The Phase-Out of Leaded Gasoline in the EU:

A Successful Failure?[1]

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Abstract
The objective of this paper is to analyze in both descriptive and econometric terms the phase-out of leaded gasoline consumption in the EU countries. The phase-out process is characterized by increased consumption of unleaded gasoline. We analyze the importance of price differences, share of catalytic converters, income per capita, and country characteristics in the phase-out process. Since the expected maintenance costs of using unleaded gasoline in cars without catalytic converters compared to the use of leaded gasoline differ insignificantly according to available evidence, and consumers still use leaded gasoline even though unleaded gasoline is cheaper; we interpret this as a lack of reliable information. The results indicate that countries, which have not yet phased out leaded gasoline, should do this by either banning leaded gasoline or by increasing the tax differential between leaded and unleaded gasoline depending on the objective of the social planner.

Keywords: Leaded gasoline, unleaded gasoline, policy instruments, tax differential

JEL Classification : D12, D80, Q41, Q48.

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I. INTRODUCTION

The justifications of this study are manifold. First, to suggest policies for those countries that have not started to phase-out leaded gasoline; second, to suggest policies to speed up the phase-out in transition countries. Third, to analyze the tax differentials between gasoline types. The rationale for phasing out leaded gasoline are mainly due to environmental and health reasons. Our results, in the econometric part of the paper, show that tax differentials have contributed to the phase-out of leaded gasoline. Still, we argue in the descriptive part of the paper, that the magnitude of the price effect could have been larger if a mixed policy had been used. A crucial part of the mixed policy should be information regarding technical feasibility compatibility of engine and gasoline type.

The literature on estimation of gasoline demand is extensive (e.g. Baltagi and Griffin, 1997, Baltagi and Griffin, 1983, Dahl and Sterner, 1991, and McRae, 1994). These studies typically show significant price effects. More recent studies concerning the phase-out of leaded gasoline indicate that the tax differential has been an important instrument for the phase-out of leaded gasoline (Lovei 1996 and 1997, Swedish EPA 1997, Borenstein 1993 etc.). Even if there is evidence of that market-based policy instruments often are superior on the basis of allocative efficiency, we should not expect any automatism when there are market failures, as seems to be the case regarding knowledge of the substitution possibility between leaded and unleaded gasoline. This shall not be interpreted as an argument against the use of market-based policy instruments, but rather that we need to acknowledge the importance of complementing these policies with correct and efficient information, and that sometimes command and control instruments should be preferred.

Lead has long been known to be toxic and can cause neurological dysfunctions, renal damage, and at high doses death (Lovei, 1996). Children are especially sensitive for exposure to lead, and the effects are well documented. A child that is exposed to lead every day is at high risk of getting reduced IQ, learning difficulties, behavioral problems and hyperactivity (Thomas, 1995)[2]. One of the main sources of lead discharge is leaded gasoline used in the transportation sector.

The paper is organized as follows. In section two the data set is described and existing policy instruments and technical feasibility are discussed. Section three contains the econometric analysis; limitations and problems regarding modeling the phase-out is

2 In Thomas (1995) several studies are reviewed concerning health effects of leaded gasoline.

discussed, the economic models are formalized, specification tests are performed, and parameter estimates are presented. In section four we provide a descriptive analysis of uncertainty regarding substitution possibility, and the importance of information. We end the paper with concluding remarks and policy recommendations.

II. BACKGROUND

Data and Policy Instruments

We have yearly data[3] on gasoline consumption in EU member countries during 1985-1997. The data set consists of nine EU countries (6-10 observations per country) - Austria, Denmark, Finland, France, Greece, Germany, Portugal, Sweden, and the UK - where we have data on the share of cars equipped with catalytic converters and consumption of both leaded and unleaded gasoline. The data set can only be increased by including more recent observations for those countries that have not completed the phase-out. There is one limitation with just looking at the consumption of gasoline for passenger cars, since diesel and LPG (Liquefied Petroleum Gasoline) stands for a significant part of passenger cars' consumption in many countries. However, we neglect the use of diesel and LPG in our analysis. If we think of possible substitution between gasoline and other fuels, this can only be done ex ante purchase of car. Ex post there are no substitution possibilities between diesel and LPG, and gasoline. Countries introduce unleaded gasoline and phase-out the leaded gasoline at different points in time. Obviously, we do not have consumption and price of unleaded gasoline prior to the entry of unleaded gasoline. Similarly, there are no price or consumption of leaded gasoline after the completion of the phase-out. Typically, the introduction of unleaded gasoline precedes the introduction of catalytic converters. One central fact for our study is that *all* cars can use unleaded gasoline, i.e. even cars with soft valve seats (for a more detailed discussion on this see *Technical Feasibility* below).

3 The data on gasoline consumption and prices are obtained from the International Energy Agency (IEA), (1992, 1995a,b, 1997a,b). The consumer price index, gross domestic product, population and exchange rates are taken from International Financial Statistics. Number of cars was found in International Road Statistics (1991, 1997), and the introduction year of catalytic converters in Walsh (1997). Contacts have been made with national organizations in transport sector in order to get the share of passenger cars equipped with catalytic converters.

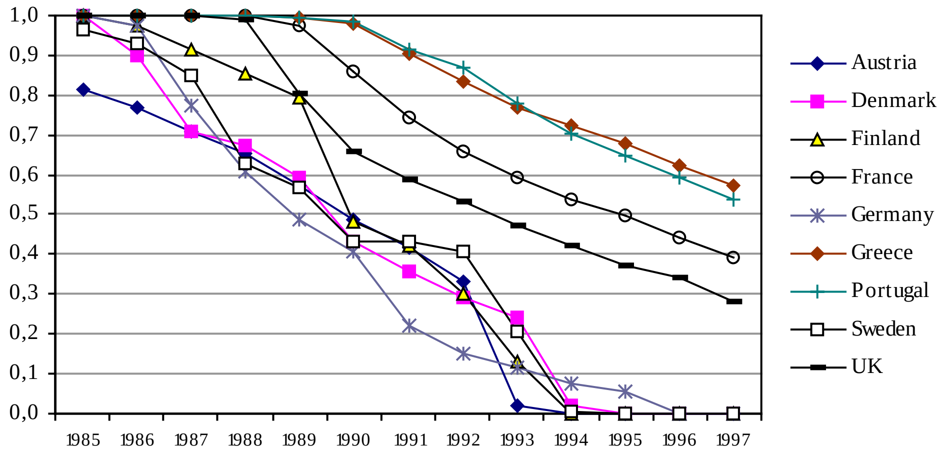
TABLE 1. SUMMARY STATISTICS

Variable	*Unit*	*N*	*Mean*	*Std Dev*	*Minimum*	*Maximum*
Share of leaded gasoline	Share	74	0.579	0.263	0.006	0.989
Price difference between leaded and unleaded gasoline	US-dollars/liter	74	0.046	0.023	0.003	0.107
GDP per capita	US-dollars/capita	74	15210.48	2983.88	9238.20	21300.69
Share of cars equipped with catalytic converters of total car stock	Share	74	0.161	0.163	0	0.628

The gross domestic product (GDP) per capita and the price differences are adjusted with purchasing power parities (OECD PPP) for each year consecutively, and increase for all countries over time. Also included in the data set is the share of cars with catalytic converters of the total car stock. The descriptive data for share of leaded gasoline, price difference, and share of catalytic converters is presented in appendix.

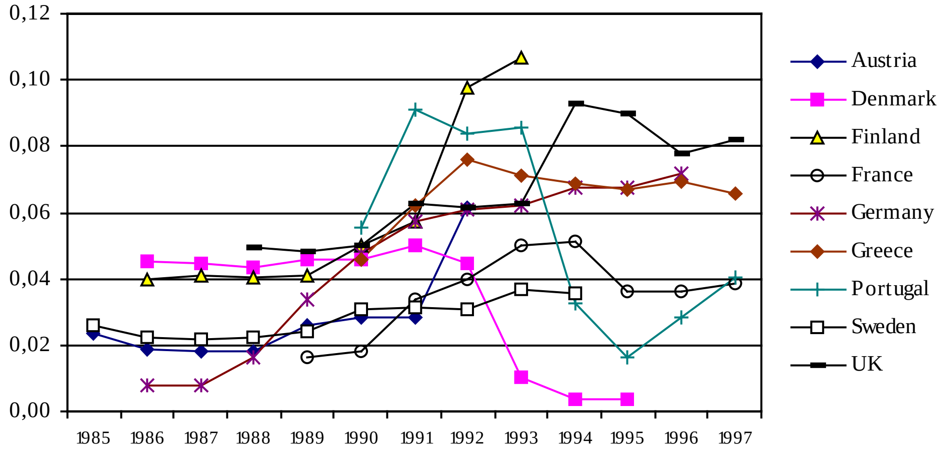
The panel is unbalanced. The phase-out period varies between countries; some have completed the phase-out (100% unleaded), while some countries are only half way (≈50% unleaded). The time paths, per country, of the share of leaded gasoline are shown in figure 1 below. the phase out is not completed for Greece, Portugal, the UK, and France in 1997.

FIGURE 1 SHARE OF LEADED GASOLINE, NINE EU-COUNTRIES, 1985-1997



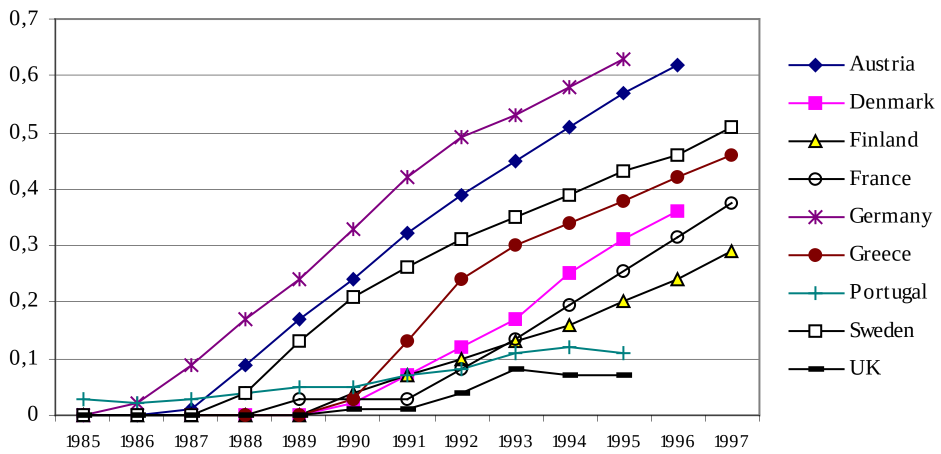
In figure 2, we see that the price of leaded gasoline is always higher than the unleaded type. However, besides this general structure we see some interesting facts regarding how price differences differ between countries and points in time. For some countries – Austria, Finland, Germany, and Sweden – the price differential is increased as the phase-out approaches completion. Denmark is an example of the reverse pattern. For the other countries there is no clear trend, and these countries are also still far from having completed the phase-out.

FIGURE 2 PRICE DIFFERENCES BETWEEN LEADED AND UNLEADED GASOLINE, NINE EU-COUNTRIES, 1985-1997



Regulations implying that cars must be equipped with catalytic converters were introduced in the European countries during the mid-, and late eighties as a result of stricter rules on emissions of hydrocarbons, carbon monoxide, and nitrogen oxides (HC, CO, NO_x). Since cars equipped with catalytic converters can not use leaded gasoline, the introduction of catalytic converters implies in itself an increased consumption of unleaded gasoline. Furthermore, the introduction of unleaded gasoline poses the question, which we address in this paper, to what degree the substitution possibilities between leaded and unleaded gasoline for cars without catalytic converters have contributed to the phase out of leaded gasoline? Figure 3 below shows an increasing trend for catalytic converters for all countries over time.

FIGURE 3. SHARE OF CATALYTIC CONVERTERS, NINE EU-COUNTRIES, 1985-1997



Regarding the group of countries that had completed the phase out in 1996, the share of catalytic converters ranges between 30 and 60 percent at the end of the phase out period.

Many countries implemented laws during the period that new cars should be equipped with catalytic converters and laws regulating the lead content in gasoline[4]. Laws regarding lead content in gasoline were introduced in the EU in 1985 (Council Directive 78/611/EEC of 29 June 1978). From January 1981 the maximum permitted lead compound content must be 0.40 grams per liter according to the directives from the European Council. However, each country could decide to have a lower maximum limit, but no limits lower than 0.15 grams per liter were allowed. The law emphasizes that other pollutants should not increase because of the decrease in lead content, and that no deterioration in the quality in gasoline should be the effect of the lead reduction. On the 20th March 1985, a new directive was issued (Council Directive 85/210/EEC). Unleaded gasoline was defined as petrol not containing more than 0.013 grams lead per liter of gasoline, while leaded gasoline could contain between 0.15 and 0.40 grams per liter. Now the member states were required, as soon as they considered it appropriate, to reduce the maximum level of lead to 0.15 grams per liter. Member states should also ensure that unleaded gasoline was available (or introduced) by a given date. In 1987 the latest directive regarding lead control in gasoline was published (Council Directive 87/416/EEC of 21 July 1987). The directive replaced article two from the previous article, in 1985. The new directive enhanced the importance of the availability of unleaded gasoline within each country.

Technical Feasibility[5]

Lead as an additive was introduced in the 1920's. Lead (or tetra-ethyl lead) in gasoline enhance engine performance since it has the property of increasing the octane rating/number in gasoline[6], which makes the fuel resist knocking better. Using lead is a cheap way to achieve this desired property. Lead also serves as a lubricant for the exhaust valves (valve seats). The oil companies continued to use lead[7] from the 1920's, aimed primarily for

4 Information on regulations on lead content is taken from Ercmann (1996).
5 This section is based upon Thomas (1995) and Lovei (1996) unless otherwise stated.
6 The octane number is also called the antiknock rating, and is a measure of the ability of a fuel to resist knocking when ignited in a mixture with air in the cylinder of an internal-combustion engine. The octane number is determined by comparing, under standard conditions, the knock intensity of the fuel with that of two reference fuels: isooctane, which resists knocking, and heptane, which knocks readily. The octane number is the percentage by volume of isooctane in the isooctane-heptane mixture that matches the fuel being tested in a standard test engine.
7 Octel Ltd is the major producer of lead gasoline additives in the world, with total sales of lead additives to about $1 billion per year. Further, Octel Ltd argue that unleaded gasoline only should be used with cars equipped

consumption by the transport sector. The introduction of catalytic converters[8] was a turning point, and forced refineries to develop substitutes for lead additives during the 80's. Introduction of catalytic converters implies the use of unleaded gasoline since lead destroys the catalytic converters. Thus, it increased the speed of the phase-out process. The introduction of catalytic converters was, however, not a policy used for addressing lead discharge, but to reduce emissions of hydrocarbons, carbon monoxide, and nitrogen oxides. The countries that allow the highest lead levels today, are all developing countries[9].

Valve-seat recession (VSR) is one of the major problems when discussing the phase-out of leaded gasoline. Cars can be divided in three groups with regard to their sensitivity to VSR, namely cars with soft valve-seats, cars with hard valve-seats, and cars with hard valve-sets plus catalytic converters. Cars with catalytic converters can not, as discussed earlier, use leaded gasoline. Cars with hardened valve-seats can use both leaded and unleaded gasoline, without risking VSR. The problem occurs when discussing cars with soft valve-seats. These cars are still an important part of the total car-fleet even if this share decreases (Shell, 1995), and are hence an important part of the gasoline users on the market. The crucial question is therefore whether or not a car with soft valve-seats can use unleaded gasoline. This matter has been under heavy investigation. It seems to be a matter of interpretation since conclusions differ between studies, *even if* the results are coinciding. One fact that researchers, oil companies, and vehicle salesmen agree upon is that only 0.05g lead per liter is sufficient to prevent VSR (McArragher et.al., 1994). Hence the EU directive on leaded gasoline of a maximum limit of 0.15g lead per liter leaded gasoline (see section above) can be adjusted downwards. This limit (0.05g/liter) is tested under severe driving conditions. The conclusions differ on whether or not lead additives are necessary at all for cars with soft valve-seats. All studies show that under extreme driving conditions cars with soft-valve seats bear a high risk of VSR. Still, several studies have shown that unleaded gasoline can be used by cars with soft valve seats. The maintenance cost of using only unleaded gasoline in cars with soft valve seats compared to use of leaded gasoline differs insignificantly. The former studies have been ignored especially in Europe and Australia, and drivers have been

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with catalytic converters due to benzene emission (Octel Ltd, 1996), but this has been rejected in other studies (see Thomas, 1995, for an overview).

8 Catalytic converts was first introduced in California during the seventies (Lovei 1996).

9 Aruba, Bahamas, Barbados, Belize, Benin, Burkina, Burundi, Cape Verdi Islands, Central African Republic, Chad, Cuba, Curacao, Dominican Republic, Ecuador, Equatorial Guinea, Fiji, Guinea, Guinea-Bissau, Haiti, Honduras, Indonesia, Ivory Coast, Jamaica, Lebanon, Libya, Macao, Madagascar, Mali, Maritius, Marshall Islands, Myanmar (Burma), Nauru, New Caledonia, Norfolk Island, Panama, Papua, Paraguay, Peru, Rwanda, Sahara West, Saint Martin, Seychelles, Sierra Leone, Solomon Islands, Somalia, Uganda, Virgin Islands, West Samoa, and Zimbabwe (Thomas, 1995).

recommended to use leaded gasoline every third to sixth fill (if not more). Hence, Europe is one of the biggest markets for lead additives. (Thomas, 1995)

Adding organic compounds such as methanol and ethanol (MTBE), and also ethyl, butyl and ether (ETBE) can increase octane. Gasoline additives such as sodium, potassium, and phosphorus can also be used in gasoline as substitutes for lead. The use of the latter as an additive has been banned in many countries, due to environmental negative effects. Still, the cost of using other additives instead of lead or produce unleaded gasoline increases the production cost. Refinery production of unleaded gasoline requires more crude oil, and more energy to run the refinery components, than would be needed for leaded gasoline of the same octane rating[10]. Hence, more energy will be needed to be able to produce unleaded gasoline, but the unleaded gasoline will provide more energy, when used as fuel. This follows from that the lead additive itself has no energy value. To sum up, the objective choice for a large part of the consumers of gasoline indicates that an immediate substitution between leaded and unleaded gasoline is possible.

III. ECONOMETRIC ANALYSIS

If the car is not equipped with a catalytic converter, there is an immediate choice between consuming leaded and unleaded gasoline. Following the nature of our data set, we obviously run into problems when measuring the effects of policies on the phase out of leaded gasoline[11]. Theoretically, we can argue that the price difference between unleaded and leaded gasoline, income, and catalytic converters should be included in our model. Since we also expect differences between countries, it is relevant to include country dummies in order to capture country heterogeneity not captured by other variables. The above is our minimum requirements for our choice of model. However, we also have an interest in looking into how a time dimension (not to be confused with a dynamic model) affects our results. Based on our econometric results, we argue below that there are reasons to exclude the time dimension in the model, since this is captured, primarily, in the parameter for catalytic converters.

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10 One important factor in preventing knocking is the compression ratio, which is a property of the engine of the car. The result is that each unit of octane number provides the potential of a 1% increase in fuel efficiency of the car. For a given car, increasing the octane will in itself not change the fuel efficiency.

[11] The reasons for choosing a static specification are our relatively short time period. We acknowledge possible mis-specification due that the phase out is a dynamic economic phenomena (as many economic phenomena are). Also, related to this, estimating unbalanced dynamic panels with relatively few observations is typically troublesome.

The Model

The model specifications are:

(i) $$q_{it} = \alpha + \beta_p p_{it} + \beta_y \ln y_{it} + \beta_{cc} cc_{it} + \sum_i \beta_i D_i + \varepsilon_{it}$$

(ii) $$q_{it} = \alpha + \beta_p p_{it} + \beta_y \ln y_{it} + \beta_{cc} cc_{it} + \beta_{trend} t + \sum_i \beta_i D_i + \varepsilon_{it}$$

(iii) $$q_{it} = \alpha + \beta_p p_{it} + \beta_y \ln y_{it} + \beta_{cc} cc_{it} + \sum_i \beta_i D_i + \sum_t \beta_t D_t + \varepsilon_{it}$$

(iv) $$q_{it} = \alpha + \beta_p p_{it} + \beta_y \ln y_{it} + \beta_{cc} cc_{it} + (\sum_i \beta_i D_i) * (\sum_t \beta_t D_t) + \varepsilon_{it}$$

where subscript *i* refers to an individual country and subscript *t* refers to a particular year.

TABLE 2 DEFINITION OF VARIABLES

Variable	*Description*	*Unit*
q	share of leaded gasoline	share, 0<q<1
p	price difference between leaded and unleaded gasoline	$/liter
y	GDP/capita	$
cc	share of cars equipped with catalytic converters	share, 0<cc<1
D_i	individual country dummies	dummy (0,1)
D_t	year dummies	dummy (0,1)
t	time trend	year-1984

Cars with catalytic converters must use unleaded gasoline, i.e. cc captures the consumption that is not subject to direct choice. Since the tax difference, which in turn induces changes in relative gasoline prices, is one of the most frequently used market based policy instruments[12], it is of central importance to see if differences in prices have had any effect on the consumption of unleaded and leaded gasoline. We use a logarithmic specification of income per capita in order to decrease the variation in the scale of the variable, and thereby reducing potential problems of heteroscedasticity. β_i's are unobserved country-specific effects, and β_t's are unobserved year-specific effects. The ε_{it} components are assumed to be independently and identically distributed (IID) with mean zero and constant variance.

In the panel data literature (see e.g. Hsiao, 1986 and Baltagi, 1995) estimation of the error component models has been developed in two directions. In the fixed effects (FE) model the country-specific effects are assumed to be fixed and correlated with the regressors.

In the random effects (RE) model, the country-specific effects are assumed to be random and uncorrelated with the regressors. For the random effects model $\beta_i \sim$ IID $(0,\sigma^2_\beta)$, and β_i is independent of the ε_{it}. We have estimated both fixed effects models and random effects models. The fixed effects models and random effect models are estimated with and without a time trend (models i and ii). Those models have an error term that follows a one-way additive error component structure. The country heterogeneity is introduced in the demand model specification through the error component term. These effects are in general viewed as country specific intercept. They capture all time-invariant country-specific effects, such as factors that characterize a country and distinguish it from the other sample countries. Furthermore, we estimate two additional fixed effects models with a two-way error component structure; (iii) has a two way additive error component, and (iv) has a multiplicative error component structure, where we for identification purpose normalize β_t by allowing $\beta_{t=1986}$ =1. The reason for having a multiplicative error term is that the country effects are time-invariant, while the time effects are country-invariant, and the assumption of no linkage between these two components is restrictive. Following Lee and Schmidt (1993) the two components may appear multiplicatively and in model (iv) we allow the joint effect to change both over time and across countries. The additive error component models are linear and estimated using least squares dummy variables method (LSDV), while the multiplicative error component models are nonlinear and are estimated using nonlinear iterative procedures.

Specification Tests and Estimation Results

A Hausman's specification test has been conducted in order to test the hypothesis of no misspecification in the model (Maddala, 1992). The Hausman's specification test show that a random effects model specification (assuming the random error is uncorrelated with the exogenous variables) is in favor of a fixed effects model. Various Chow tests show that we cannot reject that country- and time-specific effects should be included in the model specifications. Still, we find it plausible to present the results from the fixed effects model since we do not have a random sample from a large population. We get almost the same result for the same model specification irrespectively of if we use fixed or random effects for models (i) and (ii). There are reasons for choosing (i) preferred to (ii)-(iv). Comparing the results for all models and estimation methods, including a time trend or time dummies, significance levels drop for price difference, income, and catalytic converters (with a few

12 Other possibilities are for instance subsidies on catalytic converters, tax differentiation for sales of new cars, and scrap premium for old cars.

exceptions)[13]. We interpret this as if the time dimension captures explanatory power from the theoretically justifiable variables. Possible spuriousity is hence rejected out of theoretical reasons, and since a time series analysis is not appropriate to undertake with a short unbalanced data set, we will henceforth concentrate on model (i). These results (for both fixed and random effects estimation) are presented below in table 4.1. The marginal effects are not directly interpretable as elasticities since we do not have a log-linear functional form, mainly due to that we have a share as a dependent variable. However, we conclude that all of the elasticities, defined as [(*da/db*)*(*b/a*)], are of expected sign[14]. A more suitable measure is the change in the share of leaded gasoline given a percentage change in respective explanatory variable. The calculations are straightforward and our measures follow from the properties of the data and model specification.

The change in the share of leaded gasoline (measured in percentage units) due to a one percentage increase in the price difference is given by $\beta_p p$ where p is sample mean. The change in the share of leaded gasoline (measured in percentage units) due to a one-percentage increase in income is given by β_y , and the change in the share of leaded gasoline (measured in percentage units) due to a one unit increase in catalytic converters (which is defined as a share) is given by β_{cc}.

[13] The econometric results for (ii)-(iv) are available from the authors upon request.
[14] See appendix A.2

TABLE 3. PARAMETER ESTIMATES, UNBALANCED PANEL DATA SET (74 OBS)

DEPENDENT VARIABLE (Q): SHARE OF LEADED GASOLINE (STANDARD ERRORS IN PARENTHESES)

Variable	Fixed effects one way error component (i)	Random effects one way error component (i)
Intercept	9.611 [a]	9.011 [a]
	(1.664)	(1.175)
Price difference (p)	-1.968 [b]	-1.901 [b]
	(0.806)	(0.746)
Income (y)	-0.915 [a]	-0.857 [a]
	(0.172)	(0.124)
Catalytic converters (cc)	-0.659 [a]	-0.694 [a]
	(0.193)	(0.146)
Austria	-0.131	___
	(0.082)	
Denmark	-0.145 [b]	___
	(0.058)	
Finland	-0.099 [c]	___
	(0.0578)	
France	0.192 [a]	___
	(0.062)	
Germany	-0.062	___
	(0.087)	
Greece	0.006	___
	(0.116)	
Portugal	-0.093	___
	(0.092)	
Sweden	-0.092	___
	(0.073)	
UK	0	___
Variance Component for Cross Sections[1] (Random effects model)	___	0.008418
R^2	0.8578	0.7976
Root MSE	0.107717	0.108155
F-value	7.4120	___
Hausmann test[15]	___	0.2262

a=significant at less than 0,01%, b=significant at less than 0,05%, c=significant at less than 0,10%.

1.The parameters for the individual dummies are assumed random with IID $(0,\sigma^2)$ and β_i is independent of the ε_{it}.

The parameters associated with price difference, income per capita and share of catalytic converters all have the expected signs. Noteworthy is that, compared to the other variables, the corrected price elasticity has the smallest effect on the phase out of leaded gasoline (a one percent change in the price difference give 0.09 percentage units reduction in the share of leaded gasoline evaluated at sample mean), i.e. the tax differential used in all countries studied have contributed to the phase out, even though its effect has been of less importance compared to other effects.

It should be noted that one percent change in income have bigger effect than a one percent change in any other variable (a one percent change in the income give 0.915 percentage units reduction in the share of leaded gasoline). This should however be interpreted with some caution since share of catalytic converters is most likely correlated with this variable. Hence, the size of this effect is ambiguous, even though it is not challenging to say that income per capita most certainly has a positive effect on the speed of the phase out.

As expected, the corrected elasticity for catalytic converters show that this have a large effect on the phase out. A one unit change in the share of catalytic converters results in 0.659 percentage units reduction in the share of leaded gasoline. Also with respect to catalytic converters we need to acknowledge correlation with the turnover rate of the car stock, which in turn are correlated with income.

The country effects give us the remaining variation to be explained by the model. The country effects generally have a negative impact on the phase out, remembering that the UK is the benchmark country. Direct country comparison should also be done with some caution since the econometric results are based on an unbalanced panel (again as a result of data availability); comparisons between figure 1. and country effects in table 3. are for some countries paradoxical. The corrected elasticities for individual country dummies shall be interpreted as the change in share of leaded gasoline attributed to a particular country. By assumption, no individual dummies are reported for the random effects model.

IV. CONCLUDING REMARKS - A SUCCESSFUL FAILURE

In this paper we have studied the phase-out process of leaded gasoline consumption in nine EU-countries during 1985-1997. The share of leaded gasoline demand is modeled and estimated assuming static structures, thereby acknowledging the immediate choice of each consumer, who uses gasoline in a car without a catalytic converter. Due to the negative health effects of lead, especially on children, governments have decided to implement policies to phase-out lead from gasoline. Those direct and indirect policies have consisted of taxes on

15 Probability value is presented. We cannot reject the null hypothesis that regressors and error terms are independent. Hence the random effects model without time trend, and an additive one-way error component structure is in favor of a fixed effects model specification.

leaded gasoline, regulation on the amount of lead in gasoline, and regulations regarding catalytic converters in all new cars sold on the European market.

Catalytic converters by definition imply consumption of unleaded gasoline. Our results show that a one-unit percentage increase of the share of catalytic converters will give 0.659 percentage units reduction in the share of leaded gasoline. Income is significant in our model, and has a negative effect on the share of leaded gasoline (a one percent change in the income give 0.915 percentage units reduction in the share of leaded gasoline), which is in line with some of the research on the environmental Kusnetz curve (see e.g. Hilton and Levinson, 1998).

There has been a rationale for governments to implement a tax on leaded gasoline, since unleaded gasoline can be used in all cars (even in cars with soft valve seats). Unleaded gasoline has been cheaper in all countries due to a tax differential, and the phase-out has progressed. Seemingly this is a success story for incentive based economic policy instruments. However, the effect of the price difference on the share of leaded gasoline is surprisingly low (a one percent change in the price difference give 0.09 percentage units reduction in the share of leaded gasoline) taking into account the technical possibilities of substitution.

Car owners without catalytic converters have an objective choice between unleaded and leaded gasoline, but we find it relevant to stress the consumers' own perceptions, which, we argue are subject to imperfect information. From a policy perspective, the objective substitution possibilities are only the first step towards an effective policy action. Recognizing that transaction costs can be substantial in order to find information regarding substitution possibilities; the crucial question is how behavior can be changed most efficiently; i.e. policy makers must take imperfect information explicitly into account in order to reach more efficient and effective policies. The car fleet in most countries in the world consists of a large fraction of cars without catalytic converters, and car owners clearly do not want their engine to break down. Given the discussion in the section above, that the maintenance cost of using only unleaded gasoline in cars with soft valve seats compared to the use of leaded gasoline differs insignificantly, we argue that car salesmen and mechanics have (or had) incentives[16] not to support the use of unleaded gasoline. Costs from damages on the valve seats can be assigned to the use of unleaded gasoline, while increased maintenance costs on the engine

[16] Since it is primarily old cars that have no catalytic converters, which initially run on leaded gasoline, this might affect future fuel choices as well. Hence the advice from car salesman and/or car manufacturer is potentially important.

from the use of leaded gasoline are more diffuse, and not as easily assigned to fuel use. Hence, there are stronger incentives of advocating the use of leaded gasoline from a law and economics perspective: The risk of being sued for engine damages increases if costs can be *clearly* attributed to fuel use.

How do consumers conceive the tax differential between leaded and unleaded gasoline? It can be seen as a risk premium for choosing unleaded gasoline. Since data indicates that substitution to unleaded gasoline, given the objective substitution possibilities, is slower than what would be expected (the expected phase out should have been instantaneous without transaction costs and possible risk premiums), we could interpret this as if the tax differential has not been sufficiently high to realize the phase-out. Would it be sufficient just to increase the tax differential? Even if prices and income are central variables, policy suggestions based on these only, presuppose crucial information requirements. Of course, letting the tax differential be very large would likely yield an effective solution, but this would hardly be a feasible political solution. We therefore conclude that the tax policy regarding the phase-out of leaded gasoline would probably have been more effective if complemented with better information on technological substitution possibilities. It seems plausible that if we were able to include a variable that measures the degree of misperceptions - of what is technologically feasible – in the model, the explanatory power of the model would improve.

Hence, if the policymakers want to maximize social welfare, which in this case incorporates clear cut evidence for children being hurt, and no need for lead in gasoline, we only see a regulation or a tax complemented with information as a mean to achieve this. We argue therefore that a regulation is the best policy option for developing countries, due to the strong impact of GDP/capita, implying that third world countries faces a longer phase out period.

We cannot but conclude that a mixed policy strategy (with emphasis on information) or a regulation of leaded gasoline would have been preferable to the actual policies used. Hence, we would like to characterize the phase out process as a successful failure. Leaded gasoline has indeed been phased out in some countries, which indicates successful policies. On the other hand we need to be aware of that the phase out could have been even more efficient, which should be considered for policy making in those countries, where leaded gasoline still is supplied.

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V. APPENDIX

TABLE A.1 DESCRIPTIVE STATISTICS PER COUNTRY AND YEAR

				Share of Leaded Gasoline					
Year	*Austria*	*Denmark*	*Finland*	*France*	*Germany*	*Greece*	*Portugal*	*Sweden*	*UK*
1985	0.81	1.00	1.00	1.00	1.00	1.00	1.00	0.97	1.00
1986	0.77	0.90	0.98	1.00	0.97	1.00	1.00	0.93	1.00
1987	0.71	0.71	0.91	1.00	0.77	1.00	1.00	0.85	1.00
1988	0.65	0.67	0.86	1.00	0.61	1.00	1.00	0.63	0.99
1989	0.57	0.59	0.80	0.98	0.49	1.00	1.00	0.57	0.81
1990	0.49	0.43	0.48	0.86	0.41	0.98	0.98	0.43	0.66
1991	0.42	0.36	0.42	0.74	0.22	0.91	0.92	0.43	0.59
1992	0.33	0.29	0.30	0.66	0.15	0.83	0.87	0.41	0.53
1993	0.02	0.24	0.13	0.59	0.11	0.77	0.78	0.21	0.47
1994	0.00	0.02	0.00	0.54	0.08	0.72	0.70	0.01	0.42
1995	0.00	0.00	0.00	0.50	0.06	0.68	0.65	0.00	0.37
1996	0.00	0.00	0.00	0.44	0.00	0.62	0.59	0.00	0.34
1997	0.00	0.00	0.00	0.39	0.00	0.57	0.54	0.00	0.28

				Price Differences (dollar/liter adjusted by OECD PPP) *Price of leaded gasoline minus price of unleaded gasoline*					
Year	*Austria*	*Denmark*	*Finland*	*France*	*Germany*	*Greece*	*Portugal*	*Sweden*	*UK*
1985	0.023							0.026	
1986	0.018	0.045	0.040		0.008			0.022	
1987	0.018	0.045	0.041		0.008			0.022	
1988	0.018	0.044	0.040		0.016			0.022	0.050
1989	0.026	0.046	0.041	0.016	0.033			0.024	0.048
1990	0.029	0.046	0.050	0.018	0.048	0.046	0.055	0.031	0.050
1991	0.028	0.050	0.057	0.034	0.057	0.062	0.091	0.031	0.063
1992	0.062	0.045	0.098	0.040	0.061	0.076	0.084	0.031	0.061
1993		0.010	0.107	0.050	0.062	0.071	0.085	0.037	0.063
1994		0.003		0.051	0.068	0.069	0.033	0.035	0.093
1995		0.003		0.036	0.068	0.067	0.016		0.090
1996				0.036	0.072	0.069	0.029		0.078
1997				0.039		0.066	0.041		0.082

				Share of Catalytic Converters					
Year	*Austria*	*Denmark*	*Finland*	*France*	*Germany*	*Greece*	*Portugal*	*Sweden*	*UK*
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00

1987	0.01	0.00	0.00	0.00	0.09	0.00	0.03	0.00	0.00
1988	0.09	0.00	0.00	0.00	0.17	0.00	0.04	0.04	0.00
1989	0.17	0.00	0.00	0.03	0.24	0.00	0.05	0.13	0.00
1990	0.24	0.02	0.04	0.03	0.33	0.03	0.05	0.21	0.01
1991	0.32	0.07	0.07	0.03	0.42	0.13	0.07	0.26	0.01
1992	0.39	0.12	0.10	0.08	0.49	0.24	0.08	0.31	0.04
1993	0.45	0.17	0.13	0.14	0.53	0.30	0.11	0.35	0.08
1994	0.51	0.25	0.16	0.20	0.58	0.34	0.12	0.39	0.07
1995	0.57	0.31	0.20	0.26	0.63	0.38	0.11	0.43	0.07
1996	0.62	0.36	0.24	0.32		0.42		0.46	
1997			0.29	0.38		0.46		0.51	

A.2 ELASTICITIES FOR FIXED AND RANDOM EFFECTS MODEL (i)

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1. Elasticity of demand (0<q<1) w.r.t the price difference:

$\beta_p \frac{p}{q} < 0$ if the price difference is positive. Otherwise ≥ 0

In our case we have a positive price difference for all observations, and, hence the elasticity will always be negative.

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2. Elasticity of demand (0<q<1) w.r.t the income per capita:

$$\beta_y \frac{1}{q} < 0$$

The income elasticity is always negative, following from a negative marginal effect, and that the share of leaded gasoline is always positive.

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3. Elasticity of demand (0<q<1) w.r.t share of catalytic converters:

(v) $\beta \ \frac{cc}{q} < 0$

The elasticity of catalytic converters is always negative, following from a negative marginal effect, and that the share of leaded gasoline and catalytic converters is always positive.
