THE IMPACT OF FUEL PRICE CHANGES ON TRAFFIC DEMAND: THE CASE OF A GREEK MOTORWAY CORRIDOR

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ABSTRACT

The crisis beginning in late 2008 in Greece, and still in progress, led the Greek Government to undertake a particularly harsh program aimed at restoring the primary budget surplus. The implementation of such a financial program has dramatically increased fuel taxes - about

82% for unleaded and 31% for diesel – also producing a serious impact on traffic demand. This paper deals with the analysis of impacts of fuel price growth on traffic volumes along the Elefsina – Korinthos – Patra – Pyrgos – Tsakona (EKPPT) Greek motorway corridor.
Starting from the traffic data analysis related to the 2006 – 2011 period, and according to the outcomes of the technical literature review, a first exercise of fuel price elasticity has been carried out. The aim was to assess the effects of fuel price growth on traffic demand in the short and long term scenarios, choosing the fuel price as explanatory variable but including the effects of toll fare and income level changes recently occurred in Greece. Moreover, taking into account the identified elasticity values - and in order to isolate the effects on traffic changes of fuel price fluctuations from other variables affecting traffic demand - a simplified macro-econometric model was also developed. Both such methodologies have provided specific and reliable fuel price elasticity values, which were also consistent with the main literature findings.

Keywords: road transport, fuel price elasticity, traffic demand

THE GEOGRAPHICAL FRAMEWORK

The crisis beginning in late 2008 in Greece, and still in progress, led the Greek Government to undertake a particularly harsh program under the joint auspices of the International Monetary Fund, the European Union and the European Central Bank in order to restore the primary budget surplus. The implementation of this program in which are included specific taxes on fuel (levies and VAT) and the resulting economic recession has had a serious impact also on traffic volume on the EKPTT motorway.
The EKPPT motorway corridor is a stretch of 365 kilometers length toll road project, starting from Elefsina on the outskirts of Athens, through Korinthos to Patra and beyond to Pyrgos and Tsakona, in the South - West of the Peloponnese. Two motorway sections are operating - Athens to Korinthos and also to a lesser degree Korinthos to Patra where the existing road is being completely rebuilt to modern motorway standards - and the rest has not yet been built. In detail, the Elefsina – Korinthos section (Figure 1) is a six-lane toll road that extends for 63 km, where tolls are currently collected at two one-way toll plazas located at Elefsina (westbound toll) and Isthmos (eastbound toll) and at two ramp toll plazas located at Nea Peramos and Ag. Theodori; a further ramp toll plaza is planned at Pachi. On this section the two-way traffic volumes have fallen more by 20% in the 2006-2011 period, with a 10% average decrease between 2010 and 2011. Regarding the existing un-tolled roads alternative to the motorway corridor, there is a parallel route which runs along the coast and links Elefsina to Korinthos in about 70 minutes and a local diversion route around the Elefsina toll plaza, only suitable for light vehicles.

Figure 1 – The Elefsina – Korinthos motorway section

The Korinthos – Patra section (Figure 2) is to be upgraded to full motorway standard, by widening some existing sections and constructing some completely new sections on a different alignment.

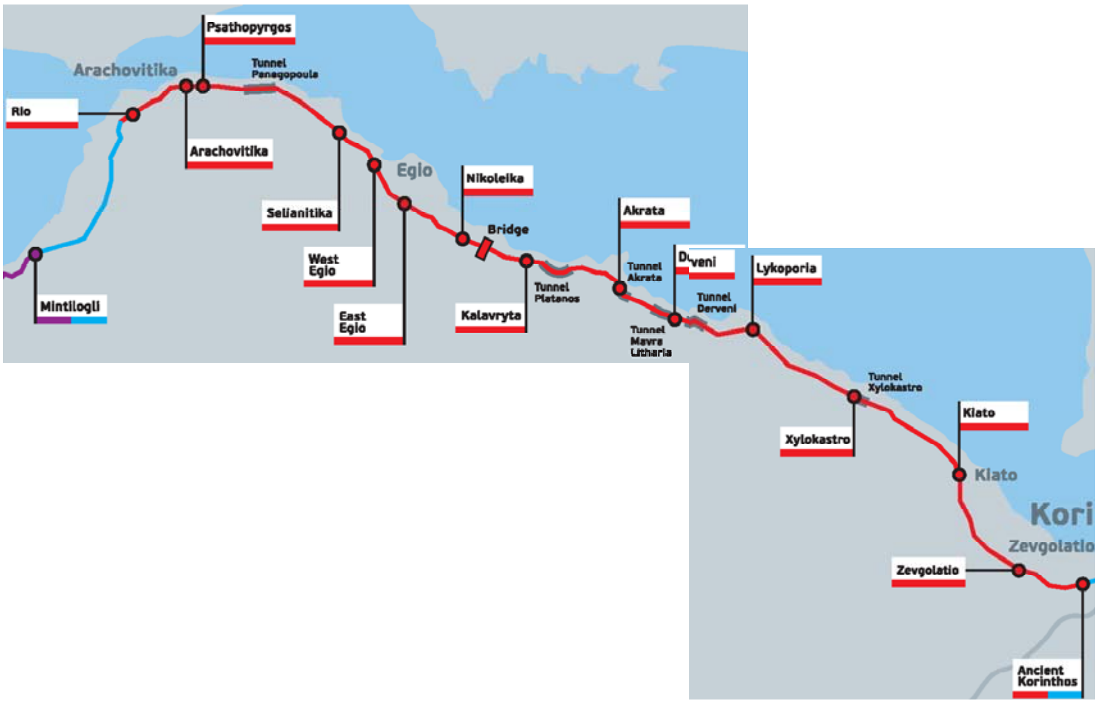


Figure 2 - The Korinthos –Patra motorway section

Currently the road is a 120 km grade-separate highway, mostly single-carriageway, with a high accident rate, which makes this section one of the most dangerous highways in Europe. Tolls are collected at two one-way mainline plazas, located at both ends of the section; a third mainline toll station is planned at Nikoleika. In this section total traffic has fallen by approximately 24% from 2006 to 2011, with a relevant decrease accounting for 12% between 2010-2011. Between Korinthos and Patra the old coastal road runs parallel to the motorway; current journey time between Korinthos and the junction with the Patra Bypass is about 130 minutes. Currently the observed flows imbalance at the one-way toll plazas is respectively around 1,000 vehicles per day at Zevgolatio and 3,000 vehicles per day at Rio.

DATA ANALYSIS

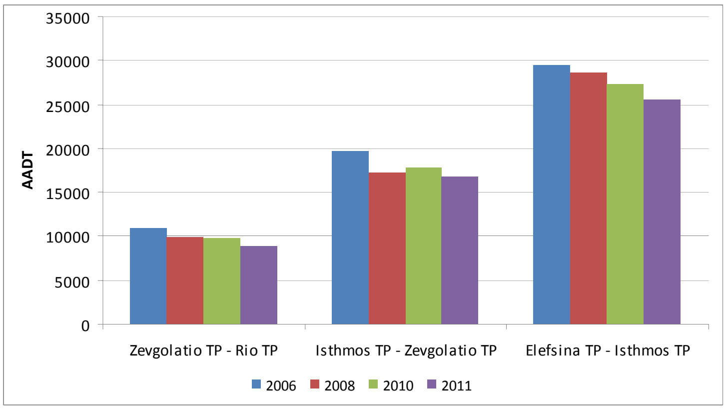
Traffic counts

Traffic counts data collected from March 2006 to June 2011 at 10 survey stations, located both along the motorway "toll corridor" and on "toll-avoiding" roads parallel to the motorway, were analysed, in order to provide a reliable snapshot of the important traffic volume fluctuations in both directions along the entire corridor and compare the variation trends occurring on the motorway corridor with those on the no-tolled corridor parallel to the motorway. Focus has been also put on the toll diversion rate and its changes, compared to the real fuel price growth and the GDP trends since the beginning of the economic crisis.
With reference to the toll corridor, traffic count data collected along the Elefsina – Patra corridor have been collected from three sections running from East to West, as follows:

- Elefsina Toll Plaza – Isthmos Toll Plaza;
- Isthmos Toll Plaza – Zevgolatio Toll Plaza;
- Zevgolatio Toll Plaza –Rio Toll Plaza

and the Average Annual Daily Traffic (AADT) values have been determined for each. To this end, Figure 3 shows the changes in traffic volume along the motorway corridor over a five-year period (2006 to 2011) in both directions: a) to Patra, b) to Athens.

a) *to Patra*



b) *to Athens*

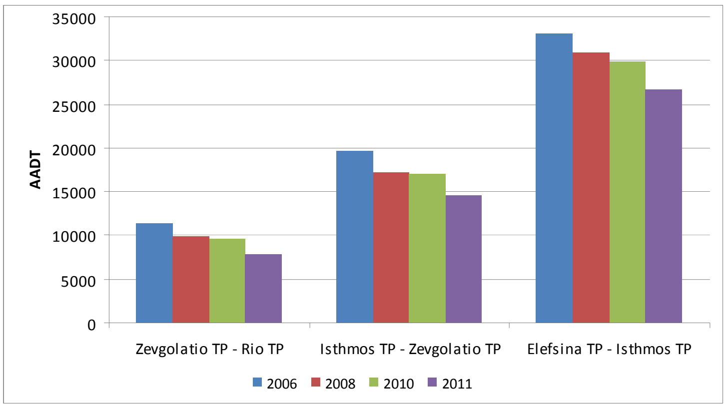
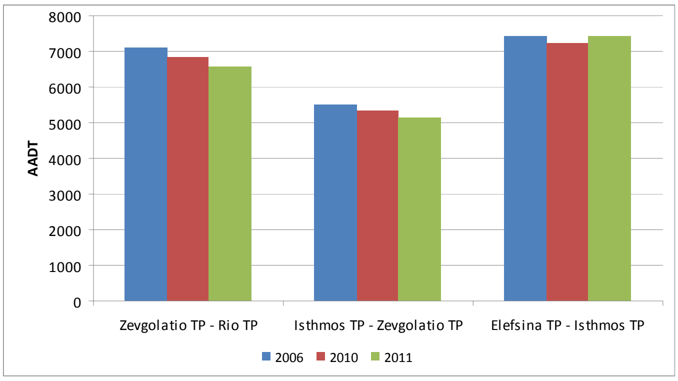


Figure 3 - AADT changes on the toll corridor

Overall, it is notable that a significant fall in traffic volume was identified on the whole corridor for every time period (except for the Isthmos Toll Plaza – Zevgolatio Toll Plaza stretch, between 2008 and 2010) with the majority of this decrease occurring on the Zevgolatio Toll Plaza – Rio Toll Plaza section. Looking at the graph, over the whole five-year period, an average decrease of approximately 20.5% is evident, respectively -25.3% in the eastbound direction and -15.7% in the westbound one. More specifically, during the first two-year period (2006-2008), traffic flows fell significantly in both directions (-9% towards Patra and –11% towards Athens) while between 2008 and 2010 traffic volumes remained fairly constant: a decrease of around -0.9% and -3.3% occurred respectively towards Patra and Athens. Nevertheless the highest decrease occurred in the last 12 months: from 2010 to 2011 there has been a fall of around -7% towards Patra and -14% towards Athens; this means that traffic volumes decreased approximately double compared with the annual-based trends registered from 2006 and 2010.

Regarding the toll-avoiding corridor, the automatic traffic counts from five survey stations located on roads parallel to the toll plazas have been combined according to the corridor sections articulation in order to define AADT values comparable with those registered on the toll corridor. Figure 4 presents the AADT variations along the toll avoiding corridor.

a) to Patra



b) *to Athens*

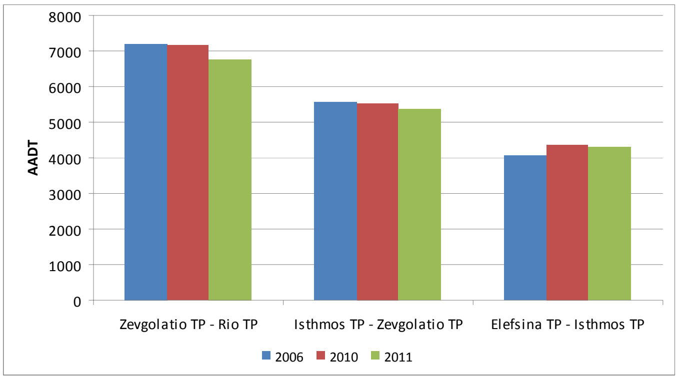


Figure 4 - AADT changes on the toll-avoiding corridor

The key information in the comparison of this graph with the previous one (Figure 3) is that in the five-year period of analysis, traffic demand was fairly similar on the routes parallel to the motorway; an average decrease of merely -1.4% was registered. Moreover, in the Elefsina Toll Plaza – Isthmos Toll Plaza section, a low increase of traffic demand was registered between 2006 and 2010 towards Athens (+7.0%) and between 2010 and 2011 towards Patra (2.8%); the former is mostly due to a growth accounting for around 500 vehicles per day at survey station D (Old National Road, between Kineta and Ag. Theodori) and the latter mostly to a growth of over 600 vehicles per day registered at survey station C (Service Road).

Nevertheless, it can be seen that an overall decrease occurred in the toll avoiding corridor, considering both the five-year period from 2006 to 2011(-4.7% towards Patra and –1.3% towards Athens) and the last 12 months (-1.5% towards Patra and –3.9% towards Athens). The diverted traffic due to the toll can be identified from the directional imbalance in flows registered on the alternative routes parallel to the toll plazas. Figure 5 shows the flow asymmetry displayed at all the stations surveyed in 2011 on the toll avoiding corridor (Station S: Isthmos, located on the Old National Road, 800m East of the first intersection Paleo Kalamaki).

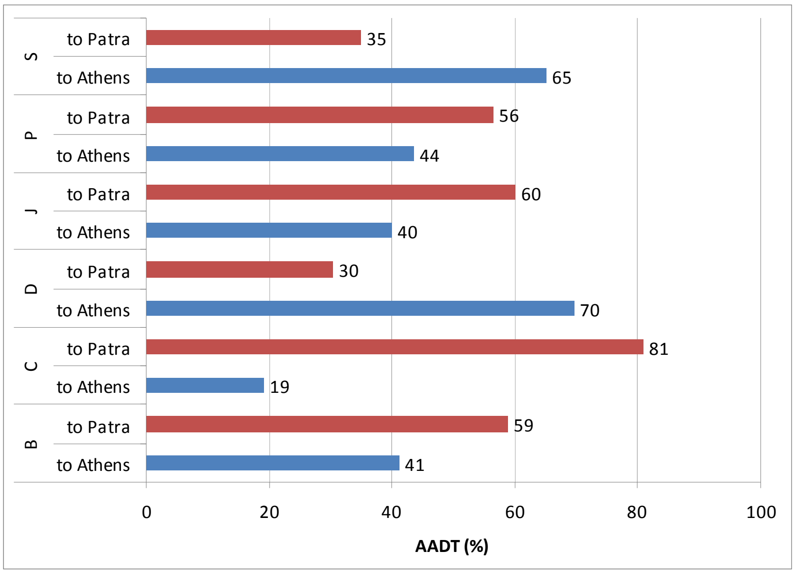


Figure 5 - Directional traffic imbalance on the toll-avoiding corridor

The diverted traffic peaked at survey station C, located on the Service Road close to the Elefsina Toll Plaza, with a directional traffic imbalance of more than 7,700 vehicles per day towards Patra and at survey station D, located on the Old National Road between Kineta and Agh. Theodori ramps, with a directional traffic imbalance of about 2,400 vehicles towards Athens.

Whole corridor

The traffic volume data reported in previous section for the toll corridor and for the toll avoiding corridor was then combined to provide a reliable analysis of traffic movements along the entire Elefsina – Patra corridor. Figure 6 shows the two-way AADT changes in the total corridor from 2006 to 2011, along with variations registered in the toll corridor and in the toll avoiding corridor.

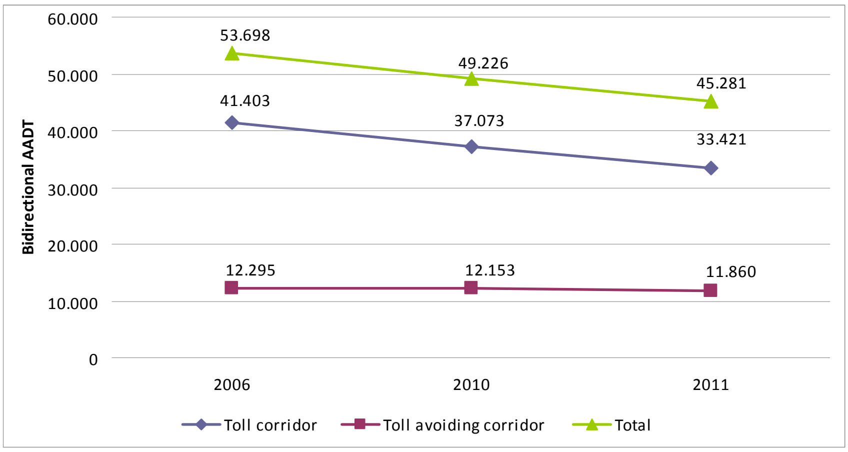


Figure 6 - Bidirectional AADT changes on the whole corridor

It is noteworthy that the traffic demand from Athens to Patra and vice versa have been assigned only to the motorway or to the routes parallel to the motorway surveyed in the traffic counts campaigns, because of the physical constraints that form the boundaries of the corridor. Moreover, the percentage changes are reported in Table 1.

Table 1 - AADT changes along the whole corridor

AADT changes	Δ 2006/10	Δ 2010/11
Whole corridor	-15.7%	-8.0%
Toll corridor	-19.2%	-9.8%
Toll avoiding corridor	-3.5%	-2.4%

The traffic volumes appear to have fallen by 15.7% in the whole corridor between Elefsina and Patra from the beginning of the concession period until now; with a decrease of around 8.0% observed from 2010 to 2011. In terms of AADT, a total decrease accounting for around -8,400 vehicles per day was registered in the 2006-2011 period with the majority of this decrease occurring on the toll corridor (-7,900 vehicles per day). Looking at the graph, it stands out that between 2006 and 2010 traffic volumes remained fairly constant on the toll-avoiding corridor (-1.1%) and fell significantly on the toll corridor (-10.4% of daily flows resulting in around -4.400 vehicles per day). During the past year also an additional decrease was registered both on the toll corridor (-9.8%) and on the toll-avoiding corridor (-2.4%).

FIRST EXERCISE ON FUEL PRICE ELASTICITY

The transferability of traffic elasticity results from literature

The review of the technical literature has allowed the identification of key concepts dealing with the road traffic elasticity, with respect to selected variables. In order to provide a comprehensive framework of the research context a broad analysis on the elasticity issue was produced, focussing on elasticity of road traffic demand (and fuel consumption) with respect to income and prices as well as with respect to toll.

Such an analysis provided an outline of road elasticity-related criteria and principles that have featured the past European and worldwide approaches and practices, also including analytical reference values both for short and long-run scenarios. The literature review also illustrated some strong, repeated and consistent results on road traffic-related demand elasticities and the relationship between their magnitudes. With reference to price and income, the main well-established results can be summarized as follows:

- the effects of a traffic demand increase both for price and income are opposite to the effects of a reduction; most of the studies analysed assume a "symmetrical" elasticity behaviour (Goodwin, Dargay and Hanly, 2004);
- price elasticity analyses are commonly based on real prices, adjusted for inflation, and not on nominal or current prices (Litman, 2011);
- although elasticities are often reported as single, point estimates, there are many factors affecting the price sensitivity of a particular "good". Elasticities are actually functions of several possible variables, including the type of market, type of consumer and time period (Litman, 2011);
- transportation elasticities tend to increase over time as consumers have more opportunities to take prices into effect when making long-term decisions. This means that the full effect of a price change often takes many years (Button 1993; Dargay and Gately 1997). Long-run elasticities are commonly greater than short-run elasticities by factors of 2-3 (Goodwin et al., 2004);
- the relatively low driving elasticity with respect to fuel prices hides a much higher overall driving elasticity. Fuel is only about a quarter of the total cost of driving. An elasticity of –0.3 for vehicle travel with respect to fuel price indicates that the overall price elasticity of driving is about –1.2, making driving an elastic "good" in relation to total vehicle costs (Litman, 2011).

It is important to note that such a technical review showed that the existence of heterogeneous environments as well as different operating and surrounding conditions leads to the estimation of different road traffic related elasticities. Furthermore, the elasticity values are not stable over time and the related magnitudes are mainly influenced by economical and financial conditions and by geographical frameworks. This means that, the matter being quite complex, there is not a specific "recipe" for applying the transferability procedure "as/is" to the Greek situation. Nevertheless, despite the heterogeneity of the available studies, the transferability exercise has taken its origin from some similarities in the literature analysis and a set of different elasticity typologies ranges, which could likely be transferred to the Greek situation, is summarized in Table 2.

Table 2 - Possible ranges of elasticities (to be referred to the Greek case)

Elasticity Typologies	Short run	Long run
Car trips elasticity with respect to fuel price	-0.18 and -0.30	-0.35 and -0.70
Car-km elasticity with respect to fuel price	0.05 and -0.16 (-0.10 on average)	-0.25
Car trips elasticity with respect to generalized cost	-0.70 to -1.0	-1.0 to -2.0
GDP elasticity with respect to VOT	+0.8 and +1.00	
Car trips elasticity with respect to vehicle operating costs	-0.15 to -0.25	
Car trips elasticity with respect to toll	-0.15 to -0.20	
Fuel demand elasticity with respect to income	+0.39 to +1.00	

Evaluation of the effects of the fuel prices and tax changes on traffic demand

Traffic demand elasticity with respect to price is a dynamic variable (both for the generalised cost of transport and for its various components), considering that it varies over time for a considerable period following the price changes. This widely recognised assumption has at least three implications significant in the evaluation exercise:

- if the response to changes in costs takes place over time, then in a time when price stability is absent, traffic registered at a specific point of the demand function cannot be analysed considering that the observed demand is in equilibrium with the observed travel cost, with the well-known computational consequences (Goodwin, 2002);
- a 20% travel cost increase in real price in year one followed by a cost decrease of 25% in year two, leading to a 10% overall reduction, will have a different effect on demand with respect to a change of 10% in real price in year two (Balcombe et al., 2004);
- there are many reasons why it makes sense that the range of response is greater in the long-run than in the short-run. Firstly, users' behaviour is mostly affected by habits which may change gradually, even when they fully appreciate the change in travel cost. Secondly, in the short term, some travellers will be constrained to not change their behaviour by various factors (e.g. workplace and residential locations are commonly considered relatively fixed in the short-run, whereas they can change in the long-run) (Goodwin, 2002; Litman, 2005; Balcombe et al., 2004).

As a consequence, presently it is common for analysts to distinguish between short and long-run effects of price elasticities on traffic demand. There are different definitions of short and long-run (sometimes also medium-run elasticity values are considered) based on the length of the time period considered or on assumptions about users' behaviour. Goodwin (in Goodwin et al, 2004) define short-run as "*the responses made within one period of the data used for the study, most commonly, in this context, within one year" and long-run as "the asymptotic end state when responses are completed*."
Once again the broad relationship existing between income level and road traffic demand should be noted. It is statistically tested that income growth can be expected to increase the number of trips and their length in all transportation modes. In almost all Western European Countries, total passenger-km has risen by approximately 1 to 2% per year, a little less than the growth in real GDP (Balcombe et al., 2004); moreover, empirical evidences exist which suggest that as people become wealthier the proportion of income devoted to transport increases. For instance, according to the data from the Family Expenditure Survey of Great Britain, the household expenditures on travel have increased over time, from 14.9% in 1981 (14.8 not including air travel expenditures) to 17.2% in 2000 (16.9 not including air travel expenditures).
All these direct effects are commonly considered in the traffic demand elasticity with respect to income level. But, the full income elasticity also includes an indirect effect (via the value of time) on the road traffic elasticity with respect to price. To the best of the authors' knowledge,

no empirical study has tested the twofold effect of income on traffic demand elasticity or has quantitatively assessed this effect, and, as stressed in Hanly et al. (2002), such an indirect effect *"is rarely if ever made explicit, though it will be embodied in modelled outputs and therefore be relevant for interpretation".*
As a consequence, the results presented below show different fuel price elasticity ranges of values estimated considering the fuel price as explanatory variable, but including the effects of the changes in toll fares and in the income level occurring in Greece in recent years.

Short-term scenario

A specific model has been used in order to assess the fuel price elasticity on traffic demand in the short-term scenario. The mathematical arc elasticity formulation is one of several formulations existing in literature, but it seems to respond better to the lack of stability of the elasticity value due to the strong variation of the variables affecting the transportation demand during a crisis period. Moreover, such a formulation is based on the assumption that the demand function is convex; whereas linear formulation presumes the demand function is linear, so that a linear elasticity applied to a significant change in the variables can be expected to generate unrealistic predictions.

$$\eta_P = \frac{\Delta(\log Q)}{\Delta(\log P)} = \frac{\log Q_2 - \log Q_1}{\log P_2 - \log P_1} \tag{1}$$

$Q_1 = original\ value\ of\ the\ traffic\ demand$ $Q_2 = final\ value\ of\ the\ traffic\ demand$
$P_1 = original\ value\ of\ the\ fuel\ price$ $P_2 = final\ value\ of\ the\ fuel\ price$

The exercise has been carried out using the traffic volume data collected on the Elefsina-Patra motorway corridor in different campaigns undertaken in the crisis period (i.e. between 2008 and 2011); this implies that traffic demand and its variation over time is expressed in AADT. Concerning factors affecting demand, toll fares data have been made available by vehicle category and by plaza from August 2008 to date, and unleaded fuel prices data have been made available from November 2006 to August 2011, covering *average fuel price, fuel levy, taxes, pre-taxes retail price* and *price without change in law* (i.e. price considering the fuel levy fixed by law n. 3483/2006). The GDP changes over time were estimated according to the data published in September 2011 by the International Monetary Fund (IMF).
The traffic demand along the motorway corridor is subject to a toll payment, which has increased over time, so it has been assumed, according to the literature review, a toll elasticity accounting for -0.2 in order to remove the toll-related effect from the traffic variation.
The estimation has been carried out for two time periods (2008-2011 and 2010-2011) comparing the traffic counts data collected on the motorway respectively in November-December 2008, May-June 2010 and May-June 2011.
The toll values and the traffic data used for the estimation are summarized in Table 3.

Table 3 – Toll changes and traffic data

Toll-related data	2008 -2011	2010-2011
Average Toll Fare changes(€)	0.38	0.25
Bidirectional AADT changes observed	-7,098	-3,995
Bidirectional AADT changes due to the toll (η = -0.2)	-915	-545
Bidirectional AADT changes toll-adjusted	-6,183	-3,450

As a result, Table 4 shows the elasticity values obtained by eliminating the effect of toll changes in traffic reduction using the arc formulation and assuming the average fuel price as the explanatory variable.

Table 4 - Traffic demand elasticity with respect to fuel price, short-run, overall value

2008-2011	2010-2011
-0.35/-0.38	-0.51/-0.70

The range of elasticity values for the 2008-2011 period is significantly lower than the one obtained for the 2010-2011 period. This gap cannot be directly compared with changes in fuel price occurred in the same time period, because of the dynamic behaviour of the traffic demand elasticity and its dependence on the sequence of prices changes. However, comparing the annual based average fuel price, it should be noted that it is grown by around 0.60 €/litre in the whole period analysed with the 40% of this increase occurred from 2010 to 2011 (in addition a decrease accounting for -9% between 2008 and 2009 can be observed). Therefore, in accordance with the outputs of the theoretical approach, users' sensitivity with respect to the monetary cost of travel appears to be positively related to fuel price and increasing as fuel price reaches relatively high level. In other words, values shown in the previous table represent approximate measures of aggregate responses to fuel price changes, including the effects of income fluctuation on the price sensitivity of travellers' behaviour. Separating the effects of the two variables (fuel price and income) on the traffic demand elasticity is a complex problem relative to the collinearity that exists between them. According to a common method (Balcombe et al., 2004) usually applied for providing quantitative indications on different factors influencing transport demand changes between two time periods, when direct evidence on an elasticity value is unavailable, the variation of the toll–adjusted traffic (i.e. assessed by removing the toll-related effect) can be modelled as a function of fuel price and income, as follows:

$$\frac{Q_{toll-adj\ 2}}{Q_{toll-adj\ 1}} = \left(\frac{P_2}{P_1}\right)^{\eta_P} \left(\frac{GDP_2}{GDP_1}\right)^{\eta_I} \tag{2}$$

where GDP_1 and GDP_2 are respectively the original and final values of the GDP per capita, according to the IMF data, and P_1 and P_2 are the original and final fuel price values.
Since the variation in traffic demand is known, the magnitude of the elasticity relative to the fuel price variation (η_P) has been found (Table 5) solving the above equation and considering

that, according to the literature review (Goodwin et al., 2004, the size of income effects on road traffic demand (η_I) is greater than the fuel price ones (η_P) mostly by factors 1,5-3.

Table 5 - Traffic demand elasticity with respect to fuel price, short-run

2008-2011	2010-2011
-0.19/-0.25	-0.28/-0.37

As between the road traffic elasticity with respect to the generalised cost and the road traffic elasticities with respect to various components exists the same proportional relationship between the generalised cost of transport and the relative weights of its components (Litman, 2011), this means that the share of fuel price elasticity due to fuel taxes has been estimated considering their relative weights in the average fuel price values. Table 6 shows the traffic demand elasticity with respect to fuel taxes, estimated in the last year of analysis and in the whole crisis period. Note that the tax share in the average fuel price has been assessed considering, for each year, the fuel levy and the VAT.

Table 6 - Traffic demand elasticity with respect to fuel taxes, short-run

2008-2011	2010-2011
-0.10/-0.14	-0.17/-0.22

The above calculated elasticity values with respect to fuel taxes are a picture of the splitting of fuel price elasticity into its components; however for the purpose of assessing the effect of the changes in law, it will be used the general elasticity to fuel prices (Table 5) applied to the specific difference between the actual retail fuel prices and their theoretical value dealing with the legal provisions on fuel taxation in force as of November 18th 2006.

Considering the most recent forecasts on the Greek economic situation until 2013 and the fuel price changes observed over the last five years, two ranges of elasticity values with respect to fuel price have been assumed for the short-term scenario evaluation:

- a *pessimistic scenario*, based on the hypothesis that the traffic demand sensitivity with respect to fuel price will remain comparable to the high values assessed for the 2010-2011 period: -0.28/-0.37;
- an *optimistic scenario*, based on the assumption that the share of the traffic decrease observed in the 2010-2011 period due to fuel price growth will not remain so high until the end of 2013. This means that a more reliable range can be obtained through an equalization of the elasticity values registered on the motorway corridor, in order to reduce the effects of the instability which characterizes variables affecting transport demand during a crisis period. According to this, a more precautionary range in the fuel price elasticity has been assessed, accounting -0.22/-0.32.

Long-term scenario

The clear picture that emerges from the literature review is that the long-run fuel price elasticity is approximately two to three-times higher than the short-run one (Goodwin et al.,

2004). The long-term scenario evaluation is based on the above well-established assumption applied to fuel price elasticity values assessed for the short-term, along with the hypothesis that average fuel prices will rise until 2025 by an annual rate of 6%, estimated as the average year-on-year (Y-O-Y) growth registered from November '06 to August '11 and based on the fuel price without regard to changes in law (i.e. assuming the fuel levy is fixed by law 3483/2006).
Considering the GDP variations predicted until 2025, three forecasts are presented, as follows (Table 7):

- the IMF's forecast (September 2011);
- the EIU - Economist Intelligence Unit forecast (October 2011);
- the IOBE - Greek Foundation of Economic and Industrial Research forecast (with structural changes).

On the whole, the EIU forecast appears the most conservative one, with an average annual growth rate of around 1.13 %, while the projections made by the IMF provide a more optimistic trend, with an average annual growth higher than 2%; noting also that the IMF's forecast published in September 2011 provides annual change values up to 2016, assuming the same growth rate from 2016 to 2025.

Table 7 - Selected GDP forecasts

Year	**IMF**	**EIU**	**IOBE**	**BCV4**
	Y-O-Y percentage change			
2013	1,50	0,90	1,20	1,39
2014	2,30	1,50	1,80	1,75
2015	3,00	2,00	2,30	2,24
2016	3,30	1,50	3,00	2,30
2017	3,30	1,10	3,20	2,03
2018	3,30	0,90	3,00	1,90
2019	3,30	0,80	2,80	1,70
2020	3,30	0,70	2,60	1,63
2021	3,30	0,80	2,60	1,70
2022	3,30	0,90	2,60	1,75
2023	3,30	1,00	2,60	1,80
2024	3,30	1,20	2,60	1,90
2025	3,30	1,40	2,60	2,00

This wide range of values, which has been supposed to deal with an optimistic viewpoint, has been selected considering for the low end (-0.30) a value consistent with the maximum magnitude of the optimistic short-term scenario (-0.22/-0.32), while the high end has been assessed multiplying by 2 the maximum value of the pessimistic scenario (0.37 x 2= 0.74); in other words it has been assumed that in the long term the traffic demand elasticity will not achieve the absolute maximum value (0.37 x 3= 1.11). Such values appear also to be consistent with the outputs of the literature review.

THE ECONOMETRIC MODEL

Starting from the traffic analysis, a specific methodology was used in order to assess the fuel price elasticity on traffic demand in the short and long term scenarios, choosing the fuel price as explanatory variable but including the effects of toll fare and income level changes recently occurred in Greece. The reference scenario is a relatively short time span of three years (2008-2011) centred around the most important fluctuations in fuel price, occurred in 2010. According to the identified elasticity values - and in order to isolate the effects on traffic changes of fuel price fluctuations from other variables affecting traffic demand - a simplified macro-econometric model was developed. So, the traffic volumes (V) have been modelled as a function of three independent variables, such as: toll price (P), fuel price (F) and GDP - Gross Domestic Product (G). This means that $V = f(P,F.G)$ and, as a differential form of a composite function, it can be expressed as follows:

$$dV = \frac{\partial f}{\partial P} \cdot dP + \frac{\partial f}{\partial F} \cdot dF + \frac{\partial f}{\partial G} \cdot dG \qquad (3)$$

Starting from the common expression of the point elasticity (Pratt, 2003), where h_1, h_2 and h_3 are the traffic volumes elasticities respectively to toll price, fuel price and GDP variables, by definition the following equations are verified, for independent variations of each variable separately:

$$\frac{dV}{V} = h_1 \frac{dP}{P}; \qquad \frac{dV}{V} = h_2 \frac{dF}{F}\ ; \qquad \frac{dV}{V} = h_3 \frac{dG}{G} \qquad (4)$$

As the elasticity of traffic volumes to fuel price is a less known and more complex subject if compared to the to toll price and to GDP elasticities, the model was developed dealing with three specific fuel prices elasticity approaches, as follows:
In the *flat elasticity* approach, it was assumed that the traffic volumes fluctuations can be modelled as a classic power function of each variable:

$$\frac{V}{V_0} = \left(\frac{P}{P_0}\right)^{h_1} \cdot \left(\frac{F}{F_0}\right)^{h_2} \cdot \left(\frac{G}{G_0}\right)^{h_3} \qquad (5)$$

where V_0 and P_0, F_0, and G_0 represent the respective values in the baseline situation (at the beginning, i.e. the last quarter of 2008). In the *linear elasticity* it was assumed that the traffic elasticity to fuel varies with the fuel price itself, following a growing linear function:

$$h_2 = \alpha \cdot F + k_2 \qquad (6)$$

being α a negative coefficient and k_2 a coefficient lesser or equal to zero; it making the theoretical elasticity with zero-priced fuel. This represents the empiric and scientific observation that transport demand becomes more elastic when fuel price increases significantly. In this case, the traffic volume equation was expressed as follows:

$$\frac{V}{V_0} = \left(\frac{P}{P_0}\right)^{h_1} \cdot e^{\alpha(F-F_0)} \cdot \left(\frac{F}{F_0}\right)^{k_2} \cdot \left(\frac{G}{G_0}\right)^{h_3} \qquad (7)$$

In the *power elasticity* approach, it was assumed that the traffic elasticity to fuel price varies with the fuel price itself, following a growing power function:

$$h_2 = k_2 \cdot \left(\frac{F}{F_0}\right)^{\alpha} \qquad (8)$$

where k_2 is the elasticity of traffic volume to fuel at the reference fuel price F_0 and α is a positive coefficient, both to be determined in the modelling calculation. Consequently, the traffic volume equation was as follows:

$$\frac{V}{V_0} = \left(\frac{P}{P_0}\right)^{h_1} \cdot e^{\left[\frac{k_2}{\alpha}\cdot\left(\left(\frac{F}{F_0}\right)^{\alpha} - 1\right)\right]} \cdot \left(\frac{G}{G_0}\right)^{h_3} \qquad (9)$$

By using all three methods, the power elasticity was the method providing the best match for the Greek case (figure 7).

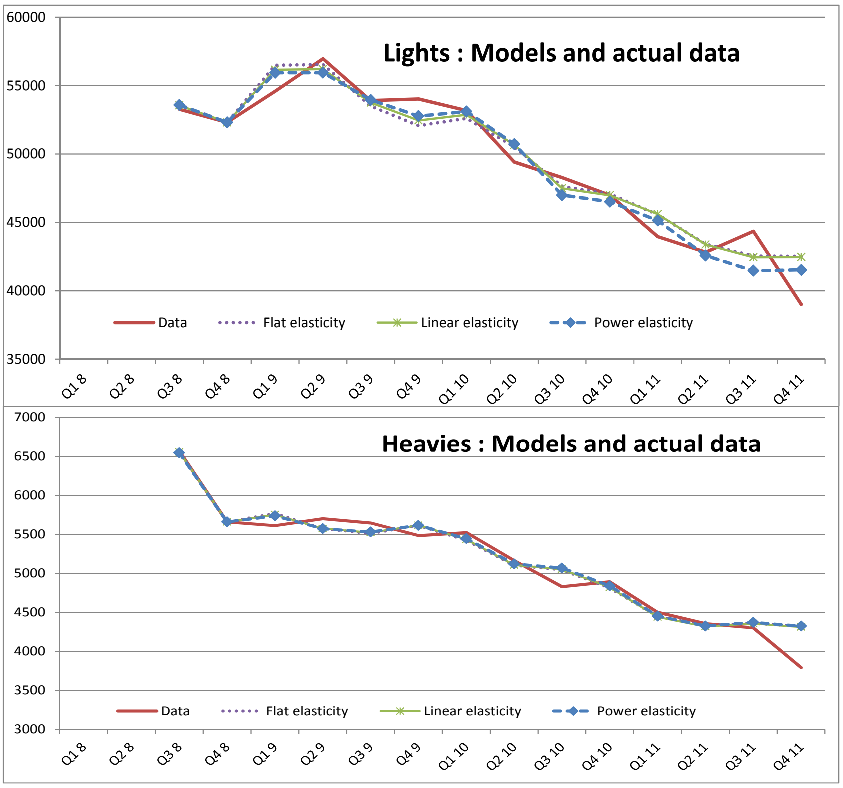


Figure 7 - Comparison between Model and Real data

Indeed, the model provides a better fit with the real traffic data (i.e. the Quarterly Average Daily Traffic), with a standard deviation of 1.8% and 2.1% for lights and heavy vehicles respectively. The resulting elasticity parameters are showed in Table 8:

Table 8 – Modelled elasticity parameters

Maximum Likelihood Estimation	Cat 1+2 (Light vehicles)	Cat 3+4 (Heavies vehicles)
h_1	-0.08	-0.38
K_2	-0.32	-0.24
α	2.11	1.71
h_3	0.54	1.01

With the above findings, it was possible to represent the variations of the fuel elasticity (power function), for various values of the fuel price variable, as follows:

$$LV \rightarrow h_2 = -0.32 \cdot (\frac{F}{1} \cdot 21)^2 \cdot 11$$
$$HV \rightarrow h_2 = -0.24 \cdot (\frac{F}{1} \cdot 08)^1 \cdot 71 \qquad (10)$$

also highlighting a higher elasticity for lights (LV) than for heavies (HV) vehicles (Figure 8).

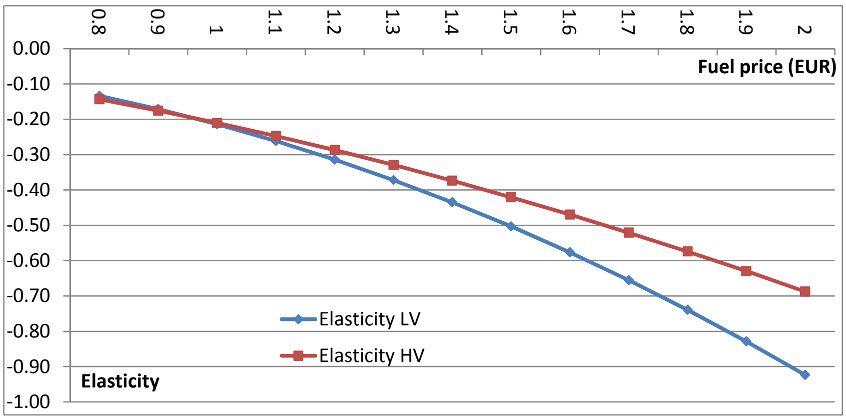


Figure 8 - Modelled elasticities with respect to fuel prices: power elasticity methods

This model provides the best matching for the data, at least for light vehicles that represent more than 80% of all traffic, as indicated by the standard deviation of the series of ratios Model/Real. Moreover, it reveals a higher fuel elasticity for lights than for heavy vehicles with an increasing gap as the fuel price goes up, which is intuitively more appropriate in a context where unleaded fuel prices reach historical highs. For fuel prices ranging from 0.8€ to 2.0€ the LV elasticity is in the range [-0.15 – -0.95] whereas the HGV elasticity is in the range [-0.10 – -0.70]. However it should be noted that the above chart represents “instant elasticities” to very small fuel price variations around any given value.

The ‘apparent elasticity’ from large variations needs a specific calculation. Indeed, there is a need to develop a proper calculation in order to determine the ‘apparent elasticity’ derived from two ‘instant’ measurements of the pair (*V*, *F*), for potentially large variations of both values: V_1, F_1 and V_2, F_2.

Defined η^* the apparent elasticity derived from the two pairs of measurements, the following relation is verified as a best approximation:

$$\eta^* = \frac{\ln(\frac{V_2}{V_1})}{\ln(\frac{F_2}{F_1})}$$

In the case of the *power elasticity* function with the unique variable F, the elasticity and the fuel price verify the following volume equations:

$$\frac{V_1}{V_0} = e^{[\frac{k_2}{\alpha}((\frac{F_1}{F_0})^{\alpha} - 1)]}$$

$$\frac{V_2}{V_0} = e^{[\frac{k_2}{\alpha}((\frac{F_2}{F_0})^{\alpha} - 1)]}$$

Therefore:

$$\frac{V_2}{V_1} = e^{[\frac{k_2}{\alpha}((\frac{F_2}{F_0})^{\alpha} - (\frac{F_1}{F_0})^{\alpha})]}$$

and finally:

$$\eta^* = \frac{1}{\ln(\frac{F_2}{F_1})} \cdot \frac{k_2}{\alpha} \cdot \left(\left(\frac{F_2}{F_0}\right)^{\alpha} - \left(\frac{F_1}{F_0}\right)^{\alpha} \right)$$

With power elasticity function, the apparent elasticity can be calculated on several combinations of three points of observation F_1, F_2, F_3 (Table 9).

Table 9 - Three points of fuel price observation F1, F2, F3

F	Period	Unleaded price	Diesel price
F_0	Average Q4-2008	1.21	1.08
F_1	Nov-Dec 2008 (2008)	0.89	1.04
F_2	May-June 2010 (2010)	1.50	1.30
F_3	May-June 2011 (2011)	1.68	1.48

and the resulting apparent elasticities η^* are summarized in Table 10:

Table 10 – Elasticity values

Time span		Flat elasticity		Linear elasticity		Power elasticity	
		Lights	Heavies	Lights	Heavies	Lights	Heavies
2008 to 2011	F_1 to F_3	-0.28	-0.26	-0.30	-0.29	-0.35	-0.31
2010 to 2011	F_2 to F_3			-0.39	-0.33	-0.57	-0.37

Showing that the achieved results in terms of effects of fuel price fluctuation on the traffic provide appropriate elasticity values consistent with those obtained by the present study.

CONCLUSIONS

From an extensive technical literature review, carried out in order to provide a full understanding of the main explanatory variables related to users' behaviour and travel preferences, it has been seen that road traffic elasticity refers primarily to price and income. Traffic demand elasticity with respect to price is a dynamic variable, which varies over time following the price changes, and its trend is exacerbated in periods of severe economic crisis like the Greek one. The broad relationship existing between income level and road traffic demand also includes an indirect effect (via the VOT - Value of Time) on the road traffic elasticity with respect to price. Thus, the combined effect of the VOT decrease together with the fuel price increase, can likely produce an upward trend in price elasticity, mainly for low-income people, who are most affected by the loss of purchasing power. Both the quantitative methodologies applied have provided specific and reliable fuel price elasticity values, which are also consistent with the main literature findings.

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