustment factor is -

0.48; the smallest adjustment factor is -0.11 for France and the largest is -0.91 for Latvia. This means that whenever there is a shock, gasoline demand adjusts on average by 40 % per period and diesel demand adjusts by 48 % per period towards long-run equilibrium. The adjustments are in opposite directions to the shock, *i.e.* negative if the shock is positive and positive if the shock is negative. The adjustment factor estimates asserted the theoretical stance that fuel demand gradually adjusts towards the long-run equilibrium.

In the estimated demands, the existence of a long-run relationship is tested using the Bounds test. As shown in Table 6 and the model summary in the Appendix, the Bounds test of long-run cointegration of gasoline demand shows that there is a long-run equilibrium relationship between gasoline consumption, gasoline price, income and number of vehicles for all of the EU-28 countries except Cyprus, Estonia, the Netherlands and Slovakia. The same test for diesel demand shows that there is a long-run equilibrium relationship between diesel consumption, diesel price, income and number of vehicles for 18 of the EU-28 countries. The selected models of each country for both fuel types pass the LM test of serial correlation, except for the gasoline demand of Malta and the diesel demand of Romania and Slovenia. The estimated gasoline demand for Malta and diesel demand for Romania and Slovenia could not be cleared of serial correlation because the limited number of observations did not allow sufficient flexibility in selecting the optimal lag orders in the estimated models. In addition, stability tests using CUSUM and CUSUMSQ that are shown in the Appendix reveal that all the estimated models free from serial correlation are stable. Thus the long-run elasticities of countries where the Bounds test shows a long-run relationship can be used for policy analysis and forecasting.

The reviews of Basso and Oum (2007), Brons *et al.* (2008) and Dahl (2012) show the average price elasticities of gasoline demand to be close to -0.20 in the short run and 1.0 in the long run. In this study the estimated average gasoline price elasticity among the EU-28 countries is -0.17 in the short run and -0.72 in the long run. The main reason for the lower average price elasticity of gasoline demand is the consideration of the number of vehicles and demographic effects (Basso and Oum, 2007; Pock, 2010).

In line with the consensus in the existing literature, the long-run price elasticities of gasoline demand are found to be higher than the short-run price elasticities for all countries in absolute values. As the long-run elasticities depend on the adjustment factor, they are found to be higher than the corresponding short-run elasticities because the estimated adjustment factor is between 0 and -1 as expected. The short-run price elasticity varies from -0.005 in Spain to -0.58 in Romania. The smallest long-run price elasticity of gasoline demand in absolute values is found to be for Malta at 0.04 and the largest is for Sweden at 1.96. However the estimation result of gasoline demand for Malta has a serial correlation problem and hence it is excluded from the analysis. The long-run price elasticity of gasoline demand show a greater variation between countries than the short-run price elasticities.

Table 6: Estimated elasticities of gasoline and diesel demand

	Gasoline demand				Diesel demand			
	Price elasticity		Income elasticity		Price elasticity		Income elasticity	
Country	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run	Short-run	Long-run
Austria[a,b,c,d]	-0.150** (0.068)	-0.414* (0.214)	0.221 (0.357)	0.560 (0.873)	-0.060 (0.067)	-0.961 (0.696)	0.213 (0.531)	1.937** (0.874)
Belgium[a,b,c,d]	-0.233** (0.092)	-1.705** (0.615)	0.292 (0.546)	-0.121*** (0.029)	-0.082* (0.045)	-0.095* (0.053)	0.852* (0.467)	0.060*** (0.005)
Bulgaria[a,b,c,d]	-0.074 (0.066)	-0.174 (0.214)	0.078 (0.302)	0.108*** (0.004)	-0.019 (0.023)	-0.017 (0.025)	0.207 (0.304)	0.80*** (0.110)
Croatia[a,c,d]	-0.343*** (0.082)	-1.085*** (0.291)	0.621** (0.265)	1.745** (0.797)	-0.168 (0.148)	-0.507 (0.558)	0.80* (0.365)	1.960 (1.668)
Cyprus[c,d]	-0.027 (0.062)	-1.937 (30.860)	0.063 (0.191)	0.553 (4.363)	-0.067 (0.044)	-0.158 (0.251)	0.393 (0.584)	0.273*** (0.035)
Czech Republic[a,c,d]	-0.279** (0.104)	-0.547** (0.201)	0.874** (0.401)	2.225** (0.998)	-0.10 (0.085)	-3.214 (13.833)	0.997* (0.430)	0.508 (2.111)
Denmark[a,c,d]	-0.109*** (0.026)	-0.952* (0.479)	0.254 (0.161)	3.424*** (0.938)	-0.044 (0.066)	-0.422 (0.579)	0.227 (0.449)	1.272 (6.354)
Estonia[c,d]	-0.093 (0.066)	-0.115 (0.224)	0.519*** (0.129)	1.174 (0.649)	-0.027 (0.099)	-0.133 (0.308)	0.650** (0.184)	0.830 (0.510)
Finland[a,b,c,d]	-0.101** (0.039)	-0.763*** (0.180)	0.336** (0.124)	1.421** (0.599)	-0.062** (0.025)	-0.30*** (0.053)	0.362*** (0.084)	0.104*** (0.028)
France[a,b,c,d]	-0.174*** (0.026)	-0.624*** (0.078)	0.456** (0.174)	1.222* (0.605)	-0.071* (0.038)	-0.280** (0.126)	0.017 (0.279)	1.398** (0.622)
Germany[a,b,c,d]	-0.042 (0.043)	-1.165 (2.310)	0.456** (0.218)	6.494 (11.926)	-0.160** (0.070)	-0.270** (0.096)	0.503 (0.314)	0.371 (0.585)
Greece[a,b,c,d]	-0.126*** (0.019)	-0.289*** (0.041)	0.423*** (0.087)	0.946*** (0.282)	-0.120*** (0.039)	-0.231*** (0.021)	0.682*** (0.211)	0.704*** (0.153)
Hungary[a,b,c,d]	-0.106** (0.048)	-0.128 (0.113)	0.412** (0.178)	1.150** (0.552)	-0.237*** (0.061)	-1.0 (1.329)	1.083*** (0.292)	5.723 (3.914)
Ireland[a,c,d]	-0.032 '(0.043)	-0.217 (0.181)	0.520** (0.181)	1.028** (0.459)	-0.087 (0.053)	-0.147** (0.065)	0.286 (0.204)	0.300*** (0.069)
Italy[a,b,c,d]	-0.125** (0.059)	-0.359** (0.131)	0.485 (0.312)	1.329 (1.280)	-0.056** (0.018)	-0.725* (0.322)	0.917*** (0.140)	4.938** (1.647)
Latvia[a,b,c,d]	-0.358** (0.063)	-0.468 (0.239)	0.761*** (0.117)	1.520** (0.270)	-0.387** (0.110)	-0.479* (0.230)	1.320*** (0.207)	1.572*** (0.316)
Lithuania[a,b,c,d]	-0.475** (0.187)	-1.362** (0.595)	1.320* (0.154)	4.044* (1.907)	-0.681*** (0.104)	-0.829*** (0.213)	0.735*** (0.155)	1.648** (0.518)
Luxembourg[a,b,c,d]	-0.248*** (0.074)	-0.260 (0.216)	0.883*** (0.212)	3.060*** (0.889)	-0.056 (0.064)	-1.004** (0.400)	0.152 (0.258)	0.540 (0.799)
Malta[a,d]	-0.010 (0.023)	-0.046 (0.135)	0.897** (0.217)	-4.366 (2.623)	-0.095 (0.191)	-0.115 (0.221)	-0.096 (0.740)	0.447 (1.417)
Netherlands[b,c,d]	-0.061* (0.027)	-0.507 (1.059)	0.347** (0.109)	0.0728 (0.768)	-0.035 (0.080)	-0.301 (0.341)	1.270** (0.568)	1.494 (1.454)
Poland[a,c,d]	-0.178*** (0.053)	-0.262*** (0.026)	0.384 (0.302)	0.539 (0.379)	0.122* (0.060)	-0.051 (0.098)	0.927** (0.405)	0.333 (0.414)
Portugal[a,b,c,d]	-0.029 (0.049)	-0.940 (1.026)	0.473** (0.217)	4.850 (5.070)	-0.115** (0.050)	-0.186 (0.228)	0.922*** (0.214)	2.278 (1.688)
Romania[a,c]	-0.581*** (0.068)	-0.90* (0.454)	0.603** (0.233)	1.358* (0.618)	-0.460** (0.115)	-0.207 (0.693)	1.30** (0.374)	0.372 (1.588)
Slovakia[b,c,d]	-0.430***	-0.509***	0.407	0.538**	-0.048	-0.105	0.870**	1.841

	(0.136)	(0.092)	(0.322)	(0.201)	(0.113)	(0.370)	(0.310)	(1.427)
Slovenia[a,c]	-0.186 (0.107)	-0.317 (0.200)	0.561 (0.329)	0.561 (0.666)	-0.059 (0.129)	-0.430 (3.036)	-0.055 (0.358)	1.155 (2.362)
Spain[a,b,c,d]	-0.010 (0.063)	-1.854** (0.809)	0.018 (0.407)	0.364*** (0.105)	-0.142* (0.064)	-1.127 (1.037)	1.344** (0.543)	3.479 (2.497)
Sweden[a,b,c,d]	-0.154*** (0.033)	-1.965 (3.538)	0.048 (0.189)	4.220 (7.996)	-0.073 (0.043)	-0.121* (0.069)	0.685** (0.301)	0.101 (0.215)
United Kingdom[a,b,c,d]	-0.013 (0.040)	-0.466** (0.160)	0.067 (0.248)	0.439 (1.376)	-0.074* (0.036)	-0.465 (0.699)	0.834*** (0.215)	1.715 (2.673)

Note: ***, **, * indicate significance at 1 %, 5 % and 10 % respectively

> *- **a** and **b** indicate that the Bounds test confirms there is a long-run cointegration in the gasoline and diesel demand estimation respectively*
>
> *- **c** indicates stability and no serial correlation in gasoline demand estimation*
>
> *- **d** indicates stability and no serial correlation in diesel demand estimation*
>
> *- standard errors are in parentheses*

The short-run income elasticity of gasoline demand varies from the smallest estimate of 0.018 in Spain to the largest estimate of 1.32 in Lithuania. The long-run income elasticity of gasoline demand ranges from the least estimated value of -0.12 in Belgium to the highest value of 6.49 in Germany, with a higher variation than their short-run counterparts. The average estimated income elasticity of gasoline demand in this study is 0.45 in the short run and 1.44 in the long run, which is not considerably different from the literature reviewed by Ajanovic *et al.* (2012).

The long-run income elasticities are higher than the short-run elasticities because of the adjustment coefficient. In addition, the long-run income elasticity estimates of gasoline demand have higher variation between countries than the short-run estimates. The elasticity variations between the countries shows that using the same elasticity across several countries for policy analysis is likely to result in biased outcomes. The bias is likely to become higher in the long run because of the higher variations in the long-run estimates. Moreover, in absolute values, both average short-run and long-run income elasticities of gasoline demand are higher than the respective price elasticities. This shows that on average gasoline demand is more income sensitive than price.

In the estimated short-run price elasticity of diesel demand, in absolute values Bulgaria has the lowest at 0.020 and the highest estimate is 0.68 for Lithuania. The estimated short-run price elasticity of diesel demand is relatively concentrated around -0.14, with 23 countries falling in the range of -0.02 to -0.4. Overall the short-run price elasticity of diesel demand vary slightly less than the short-run price elasticity of gasoline demand. As a result of the estimated adjustment factors being within the expected range, the entire long-run price elasticity estimates of diesel demand are higher in absolute values than their short-run counterparts except for Bulgaria, Romania and Poland. The long-run price elasticity of diesel demand has larger variation than the gasoline counterparts. The lowest estimated long-run price elasticity of diesel demand, in absolute values, is for Bulgaria at 0.017 and the highest is for the Czech Republic at 3.21. The average estimated short-run and long-run price elasticities of diesel demand (-0.13 and -0.49 respectively) are lower than the average of the studies reviewed by Brons *et al.* (2008). The

likely reason for the lower estimates is the consideration of the number of vehicles and demographic effect in the estimation (Pock, 2010).

The short-run income elasticity of diesel demand varies more than the short-run income elasticity of gasoline demand. The long-run income elasticity of gasoline demand has a larger variation than the long-run income elasticity of diesel. The lowest short-run income elasticity of diesel demand estimated is for Malta at -0.096 and the highest is for Spain at 1.34. The short-run elasticities are concentrated around 0.5 and 1.0, with 13 countries falling within the range of 0.2 to 0.8. The long-run income elasticities of diesel are between 0.05 for Belgium and 5.72 for Hungary. They are highly concentrated around 1.2 and the estimates of 15 countries are between 0.5 and 2.0. The average estimated income elasticities of diesel demand are 0.65 in the short run and 1.36 in the long run. The average short-run elasticity is higher than the average of the studies reviewed by Ajanovic *et al.* (2012) but the long-run estimates are equal. In addition both the average short-run and long-run income elasticities of diesel demand are higher than the average short-run and long-run price elasticities in absolute values. Thus diesel demand is more income elastic than price elastic. Moreover, both average long-run income and price elasticities of diesel demand are less elastic than their gasoline counterparts, indicating that a policy affecting both gasoline and diesel would have a higher impact on average on gasoline than on diesel in the long run.

A simple line plot of elasticities against average per capita incomes during the sample period is shown in Figure 3. Table 7 provides calculated correlation coefficients. In contrast to the study by Dahl (2012), Figure 3 and Table 7 do not indicate any strong systematic relationship between the level of average per capita GDP and estimated elasticities. However, while all of the estimated long-run elasticities vary unsystematically between countries, the short-run elasticities show a general downward trend as income increases. In particular, the short-run price elasticity of diesel is relatively high for an average income of less than 6,000 USD per year during the whole sample period, and has a general downward trend for higher income countries. The top ten countries with an average per capita income above 29,000 USD per year have relatively low income elasticities of gasoline demand in the short run.
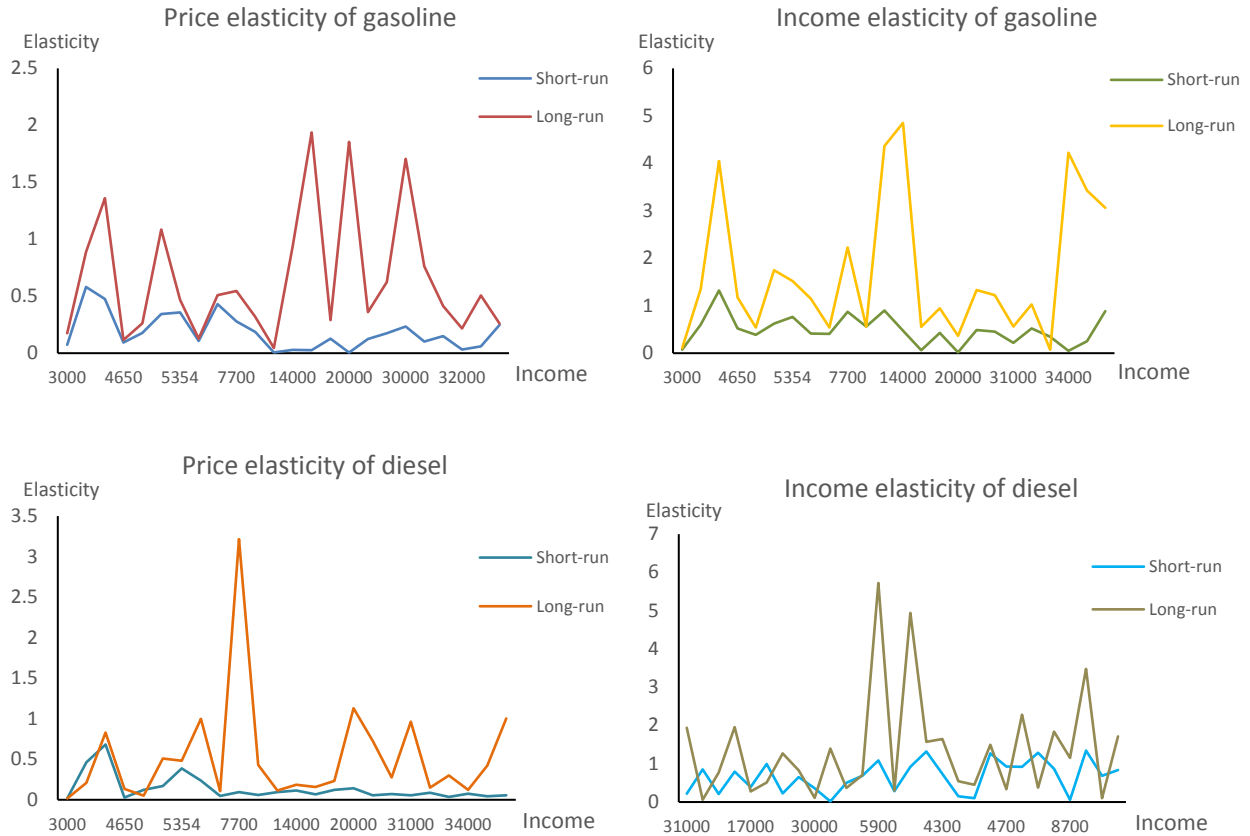
Figure 3: Elasticities and GDP per capita for different countries

Table 7: Correlation between elasticities, in absolute values, and average GDP per capita

	Gasoline				Diesel			
	Price elasticity		*Income elasticity*		*Price elasticity*		*Income elasticity*	
	Short-run	*Long-run*	*Short-run*	*Long-run*	*Short-run*	*Long-run*	*Short-run*	*Long-run*
Av. GDP Per Capita	-0.358	0.149	-0.243	0.164	-0.429	-0.025	-0.340	-0.142

6. Fuel tax implications in relation to the EU 2030 emission goal

The European Commission (2014) reports that between 1990 and 2007, greenhouse gas emissions has increased by 33 %, with this trend expected to continue in the following decades. In an effort to halt the continuous rise in emissions, the EU has set a goal to reduce greenhouse gas emissions from fuel consumption in the transport sector by about 20 % by 2030 compared to emissions in 2008. In order to achieve this goal, a minimum fuel tax has been set. The European Commission (2014) analysis shows that EU emission targets lead to a significant reduction in air pollution. The economic valuation of

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different scenarios by the report estimates that reduced mortality and better health from lower pollution rates has an estimated value of € 2.9 to € 35.5 billion.

The 2003 EU Energy Tax Directive put forward a minimum tax level on gasoline and diesel for road transport in each EU member country, which has applied since 2013. However the directive bans tax on international aviation and shipping. The minimum tax rate imposed is € 0.359/liter on gasoline and €0.330/liter on diesel (Directive, 2003). It corresponds to 48 % of the average EU member countries' tax on diesel and 43 % of the average EU member countries' tax on gasoline in 2013. There is an ongoing discussion and proposal to raise the minimum tax rate and also introduce tax in the excluded sectors.

The implication of a minimum tax rate on total fuel consumption and emissions is determined by, among other things, how consumers in each country respond. An examination follows of whether the current tax scheme is sufficient to reach the EU's 2030 goals using the elasticity estimates in Section 5. For the countries where the Bounds test did not confirm the existence of a long-run relationship and the estimated models were not free from serial correlation, the average EU long-run elasticity is used to project their fuel demand response to varying tax levels.

For the purposes of simplicity, it is assumed that the EU's goal to reduce greenhouse gas emissions from the transport sector translates to reducing emissions from gasoline and diesel by 20 % each in 2030 compared to emissions in 2008. Emissions from gasoline and diesel are calculated from their respective consumption using "Government emission conversion factors for greenhouse gas company reporting" (2016).

In order to examine whether the EU's 2030 goal could be reached with the current trends, projected emissions in 2030 were calculated. The projected emission level from gasoline and diesel consumption in 2030 in the transport sector is calculated using the projected annual percentage change of emission from energy consumption in the transport sector from Capros *et al.* (2016). The basic assumption behind the projections of Capros *et al.* (2016) is that the EU and member states would implement agreed policies by December 2014 and that the 2020 targets of greenhouse gas emission and renewable energy sources would be achieved. The projection takes into account population growth, GDP growth, technology development and recent developments in fuel prices.

When it is assumed that each country is expected to achieve the 2030 target independently then, as shown in Table 8, the projected 2030 emissions level from gasoline consumption in 17 countries and all of the EU-28 countries' projected emissions from diesel consumption are higher than the target. Also, when it is assumed that the EU-28 countries are expected to achieve the 2030 goal collectively, then the last row of Table 8 shows that the projected 2030 emission from gasoline and diesel consumption would be higher than the targets. Consequently, the required percentage change in price in the form of a tax increment in order to reach the 2030 emission goal is calculated from:

$$D_{e,j,2030} * \left(1 + Tax_{e,j} * \epsilon_{LP,e,j}\right) = 80\% D_{e,j,2008}$$

$$Tax_{e,j} = \frac{80\% D_{e,j,2008} - D_{e,j,2030}}{\epsilon_{LP,e,j} * D_{e,j,2030}}$$

where $\epsilon_{LP,e,j}$ is long-run price elasticity of j=1 (gasoline), 2 (diesel) for the 28 EU countries $e = 1,2,\dots,28$, $Tax_{e,j}$ is the required percentage change in price in the form of a tax increment. $D_{e,j,2008}$ and $D_{e,j,2030}$ are fuel demands in 2008 and 2030 respectively.

Table 8: Projected emissions, targets, and required tax increment to achieve the EU's 2030 emission goals

Country	Projected annual % change 2010 to 2020	2020 to 2030	2030 targets 80 % of 2008 gasoline emission million tons CO2e	80 % of 2008 diesel emission million tons CO2e	2030 gasoline emission million tons CO2e	2030 diesel emission million tons CO2e	Required gasoline price change in the form of tax increase	Required diesel price change in the form of tax increase
Austria	-0.52	-0.55	4.37	13.17	4.82	14.90	22 %	12 %
Belgium	-1.17	0.37	3.50	18.36	3.38	21.19	-	141 %
Bulgaria	0.09	0.27	1.49	3.89	1.88	4.71	118 %	35 %
Croatia	-0.80	-0.05	1.69	3.02	1.83	3.40	7 %	23 %
Cyprus	-1.13	0.33	0.93	0.84	1.12	0.97	24 %	26 %
Czech Republic	-0.35	0.15	5.03	9.35	5.41	10.60	13 %	24 %
Denmark	-1.33	-0.27	4.25	6.82	4.00	7.04	-	6 %
Estonia	-0.62	-0.32	0.80	1.11	0.78	1.29	-	28 %
Finland	-0.74	-0.92	3.94	5.87	3.94	6.41	0.15 %	29 %
France	-0.08	-0.36	20.61	77.35	21.92	94.38	10 %	65 %
Germany	-0.40	-1.02	49.80	66.89	49.07	76.63	-	47 %
Greece	-1.38	-0.82	10.07	6.36	9.20	6.84	-	30 %
Hungary	-0.95	0.47	3.73	6.66	3.82	7.30	18 %	9 %
Ireland	-0.11	0.60	4.26	6.53	4.70	7.44	43 %	25 %
Italy	-0.86	-0.55	27.20	61.23	26.48	61.63	-	1 %
Latvia	-0.64	0.15	0.92	1.90	0.83	2.17	-	26 %
Lithuania	0.24	-0.45	1.02	2.55	0.85	2.88	-	14 %
Luxembourg	0.21	0.72	1.02	4.41	1.20	6.06	56 %	27 %
Malta	0.32	0.15	0.18	0.26	0.24	0.34	36 %	45 %
Netherlands	-0.77	-0.75	10.37	17.26	10.60	18.16	3 %	16 %
Poland	1.07	0.34	9.97	21.26	14.18	34.49	113 %	77 %
Portugal	-1.06	0.13	3.72	11.24	3.92	12.44	6 %	52 %
Romania	0.41	0.99	3.62	8.14	4.88	11.34	36 %	57 %
Slovakia	0.06	0.59	1.62	3.28	1.91	4.81	21 %	303 %
Slovenia	-0.03	-0.62	1.61	3.255	1.68	3.256	13 %	0.1 %
Spain	-1.01	0.14	15.34	67.09	15.19	68.79	-	2 %
Sweden	-1.56	-0.81	8.40	8.70	7.61	8.94	-	22 %
United Kingdom	-0.60	-0.75	41.30	55.85	39.78	61.48	-	20 %
EU-28	-0.52	-0.38	240.75	492.62	247.97	556.20	4 %	23 %

The required tax increments are calculated using long-run price elasticities, therefore the tax change needs to be implemented well ahead of the target so that the full long-run effect materializes by 2030. When it was assumed that the EU-28 countries are expected to achieve the target independently, the required tax increment varies highly between countries for both fuel types. To keep the emissions close to the target level, the gasoline price needs to increase by at least 0.15 % in Finland or by a maximum of 113 % in Poland, and the range of diesel price increases is from 0.1 % in Slovenia to 303 % in Slovakia.

When it was assumed that the EU-28 countries are expected to achieve the goal collectively, the required tax increment is 4 % on gasoline and 23 % on diesel in all of the EU-28 countries. This corresponds to a rise in the minimum tax rate by € 0.0144/liter on gasoline and € 0.0759/liter on diesel.

As shown by the wide variation in the required tax increase between countries, if the EU were able to increase the minimum tax rate for individual countries separately, it would have highly varying effects on each country in terms of tax revenue and change in consumer surplus. However, the EU can only control the common minimum tax rate. Countries that require a high tax increase would be able to avoid loss in consumer surplus while the EU collectively achieves its 2030 goal.

7. Conclusions

The review in this study showed that gasoline and diesel demand studies cover multiple theoretical and empirical frameworks. However, a majority of the studies have been based on the premise that fuel demand follows a partial adjustment structure, where it is assumed that demand converges to a long-run equilibrium. In this framework, whenever a shock happens, demand is assumed to adjust slowly over time towards the long-run equilibrium. Several studies within this framework have used time series data for a single country or panel data for multiple countries that are usually part of an economic alliance such as the OECD. The distribution of studies between the two fuels is disproportionally weighted towards gasoline. The general consensus among fuel demand studies is that both long-run price elasticities and long-run income elasticities of gasoline and diesel demand are more elastic than their short-run counterparts. The average of most studies' estimated short-run price elasticity is close to 0.2 and long-run elasticity is close to unity (Brons *et al.*, 2008).

Literature review studies have shown that elasticity estimates across gasoline and diesel demand studies vary based on the underlying model, estimation technique, data type, study area and number of exogenous factors considered in the study (Basso and Oum, 2007). When these varying elasticities are used for analyses, they will give results that differ because of the dissimilarities between the elasticities. Gasoline and diesel demand elasticities that are consistent in terms of estimation methodology are needed to analyze and forecast the effects of EU-level fuel policy across each member state. However, no study has estimated such elasticities. The present study set out to address this literature gap and provide comparable gasoline and diesel demand elasticities across the EU-28 that will eliminate the dissimilarities. To this end, short-run and long-run price and income elasticities of gasoline and diesel demand are estimated using the ARDL Bounds testing approach of Pesaran *et al.* (2001). For the estimation of each country's elasticities, a time series data on gasoline and diesel consumption and

price, number of vehicles and population is used. There are caveats in relation to the differences in data availability between the countries. The time length of the data for some countries is longer than others. Due to a lack of sufficient data, the number of vehicles in the estimation is not disaggregated to diesel and gasoline-powered vehicles. Therefore it is not possible to observe fuel-switching behavior from the estimation. Due to a multicollinearity problem in some countries, the diesel price is not included in the estimation of gasoline demand and *vice versa*. Even though this does not compromise the robustness of the estimation, it is not possible to infer cross-price elasticities (Dahl, 2012).

The result of the estimation shows that elasticities vary considerably between the EU-28 countries. The variation in the estimated elasticities ranges from -0.005 to 6.49. The average short-run price elasticity of gasoline is estimated to be -0.17 and the long-run is -0.73. The short-run income elasticity of gasoline demand is estimated to be 0.46 and the long-run is 1.45. The average estimated short-run price elasticity of diesel demand is -0.13 and the long-run is -0.5. The average short-run income elasticity of diesel demand is more elastic than the average short-run income elasticity of gasoline demand. However, the average long-run income elasticity of diesel demand is less elastic than the average long-run income elasticity of gasoline demand. The average short-run income elasticity of diesel demand is 0.66 and the average long-run income elasticity is 1.36.

Both short-run and long-run income elasticities of gasoline and diesel demand are found to be more elastic than their price equivalents. This implies that if a policy intends to decrease emissions by increasing price, then price needs to rise faster than income, which is in line with the findings of Graham & Glaister (2002, 2004). Moreover, the variation in elasticities between countries did not show any strong systematic relationship with income. This is in contrast to the argument of Dahl (2012), but in line with the findings of Goodwin *et al.* (2004), who were also not able to formulate a systematic pattern to explain the variations.

Using the estimated elasticities, the final section evaluated the achievability of the EU's 2030 environmental goal of emission reduction from the transport sector. Each country's demand characteristics are reflected in the estimated elasticity and different tax levels for each country would be required to achieve the environmental goals. However this approach is not practical on an EU level and the goal can be achieved by raising the common minimum tax rate on gasoline and diesel. Differences in the countries' demand characteristics imply that imposing a common tax would benefit some countries more than others. The analysis of the EU's long-term transport emission reduction targets using the estimated long-run elasticities shows that there is no guarantee that the goal will be achieved with the current tax level, and thus a more stringent fuel tax policy is required.

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9. Appendix

9.1. Selected model, cointegration test and serial correlation test

Table 9: Gasoline demand estimation

Country	Selected Model (lg lpg lgdp lvt)	Cointegrating coefficient	Break Years	Test statistic value F-statistic	10% I0	10% I1	5% I0	5% I1	1% I0	1% I1	LM(1)
Austria	ARDL(1, 1, 0, 0)	-0.41* (0.099)	1992, 2008	4.338**	2.37	3.2	2.79	3.67	3.65	4.66	0.904
Belgium	ARDL(4, 4, 4, 4)	-0.4* (0.06)	1986, 1989, 1996, 2007	5.225*	2.01	3.1	2.45	3.63	3.42	4.84	1.451
Bulgaria	ARDL(4, 2, 0)	-0.701* (0.168)	-	5.197**	2.17	3.19	2.72	3.83	3.88	5.3	0.037
Croatia	ARDL(1, 0, 0, 0)	-0.38* (0.102)	2008	5.975*	2.37	3.2	2.79	3.67	3.65	4.66	0.502
Cyprus	ARDL(1, 0, 0, 1)	-0.01** (0.004)	1984, 2000, 2004, 2008	1.989	2.01	3.1	2.45	3.63	3.42	4.84	0.376
Czech Republic	ARDL(1, 0, 1, 0)	-0.52* (0.11)	2003	5.431*	2.37	3.2	2.79	3.67	3.65	4.66	1.654
Denmark	ARDL(1, 0, 0, 0)	-0.108* (0.011)	1991, 2000, 2006	9.744*	2.37	3.2	2.79	3.67	3.65	4.66	2.557
Estonia	ARDL(3, 0, 0, 2)	-0.501* (0.085)	1994, 1998, 2002	1.392	2.97	3.74	3.38	4.23	4.3	5.23	1.393
Finland	ARDL(2, 2, 0, 0)	-0.171* (0.031)	1995	3.962***	2.97	3.74	3.38	4.23	4.3	5.23	0.265
France	ARDL(1, 2, 0, 1)	-0.274* (0.03)	2008	12.434*	2.97	3.74	3.38	4.23	4.3	5.23	1.194
Germany	ARDL(1, 0, 0, 0)	-0.04* (0.01)	1994, 2000	4.608**	2.97	3.74	3.38	4.23	4.3	5.23	0.147
Greece	ARDL(1, 0, 0, 4)	-0.468* (0.063)	2008	9.413*	2.97	3.74	3.38	4.23	4.3	5.23	0.187
Hungary	ARDL(1, 0, 0, 0)	-0.416* (0.063)	1989	5.748*	2.97	3.74	3.38	4.23	4.3	5.23	0.598
Ireland	ARDL(1, 3, 0, 0)	-0.44* (0.062)	1995	8.968*	2.97	3.74	3.38	4.23	4.3	5.23	1.721
Italy	ARDL(4, 2, 4, 0)	-0.328* (0.07)	1989, 1996	3.286***	2.37	3.2	2.79	3.67	3.65	4.66	2.369
Latvia	ARDL(3, 2, 2)	-0.995* (0.109)	1998, 2004	8.51*	3.38	4.02	3.88	4.61	4.99	5.85	2.702
Lithuania	ARDL(1, 0, 0, 2)	-0.357* (0.051)	2002	3.916**	2.37	3.2	2.79	3.67	3.65	4.66	0.120
Luxembourg	ARDL(2, 3, 3, 0)	-0.534* (0.103)	-	4.444**	2.97	3.74	3.38	4.23	4.3	5.23	0.582
Malta	ARDL(3, 0, 1, 1)	-0.511* (0.045)	2001, 2008	10.118*	2.97	3.74	3.38	4.23	4.3	5.23	2.966***
Netherlands	ARDL(3, 4, 1, 4)	-0.132* (0.024)	1985, 1988, 1996, 2006	0.412	2.37	3.2	2.79	3.67	3.65	4.66	1.170
Poland	ARDL(1, 0, 0, 0)	-0.808* (0.239)	2002	4.102***	2.97	3.74	3.38	4.23	4.3	5.23	0.238
Portugal	ARDL(1, 2, 0, 3)	-0.083* (0.011)	2000	7.506*	2.37	3.2	2.79	3.67	3.65	4.66	0.223
Romania	ARDL(2, 2, 0, 1)	-0.447* (0.045)	1996, 2008	6.719*	2.37	3.2	2.79	3.67	3.65	4.66	2.572

Slovakia	ARDL(1, 0, 0, 1)	-0.974* (0.24)	1997, 200, 2004	1.911	2.37	3.2	2.79	3.67	3.65	4.66	1.405
Slovenia	ARDL(1, 0, 0, 2)	-0.781* (0.151)	2000	3.239***	2.37	3.2	2.79	3.67	3.65	4.66	0.835
Spain	ARDL(3, 3, 0, 0)	-0.082* (0.015)	1989	6.389*	2.01	3.1	2.45	3.63	3.42	4.84	0.040
Sweden	ARDL(3, 3, 4, 3)	-0.136* (0.017)	1988, 1993, 2002, 2007	9.669*	2.97	3.74	3.38	4.23	4.3	5.23	1.725
United Kingdom	ARDL(1, 3, 4, 2)	-0.299* (0.051)	1999, 2006	5.891*	2.97	3.74	3.38	4.23	4.3	5.23	1.141

Note: lg is log of gasoline consumption per driver, lpg is log of real price of gasoline, lgdp is log of real GDP per capita, lvt is log of number of vehicles per driver. (lg lpg lgdp lvt) indicates the order of the variables lag in the selected model. *, ** and *** denote significance at 1 %, 5 % and 10 % respectively. Standard errors are in parenthesis. LM(1) is Breusch-Godfrey Lagrange multiplier test of up to 1 lag

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Table 10: Diesel demand estimation

Country	Selected Model (ld lpd lgdp lvt)	Cointegrating coefficient	Break Years	Bounds test Test statistic value F-statistic	Critical value bounds 10% I0	I1	5% I0	I1	1% I0	I1	LM(1)
Austria	ARDL(2, 3, 3, 0)	-0.277* (0.049)	1996	3.546***	2.37	3.2	2.79	3.67	3.65	4.66	1.130
Belgium	ARDL(3, 2, 1, 1)	-0.797* (0.109)	1988, 1996, 2008	10.692*	2.01	3.1	2.45	3.63	3.42	4.84	0.637
Bulgaria	ARDL(2, 0, 2, 1)	-0.88* (0.239)	1997, 2009	5.664*	2.37	3.2	2.79	3.67	3.65	4.66	0.299
Croatia	ARDL(1, 0, 0, 0)	-0.401** (0.131)	1998, 2003, 2010	2.877	2.37	3.2	2.79	3.67	3.65	4.66	1.823
Cyprus	ARDL(1, 0, 0, 0)	-0.267* (0.092)	1995	2.497	2.01	3.1	2.45	3.63	3.42	4.84	1.855
Czech Republic	ARDL(1, 0, 0, 0)	-0.076* (0.015)	2005	4.223**	2.01	3.1	2.45	3.63	3.42	4.84	1.865
Denmark	ARDL(2, 5, 5, 5)	-0.276** (0.071)	1988	1.451	2.97	3.74	3.38	4.23	4.3	5.23	0.001
Estonia	ARDL(5, 0, 0, 0)	-0.755** (0.21)	1996, 2001, 2010	0.433	2.97	3.74	3.38	4.23	4.3	5.23	0.168
Finland	ARDL(1, 2, 3, 2)	-0.605* (0.099)	1994	7.116*	2.01	3.1	2.45	3.63	3.42	4.84	0.739
France	ARDL(1, 0, 0, 0)	-0.315* (0.059)	1997, 2002, 2007	5.539*	2.37	3.2	2.79	3.67	3.65	4.66	0.032
Germany	ARDL(1, 0, 0, 1)	-0.534* (0.075)	1989, 1999, 2008	6.478*	2.97	3.74	3.38	4.23	4.3	5.23	0.366
Greece	ARDL(1, 2, 0, 0)	-0.835* (0.175)	2003	4.141**	2.37	3.2	2.79	3.67	3.65	4.66	0.358
Hungary	ARDL(2, 2, 2, 2)	-0.226* (0.02)	1991, 1998, 2005, 2009	12.473*	2.97	3.74	3.38	4.23	4.3	5.23	2.575
Ireland	ARDL(4, 0, 2, 0)	-0.643* (0.135)	2009	2.768	2.01	3.1	2.45	3.63	3.42	4.84	2.433
Italy	ARDL(4, 4, 4, 5)	-0.446* (0.033)	1993, 2007	29.327*	2.97	3.74	3.38	4.23	4.3	5.23	2.393
Latvia	ARDL(5, 0, 0, 0)	-0.914* (0.207)	1998, 1999, 2004	3.833**	2.37	3.2	2.79	3.67	3.65	4.66	1.426
Lithuania	ARDL(3, 1, 0, 0)	-0.663* (0.12)	1998, 2000, 2009	21.492*	2.37	3.2	2.79	3.67	3.65	4.66	0.018
Luxembourg	ARDL(1, 3, 0, 4)	-0.429* (0.062)	1994, 1991	4.759**	2.97	3.74	3.38	4.23	4.3	5.23	1.907
Malta	ARDL(1, 0, 0, 0)	-0.67 (0.677)	2002, 2005, 2009	1.797	2.37	3.2	2.79	3.67	3.65	4.66	0.001
Netherlands	ARDL(1, 0, 0, 0)	-0.278* (0.078)	1983	3.640***	2.37	3.2	2.79	3.67	3.65	4.66	0.469
Poland	ARDL(1, 1, 1, 0)	-0.357** (0.138)	2000	0.633	2.01	3.1	2.45	3.63	3.42	4.84	0.249
Portugal	ARDL(1, 1, 2, 2)	-0.199* (0.041)	1996, 2008	4.310**	2.97	3.74	3.38	4.23	4.3	5.23	1.473
Romania	ARDL(1, 2, 3, 3)	-0.77* (0.168)	1999	1.259	2.37	3.2	2.79	3.67	3.65	4.66	7.824*

Slovakia	ARDL(3, 0, 0, 0)	-0.389* (0.109)	2001, 2004, 2009	4.120**	2.37	3.2	2.79	3.67	3.65	4.66	0.049
Slovenia	ARDL(2, 2, 0)	-0.241** (0.09)	2008, 2009	1.018	2.63	3.35	3.1	3.87	4.13	5	4.986**
Spain	ARDL(4, 4, 4, 4)	-0.438* (0.079)	1987, 2002, 2008	4.163**	2.37	3.2	2.79	3.67	3.65	4.66	0.513
Sweden	ARDL(3, 0, 1, 0)	-0.532* (0.087)	1983	5.063*	2.37	3.2	2.79	3.67	3.65	4.66	0.707
United Kingdom	ARDL(1, 0, 1, 0)	-0.161* (0.03)	-	8.569*	2.97	3.74	3.38	4.23	4.3	5.23	0.984

Note: ld is log of diesel consumption per driver, lpd is log of real price of diesel, lgdp is log of real GDP per capita, lvt is log of number of vehicles per driver. (ld lpd lgdp lvt) indicates the order of the variables lag in the selected model. *, ** and *** denote significance at 1 %, 5 % and 1 0% respectively. Standard errors are in parenthesis. LM(1) is Breusch-Godfrey Lagrange multiplier test of up to 1 lag

9.2. Stability test of estimated model

9.2.1. Gasoline demand CUSUM and CUSUMSQ plots
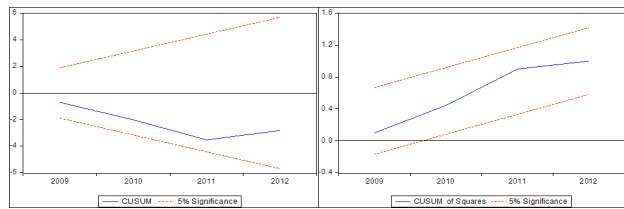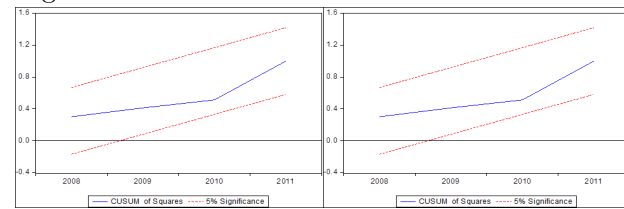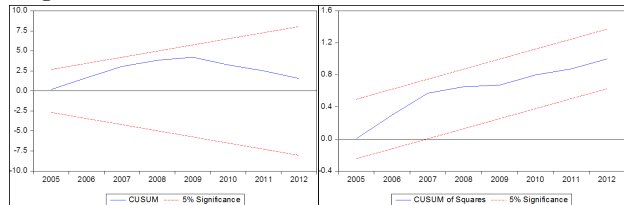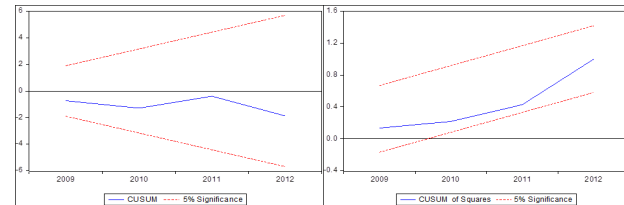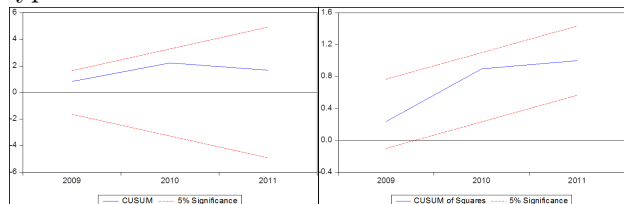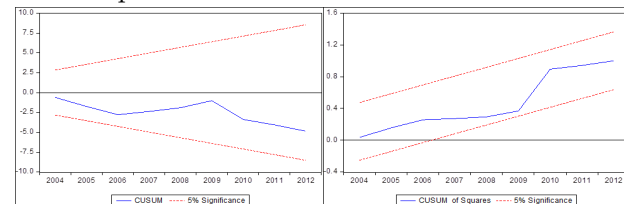
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Belgium

Bulgaria

Croatia

Cyprus

Czech Republic

Denmark
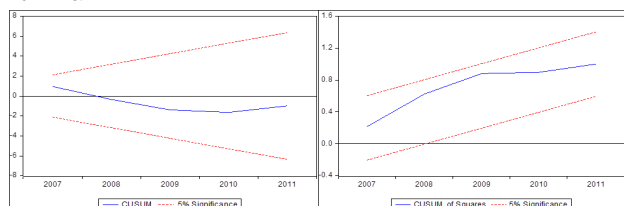
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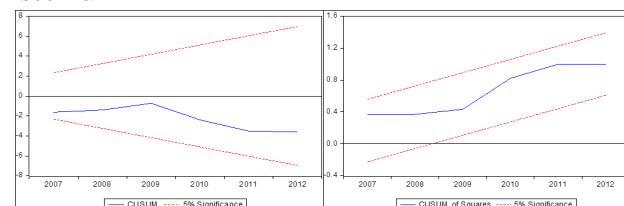
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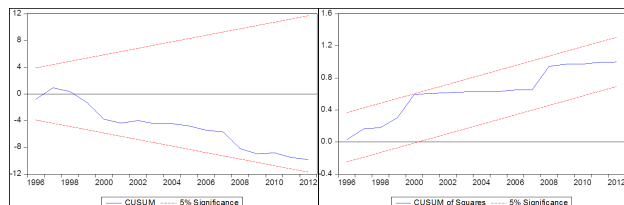
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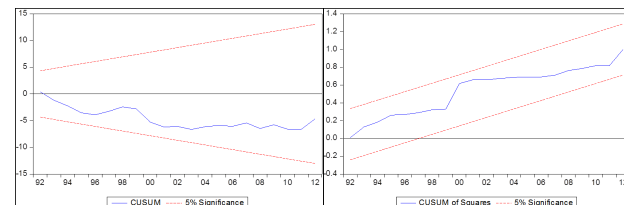
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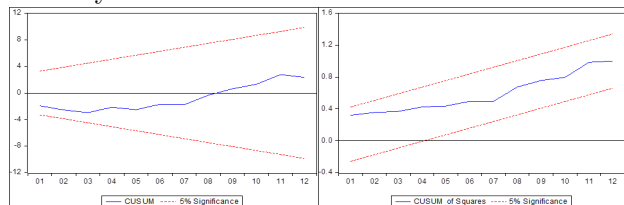
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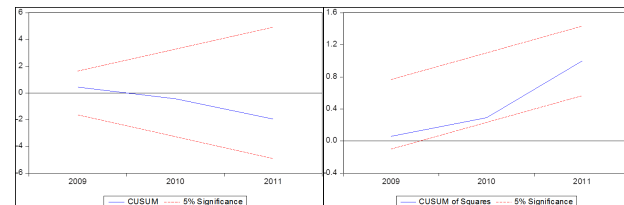
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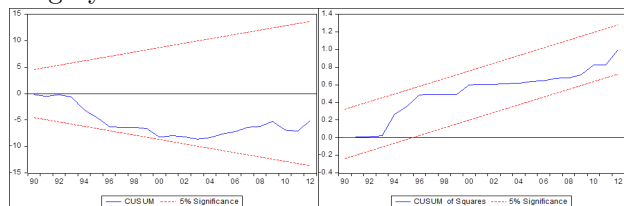
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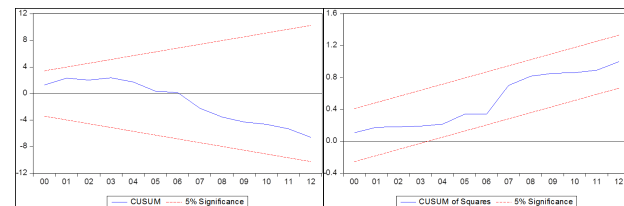
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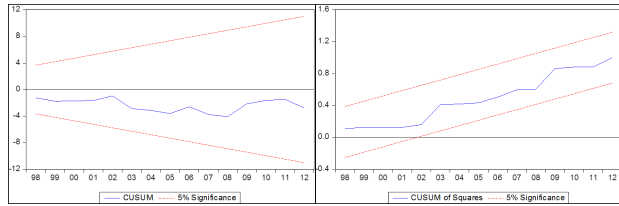
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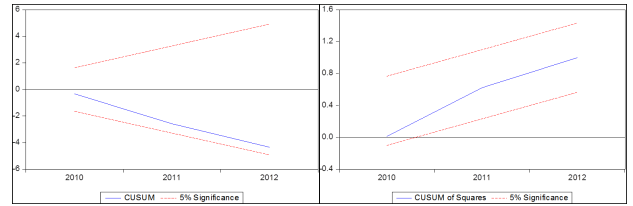
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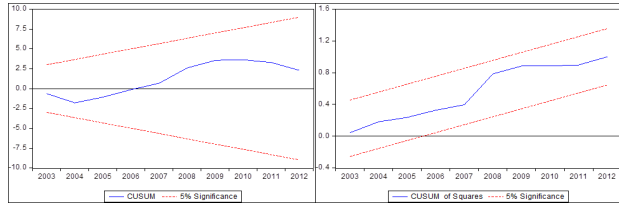
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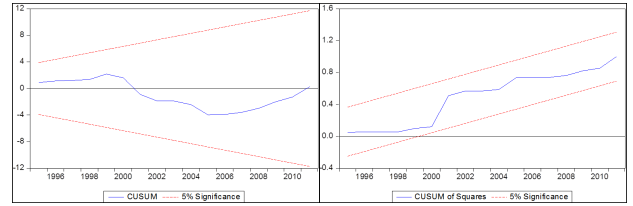
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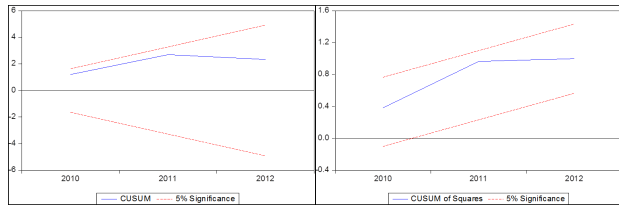
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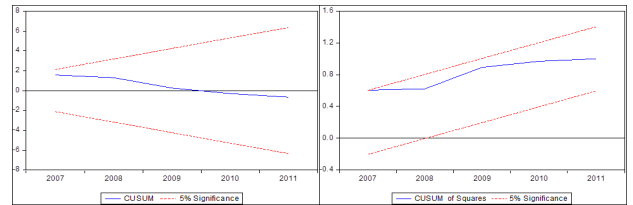
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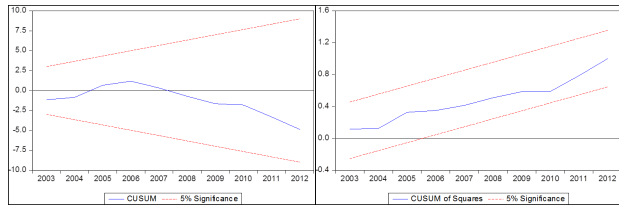
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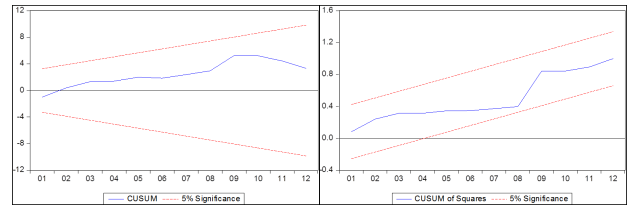
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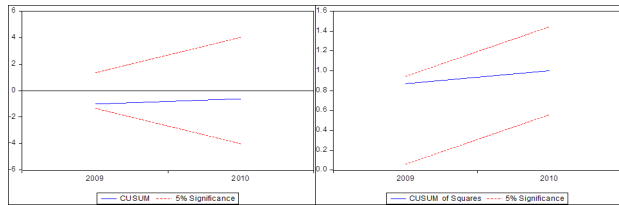
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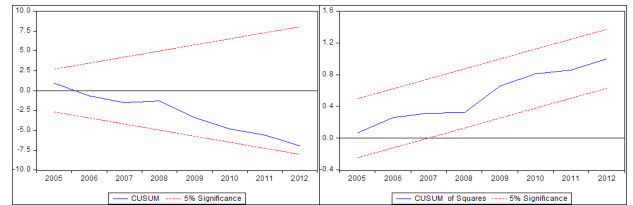
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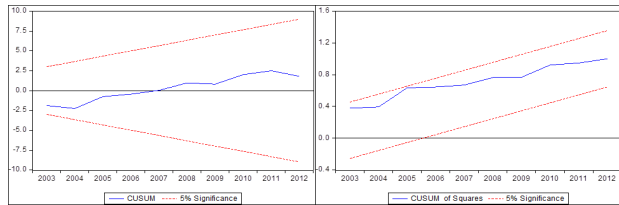
Spain
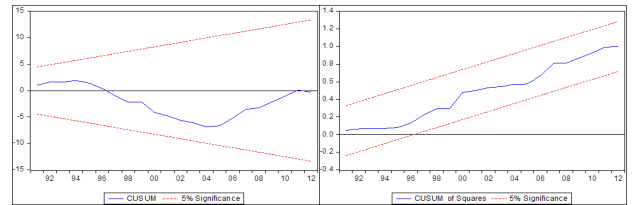
Sweden
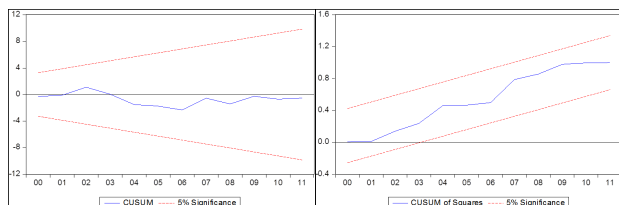
United Kingdom
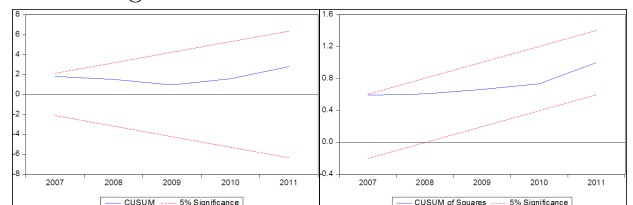
9.2.2. Diesel demand CUSUM and CUSUMSQ plots

Austria

Belgium

Bulgaria

Croatia

Cyprus

Czech Republic

Denmark

Estonia

Finland

France

Germany

Greece

Hungary

Ireland

Italy

Latvia

Lithuania

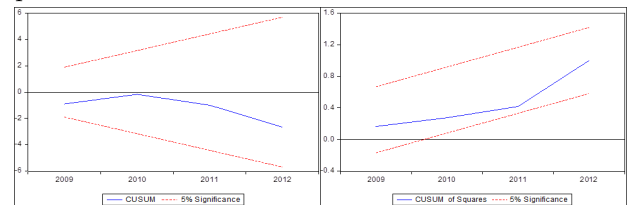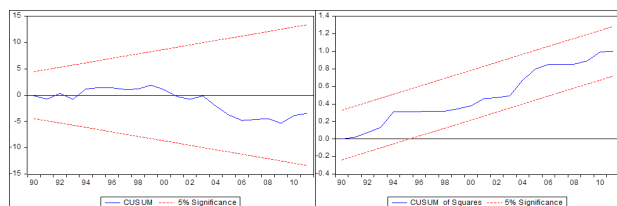
Luxembourg

Malta

Netherlands

Poland

Portugal

Romania

Slovakia

Slovenia

Spain

Sweden

United Kingdom

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