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FUEL DEMAND AND ROAD TRANSPORT CO2 EMISSIONS: EVIDENCE FOR THE GREATER PORTO REGION

EMMANOUIL-STELIOS GAVVES, IMPERIAL COLLEGE LONDON

DR. PATRICIA MELO, IMPERIAL COLLEGE LONDON (CORRESPONDING AUTHOR: PATRICIA.MELO@IMPERIAL.AC.UK)

DR. DANIEL GRAHAM, IMPERIAL COLLEGE LONDON

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FUEL DEMAND AND ROAD TRANSPORT CO_2 EMISSIONS: EVIDENCE FOR THE GREATER PORTO REGION

Emmanouil-Stelios Gavves, Imperial College London
Dr. Patricia Melo, Imperial College London (corresponding author: patricia.melo@imperial.ac.uk)
Dr. Daniel Graham, Imperial College London

ABSTRACT

Absence of adequate legislation about transport and the environment facilitates an extensive use of private cars. The excessive use of private cars results in urban and environmental problems, in particular congestion and air pollution. The European Union (EU) has set new legislation for transport CO_2 emissions. By 2020 GHG emissions will have to be 20% lower than 1990 levels. In order to design policies that can ensure sustainable cities, it is important to understand which factors can be used to change behavior towards more sustainable choices. This can be achieved through the estimation of fuel demand elasticities in urban contexts. This study estimates fuel demand elasticities for the Greater Metropolitan Area of Porto (GAMP), which are then used in a scenario-based analysis of future road transport CO_2 emissions. If the new EU target is to be met, the increase in real fuel price in the baseline scenario would have to be 4.8% per annum (p.a.). If additional measures relating to vehicle stock energy efficiency are also considered, the corresponding change in real prices of fuel is estimated to be 4.4% p.a.

Keywords: dynamic fuel demand models, road transport CO_2 emissions, Greater Metropolitan Area of Porto (GAMP)

1. INTRODUCTION

Transport has a crucial role in the European economy. It is at the centre of the supply chain and facilitates the movement of people and goods and economic growth. Europe is facing specific challenges, such as climate change, congestion and overdependence on fossil fuels, which need to be confronted if Europe wants to create an efficient and sustainable European transport network and regain its competitiveness. The pressing nature of these challenges has led the EU to adopt policies that aim to control the rising of the global temperature. The main target of such policies is the reduction of the carbon dioxide (CO_2) emissions which comprise the greatest part of greenhouse gas (GHG) emissions causing climate change.

The transport sector is an industry that contributes greatly to CO_2 emissions due to the growing need for moving goods and people, and the dependency on fossil fuels. Currently, the transport sector has a share of 23% of all CO_2 emissions in the 27 EU member states and the concerning fact is that in contrast with all other sectors, the change of GHG emissions from 1990 to 2010 is positive; if this trend keeps on, transport will account for more than 50% of the total CO2 emissions by 2050. Figure 1 compares road transport CO_2 emissions in EU27 with CO_2 emissions for all transport modes (European Environment Agency, 2012).

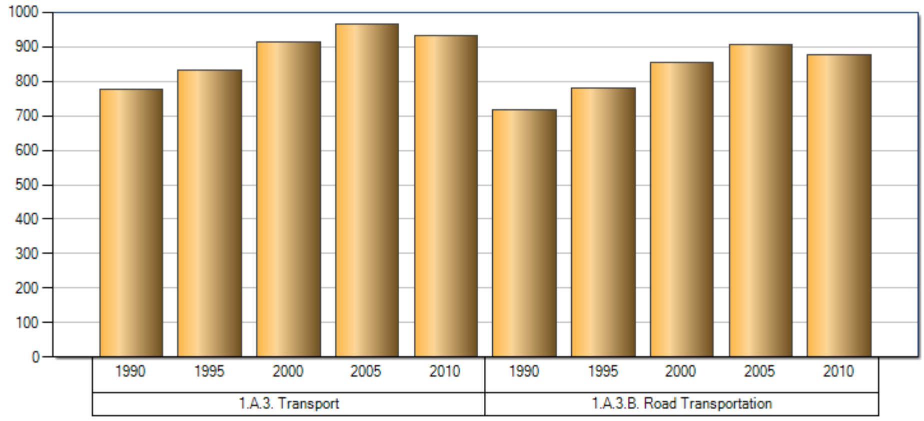

Figure 1: Share of GHG emissions, 2010, Source: (European Environment Agency, 2012)

A key target in EU transport policy is to secure the sustainability of the transport system. By 2020 the EU aims to reduce by at least 20% the GHG emissions compared to 1990 levels- if other developed countries reduce GHG emissions by 30% the EU will try to make a comparable reduction (European Comission Directorate, 2010). Looking further in the future, EU is committed to meet a 60% reduction in GHG emissions from transport by 2050 with respect to 1990 levels (European Comission, 2011).

While emissions from other sectors are generally falling, those from transport have increased 29% since 1990 (Hill & Skinner, 2012). The European Union is looking to find cost-effective ways to make the European economy more climate friendly and less energy consuming. To achieve this, measures can be taken in two different levels at the European Union level and at the national level. Three policy priorities are currently under consideration.

- Increasing energy efficiency that requires technological advances, as to increase the average distance travelled with a litre of fuel. Automobile industry is forced by fuel efficiency regulations to develop new technologies and engines that will reduce the CO2 emissions per litre of fuel consumed (e.g. under Regulation No 443/2009 new passenger cars will need to emit under 130gr CO_2/km by 2015 and 95gr CO_2/km by 2020).

- Increasing transport efficiency aims at making infrastructure and services more efficient. Modal shift from road to public transport and cycling (for passengers) and rail and waterway transport (for freight) is considered as an option. Moreover, Intelligent Transport Systems (ITS) can increase efficiency in all transport modes.

- Alternative fuels and propulsion systems that will enable the shift to a less carbonised transport by reducing the dependency on fossil fuels (e.g. by 2020, fuel suppliers have to decrease by 6% the GHG emissions in their products either by adding biofuels to petrol and diesel, or by improving production technologies in refineries).

With respect to these priorities, policies such as the Emissions Trading System (ETS) or CO_2 emissions targets for cars have been implemented. In order to meet the short- and long-term goals, the knowledge of accurate and reliable fuel demand elasticities is a matter of utmost importance for policy makers. Governments can use these elasticities as a way to influence the behaviour of motorists and hence fuel consumption. This can be pursued through fuel tax increases or regulation that promotes the use of alternative fuels or other means of transport, as to reduce the total volume of road transport emissions.

This study attempts to contribute to the debate on how to reduce road transport CO_2 emissions in the following way. We estimate fuel demand models for the Greater Metropolitan Area of Porto (GAMP) and apply the elasticities obtained from the fuel demand models to a scenario-based analysis to investigate whether Portugal will be able to meet the EU 2020 GHG emissions targets. To our knowledge, this is the first study of fuel demand for the GAMP and uses a dataset created specifically for this purpose. In addition to the estimation of the fuel demand elasticities, we use the fuel demand elasticities to investigate the potential future trends in road transport CO_2 emissions.

The rest of the paper has the following structure: Section 2 presents an overview of existing evidence in the fuel demand literature. Section 3 describes the data used in this study. Section 4 describes the methodology used to estimate the fuel demand models and Section 5 reports and discusses the results. In Section 6 we present the scenario-based analysis of road transportation emissions . We present our main conclusions in Section 7.

2. OVERVIEW OF THE LITERATURE

Fuel demand has been an area of study for over 35 years. In the past the incentive for the research was mainly conservation and security issues. More recently, environmental reasons lead the race to a better understanding of the way motorists change their fuel consumption when changes in fuel price, income and other variables take place (Basso & Oum, 2007). This is a result of increasing concerns over the effects of global warming and greenhouse gases in our life. Studies show that contribution of the transport sector to the total volume of GHG emissions ranges from 14% (Hensher, 2008) to almost 25% for Europe (Hill & Skinner, 2012). This fact causes pressure for changes in the legislation of countries in order to reduce their total GHG emissions.

Research has mainly concentrated in the effect of gasoline price and income changes in the overall fuel consumption. Many different approaches and methodologies have been used to estimate fuel demand elasticities. Hence, a wide range of elasticity values has been observed.
The most popular techniques in the empirical literature are based on reduced-form demand models using aggregate data at the national or regional level, which are more easily available than disaggregate household level data. These models have their foundation on the microeconomic theory of consumer demand, and specify fuel demand as a function of relevant variables such as income, and price of fuel (although vehicle ownership and fuel efficiency have often also been considered).

The simplest functional form considers a static model, where the dependent variable is a measure of fuel demand and the independent variables are fuel price and income (typically per person). Static models do not allow for adjustment in consumers (here drivers) behaviour over time and are thus expected to produce intermediate-run elasticities (Goodwin, 1992; Dahl & Sterner, 1991). In contrast, dynamic models of fuel demand allow for such adjustment. Changes in income or fuel price trigger reactions from consumers. People can decide to drive less or start using public transport if their income decreases or fuel price has a rapid increase. These responses occur over time and can take from weeks to years to take place (Basso & Oum, 2007).

More comprehensive model specifications include vehicle stock, or vehicle ownership, and vehicle characteristics, as a way to capture long-run effects of changes in vehicle stock and driving habits of motorists. Including these variables generally results in lower short-run and long-run price and income elasticities. The reason for that is that by including vehicle ownership and/or fuel intensity, changes in fuel consumption are measured only through driving and not through changes of vehicle stock (Basso & Oum, 2007).

Table 1 shows the range of elasticity values obtained from three surveys of existing empirical evidence (Graham & Glaister, 2002; Espey, 1998; Goodwin, 1992). All three surveys agree that price elasticity tends be between -0.2 and -0.3 in the short run and between -0.6 and -0.8 in the long run. This shows that fuel consumption tends to be fairly inelastic with respect to changes in prices even in the long run. Therefore, policies focused only in fuel price may not be very effective.

Regarding the income elasticity, Graham and Glaister (2002) indicate that values range between 0.35 and 0.55 in the short run. Espey's (1998) findings are in agreement with this and suggest a short run elasticity of 0.47. However, Espey (1998) suggests a more inelastic response in the long run, with an elasticity value of 0.88, while Graham and Glaister (2002) suggest values between 1.10 and 1.30. Consequently, fuel prices in a growing economy have to rise at a greater rate than income just to maintain fuel consumption at the same levels; if the target is to reduce fuel demand, fuel prices will have to increase at a considerable higher rate than income. Goodwin et al. (2004) provide a summary of 175 estimates for the period between 1929 and 1998. The average value of the price elasticity estimates included in the review is -0.25 for the short run and -0.6 for the long run. The average value of the short- and long-run income elasticity is 0.4 and 1.0 respectively. Basso and Oum (2007) provide a survey of the literature with a special attention to the role of the different empirical approaches and methods. They report values for fuel price elasticities between -0.2 and -0.3 in the short run, and between -0.6 and -0.8 in the long run. As for income elasticities, their values tend to fall between 0.3 and 0.5 in the short run and between 0.9 and 1.3 in the long run. Brons et al. (2008) analyse a sample of 312 estimates of fuel consumption (obtained from 43 studies) and estimate an overall mean price elasticity of total gasoline consumption equal to -0.53.

Table 1: Price and income elasticities from reviews

Study	**Elasticity of price**	**Elasticity of income**
Brons et al. (2008)	-0.53 (mean)	
Basso and Oum (2007)	SR: -0.2 to -0.3	SR: 0.3 to 0.5
	LR: -0.6 to -0.8	LR: 0.9 to 1.3
Goodwin et al. (2004)	SR: -0.25	SR: 0.4
	LR: -0.6	LR: 1.0
Graham & Glaister (2002)	SR: -0.2 to -0.3	SR: 0.35 to 0.55
	LR: -0.6 to -0.8	LR: 1.10 to 1.30
Espey (1998)	SR: -0.26	SR: 0.47
	LR: -0.58	LR: 0.88
Goodwin (1992)	SR: -0.27	
	LR: -0.73	

3. DATA

The study area is the Greater Porto Metropolitan Area (GAMP). The region is composed of 16 municipalities.[1] According to the Portuguese Office for National Statistics (INE), the area

[1] Arouca, Espinho, Gondomar, Maia, Matosinhos, Oliveira de Azeméis, Porto, Póvoa de Varzim, Santa Maria da Feira, Santo Tirso, São João da Madeira, Trofa, Vale de Cambra, Valongo, Vila do Conde e Vila Nova de Gaia.

of the GAMP accounts for about 2% of continental Portugal's territory and nearly 1.7 million inhabitants (2010), which is about 17% of the total population. The GAMP is the second largest economic region of Portugal and it accounted for 17% of the number of enterprises and Gross Value Added (GVA) of continental Portugal in 2009.

The data available for this study are as follows: (i) fuel demand (gasoline and diesel), (ii) average fuel price (gasoline and diesel), (iii) average monthly income, (iv) population, (v) average price of public transport (monthly travelcard), (vii) number of commuter rail and metro stations, (vii) vehicle stock. Data for fuel demand, income and population were obtained from Instituto Nacional de Estatistica (INE), the Portuguese office for national statistics. Inflation data based on the Consumer Price Index (CPI) were also obtained from INE to calculate real income and real price data. Real income and prices are expressed in terms of 1999 values. Data for income are missing in the years 2004 and 2010. Income for 2004 was assumed to be the average of 2003 and 2005 while income in 2010 was assumed to remain at the level of 2009. Data for fuel prices were obtained from the Directorate-General for Energy and Geology (DGEG), which belongs to the Ministry of Economy, Innovation and Development. Data for vehicle stock were obtained from Instituto de Seguros de Portugal (ISP), the national authority for regulation and supervision of insurance and pension fund. Data for public transport were obtained from the relevant public transport operators.

To ensure data consistency over time, we combined the data for the municipalities of Trofa and Santo Tirso into one single municipality (before 1999 Trofa and Santo Tirso were one municipality). As a result the final dataset consists of data for 15 municipalities during the period 1999-2010.

Figure 2 shows the evolution of some of the main variables considered in the fuel demand models during the period 1999-2010, while Table 2 shows some basic descriptive statistics. The variables displayed in Figure 2 refer to total fuel consumption, car ownership, real average fuel price, and real average monthly income. The values are indexed to 100 in 1999. The variable with the strongest increase during the period under analysis is fuel price. The increase was particularly strong between 2004 and 2008, with the price of fuel being 47% higher than in 1999 in real terms. The price of fuel fell in 2009, but reached 2008 levels in 2010.[2] Average real incomes have risen gradually during the period: in 2009 the average monthly real income per capita was 20% higher than in 1999. Fuel demand and car ownership have a relatively similar pattern, except between 2003 and 2007 during which car ownership was increasing from a value lower than in 1999 but fuel consumption did not show an overall upward trend. There was a strong reduction in car ownership levels in 2003, which resulted from the international and internal economic crisis of 2002-2003.In 2010, the level of car ownership and fuel demand was only 13% and 12% higher than in 1999 respectively.

[2] Fuel prices have continued to increase steadily since 2010.

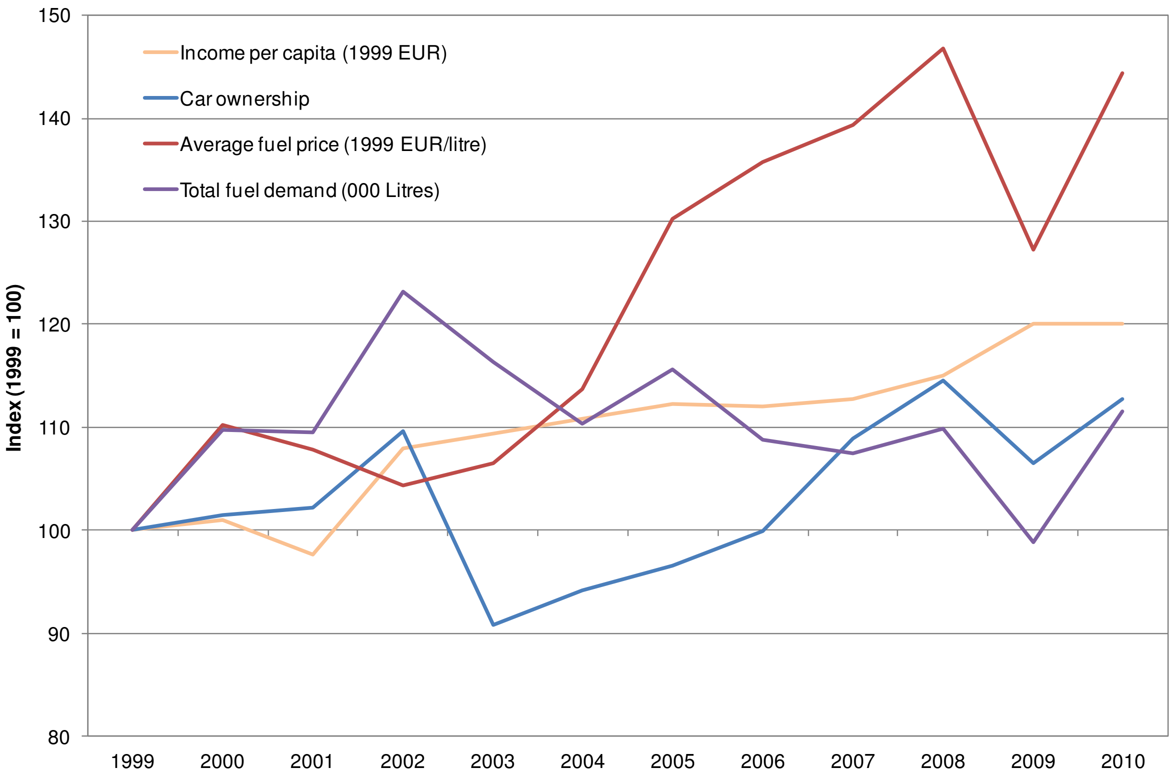

Figure 2: Evolution of fuel demand, fuel price, income, and car ownership between 1999 and 2010

Table 2: Descriptive statistics

	Fuel consumption per vehicle (litres/ vehicle)	Average fuel price (€)	Average monthly income (€)	Vehicle ownership (cars/ person)	Density of rail stations (stations per 100,000 people)	Price of monthly travelcard (€)
Min	560	0.668	434	0.000	0.0	16.1
Max	5331	0.975	957	0.991	13.3	40.5
Mean	1691	0.719	653	0.541	4.6	32.3
Standard deviation	1147	0.281	106	0.119	4.0	5.9
First quartile	935	0.699	574	0.472	1.4	27.5
Third quartile	1915	0.904	701	0.594	6.2	37.3

4. METHODOLOGY

We estimate a dynamic panel data fuel demand model using the data described in the previous section. The dependent variable is fuel consumption per vehicle to reduce issues of multicollinearity. The variables shown in Table 2 have been included in the specification of the various fuel demand models.

- Model i: price of fuel, average income

- Model ii: price of fuel, average income, car ownership
- Model iii: price of fuel, average income, price of public transport
- Model iv: price of fuel, average income, car ownership, price of public transport
- Model v: price of fuel, average income, price of public transport, density of rail stations
- Model vi: price of fuel, average income, car ownership, price of public transport, density of rail stations

The dynamic panel data fuel demand model is shown in Eq. 1 below.

$$\ln\left(\frac{Fuel}{Car}\right)_{i,t} = \theta\ln\alpha + (1-\alpha)\ln\left(\frac{Fuel}{Car}\right)_{i,t-1} + \theta\beta\ln\left(\frac{P_f}{CPI}\right)_{i,t} + \theta\gamma\ln\left(\frac{Y}{N}\right)_{i,t} + \theta\delta\ln\left(\frac{CAR}{N}\right)_{i,t} + \theta\varepsilon\ln\left(\frac{RAIL}{N}\right)_{i,t} + \theta\rho\ln\left(\frac{P_{PT}}{CPI}\right)_{i,t} + \mu_i + v_{i,t} \quad (1)$$

where *i* identifies the municipality and *t* refers to the time periods (1999 to 2010). The parameters $\theta\beta$, $\theta\gamma$, $\theta\delta$, $\theta\varepsilon$ and $\theta\rho$ give the short-run elasticity estimates of fuel price (i.e. P_f/CPI), average income (i.e. Y/N), car ownership (i.e. CAR/N), density of rail stations (i.e. RAIL/N), and price of public transport (i.e. P_{PT}/CPI) respectively. The price and income variables are transformed to be in real terms using the Consumer Price Index (CPI) with base year for 1999. Finally, μ_i is an individual-specific effect (i.e. municipality) which captures unobserved heterogeneity, and v_{it} is the random error term of the model. Note that the elasticity of fuel demand with respect to vehicle stock is equal to δ+1. The long-run elasticity estimates can be obtained by dividing the short-run estimates by the factor (1-θ), which measures the speed of adjustment to the long run equilibrium.

We estimate dynamic fuel demand models using different panel data econometric estimators: pooled OLS, fixed-effects (FE), random-effects (RE), and dynamic GMM (difference-GMM and system-GMM) estimators. The main distinction between the estimators above concerns their ability to produce consistent and unbiased model parameter estimates. When considering a dynamic demand model neither of the pooled OLS, the FE, and the RE estimators can ensure consistent model parameter estimates. Only the dynamic GMM estimators can provide consistent model parameter estimates (Arellano & Bond, 1991; Blundell & Bond, 1998). The key issue to be addressed is the correlation between the lagged dependent variable and the individual-specific effects, which cannot be removed through the usual use of a FE model (e.g. Baltagi, 2008). In the context of estimation of a dynamic panel model, the Generalised Method of Moments (GMM) can offer a means of obtaining consistent parameter estimates. The basic idea is to construct a set of valid instruments based on the time series nature of the dataset, which are correlated with the covariates but uncorrelated with the error term.

Arellano and Bond (1991) and Blundell and Bond (1998, 2000) proposed two different dynamic GMM estimators: difference-GMM and system-GMM. The difference-GMM uses first-differences to remove unobserved time-invariant individual-specific effects, and then instruments the lagged dependent variable in the first-differenced equation using levels of the series lagged two periods or more, under the assumption that the time-varying disturbances in the original levels equations are not serially correlated. The system-GMM combines the standard set of equations in first-differences with suitably lagged levels as instruments, with an additional set of equations in levels with suitably lagged first-differences as instruments. In the presence of data with little variation over time, the system-GMM estimator has been shown to be preferred to the difference-GMM, on the grounds that it can provide increased efficiency and less finite sample bias (e.g. Arellano & Bover, 1995; Blundell & Bond, 2000).

In order to produce consistent parameter estimates, the dynamic GMM estimators need to conform to two main criteria: (1) there should be no first-order serial autocorrelation in the errors of the level equation; (2) the set of instruments should be uncorrelated with the residual term. To assess the presence of serial correlation, we use the Arellano and Bond serial autocorrelation tests with null hypothesis that there is no second-order serial correlation in the first differenced residuals, implying that the errors from the levels equations are serially uncorrelated (Arellano & Bond, 1991). To evaluate instrument exogeneity, we consider the Hansen test of overidentifying restrictions, which tests the null hypothesis that instruments are orthogonal to the error term (Hansen, 1982).

5. RESULTS

Table 3 shows the results obtained for the six model specifications described in the previous section and the pooled OLS, RE and FE estimators, while Table 4 illustrates the same results for the dynamic GMM estimators.

For the dynamic GMM estimators, fuel price, income, vehicle ownership, rail density and price of public transport are treated as strictly exogenous variables. Various combinations of time dummies were tested in the specification of the GMM estimators, as their inclusion is strongly recommended for the consistency of the estimator (Roodman, 2006). Finally, the dummies included are for years 2000, 2001, 2002 and 2006, 2007, 2008.

Almost all model specifications and estimators agree on the sign of the elasticities. However, the magnitude of these elasticities differs greatly among the different options considered. For the consistent dynamic GMM estimators (System- and Difference-GMM) the rate of adjustment has a range from 0.45 to 0.88, the income elasticity is between 0.10 and 0.55 (short run), the price of fuel elasticity is between -0.35 and -0.53 (short run) and the vehicle ownership is in the range of -0.27 and -0.61 (short run).

No conclusive evidence was found for the influence of public transport supply on fuel consumption per vehicle. Neither price of public transport nor density of rail stations managed to produce significant elasticities. This may result partially from the inability of our measures to appropriately represent the generalised cost of public transport (which includes travel time, but also walking and transfer time) and public transport supply (which includes service levels besides measures of existing physical infrastructure). Unfortunately, such data were not available to this study.

The choice of the preferred GMM model for the various specifications is based on the Arellano-Bond autocorrelation tests, AR(1) and AR(2) in first differences, the Sargan and Hansen test of overidentifying restrictions and the Difference-in-Hansen tests of exogeneity of the various instruments. Various specifications passed these tests, thus the selection of the final GMM estimator (and model specification) was done based on the signs of the elasticities and whether they produce counterintuitive results. Models (i-ii) and (v-vi) had the problem that the inclusion of vehicle ownership should have decreased the elasticity of income, as part of its effects is captured by the change occurring through vehicle stock. However, this did not hold true for the System-GMM estimator of these models. This led to the selection of model iv. System-GMM was preferred to Difference-GMM as the autoregressive parameter Y_{t-1} from Difference-GMM was close to the respective value of the FE estimator. The elasticities for the preferred model are shown in **Error! Reference source not found.**Table 5 and corresponding test results are shown in Table 6.

The rate of adjustment for the System-GMM estimator was found to be significant at the 99% confidence level. It value is 0.5683 and lies, as expected, within the values obtained from the pooled OLS (0.3455) and FE estimator (0.9316). The model gives significant results for price of fuel, income and vehicle ownership. The short-run elasticity of price of fuel is -0.392 while the long-run elasticity is -0.907. The income elasticity has a value of 0.378 in the short run and 0.877 in the long run. Fuel price and income elasticities both in the short run and in the long run are within the range proposed by existing surveys of previous empirical evidenced (see literature review). The elasticity of vehicle ownership has a value of -0.438 in the short run and -1.015 in the long run. This implies a short-run and long-run elasticity of vehicle stock equal to 0.562 and 1.302 respectively.

Table 3: Elasticities from dynamic models using pooled OLS, RE and FE estimators

Variable	Estimator/ Model	i	ii	iii	iv	v	vi
		(P_f/CPI), (Y/N)	**P_f/CPI), (Y/N), (CAR/N)**	**P_f/CPI), (Y/N), (P_{PT}/CPI)**	**P_f/CPI), (Y/N), (CAR/N), (P_{PT}/CPI)**	**P_f/CPI), (Y/N), (RAIL/N), (P_{PT}/CPI)**	**P_f/CPI), (Y/N), (CAR/N), (RAIL/N), (P_{PT}/CPI)**
(FUEL/CAR)$_{t-1}$	Pooled OLS	0.9490***	0.9405***	0.9434***	0.9316***	0.9422***	0.9277***
	RE	0.9490***	0.9405***	0.9434***	0.9316***	0.9422***	0.9277***
	FE	0.5974***	0.3452***	0.5983***	0.3455***	0.6032***	0.3371***
P_f/CPI	Pooled OLS	-0.2776***	-0.2661***	-0.2727***	-0.2573**	-0.2797***	-0.2734***
	RE	-0.2776***	-0.2661***	-0.2727***	-0.2573**	-0.2797***	-0.2734***
	FE	-0.4404***	-0.3129**	-0.4430***	-0.3276***	-0.4251***	-0.3433**
Y/N	Pooled OLS	0.1343*	0.1307*	0.1251	0.1182	0.1268	0.1220
	RE	0.1343***	0.1307*	0.1251**	0.1182**	0.1268**	0.1220
	FE	0.3986**	0.2021	0.3924**	0.1570	0.4077**	0.1389
CAR/N	Pooled OLS		-0.0723		-0.0882		-0.0957
	RE		-0.0723		-0.0882		-0.0957
	FE		-0.6461***		-0.6602		-0.6695***
RAIL/N	Pooled OLS					0.0030	0.0074
	RE					0.0030	0.0074
	FE					-0.0126	0.0122
P_{PT}/CPI	Pooled OLS			-0.0242	-0.0306	-0.0250	-0.0331
	RE			-0.0242	-0.0306	-0.0250	-0.0331
	FE			0.0459	0.2992	0.0805	0.2693

Notes: p-value <10% *, p-value <5% **, p-value <1% ***

Table 4: Elasticities from dynamic models using dynamic GMM estimators

Variable	Estimator/ Model	i	ii	iii	iv	v	vi
		(P_f/CPI), (Y/N)	P_f/CPI), (Y/N), (CAR/N)	P_f/CPI), (Y/N), (P_{PT}/CPI)	P_f/CPI), (Y/N), (CAR/N), (P_{PT}/CPI)	P_f/CPI), (Y/N), (RAIL/N), (P_{PT}/CPI)	P_f/CPI), (Y/N), (CAR/N), (RAIL/N), (P_{PT}/CPI)
$(FUEL/CAR)_{t-1}$	GMM Difference	0.7697***	0.5207***	0.7867***	0.4519**	0.8863***	0.6217***
	GMM System	0.8048***	0.6203***	0.6843***	0.5683***	0.6840***	0.6517***
P_f/CPI	GMM Difference	-0.4550***	-0.3489***	-0.4628***	-0.3762***	-0.4499***	-0.3680***
	GMM System	-0.3994***	-0.4371***	-0.4633***	-0.3916***	-0.5286***	-0.4926***
Y/N	GMM Difference	0.4118**	0.2557*	0.3968**	0.1057	0.4116**	0.2399
	GMM System	0.3954***	0.4726***	0.4343**	0.3784*	0.4333**	0.5490***
CAR/N	GMM Difference		-0.5111***		-0.6118**		-0.4632**
	GMM System		-0.3713**		-0.4381***		-0.2692**
RAIL/N	GMM Difference					-0.0199	-0.0034
	GMM System					0.0347	0.0317
P_{PT}/CPI	GMM Difference			0.1932	0.8346	0.3637**	0.4236***
	GMM System			-0.1027	-0.1284	-0.1046	-0.1131

Notes: p-value <10% *, p-value <5% **, p-value <1% ***

Table 5: Preferred model using GMM System estimator

	Short Run	Long Run	
Rate of adjustment	0.5683		***
Price of fuel (real)	-0.392	-0.907	***
Income (real)	0.378	0.877	*
Vehicle stock	0.562	1.302	***
Price of public transport (real)	-0.128	-0.297	

Note: p-value<10% *, p-value<5% **, p-value<1% ***

Table 6: Preferred model test results

Variable	Value
AR(1) in first differences	0.009
AR(2) in first differences	0.193
Sargan test	0.582
GMM instruments for levels (Hansen test)	0.274
Instruments	15
Number of cross-sections used	15
Number of observations	165

6. ROAD TRANSPORT CO_2 EMISSIONS SCENARIOS

Road transport GHG emissions in Portugal have almost doubled between 1990 and 2010, as can be seen in Figure 3. In 1990 they accounted for 9,628 million tonnes while in 2010 the value had risen to 18,255 million tonnes of CO_2 emissions. If Portugal is to meet the EU 2020 target of -20% GHG emissions compared to 1990 levels, the absolute value of CO_2 emissions has to drop to 7,702 tonnes. Therefore, a 58% decrease from 2010 emissions has to be achieved nationwide.

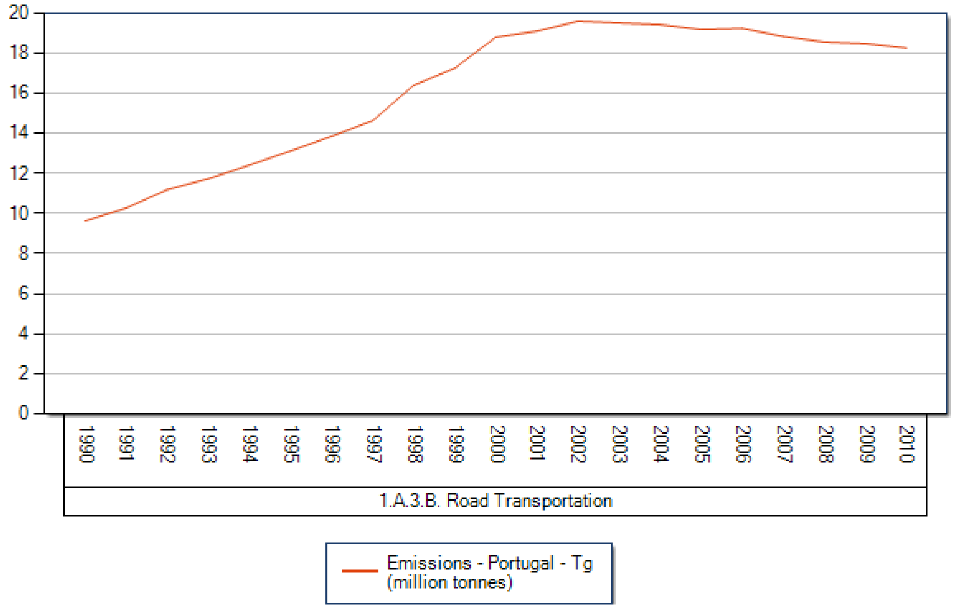

Figure 3: Evolution of road transportation GHG emissions in Portugal, Source: (European Environment Agency, 2012)

The short-run and long-run elasticity estimates, as obtained in the previous section, will be used to estimate the adjustment of policies required to help Portugal (and specifically the GAMP) meet the 58% GHG reduction that is required by 2020. Three macroeconomic scenarios are used to mitigate the future uncertainty over the change in real income per capita. The fuel demand elasticities calculated relate to total fuel consumption. Consequently, the 58% reduction in GHG reduction has to be converted in a percentage reduction of total fuel consumption.

According to the United States Environmental Protection Agency (EPA), a passenger car emits 1,954.8 grams CO_2 per litre (g CO_2/l) of gasoline and 2,239.2 g CO_2/l of diesel (United States Environmental Protection Agency (EPA), 2011). As in the dataset there is no segregation of passenger cars and heavy vehicles it is impossible to calculate the exact amount of emissions of heavy vehicles. In order to capture the increased emissions of trucks, the factor used to convert fuel consumption to tonnes of GHG gases will be the one of diesel (2,239.2 g CO_2/l).

From 2000 to 2009 the average increase in efficiency (l/100km) of vehicle stock in Portugal was 0.79% per year (Odyssee, 2012). Furthermore, the population growth in the GAMP from 2005 to 2010 was 0.67% (Instituto Nacional de Estatistica, 2012) and the average yearly growth of vehicle stock from 2008 to 2011 was 0.91% (Instituto de Seguros de Portugal (ISP), 2012). Considering the energy-efficiency policies EU implemented lately, it is rational to assume that the vehicle stock in the GAMP will increase its efficiency with a rate of 0.8% per annum or more. If the fleet improves its energy efficiency with a 0.8% p.a., in 2020 the CO_2 emissions per litre will be equal to $(1-0.008)^{10} \times 2,239.2 = 2,066.5 \approx 2,067\,\mathrm{g\,CO_2/l}$.

In 2010 the total fuel consumption in GAMP was 1,470 million litres or $1,470 \cdot \times 10^6\,(l) \times 2,239.2 (g\,CO_2\,/\,l) = 3.29$ million tonnes CO_2. In 2020 the GHG emissions will have to be $3.29\times(1-58\%)=1.382$ million tonnes CO_2, if Portugal is to meet the 2020 emissions targets. Assuming that in 2020 the CO_2 emissions per litre will be 2,067 g CO_2/l the fuel consumption will be equal to $1,382\ (\text{million kg } CO_2)/\,2.067\,(\text{kg } CO_2/\text{l}) = 668.5$ million litres of fuel.

$$\left.\begin{array}{l} Fuel\,Cons.^{2010} = 1,470 \text{ million litres} \\ Fuel\,Cons.^{2020} = 668.5 \text{ million litres} \end{array}\right\} Fuel\,Cons.^{2020} = \frac{668.5}{1,470} = 45.4\%\,Fuel\,Cons.^{2010}$$

Consequently, fuel consumption in 2020 has to be the 45.4% of the one of 2010. Therefore, the necessary reduction of fuel consumption from 2010 to 2020 will have to be 56.4%. Following the same methodology fuel consumption will have to be reduced by 48.6% if the energy efficiency of the vehicle stock increases with a rate of 2.0% p.a.

Three macroeconomic scenarios have been taken into consideration. Portugal had a -1.6% GDP growth in 2011 and the projection for 2012 and 2013 is -3.2% and -0.9% respectively (OECD, 2012). The pessimistic scenario predicts an annual 2% decline in the GDP of Portugal between 2010 and 2015 and a 1% decline per annum for the period 2015-2020. In this scenario the vehicle stock is assumed to change with a -1.0% rate p.a., as it is expected that the change in vehicle stock is strongly correlated with the real income. The baseline scenario assumes that nothing will change in the GDP of Portugal in the next 10 years, thus the real income of people in 2010 will be the same as the one in 2020. In this scenario there is the assumption that the change in vehicle stock over the next 10 years will be 0% p.a. Finally, there is one optimistic scenario that foresees a 1% increase per annum in the GDP growth of Portugal for the period 2010-2020. In this last scenario the vehicle stock is assumed to change with a rate of 0.5% p.a. The rate is smaller than the change in GDP growth as the vehicle ownership in GAMP and the population growth projections in Portugal do not give solid ground for an assumption of a rapid increase in the vehicle stock.

Using the preferred model's long run elasticities of income, price of fuel and vehicle stock, two different national policy measures are considered.

Policy A: Increase only in real price of fuel
Policy B: Increase in real price of fuel combined with car schemes (e.g. scrappage scheme) that will increase the energy efficiency of the fleet by 2.0% p.a.

Table 7 summarises the assumptions taken for the different policies and scenarios while Table 8 presents the proposed policy measures under scenarios 1, 2 and 3 and policy A and policy B.

Policy A forecasts that energy efficiency of the vehicle stock from 2010 to 2020 will increase at the current rate of 0.8% p.a. The 2020 emissions target is a 54.6% decrease in the fuel consumption compared to 2010 levels.

- Pessimistic scenario 1 projects a 14.0% decrease in real income and a 9.6% decrease of the vehicle stock. The target would be met only if there was a 32.8% increase in real fuel price from 2010 to 2020. This increase would be equivalent to a 2.9% increase in real fuel price annually.

- In the baseline scenario 2 the real income in 2020 will be the same as in 2010 while the vehicle stock will have a 0.0% growth over this period. The 54.6% reduction target would require a 60.1% increase of real fuel price. This would be equivalent to 4.8% increase of real fuel price annually.

- In the optimistic scenario 3 the real income in 2020 will be increased by 10.5% while the vehicle stock will be increased by 5.1%. The 2020 target would be met only if there was a 77.5% increase in real fuel price compared to 2010 prices. This increase would be equivalent to a 5.9% annual increase in real fuel price.

All three scenarios under policy A would require a significant annual increase in real fuel price for the period 2010-2020. Therefore, the rise of fuel price should be accompanied by other policies that will aim firstly at making the vehicle stock more energy efficient and secondly at reducing the number of vehicles. Under this logic, government should continue and extend the scrappage scheme that was firstly introduced in 2000, as it can help in both directions; some people will "sell" their old, energy intensive vehicle that they do not use often enough (maybe it is the second or third vehicle in the family), while others will "sell" their car and buy a new one with much improved environmental credentials.

Taking into consideration the above, **policy B** seems a more viable political decision. Policy B assumes policies that lead to a 2.0% increase p.a. in the energy efficiency of the vehicle stock. However, the possible reduction of the vehicle stock from such policies is not easily quantifiable, thus the rates of change of the vehicle stock were adopted from policy A.

Policy B forecasts that energy efficiency of the vehicle stock from 2010 to 2020 will increase at a rate of 2.0% p.a. The 2020 emissions target is a 48.6% decrease in the fuel consumption compared to 2010 levels. As it can be seen below, the adoption of policy B leads to slightly milder increases of real fuel price.

- Pessimistic **scenario 1** projects a 14.0% decrease in real income and a 9.6% decrease of the vehicle stock. The target would be met only if there was a 26.2% increase in real fuel price from 2010 to 2020. This increase would be equivalent to a 2.4% increase in real fuel price annually.

- In the baseline **scenario 2** the real income in 2020 will be the same as in 2010 while the vehicle stock will have a 0.0% growth over this period. The 48.6% reduction target would require a 53.5% increase of real fuel price. This would be equivalent to 4.4% increase of real fuel price annually.

- In the optimistic **scenario 3** the real income in 2020 will be increased by 10.5% while the vehicle stock will be increased by 5.1%. The 2020 target would be met only if there was a 70.9% increase in real fuel price compared to 2010 prices. This increase would be equivalent to a 5.5% annual increase in real fuel price.

Table 7: Assumptions of GDP growth, population growth, vehicle efficiency and vehicle stock growth for different scenarios and policies

Assumptions	**Policy A**			**Policy B**		
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 1**	**Scenario 2**	**Scenario 3**
GDP Growth	2010-2015: -2% p.a. 2015-2020: -1% p.a.	2010-2020: 0% p.a.	2010-2020: 1% p.a.	2010-2015: -2% p.a. 2015-2020: -1% p.a.	2010-2020: 0% p.a.	2010-2020: 1% p.a.
Growth of Vehicle Stock	2010-2020: -1.0% p.a.	2010-2020: 0.0% p.a.	2010-2020: 0.5% p.a.	2010-2020: -1.0% p.a.	2010-2020: 0.0% p.a.	2010-2020: 0.5% p.a.
CO_2 Emissions from Typical Vehicle	2010: 2,239 g CO_2/l			2010: 2,239 g CO_2/l		
Growth of GAMP population	2010-2020: 0.15%					
Increase in Efficiency of Vehicle Stock	2010-2020: 0.8% p.a.			2010-2020: 2.0% p.a.		
Target change (2010-2020) of Fuel Consumption	**-54.6%**			**-48.6%**		

Table 8: Policy measures for different macroeconomic scenarios

Period: 2010-2020	**Policy A (only changes in fuel price)**			
	Scenario 1		**Scenario 2**	**Scenario 3**
Change in Real Income	-14%	(2010-15 -2% p.a.) (2015-20 -1% p.a.)	0.0% (0% p.a.)	10.5% (1% p.a.)
Change in Real Price of Fuel	32.8% (2.9% p.a.)		60.1% (4.8% p.a.)	77.5% (5.9% p.a.)
Change in Vehicle Stock	-9.6% (-1.0% p.a.)		0.0% (-0.0% p.a.)	5.1% (0.5% p.a.)
Change in Fuel Consumption	**-54.6%**		**-54.6%**	**-54.6%**

Period: 2010-2020	**Policy B (changes in fuel price and efficiency of vehicle stock)**			
	Scenario 1		**Scenario 2**	**Scenario 3**
Change in Real Income	-14%	(2010-15 -2% p.a.) (2015-20 -1% p.a.)	0.0%	10.5%
Change in Real Price of Fuel	26.2% (2.4% p.a.)		53.5% (4.4% p.a.)	70.9% (5.5% p.a.)
Change in Vehicle Stock	-9.6% (-1.0% p.a.)		0.0% (-0.0% p.a.)	5.1% (0.5% p.a.)
Change in Fuel Consumption	**-48.6%**		**-48.6%**	**-48.6%**

7. CONCLUSIONS

Short-run and long-run elasticities of fuel demand were estimated the Greater Porto Metropolitan Area (GAMP) and the period 1999-2010. The preferred model specification estimated that the short-run elasticities of fuel price, income and vehicle stock are -0.39, 0.38 and 0.56 respectively. The corresponding long-run elasticities are -0.91, 0.88 and 1.3 respectively. The elasticities of income and price of fuel are almost equal showing that in a growing economy the fuel prices will have to grow at least at the same rate as income if fuel demand is to be controlled.

The fuel demand elasticities obtained were then used in a scenario-based analysis to investigate the potential future trends in road transport GHG emissions and evaluate whether Portugal may meet the target of 20% reduction of GHG emissions by 2020. Three different macroeconomic scenarios were selected for the next ten years; one pessimistic, one baseline and one optimistic. For each of these scenarios the necessary change in real fuel price was estimated for two different policy measures: the first (no action) assumed the increase in vehicle stock energy efficiency to remain at current levels, while the second policy incorporated an increase in vehicle stock energy efficiency.

The results show that if the second policy framework is selected the annual increase of real fuel price will be slightly milder. In the no action policy the highest increase would be for the optimistic macroeconomic scenario with a 5.9% p.a., while the lowest increase would be for the pessimistic macroeconomic scenario with a 2.9% annual increase. If the energy efficiency of the vehicle stock is also increased, the respective changes for the aforementioned scenarios are 5.5% p.a. and 2.4% p.a. respectively.

In both cases the increase required will probably cause major political problems to the government that will have to face public unrest. Therefore, complementary measures should be taken that will try to create feasible substitutes for the private vehicle. A solution would be the extra tax-money that comes from the fuel price increase to be immediately redirected to improvement of the public transport network; a fast, high-frequency, affordable and reliable public transport system can help motivate people to shift from cars to public transport.

Due to data limitations, our analysis did not identify a statistically significant effect for the role of public transport price and supply on fuel demand. Future research should attempt to find data that can allow constructing better measures of public transport accessibility, public transport supply, and the generalised cost of using public transport.

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