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Halkos, George and Kevork, Ilias and Tziourtzioumis, Chris

Department of Economics, University of Thessaly

25 November 2014

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George Halkos, Ilias Kevork & Chris Tziourtzioumis
Laboratory of Operations Research, Department of Economics,
University of Thessaly, Korai 43, 38333, Volos, Greece
halkos@uth.gr kevork@uth.gr tziourtz@econ.uth.gr

Abstract
In this paper we present for Greece a methodology for predicting emissions and estimating the abatement costs of the transport sector, focusing our analysis on passenger cars. In the first section we estimate for the period 2000-2030 the annual emissions of the most important pollutants using the Tier 2 method. For the application of this method, we forecast the number of passenger cars and the annual average distance driven per car technology, fuel type and displacement category. In particular, the forecasts for the number of cars are obtained by fitting trend and double exponential smoothing models to the available data from 2000 to 2013. Necessary adjustments to the number of cars of the latest technologies are made for each year such that the sum of predictions equals to the estimated total number of cars obtained through an econometric model that relates the changes in the number of cars and the changes in GDP (at current prices). In the second part of the study we estimate the total pollution cost at 2013 prices for four alternative scenarios, where for each scenario we assume changes for the period 2013-2030 to the composition of the fleet of passenger cars for the benefit of either gasoline or diesel or hybrids or LPG cars. The costs analyzed are capital, operation and maintenance and fuel.

Keywords: Transport sector; passenger cars; tier 2 method; abatement costs; emissions.

JEL codes: Q50; Q53; Q54; Q58; M21; R40; C53.

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* Work in this research has received funding from the "GHGsMETI" program, which takes place within the **SYNERGASIA 2011** action and is supported by the European Regional Development fund and Greek National Funds, project number **11SYN_8_118**. The text represents the authors' views.

ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ
ΕΥΡΩΠΑΪΚΟ ΤΑΜΕΙΟ ΠΕΡΙΦΕΡΕΙΑΚΗΣ ΑΝΑΠΤΥΞΗΣ

Υπουργείο Παιδείας και Θρησκευμάτων
ΕΥΔΕ-ΕΤΑΚ

Ε. Π. Ανταγωνιστικότητα και Επιχειρηματικότητα (ΕΠΑΝ ΙΙ), ΠΕΠ Μακεδονίας – Θράκης, ΠΕΠ Κρήτης και Νήσων Αιγαίου, ΠΕΠ Θεσσαλίας – Στερεάς Ελλάδας – Ηπείρου, ΠΕΠ Αττικής

1. Introduction

The transport sector in Greece is composed of the road, air, maritime and rail transport. According to the report by the Ministry of Environment, Energy and Climate Change (2013) the share of greenhouse gases emitted by inland shipping for the period 1990-2011 ranges from 9% to 15%, with this share to reach 11% in 2011. The corresponding share for the air transport ranges between 1.7% and 3.5%, with the minimum value to appear in 2011. For the rail transport this share for the same period reaches very low levels, from 1.6% in 1990 to less than 0.3% in 2011.

It is evident, therefore, that for the transport sector the largest share of greenhouse gas emissions for the period 1990-2011 is attributed to the road transport. According to that report this share had increased from 82% in 1990 to 87% in 2011. This increase was the result of two conflicting factors: (a) the large increase in the number of vehicles in Greece, and (b) the significant progress achieved in engine technologies for vehicle pollution control. These trends constitute the main reason for this work to focus the analysis on a very interesting sub-sector of road transport which is passenger cars.

More specifically, in this paper we forecast pollutant emissions for the period 2014-2030 by type of pollutant (eg. ozone precursors, greenhouse gases) and by several categories of passenger cars distinguished according to technology (Euro 1, 2, 3, etc..), fuel type (petrol, diesel, LPG) and displacement. The predictions are obtained based on data available for number of cars, annual average distance driven (in kilometers), emission factors and average fuel consumption (grams per kilometer) for each combination of car technology/displacement. The data for the period 2000-2013 is available from EMISSIA SA.[1]

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[1] EMISSIA SA is an innovative company of the Aristotle University/Laboratory of Thermodynamics, which was founded in 2008 and specializes in emissions inventories and forecasts, emissions models, and studies for the impact of environmental policies. http://www.emisia.com/

Most importantly, to make these predictions we take into account the crisis in the market of passenger cars, which had as a result the reduction of car sales for the period 2010-2013. To remove the effect of the crisis, first we develop for the period 1985-2013 a bivariate linear econometric model that relates the annual changes in the number of cars which were in circulation at the end of each year with the corresponding changes in the gross domestic product (GDP) at current prices. Using the GDP forecasts for the period 2014-2030 according to the OECD conservative scenario from Halkos et al. (2014), through the estimated regression model we proceed to forecast the total number of cars in circulation at the end of each year for the same period. Finally, the existing forecasts for the number of cars in each combination of technology/fuel type/displacement are adjusted for each prediction year by using their weights and the predicted total number of cars obtained through the estimated regression model.

Particularly important is also the part which refers to cost policies of emissions control for the period 2014-2030. These policies are related to changing the composition of car fleet at the end of each year by increasing the share of diesel or hybrid or LPG cars against the share of gasoline cars. These policies are in place according to international research results or information received from service department managers of car companies.

Finally, for the first time we give for the Greek sub-sector of passenger cars the estimated total cost incurred after applying these policies. The total cost is composed of the capital cost, the fixed and variable operating and maintenance cost and the fuel cost. For the calculation of these different cost elements we conducted extensive research to collect data for car prices, circulation taxes and insurance annual amounts by technology, fuel type and engine capacity of the car. The total cost was estimated at 2013 prices.

2. Statistics for passenger cars

The Hellenic Statistical Authority (EL.STAT)[2] defines as **vehicle,** independently of the number of wheels, that one which is moved by a motor and is intended to transport persons or goods, or both of them either by the same single vehicle or by a trailer carried by the main motor vehicle. The survey conducted by EL.STAT is exhaustive and uses the Registry of the Ministry of Infrastructure, Transport and Networks. This registry includes all the monthly changes in vehicle registration licenses in Greece. The corresponding data for Greece are reported by vehicle category (Passenger cars, Buses, Trucks, Motorcycles) and refer to the number of vehicles which are released for the first time in Greece (a) by make and (b) according to whether the vehicle is new or used.

New vehicle is that one which is registered for the first time in Greece and has not been released in any other country. Instead, **used vehicle** is that one which is registered for the first time in countries other than Greece and has been imported from them.

From the census of EL.STAT, vehicles that move on rails, trolley – buses, agricultural tractors and machinery are excluded. Also all vehicles of Armed Forces, Police, Fire Brigade, State Services, Diplomatic Body, Foreign Missions, and Invalids of War as well as motorcycles having engine capacity below 50 cc are not included in the exhaustive survey.

Passenger car is defined as the vehicle which is used to move people having maximum 9 seats including the driver's seat. In Table 1 we present the data of EL.STAT for the number of passenger cars in circulation in Greece at the end of each year from 1985 until 2013 and the number of cars (new plus used) which were first released in Greece (new entries) from 2000 until 2013. In the last two columns we give respectively the number of the erased-withdrawn cars and their share in the total number of cars in circulation at the end of

[2] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A1106

each year. The number of erased-withdrawn cars in each year was calculated as the number of new registrations on the same year minus the difference in the number of cars in circulation between the current and the previous year. In the period 2007-2012 we observe a continuous decrease in the annual rates of change. This has as a result, after 2010 to have continuous reductions in the total number of cars in circulation at the end of each year. Regarding new registrations, between 2007 and 2012, they decreased by 80%, while in 2013 this reduction appears slightly to recover. Finally, throughout the period 2000-2012 the share of the withdrawn- erased cars ranges between 1.14% and 2.66% with an average of 1.82%.

Table 1: Time series for passeneger cars in Greece for the period 1985-2013

Year (1)	Number of cars in circulation in Greece at the end of each year (2)	Rate of change (3)	New Registrations (4)	Number of withdrawn-erased cars (5)	% (5)/(2)
1985	1.259.335				
1986	1.355.142	7,61%			
1987	1.428.546	5,42%			
1988	1.503.921	5,28%			
1989	1.605.181	6,73%			
1990	1.735.523	8,12%			
1991	1.777.484	2,42%			
1992	1.829.100	2,90%			
1993	1.958.544	7,08%			
1994	2.074.081	5,90%			
1995	2.204.761	6,30%			
1996	2.339.421	6,11%			
1997	2.500.099	6,87%			
1998	2.675.676	7,02%			
1999	2.928.881	9,46%			
2000	3.195.065	9,09%	302.620	36.436	1,14%
2001	3.423.704	7,16%	289.943	61.304	1,79%
2002	3.646.069	6,49%	277.567	55.202	1,51%
2003	3.839.549	5,31%	272.515	79.035	2,06%
2004	4.073.511	6,09%	317.508	83.546	2,05%
2005	4.303.129	5,64%	302.613	72.995	1,70%
2006	4.543.016	5,57%	304.700	64.813	1,43%
2007	4.798.530	5,62%	317.879	62.365	1,30%
2008	5.023.944	4,70%	295.853	70.439	1,40%
2009	5.131.960	2,15%	244.539	136.523	2,66%
2010	5.216.873	1,65%	153.847	68.934	1,32%
2011	5.203.591	-0,25%	107.737	121.019	2,33%
2012	5.167.557	-0,69%	64.301	100.335	1,94%
2013	5.124.208	-0,84%	64.932	108.281	2,11%

Source: EL.STAT

To determine the total amount of pollutants emitted by passenger cars, the availability of data refering to the number of cars distinguished by different engine capacity, type of fuel, and technology was necessary. Based on the displacement, EUROSTAT classifies cars as (a) those that have displacement less than 1400 cc, (b) those with engine capacity from 1400 to 1999 cc, and (c) those with displacement larger than 2000 cc. Unfortunately neither EL.STAT nor EUROSTAT have data for Greece which give the distribution of the number of passenger cars according to engine capacity, technology, and fuel type. But as mentioned in the introductory section of this work, this kind of data for the period 2000-2013 are available from EMISSIA SA.

The data of EMISSIA SA give the total number of passenger cars in circulation at the end of each year by (a) fuel type, namely, gasoline, diesel, gas, (b) engine capacity, namely, less than 1400 cc, 1400-2000 cc, and greater than 2000 cc, and (c) technology. As shown in Table 2, the differences between the numbers reported by EL.STAT and EMISSIA SA, regarding the total number of passenger cars in circulation at the end of each year of the period 2000 to 2013, are small. However, using the weights of each combination of technology/fuel type/displacement calculated from EMISSIA SA data, the number of cars in each combination was adjusted such that the sum in each year gives the total number of passenger cars reported by EL.STAT. Furthermore, for each combination of technology/fuel type/displacement, data from EMISSIA SA are available concerning annual average distance (in kilometers) driven by passenger cars.

Table 2: Comparisons between total numbers of passenger cars in circulation at the end of each year reported by EL.STAT and EMISSIA SA

Year	2000	2001	2002	2003	2004	2005	2006
EMISSIA SA	3.312.486	3.522.178	3.718.059	3.883.417	4.097.866	4.303.129	4.543.016
ΕΛ.ΣΤΑΤ	3.195.065	3.423.704	3.646.069	3.839.549	4.073.511	4.303.129	4.543.016
Difference	117.421	98.474	71.990	43.868	24.355	0	0
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
EMISSIA SA	4.798.530	5.023.944	5.131.960	5.216.873	5.203.599	5.324.556	5.226.859
ΕΛ.ΣΤΑΤ	4.798.530	5.023.944	5.131.960	5.216.873	5.203.591	5.167.557	5.124.208
	0	0	0	0	8	156.999	102.651

3. Passenger car technologies in Greece

Cars technologies per fuel type which have been implemented in Greece are described in the report «EMEP / EEA emission inventory guidebook 2013 update September 2014», and are summarized by fuel type next.

3.1 Legislation classes for Gasoline passenger cars

The EMEP/EEA emission inventory guidebook 2013 states that, between 1970 and 1985, *all EC Member States followed the UNECE Regulation 15 amendments as regards the emissions of pollutants from vehicles lighter than 3.5 tonnes gross vehicle weight (GVW)*. Following the relevant EC Directives, the approximate implementation dates (varied from one Member State to another) of these regulations were as follows:

- pre ECE vehicles up to 1971,
- ECE-15.00 and ECE 15.01 from 1972 until 1977,
- ECE-15.02 from 1978 until 1980,
- ECE-15.03 from 1981 until 1985, and
- ECE-15.04 from 1985 until 1992.

The so-called «Euro» standards became mandatory in all Member States after 1992, by introducing a new type-approval test. Due to national incentives given in some countries, the new standards were introduced earlier in these countries than their official implementation date. Below, we provide a brief summary of the various stages, and the associated passenger cars technology, taken from the EMEP/EEA emission inventory guidebook 2013.

Euro 1: This type of passenger car was officially introduced by Directive 91/441/EEC in July 1992, and was the first to be equipped with a closed-loop, three-way catalyst. The cars of this technology also necessitated the use of unleaded fuel.

Euro 2: This type of passenger car had improved, closed-loop, three-way catalyst control and complied with lower emission limits compared with Euro 1 (30% and 55% reduction in CO and HC+NO_x respectively compared with Euro 1). The cars of this technology were introduced by Directive 94/12/EC in all Member States in 1996.

Euro 3: This emission standard was introduced in January 2000 by Directive 98/69/EC (Step 1) and introduced (a) a new type-approval test known as the New European Driving Cycle and (b) reduced emission levels compared with Euro 2 (30%, 40% and 40% for CO, HC and NOx respectively). The same Directive also introduced the need for On-Board Diagnostics (OBD) and some additional requirements (aftertreatment durability, in-use compliance, etc.). Euro 3 passenger cars were also equipped with twin lambda sensors to comply with emission limits.

Euro 4: This type of passenger car has been introduced in January 2005 by Directive 98/69/EC (Step 2), which required additional reductions of 57% for CO and 47% for HC and NO_x compared to Euro 3 standards. These requirements should be fulfilled through better fuelling and aftertreatment monitoring and control.

Euro 5 and 6: These emission standards were adopted by the European Council following the proposals by the European Commission in May 2007. Euro 5 coming into effect in January 2010 (September 2009 for new type approvals) leads to further NOx reductions of 25% compared with Euro 4, and a PM mass emission limit for Gasoline Direct Injection (GDI) cars which is similar to that for diesel cars. On the contrary, no further reductions for Euro 6 gasoline cars have been proposed.

3.2 Legislation classes for Diesel passenger cars

Diesel passenger cars of pre-1992 production are all grouped together under the car class coded as 'conventional'. This class includes non-regulated vehicles launched prior to 1985 and vehicles complying with Directive ECE 15/04 (up to 1992). Diesel vehicles in this class had been equipped with indirect injection engines. In 1992, the Consolidated Emissions Directive (91/441/EEC) introduced Euro standards for diesel cars in an analogous manner like those standards of gasoline cars. Particularly, the Euro standards for diesel cars were introduced by Directives 91/441/EEC (Euro 1, 1992-1996) and 94/12/EC (Euro 2, valid from 1996 for indirect injection and 1997 for direct injection up to 2000) and by regulations 98/69/EC Stage 2000 (Euro 3), and 98/69/EC Stage 2005 (Euro 4). More specifically:

Euro 1: This type of diesel passenger cars was the first to be regulated for all four main pollutants CO, HC, NOx and PM. Few of the cars were also equipped with oxidation catalysts.

Euro 2: For this type of cars the directive required reductions of 68% for CO, 38% for HC+NO_x and 55% for PM compared with Euro 1. Besides, oxidation catalysts were used in almost all cars of this standard.

Euro 3: For Euro 3 diesel cars, the Directive required the following further reductions compared with Euro 2 standards: 40%, 60%, 14% and 37.5% for CO, NO_x, HC and PM respectively. These reductions were achieved through exhaust gas recirculation (NO_x reduction) and optimisation of fuel injection by using common-rail systems (PM reduction). Refinements to the fuel (mainly a reduction in sulphur content) also played an important role in the reduction of PM emissions. Additionally, national incentives and competition between manufacturers leaded some Euro 3 cars to be equipped with a diesel particle filter to reduce the PM emissions to levels well below the emission standard.

Euro 4: According to these standards diesel passenger cars were required to emit 22% less CO and 50% less HC, NO_x and PM compared with Euro 3 cars. Apart from the voluntary introduction of particle filters, advanced engine technology and aftertreatment measures [e.g. cooled exhaust gas recirculation (EGR), NO_x reduction/PM oxidation techniques] made possible such significant reductions.

Euro 5, 6, 6c: The Euro 5 proposal was put in place in 2010, while Euro 6 standards would have become effective for new types of cars in September 2014, with full implementation for all type approvals starting from January 2015. For Euro 5 and Euro 6 diesel cars, reductions in NO_x emissions compared with Euro 4 of 28% and 68% will be required respectively. However, the most important reduction of 88% compared to Euro 4 concerns PM. A particle number emission limit has also been agreed ($5x10^{11}$ km^{-1}) which makes the use of a diesel particle filter mandatory. Under real-world driving, Euro 5 diesel cars have been found to be very high emitters of NO_x, many times above their type-approval emission levels. The main reason for this is the tunable emission control systems which may alter cars performance according to operation conditions.

To limit such practices, two additional standards have been introduced; the Euro 6 (2014/15) and the so-called Euro 6c (2017/18) levels. With Euro 6 cars only more strict limits are introduced compared to Euro 5. Contrary to that Euro 6c standards introduces emissions control over real-world driving. In other words, emissions will be recorded also when the car is driven on road. It is expected that Euro 6c standards will lead to significant reductions of NO_x emissions for diesel passenger cars.

3.3 Legislation classes for LPG passenger cars

LPG cars complied with legislations prior to Directive 91/441/EEC are grouped together under a general class coded as «conventional». For all the other types of LPG cars, the same Euro classes are used in an analogous manner like the gasoline and diesel cars.

3.4 Legislation classes for gasoline hybrid passenger cars

Gasoline-hybrid passenger cars constitute the intermediary link between the conventional gasoline car and (a) the plug-in hybrid (PHEV), (b) the electric car with range extender (EREV) and (c) the battery electric car (BEV). The latter three types of car can be recharged by power from the electrical grid. On the contrary, a hybrid passenger car can be recharged by power only by its own engine (Ministry of Environment, Energy and Climate change, 2012). Hence, a gasoline hybrid car uses gas as the only power source. Today, gasoline hybrids comply with the Euro 6 emission limits, but due to their advanced technology, they may have real emission levels which are actually much lower than the Euro 6 limits.

4. Forecasts for the number of cars in Greece 2014-2030

For each combination of technology/fuel type/displacement we made forecasts for the number of cars in circulation at the end of each year for the period 2013-2030 using trend and double exponential smoothing models (Makridakis et al., 1998). The models were fitted to the available series of the period 2000-2013. The selected models which were eventually used to produce the forecasts are given in Table 3 for all the combinations of technology/fuel type/ displacement. For each combination, the selection of the most appropriate model between alternative trend (e.g. linear, quadratic, s-curve) and double exponential smoothing models was made by comparing the values of the statistical accuracy measures MAPE (Mean Absolute Percentage Error), MAD (Mean Absolute Deviation) and MSD (Mean Squared

Deviation), in combination, however, with the reasonableness of the produced forecasts according to the time evolution of the number of cars between 2000 and 2013.

Table 3: Forecasting models for the number of passenger cars in circulation at the end of each year between 2013 and 2030 for each combination of technology/fuel type/displacement

Fuel type	Technology	Displacement	Model	Used period
Gasoline	PRE ECE	< 1.4 l	We don't make forecasts because from 2002 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
		1.4 - 2 l		
		> 2 l		
Gasoline	ECE 15/00-01	< 1.4 l	We don't make forecasts because from 2008 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
		1.4 - 2 l		
		> 2 l		
Gasoline	ECE 15/02	< 1.4 l	We don't make forecasts because from 2011 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
		1.4 - 2 l		
		> 2 l		
Gasoline	ECE 15/03	< 1.4 l	S-Curve Trend Model	2000-2013
		1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Gasoline	ECE 15/04	< 1.4 l	S-Curve Trend Model	2000-2013
		1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Gasoline	PC Euro 1 - 91/441/EEC	< 1.4 l	S-Curve Trend Model	2000-2013
		1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Gasoline	PC Euro 2 - 94/12/EEC	< 1.4 l	Linear Trend Model	2009-2013
		1.4 - 2 l	S-Curve Trend Model	2005-2013
		> 2 l	S-Curve Trend Model	2005-2013
Gasoline	PC Euro 3 - 98/69/EC Stage2000	< 1.4 l	Linear Trend Model	2009-2013
		1.4 - 2 l	Linear Trend Model	2009-2013
		> 2 l	Linear Trend Model	2009-2013
Gasoline	PC Euro 4 - 98/69/EC Stage2005	< 1.4 l	Quadratic Trend Model	2006-2013
		1.4 - 2 l	Quadratic Trend Model	2006-2013
		> 2 l	Quadratic Trend Model	2009-2013
Gasoline	PC Euro 5 - EC 715/2007	< 1.4 l	Linear Trend Model	2010-2013
		1.4 - 2 l	Linear Trend Model	2010-2013
		> 2 l	Linear Trend Model	2010-2013
Diesel	Conventional	1.4 - 2 l	S-Curve Trend Model	2000-2013
		> 2 l	We don't make forecasts because from 2013 and later there are not cars in Grrece with this combination of technology/fuel type/displacement	
Diesel	PC Euro 1 - 91/441/EEC	1.4 - 2 l	S-Curve Trend Model	2008-2013
		> 2 l	S-Curve Trend Model	2007-2013
Diesel	PC Euro 2 - 94/12/EEC	1.4 - 2 l	S-Curve Trend Model	2008-2013
		> 2 l	S-Curve Trend Model	2007-2013
Diesel	PC Euro 3 - 98/69/EC Stage 2000	1.4 - 2 l	Quadratic Trend Model	2000-2013
		> 2 l	Double Exponential Method	2000-2013
Diesel	PC Euro 4 - 98/69/EC Stage2005	< 2l	Linear Trend Model	2006-2013
		> 2 l	Linear Trend Model	2006-2013
Diesel	PC Euro 5 - EC 715/2007	< 2l	Linear Trend Model	2010-2013
		> 2 l	Linear Trend Model	2010-2013
LPG	Conventional	We don't make forecasts because from 2009 and later there are not cars in Grrece with this combination of technology/fuel type/displacement		
LPG	PC Euro 1 - 91/441/EEC	We don't make forecasts because from 2011 and later there are not cars in Grrece with this combination of technology/fuel type/displacement		
LPG	PC Euro 2 -94/12/EEC		S-Curve Trend Model	2007-2013
LPG	PC Euro 3 - 98/69/EC Stage2000		S-Curve Trend Model	2009-2013
LPG	PC Euro 4 - 98/69/EC Stage2005		Linear Trend Model	2006-2013
LPG	PC Euro 5 - EC 715/2007		Linear Trend Model	2010-2013

Regarding the number of hybrid cars, EMISSIA SA do not have data available for the period 2000-2013 with the explanation that this number has been very small. For our part, we proceeded to produce estimates having collected the number of TOYOTA PRIUS that has been released since 2002 in Greece (this number is available from EL.STAT, see footnote 2), the market information that in 2010 the share of TOYOTA PRIUS sales was 70% of the total hybrid sales[3], and the assumption that in the period from 2002 to 2013, no hybrid car had been erased/withdrawn. Our estimates showed that at the end of the years 2011, 2012 and 2013, the hybrid share in the total number of cars in circulation had been stabilized at the very low level of 0.07%. Based on this finding, to predict the number of hybrid cars for the period 2014-2030, we assumed that in each year the hybrids will constitute 0.07% of the total estimated number of passenger cars in circulation.

An important problem arising in the forecasting process was the inclusion of the crisis impact on the numbers of cars for the years 2010 till 2013 and therefore on the forecasts for the period 2014-2030. As mentioned before, due to the crisis, car sales dramatically decreased and this leaded to reductions of the number of cars in circulation from 2010 until 2012. In contrast, in 2013 a slight increase in sales was observed, while market estimates point out that car market will recover. This view is reinforced in particular by the policy of reduced selling prices due to the measure of withdrawal and by the attractive new car market financing programs which are offered. Many companies do not ask for an advance payment, while the number of monthly payments reaches 84 with a floating interest rate at 5% per annum and fixed at 8%.

To remove the effect of the crisis on the predicted number of cars for the period 2014-2030, firstly we developed a bivariate econometric model that related the number of cars in

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[3] http://www.zougla.gr/automoto/article/treli-i-poria-tis-toyota-stin-eliniki-agora

circulation at the end of each year to the GDP at current prices. Having available the forecasts of GDP for the period 2014-2030 from Halkos et al. (2014) according to the «OECD conservative scenario (The Organization for Economic Co-operation and Development, 2014)», and using the econometric model we obtained forecasts for the total number of cars in circulation at the end of each year of this period. Finally, the existing predicted number of cars for each combination of technology/fuel type/displacement was adjusted for each year by applying the corresponding weight to the estimated total number of cars which was obtained through the econometric model.

To estimate the linear econometric model, we used initially as dependent variable the number of cars in circulation at the end of each year for the period 1985-2013 (see Column 2 of Table 1) and as explanatory the GDP at current prices for the same period. The latter series is available either by EL.STAT[4] or by the International Monetary Fund (IMF)[5]. By applying augmented Dickey-Fuller tests (for istance, Halkos 2011, 2006; Box et al., 2008; Halkos and Kevork, 2005; Harvey 1993) to both variables, including in the test equation both a trend term and an intercept, we found out that the two series were stationary. However, applying the augmented Dickey-Fuller test to the residuals from this regression (in an Engle-Granger test), including in the test equation neither a trend term nor an intercept, we found that they were stationary in second differences as well. Therefore, there was sufficient statistical to support that this initial regression was spurious and the two time series were not cointegrated.

An alternative approach was to use in the linear econometric model as dependent variable the annual change in the number of cars in circulation at the end of each year (ΔPGC_t) and as explanatory variable the corresponding changes in GDP (ΔGDP_t). As it was expected, the application of the augmented Dickey-Fuller tests gave stationarity for these two

[4] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0702

[5] http://www.imf.org/external/data.htm

new time series (ΔPGC_t, ΔGDP_t) in first differences (see estimation output A1 of the Appendix). Moreover, applying the corresponding augmented Dickey-Fuller test to the residuals of the new regression we found that at 5% significance level the residuals were stationary in levels (see estimation output A2 of the Appendix). This offered strong statistical evidence to support that ΔPGC_t and ΔGDP_t were cointegrated.

Performing also residual diagnostic tests in the new estimated regression of ΔPGC_t against ΔGDP_t (see estimation outputs A3 and A4 of the Appendix), we obtained sufficient statistical evidence to support that the errors were normally distributed with no ARCH effect. Unfortunately, the errors were found to be serially correlated. Following these test results, we proceeded to re-estimate the linear regression model of ΔPGC_t against ΔGDP_t (see estimation output A5 of the Appendix) with the errors to be autocorrelated. Having strong indication from the sample ACF and PACF functions that the errors follow the first order autoregressive model, AR(1), the Cochranne-Orcutt method (e.g. Halkos, 2006, 2011) was used, which gave the following estimated model

$$\Delta \hat{P}GC_t = 99087,360 + 6213,104 \cdot \Delta GDP_t + \hat{\varepsilon}_t$$
$$\text{where } \hat{\varepsilon}_t = 0,676286 \cdot \hat{\varepsilon}_{t-1} \text{ and } \hat{\varepsilon}_{2013} = -72271,78. \quad (1)$$

Performing residual diagnostic tests in the estimated model (1) we obtained sufficient statistical evidence to support that the residuals (a) were uncorrelated, (b) were normally distributed and (c) did not have an ARCH effect (see estimation output A6 of the Appendix).

Substituting the forecasts of GDP changes according to the «OECD conservative scenario of GDP growth» from Halkos et al. (2014) into the estimated model (1), we took the total number of cars at the end of each year for the period 2014-2030. For each year, this number is given in the second column of Table 4. Furthermore, in the same Table we give for each year (column 3) the estimated total number of cars which is calculated as the sum of the forecasts obtained from fitting the selected trend and double exponential smoothing models to all the combinations of passenger cars technology/fuel type/displacement. These models have been presented in Table 3.

From the data in column 3 of Table 4 we confirm the negative impacts of the crisis from 2010 to 2013 on the predicted number of cars in circulation during the period 2014-2030. More specifically, the latter estimated total number of cars varies well below than the corresponding number from model (1), especially for years close to 2030, something that could be justified only by a «catastrophic scenario of negative GDP growth», which does not seem to be valid given the present conditions of the Greek economy. For this reason, as final forecasts for the number of cars in circulation were taken the numbers presented in column 2 of Table 4. Then the individual forecasts which were made with the trend and double exponential smoothing models (whose sum is given in column 3 of Table 4) for the number of cars in each combination of technology/fuel type/displacement were readjusted appropriately such that their sum gives for each prediction year the total numbers given in column 2 of Table 4. After these adjustments, the predicted total number of cars at the end of each year from 2013 to 2030 by technology and fuel type is presented in Table 5.

Table 4: Comparisons between forecasts for the total numbers of cars in circulation at the end of each year

Year	Forecasts based on model (1)	Forecasts based on trend and double exponential smoothing models
2014	5.155.189	5.063.469
2015	5.229.007	4.999.846
2016	5.317.197	4.972.044
2017	5.415.059	4.940.117
2018	5.516.952	4.921.412
2019	5.623.377	4.915.962
2020	5.731.271	4.922.175
2021	5.841.511	4.937.453
2022	5.952.228	4.958.814
2023	6.064.240	4.983.346
2024	6.176.347	5.008.470
2025	6.289.225	5.032.032
2026	6.402.068	5.052.326
2027	6.515.398	5.068.038
2028	6.628.670	5.078.166
2029	6.742.282	5.081.968
2030	6.855.845	5.078.893

Table 5: Final forecasts for the number of cars in circulation at the end of each year

	Gasoline		**Diesel**		**LPG**		**Hybrid**	
Year	**Number**	**Share**	**Number**	**Share**	**Number**	**Share**	**Number**	**Share**
2013	4.936.930	96,35%	177.082	3,46%	6.716	0,13%	3.480	0,07%
2014	4.899.283	95,04%	245.185	4,76%	7.113	0,14%	3.608	0,07%
2015	4.940.315	94,48%	277.375	5,30%	7.657	0,15%	3.660	0,07%
2016	4.995.148	93,94%	310.051	5,83%	8.276	0,16%	3.722	0,07%
2017	5.057.185	93,39%	345.066	6,37%	9.018	0,17%	3.790	0,07%
2018	5.122.424	92,85%	380.833	6,90%	9.833	0,18%	3.862	0,07%
2019	5.191.665	92,32%	417.069	7,42%	10.707	0,19%	3.936	0,07%
2020	5.262.258	91,82%	453.373	7,91%	11.628	0,20%	4.012	0,07%
2021	5.335.060	91,33%	489.772	8,38%	12.590	0,22%	4.089	0,07%
2022	5.408.284	90,86%	526.190	8,84%	13.588	0,23%	4.166	0,07%
2023	5.482.513	90,41%	562.859	9,28%	14.623	0,24%	4.245	0,07%
2024	5.556.451	89,96%	599.875	9,71%	15.697	0,25%	4.324	0,07%
2025	5.630.487	89,53%	637.525	10,14%	16.811	0,27%	4.402	0,07%
2026	5.703.664	89,09%	675.954	10,56%	17.968	0,28%	4.482	0,07%
2027	5.776.219	88,65%	715.441	10,98%	19.177	0,29%	4.561	0,07%
2028	5.847.443	88,21%	756.147	11,41%	20.440	0,31%	4.640	0,07%
2029	5.917.460	87,77%	798.339	11,84%	21.764	0,32%	4.719	0,07%
2030	5.985.702	87,31%	842.189	12,28%	23.155	0,34%	4.799	0,07%

The data from Table 5 lead us to formulate the first scenario for which the amount of emissions and their costs will be eximaned in the following sections. In this scenario which is a continuation of the 2000-2012 trends (adjusted according to OECD estimates for GDP growth after 2013), the share of diesel and LPG cars in the total number of cars in circulation increases gradually from 3.46% and 0.13% in 2013 to 12.28% and 0.34% respectively in 2030. Simultaneously, the corresponding share of gasoline cars in the same period decreases from 96.35% to 87.31%. Following this first scenario we have formulated three more emission abatement scenarios by changing the composition of the fleet of passenger cars during the period 2013-2030. These three scenarios are described next.

Scenario 2 (Diesel): In this scenario we assume that the share of diesel cars in the fleet of cars in circulation increases from 3.46% in 2013 to 25% in 2030. This assumption is based on market estimates[6] which state that the share of diesel cars in total sales is at the level of 25%. In this scenario we also assume that the share of hybrids and LPG cars remain constant

[6] http://www.autotriti.gr/data/news/preview_news/106138.asp

throughout the period and this has as a result the share of gasoline cars to decline from 96.34% in 2013 to 74.59% in 2030. The increases in the number of diesel cars were given to Euro 5 technology, while the reductions in the number of gasoline cars were made proportionally to all technologies that will be in circulation in each prediction year.

Scenario 3 (Hybrid): In this scenario we assume that the share of hybrid cars in the fleet of cars in circulation each year will increase from 0.07% in 2013 to 3% in 2030. This assumption is based on recent research results of HIS and Polk[7] which showed that new registrations of hybrid cars in the US have got a market share in 2012-2014 which fluctuates slightly around 3%. In this scenario we assume that the share of diesel and LPG cars remain constant throughout the period, and this has as a result the share of gasoline cars to decrease from 96,34% in 2013 to 84,38% in 2030. The increases in the number of hybrid cars were given to Euro 4 technology and later, while the reductions in the number of gasoline cars were made proportionally to all technologies that will be in circulation each prediction year.

Scenario 4 (LPG): In this last scenario we assume that the share of LPG in the fleet of cars in circulation each year will increase from 0.13% in 2013 to 3% in 2030. This case was based on the previous scenario of hybrids. As in the previous two scenarios, we assume that the share of diesels and hybrids are stable throughout the period, making the share of gasoline to decline from 96.34% in 2013 to 84.65% in 2030. The increases in the numbers of LPG cars were given to Euro 5 and Euro 6 technologies, while the reductions in the numbers of gasoline cars were made proportionally to all technologies that will be in circulation in each forecast year.

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[7] http://www.autoblog.gr/2014/06/13/ereyna-exei-hdh-korestei-h-agora-twn-ybridikwn-aytokinhtwn/

Finally, we note that forecasts for the annual average distance traveled (in km) by cars were made. From the data of Emissia SA we found that the annual decreasing rate of the average distance traveled during the period 2000-2013 remained constant for each combination of technology/fuel type/displacement. So, independently of the technology/ displacement of cars, we computed that for gasoline cars the annual average decreasing rate for period 2000-2013 was 5.82%, for diesel cars 4.08% and for LPG cars 2.17%. These three annual average reduction rates were used to predict the annual average distance traveled (in km) by cars until 2030.

5. Pollutant emissions from passenger cars

The categories of pollutants emitted by passenger cars, whose quantities will be estimated for the period 2000-2012 and forecasted for the period 2013-2030 are the following (EMEP / EEA emission inventory guidebook 2013 update September 2014):

(A) ***Ozone precursors*** which include:

- Carbon monoxide CO,
- Nitrogen oxides, NO_x, which is the sum of the nitrogen monoxide, NO and the nitrogen dioxide, NO_2, and
- Non-methane volatile organic compounds, NMVOCs.

(B) ***Greenhouse gases*** which include:

- Carbon dioxide, CO_2,
- Methane, CH_4,
- Nitrus oxide, N_2O.

(Γ) ***Other categories*** which include:

- Ammonia, NH_3, and Sulfur dioxide, SO_2,

- Particulate matter mass, PM,
- Carcinogenic species which include PAHs, (Polycyclic aromatic hydrocarbons) and persistent organic pollutants like indeno(1,2,3-cd) pyrene, benzo(k)fluoranthene, benzo(b)fluoranthene and benzo(a)pyrene,
- lead, Pb.

In this study, for the calculation of the pollutant emissions we adopt the Tier 2 method, which uses the number of passenger cars, the annual mileage per car and the emission factors of each pollutant. Particularly, for year t of period 2000-2030, the quantity $E_{i,j,t}$ of pollutant i emitted by the j combination of passenger car technology/fuel type/displacement is computed by

$$E_{i,j,t} = N_{j,t} \times M_{j,t} \times EF_{i,j}, \tag{2}$$

where $N_{j,t}$ is the number of passenger cars in combination j (technology/fuel type/displacement) for year t, $M_{j,t}$ is the average annual distrance (km) driven by the car in combination j (technology/fuel type/displacement) for year t and $EF_{i,j}$ is the technology specific emission factor of pollutant i for the j combination of passenger car technology/fuel type/displacement. For the aforementioned categories of pollutants emitted by passenger cars, the $EF_{i,j}$ values in grammes per kilometer are given in Tables 3.16 and 3.17 of the report «EMEP/EEA emission inventory guidebook 2013 update September 2014».

An exception to the application of equation (2) is the calculation of the emitted amount for carbon dioxide (CO_2), methane (CH_4) and Sulfur dioxide (SO_2). For the calculation of CO_2, equation (2) is modified to

$$E_{i,j,t} = N_{j,t} \times M_{j,t} \times EF'_k \times FC_j \tag{3}$$

where EF'_k is the emission factor of fuel type k and FC_j is the average fuel consumption in grammes per kilometer for the j combination of passenger car technology/fuel type/ displacement. The factor EF'_k is: 3,180 kg CO_2 per kg of Gasoline, 3,140 kg CO_2 per kg of Diesel and 3,017 kg CO_2 per kg of LPG. From Table 3.26 of the report «EMEP/EEA emission inventory guidebook 2013 update September 2014» the average fuel consumption in grammes per kilometer driven by cars is given for the combinations of technology/fuel type/ displacement. These averages have been used in our calculations.

Additionally, for the calculation of methane, the $EF_{i,j}$ was computed as the average of the Urban-Hot and the Urban-cold emission factors which are given in Table 3.72 of the report «EMEP/EEA emission inventory guidebook 2013 update September 2014». Finally, for the calculation of sulfur dioxide we used from the same report equation (2) and the values of Table 3.13.

For each one of the four aforementioned scenarios the estimated total quantities of pollutants emitted by cars for the period 2000-2012 and the corresponding predicted quantities for the period 2013-2030 are presented in Tables 6a to 6e. Changing the composition of the passenger cars fleet for period 2013-2030, as a result of extrapolating the existing trends of the period 2013-2030 and the adjustments made for the GDP growth incorporating the OECD estimates for years 2014 and 2015, leads to reductions of the total quantity of pollutants emitted by passenger cars from 97.6 million tones in 2000-2012 to 91.3 million tones in 2013-2030. From the total of 91.3 million tones of emissions for the period 2013-2030, 97.84% is attributed to greenhouse gases while 0.74% to ozone precursors. Between the different pollutants emitted by passenger cars, the most serious problem concerns the carbon dioxide which constitutes 99.98% of greenhouse gases.

In scenario 2, where in 2030 the share of diesel cars in the total fleet of passenger cars in circulation increases to 25% at the expense of the share of gasoline cars, unfortunately the total amount of pollutants emitted by passenger cars decreases less compared to scenario 1, that is, from 97.6 million tones in 2000-2012, the amount of emissions reduces to only 95.9 million tones in 2013-2030. An even worse case occurs under scenario 4, where LPG cars have 3% share of the total fleet of passenger cars in circulation in 2030 at the expense of the share of gasoline cars. In this case, we observe an increase to the total quantity of emissions from 97.6 million tones in 2000-2012 to 120.9 million tones in 2013-2030.

On the contrary, emission levels below 91.3 million tones can be attained under scenario 3 where the composition of the cars fleet changes in favor of the hybrid cars (3% share in 2030 from 0.07% in 2013) and at the same time the share of gasoline cars reduces from 96.34% in 2013 to 84.65% in 2030. In particular, with this scenario the total quantity of pollutants emitted by passenger cars declines from 97.6 million tones in 2000-2012 to 90,99 million tones in 2013-2030, with the carbon dioxide to constitute 97.8% of the total amount of emissions.

6. Abatement costs for passenger cars

In this section, firstly we estimate the total pollution cost from passenger cars for the period 2000-2012 (scenario $i = 0$), and then we forecast the total pollution cost for each scenario ($i = 1,2,3,4$) for the years 2013-2030. For the four scenarios the total pollution cost is estimated at 2013 prices and is given by

$$TC_i = C_i + FOM_i + VOM_i + F_i \tag{4}$$

where C_i is the capital cost, FOM_i is the fixed operation and maintenance cost, VOM_i is the variable operation and maintenance cost and F_i is the fuel cost.

Denoting by P_k the average price of passenger car which belongs to the k combination of fuel type/displacement at 2013 prices, the capital cost of scenario i is calculated from

$$C_i = \sum_t \sum_k S_{i,k,t} \times P_k \ , \tag{5}$$

where $S_{i,k,t}$ stand for cars sales of the k combination of passenger car fuel type/displacement for year t according to scenario i. The indicator t takes values from 2000 to 2012 for the scenario $i = 0$ and values from 2013 to 2030 for the remaining scenarios $i = 1,2,3,4$. For the period 2000-2013 as cars sales for each year we take the numbers which are given in column 4 of Table 1.

For scenarios $i = 1,2,3,4$, we consider for the period 2014-2030 that the percentage of erased/withdrawn cars to the total number of cars in circulation at the end of each year will be equal to the average percentage calculated from the last column of Table 1. This average percentage of erased/withdrawn cars for the period 2000-2013 equals to 1.82%. Then for each year between 2014 and 2030, first we calculated the number of erased/withdrawn cars using the average rate of 1.82%, and then we estimated the number of sales by taking the sum of the number of erased/withdrawn cars and the difference in the number of cars in circulation between the current and the previous year. For all scenarios, the sales were distributed across the different combinations of passenger cars fuel type/ displacement proportionally according to the number of cars of each combination.

Table 6a: Estimated pollutant emissions (in million tones) in Greece for the period 2000-2012

Passenger Cars	Ozone precursors				Greenhouse gases				Other	TOTAL
	CO	**NOx**	**NMVOC**	**TOTAL**	**CO2**	**CH4**	**N2O**	**TOTAL**	**Gases**	
Gasoline	1.919.669,26	226.367,87	197.768,55	***2.343.805,68***	89.543.903,28	28.013,70	2.634,67	***89.574.551,66***	610.886,62	***92.529.243,95***
Diesel	4.338,46	14.376,67	822,52	***19.537,66***	3.812.289,90	133,42	126,46	***3.812.549,78***	1.922,51	***3.834.009,94***
LPG	12.797,79	1.513,26	1.439,88	***15.750,92***	1.235.007,89	571,98	33,55	***1.235.613,42***	9,46	***1.251.373,81***
Hybrid	7,48	2,26	0,17	***9,92***	18.879,57	5,21	0,03	***18.884,81***	564,10	***19.458,83***
TOTAL	**1.936.812,99**	**242.260,06**	**200.031,12**	***2.379.104,18***	**94.610.080,65**	**28.724,31**	**2.794,71**	***94.641.599,66***	**613.382,69**	***97.634.086,53***

Table 6b: Forecasts for pollutant emissions (in million tones) in Greece for the period 2013-2030 according to Scenario 1

Passenger Cars	Ozone precursors				Greenhouse gases				Other	TOTAL
	CO	**NOx**	**NMVOC**	**TOTAL**	**CO2**	**CH4**	**N2O**	**TOTAL**	**Gases**	
Gasoline	518.784,91	43.881,95	41.431,68	***604.098,55***	71.947.231,75	13.943,53	913,28	***71.962.088,56***	1.292.732,27	***73.858.919,38***
Diesel	5.327,53	46.938,93	1.047,61	***53.314,07***	12.659.654,61	113,25	511,84	***12.660.279,70***	3.773,87	***12.717.367,64***
LPG	18.624,74	1.587,06	2.780,07	***22.991,87***	4.745.444,69	2.202,44	110,13	***4.747.757,26***	30,79	***4.770.779,92***
Hybrid	14,11	4,27	0,33	***18,70***	35.607,94	9,82	0,07	***35.617,83***	1.496,64	***37.133,17***
TOTAL	**542.751,29**	**92.412,21**	**45.259,69**	***680.423,19***	**89.387.938,99**	**16.269,04**	**1.535,32**	***89.405.743,35***	**1.298.033,57**	***91.384.200,11***

Table 6c: Forecasts for pollutant emissions (in million tones) in Greece for the period 2013-2030 according to Scenario 2 (Diesel)

Passenger	Ozone precursors				Greenhouse gases				Other	TOTAL
Cars	CO	NOx	NMVOC	TOTAL	CO2	CH4	N2O	TOTAL	Gases	
Gasoline	495.935,53	42.110,88	39.736,08	***577.782,49***	67.871.720,75	13.214,52	871,53	***67.885.806,80***	1.223.537,66	***69.687.126,95***
Diesel	7.680,72	79.270,40	1.523,43	***88.474,54***	21.290.874,27	171,55	723,85	***21.291.769,68***	5.397,08	***21.385.641,29***
LPG	18.624,74	1.587,06	2.780,07	***22.991,87***	4.745.444,69	2.202,44	110,13	***4.747.757,26***	30,79	***4.770.779,92***
Hybrid	14,11	4,27	0,33	***18,70***	35.607,94	9,82	0,07	***35.617,83***	1.496,64	***37.133,17***
TOTAL	**522.255,09**	**122.972,61**	**44.039,90**	***689.267,60***	**93.943.647,65**	**15.598,34**	**1.705,58**	***93.960.951,57***	**1.230.462,16**	***95.880.681,33***

Table 6d: Forecasts for pollutant emissions (in million tones) in Greece for the period 2013-2030 according to Scenario 3 (Hybrid)

Passenger	Ozone precursors				Greenhouse gases				Other	TOTAL
Cars	CO	NOx	NMVOC	TOTAL	CO2	CH4	N2O	TOTAL	Gases	
Gasoline	512.762,25	43.409,98	40.980,59	***597.152,82***	70.906.240,08	13.755,54	902,33	***70.920.897,94***	1.274.934,42	***72.792.985,19***
Diesel	5.327,53	46.938,93	1.047,61	***53.314,07***	12.659.654,61	113,25	511,84	***12.660.279,70***	3.773,87	***12.717.367,64***
LPG	18.624,74	1.587,06	2.780,07	***22.991,87***	4.745.444,69	2.202,44	110,13	***4.747.757,26***	30,79	***4.770.779,92***
Hybrid	270,81	81,87	6,30	***358,98***	683.425,61	188,52	1,26	***683.615,40***	28.725,06	***712.699,43***
TOTAL	**536.985,32**	**92.017,84**	**44.814,57**	***673.817,73***	**88.994.764,99**	**16.259,76**	**1.525,56**	***89.012.550,31***	**1.307.464,14**	***90.993.832,18***

Table 6e: Forecasts for pollutant emissions (in million tones) in Greece for the period 2013-2030 according to Scenario 4 (LPG)

Passenger	Ozone precursors				Greenhouse gases				Other	TOTAL
Cars	CO	NOx	NMVOC	TOTAL	CO2	CH4	N2O	TOTAL	Gases	
Gasoline	513.257,24	43.448,51	41.017,46	***597.723,21***	70.993.544,68	13.771,21	903,23	***71.008.219,12***	1.276.420,13	***72.882.362,46***
Diesel	5.327,53	46.938,93	1.047,61	***53.314,07***	12.659.654,61	113,25	511,84	***12.660.279,70***	3.773,87	***12.717.367,64***
LPG	127.711,13	11.440,03	20.374,65	***159.525,80***	35.072.693,51	16.278,11	813,91	***35.089.785,53***	227,54	***35.249.538,87***
Hybrid	14,11	4,27	0,33	***18,70***	35.607,94	9,82	0,07	***35.617,83***	1.496,64	***37.133,17***
TOTAL	**646.310,01**	**101.831,73**	**62.440,05**	***810.581,79***	**118.761.500,75**	**30.172,39**	**2.229,05**	***118.793.902,18***	**1.281.918,17**	***120.886.402,15***

As fixed maintenance and operating costs we consider (a) the total annual circulation taxes and (b) the cars insurance cost, and as variable operating and maintenance costs the average amount spent annually for cars service. Denoting by L_k, A_k, and M_k the annual average costs concerning tax, insurance cost, and service respectively for cars belonging to the k combination of fuel type/displacement at 2013 values, the total maintenance and operation costs are calculated from

$$FOM_i + VOM_i = \sum_t \sum_k N_{i,k,t} \times (L_k + A_k + M_k), \tag{6}$$

where $N_{i,k,t}$ is the number of cars in circulation belonging to the k combination fuel type/ displacement at the end of year t according to scenario i. Finally if we denote by B_s the cost of fuel at 2013 prices (in kg per km) of the s fuel type (Gasoline, Diesel, LPG) and with $D_{i,s,t}$ the average total distance driven in year t by cars using fuel type s under scenario i, then the cost of fuel consumption is given by

$$F_i = \sum_t \sum_s B_s \times D_{i,s,t} . \tag{7}$$

Substituting (5)-(7) into (4), the total pollution cost of scenario i at 2013 prices is determined from

$$TC_i = \sum_t \sum_k S_{i,k,t} \times P_k + \sum_t \sum_k N_{i,k,t} \times (L_k + A_k + M_k) + \sum_t \sum_s B_s \times D_{i,s,t} . \tag{8}$$

To determine P_k, L_k, and A_k an extensive primary research was carried out. To calculate P_k, selling prices of 2013 were collected for all makes of cars belonging to the k combination of fuel type/displacement. In each combination, the average selling price of all types of cars in a given make was weighted with the share that this make of car had in the total sales of 2013. For each make, data on cars sales are available by the Hellenic Statistical Authority (see footnote 2). Then, for each one of the combinations of passenger cars fuel type/displacement P_k was calculated as a weighted average, and the values of these weighted averages are given in Table 7.

Table 8 presents for each combination of passenger car fuel type/displacement the unweigthed averages of 2013 circulation taxes, which are considered as values of L_k. For the calculation of A_k, the minimum annual insurance cost for 2013 was taken depending on engine capacity of the car and on whether the driver with age over 23 years old had held a driving license for a year or for ten years. The data on insurance costs were collected for the five largest Greek cities in population, which are Athens, Thessaloniki, Patra, Larissa and Volos. The averages of the minimum annual insurance cost in each one of the combinations of passenger car fuel type/displacement are presented in Table 9, and these averages were taken as the 2013 values for A_k.

Table 7: Weighted averages for cars selling price (in €) for 2013

Car type	Displacement		
	< 1.4 lt	**1.4-2.0 lt**	**> 2.0 lt**
Gasoline	15.083	26.216	58.805
Diesel	16.264	23.452	50.892
Hybrid	17.400	20.892	63.716
LPG	16.146	25.290	-

Table 8: Average circulation tax (in €) for 2013

Car type	Displacement		
	< 1.4 lt	**1.4-2.0 lt**	**> 2.0 lt**
Gasoline	113	319	778
Diesel	41	123	384
Hybrid	47	85	301
LPG	124	317	–

Table 9: Annual average insurance cost (in €) 2013

Car type	Displacement		
	< 1.4 lt	**1.4-2.0 lt**	**> 2.0 lt**
Gasoline	214	275	328
Diesel	214	275	328
Hybrid	214	275	328
LPG	214	275	–

For the determination of M_k we have used the data of Emissia SA referring to the annual average cost of car service. These data were available for all the combinations of passenger cars fuel type/displacement but at 2009 prices. For the adjustment of the car service costs at 2013 prices, we used from EL.STAT[8] the average of three 2013 consumer price indices with base year 2009. These indices referred to car parts (1.0570), lubricant-coolant (1.0740) and maintenance-repair (0.9908). The values of M_k are displayed in Table 10.

Finally, taking the selling price of fuel from the Ministry of Development and Competitiveness for the period 04.01.2013 to 27.12.2013, averages were obtained over this period, which are dispalyed in Table 11 in € per litre. But for the conversion of the fuel price from litres to kilograms the specific weight for each fuel type was needed. The specific weight was set equal to 0,725 for gasoline, 0.845 for diesel, and 0.545 for LPG. Multiplying these specific weights by the fuel price per litre we transformed the fuel prices to euro per kg, and these latter fuel prices were taken as values of B_s presented also in Table 11.

Table 10: Annual average service cost (in €) for 2013

Car type	Displacement		
	< 1.4 lt	1.4-2.0 lt	> 2.0 lt
Gasoline	348	505	668
Diesel	359	520	688
Hybrid	–	517	–
LPG	355	515	682

Table 11: Average fuel price (in €) for 2013

	Unleaded 95	DIESEL	LPG
€/lt	1,69	1,39	0,89
€/kg	1,2252	1,1746	0,4851

Substituting the values of Tables 7-11 into equation (8) we take for each scenario the total pollutant emissions costs presented in Table 12. Taking the period 2000-2012 as the

[8] http://www.statistics.gr/portal/page/portal/ESYE/PAGE-themes?p_param=A0515&r_param=DKT87&y_param=2013_12&mytabs=0

baseline scenario for the calculation of the pollution control marginal cost, we result in the following findings:

- In scenario 1, the total pollutant emissions are reduced by 6.249.886.417,04 kg while the total pollution cost increases by 47.168.403.836 €.
- In scenario 2, the total pollutant emissions are reduced by 1.753.405.198,65 kg while the total pollution cost increases by 54.928.224.451 €.
- In scenario 3, the total pollutant emissions are reduced by 6.640.254.352,19 kg while the total pollution cost increases by 49.552.774.646 €.
- In scenario 4, both total pollutant emissions and total pollution costs increases by 23.252.315.613,60 kg and 53.331.386.824 € respectively.

Hence, the ***abatement costs*** for each scenario at 2013 prices are:

- Scenario 1: 7,55 € per kg of pollutants emitted by passenger cars
- Scenario 2: 31,33 € per kg of pollutants emitted by passenger cars
- Scenario 3: 7,46 € per kg of pollutants emitted by passenger cars
- Scenario 4: -2,29 € per kg of pollutants emitted by passenger cars

Table 12: Total pollution costs at 2013 prices

	Gasoline	Diesel	LPG	Hybrid	Total Cost
Period 2000-2012 Scenario i=0	141.336.091.299	9.012.252.566	363.335.453	140.681.724	**150.852.361.042**
Period 2013-2030 Scenario i=1	163.807.510.812	32.519.076.725	1.565.333.738	128.843.603	**198.020.764.879**
Period 2013-2030 Scenario i=2	137.569.408.097	66.517.000.055	1.565.333.738	128.843.603	**205.780.585.493**
Period 2013-2030 Scenario i=3	157.572.753.898	32.519.076.725	1.565.333.738	8.747.971.327	**200.405.135.688**
Period 2013-2030 Scenario i=4	158.127.516.130	32.519.076.725	13.408.311.408	128.843.603	**204.183.747.867**

7. Conclusions

For the period 2007-2012 we have observed a continuous decrease in the number of cars in circulation at the end of each year. The reason was the enormous reduction in new car registrations which reached 80% between 2007 and 2012. On the contrary, in 2013, there was a small increase in new car registrations and the provisional data from EL.STAT show that this increase will be much greater for 2014.

Market executives express their optimism that passenger cars market is recovering, and this is due to the following reasons: the policy of reduced selling prices due to the withdrawal measure, the attractive financing programmes for bying new cars, as well as, the economic climate that Greek people faces today. Many companies do not require advance payments, while the number of monthly payments is extended to 84 with floating interest rate 5% per annum and fixed interest rate ranging between 8% and 8.5%.

Extending the existing trends of the period 2000-2013 for the number of passenger cars per technology/fuel type/displacement, but adjusted according to GDP predicted growth where OECD estimates for 2014 and 2015 have been incorporated, and at the same time taking into account the estimates for the car market, we predict that the share of diesel and LPG cars in the total fleet in circulation will increase gradually from 3.46% and 0.13% respectively in 2013 to 12.28% and 0.34% in 2030.[9]

The share of hybrid cars will remain fixed at the very low level of 0.07%, while the share of gasoline cars will decrease between 2013 and 2030 from 96.4% to 87.1%. The new composition of the car fleet in 2030 will lead to reductions in the total amount of pollutants emitted by passenger cars from 97.6 million tons in the period 2000-2012 to 91.3 million tons in the period 2013-2030. From the 91.3 million tons of pollutants emitted in the period 2013-

[9] Obviously economic inefficiencies may arise due to the conditions hold in each country (Halkos and Tzeremes, 2009).

2030, 97.84% of them is attributed to greenhouse gases (carbon dioxide, methane, nitrous oxide) and 0.74% to ozone precursors (nitric carbon, oxides of nitrogen, volatile organic compounds except methane). Between different categories of pollutants, the most serious problem is caused by the carbon dioxide which constitutes 99.98% of greenhouse gases. Incorporating also in our analysis costs concerning car purchase, maintenance, insurance, road tax and fuel at 2013 prices, we estimate that the aforementioned reduction of emittions between 2000-2012 and 2013-2030 will cost 7,55 € per kg of pollutant emitted by passenger cars.

Further reduction of the total amount of pollutants emitted by cars, with this amount to reach 90.99 million tons, could be achieved for the period 2013-2030 if the fleet composition changed in favor of hybrids (share of 3% in 2030 from 0.07% in 2013) and at the same time the share of gasoline in the total fleet in circulation decreased between 2013 and 2030 from 96.34% to 84.65%. Even in this case, carbon dioxide emissions constitute the main problem with a share of 97.8% in total emissions. Under this policy of increasing the share of hybrids in the car fleet in circulation from 0,07% in 2013 to 3% in 2030, the marginal abatement cost cost is estimated at 2013 prices to 7,46 € per kg of pollutant.

On the other hand, less effective, and probably ineffective, are the policies according to which the composition of the car fleet between 2000-2012 and 2013-2030 increases in favor of diesel or LPG cars. In the hypothetical scenario where in 2030 the share of diesel cars in the total fleet increases to 25% at the expense of the share of gasoline cars, unfortunately the reduction in the total amount of emissions is smaller, as from 97.6 million tons for the period 2000-2012 we reach 95.9 million tons for the period 2013-2030. This reduction is paid with the relatively higher amount of 31,33 € per kg of pollutant emitted by cars at 2013 prices.

Furthermore, for the case where the LPG cars reach a share of 3% in 2030 at the expense of the share of gasoline cars, then between 2000-2012 and 2013-2030, we will not face reductions but increases in the total amount of pollutants. Particularly this amount will be increased between the two periods from 97.6 million tons to 120.9 million tons. The cause of the inefficiency of the last two policies is the trade-off between less fuel consumption which is achieved by new technologies and the longer average distance traveled in combination with lower fuel price per litre. Thus, a technology that gives lower pollutants (eg diesel engines) loses its advantage when the distances traveled increase proportionally more, either because the technology allows economical use of fuel or because this fuel is sold at a lower price.

APPENDIX

Estimation Output A1

ΔPGC_t in Levels

Exogenous: Constant

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.518226	0.8728
Test critical values:	1% level	-3.699871	
	5% level	-2.976263	
	10% level	-2.627420	

Exogenous: Constant, Linear Trend

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.213010	0.9892
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

ΔPGC_t in First Differences

Exogenous: Constant
Null Hypothesis: D(PGC) has a unit root
Lag Length: 0 (Automatic - based on SIC, maxlag=6)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.209121	0.0031
Test critical values:	1% level	-3.711457	
	5% level	-2.981038	
	10% level	-2.629906	

Exogenous: Constant, Linear Trend

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.776286	0.0039
Test critical values:	1% level	-4.356068	
	5% level	-3.595026	
	10% level	-3.233456	

ΔGDP in Levels

Exogenous: Constant

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.369684	0.9011
Test critical values:	1% level	-3.699871	
	5% level	-2.976263	
	10% level	-2.627420	

Exogenous: Constant, Linear Trend

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.999731	0.9274
Test critical values:	1% level	-4.339330	
	5% level	-3.587527	
	10% level	-3.229230	

ΔGDP in First Differences

Exogenous: Constant

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.649036	0.0116
Test critical values:	1% level	-3.711457	
	5% level	-2.981038	
	10% level	-2.629906	

Exogenous: Constant, Linear Trend

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.945489	0.0243
Test critical values:	1% level	-4.356068	
	5% level	-3.595026	
	10% level	-3.233456	

Estimation Output A2

Exogenous: None

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.161752	0.0318
Test critical values:	1% level	-2.653401	
	5% level	-1.953858	
	10% level	-1.609571	

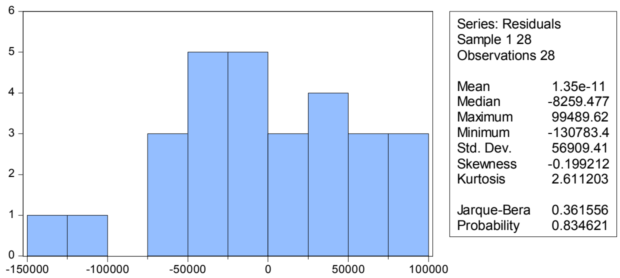
Estimation Output A3

Dependent Variable: ΔPGC_t
Method: Least Squares
Sample: 1 28
Included observations: 28

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	89898.49	13411.18	6.703252	0.0000
ΔGDP_t	8227.007	1321.137	6.227217	0.0000

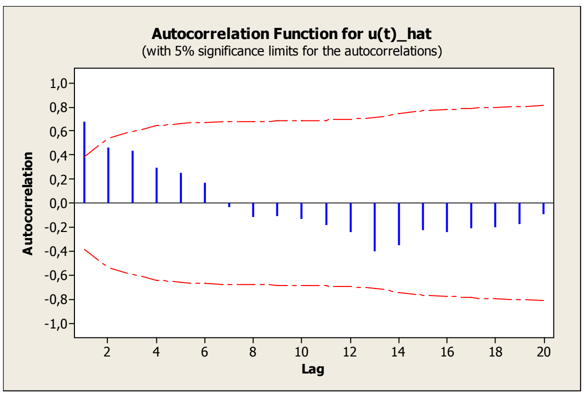
R-squared	0.598631	Mean dependent var	138031.2
Adjusted R-squared	0.583193	S.D. dependent var	89828.04
S.E. of regression	57993.49	Akaike info criterion	24.84280
Sum squared resid	8.74E+10	Schwarz criterion	24.93796
Log likelihood	-345.7992	Hannan-Quinn criter.	24.87189
F-statistic	38.77823	Durbin-Watson stat	0.622589
Prob(F-statistic)	0.000001		

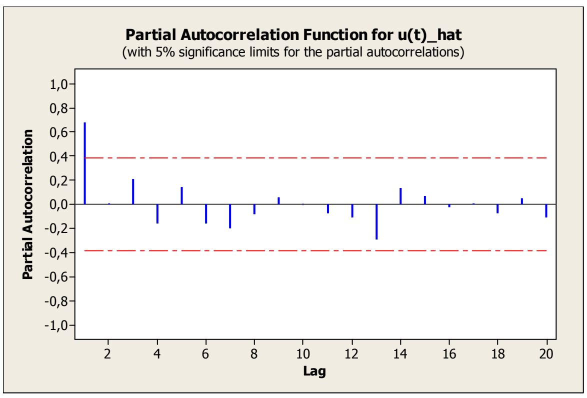
Estimation output A4:



Heteroskedasticity Test: ARCH

F-statistic	1.458799	Prob. F(1,25)	0.2384
Obs*R-squared	1.488638	Prob. Chi-Square(1)	0.2224





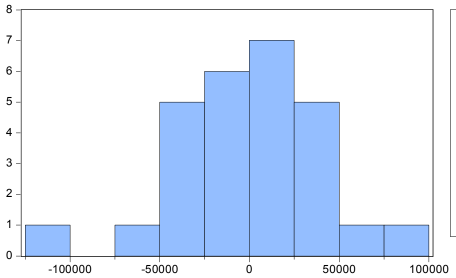
Estimation output A5:

Dependent Variable: ΔPGC_t
Method: Least Squares
Sample (adjusted): 2 28
Included observations: 27 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	32075.95	8527.432	3.761501	0.0009
ΔGDP_t	6213.104	1784.463	3.481777	0.0018

R-squared	0.326559	Mean dependent var	41703.31
Adjusted R-squared	0.299621	S.D. dependent var	50085.35
S.E. of regression	41915.75	Akaike info criterion	24.19590
Sum squared resid	4.39E+10	Schwarz criterion	24.29189
Log likelihood	-324.6446	Hannan-Quinn criter.	24.22444
F-statistic	12.12277	Durbin-Watson stat	1.778010
Prob(F-statistic)	0.001848		

Estimation output A6:



Series: Residuals
Sample 2 28
Observations 27

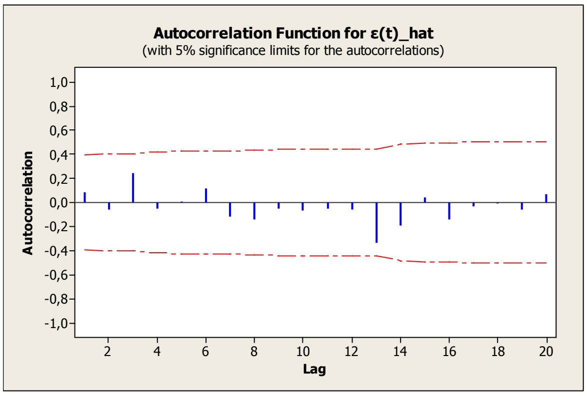
Mean	1.24e-11
Median	5589.368
Maximum	94161.57
Minimum	-109958.5
Std. Dev.	41101.77
Skewness	-0.233027
Kurtosis	3.770507
Jarque-Bera	0.912249
Probability	0.633735

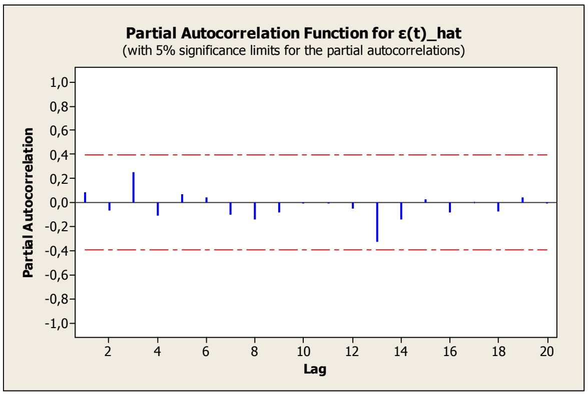
Breusch-Godfrey Serial Correlation LM Test:

F-statistic	0.127529	Prob. F(2,23)	0.8809
Obs*R-squared	0.296131	Prob. Chi-Square(2)	0.8624

Heteroskedasticity Test: ARCH

F-statistic	0.528613	Prob. F(1,24)	0.4742
Obs*R-squared	0.560322	Prob. Chi-Square(1)	0.4541





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