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Emission-Blind Flat Rebates and the Diffusion of Diesel Vehicles in Europe*

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Abstract

Over the past few years emissions targeted subsidies have fostered the adoption of alternative fuel vehicles through long-term incentive schemes or as part of cash-for-clunkers programs. In this paper we use automobile registration data from Portugal and Spain during the 1990s to show that even emission-blind subsidies have important distortionary effects on drivers' vehicle choices. In particular we show first, that well-timed cash-for-clunkers programs have long-lasting effects on the composition of the automobile fleet; and second, that emission-blind, lump-sum subsidies favor the adoption of smaller diesel vehicles that offer limited fuel savings and are more prone to generate excessive NO_x emissions.

Keywords: Cash-for-Clunkers, Diesel Automobile, Emissions, Scrappage Subsidies.

JEL Codes: L51, L62, Q28.

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1 Introduction

The 2009 U.S. Car Allowance Rebate System (CARS) was a controversial piece of legislation that reopened the debate about whether government could stimulate aggregate demand while at the same time favoring what vehicles consumers should purchase. Few years after this massive government intervention there is a growing consensus among economists that scrappage programs are ineffective in increasing aggregate demand and an expensive way to combat emissions: they have, at most, a temporary effect on demand. There is growing evidence that mixing environmental and economic stimulus goals in a single policy further limits the overall effectiveness of the scrappage program.

Given these negative results, policy makers are in need of valid arguments to favor cash-for-clunkers programs other than just stimulating aggregate demand temporarily. For instance, although enacted to stimulate the economy, European scrappage programs of the 1990s were formally aimed at increasing road security by reducing the average age of automobile fleets. Fuel savings or emissions were rarely explicitly targeted in these European scrappage plans. And yet, the European programs of the 1990s achieved much more at a small fraction of the cost. As we show in this paper, subsidies in the range of only €400-600 per vehicle (rather than the $4,000 apiece of CARS) increased sales of diesels substantially more than gasoline models both in the short and long run. The cost of these emission-blind lump-sum subsidies may easily be offset by the induced reduction in fuel consumption (miles per gallon), as well as a reduction in CO and CO_2 emissions. However, it also led to an increase in particulate matter (PM) and NO_x emissions that, until the recent VOLKSWAGEN emission scandal, have been mostly ignored by European policymakers.

We analyze the Iberian automobile market during the 1990s to show that well-timed scrappage programs may have long-lasting effects by fostering the adoption of vehicles running on alternative fuel technologies such as diesel. The Iberian automobile market during the 1990s is ideal to evaluate the potential impact of cash-for-clunkers programs as these policy interventions took place during the early diffusion of diesel vehicles in Europe. Our approach is similar to Li, Linn and Spiller (2013) and evaluates the effect of the policy applied only in one of two similar and economically integrated markets. The characteristics of automobiles sold in Portugal and Spain are identical. More interestingly Portugal never implemented any scrappage program while Spain implemented two programs between 1994 and 1995 and later established a permanent replacement subsidy policy starting in 1997. Therefore, Portugal is an excellent control for analyzing short and long term effects of scrappage subsidies in Spain.

Many interesting results arise as we allow for heterogenous treatment effects across fuel types and automobile segments. First, we show that the effectiveness of the subsidy in shifting demand in favor of fuel efficient diesel engines is not temporary but permanent. Spanish scrappage

programs take place during a period of growing preference for diesel vehicles. Thus, the effect of the scrappage subsidies spread over several years following the termination of the scrappage programs. Further, results indicate that scrappage programs are effective in increasing sales of both types of automobiles although the effect on the sales of diesels is 2.7 times larger than on gasoline vehicles. In the long run this different impact does not disappear, remaining at around 2.5 times larger for diesels than gasoline vehicles. Interestingly, the subsequent permanent scrappage subsidies only have a similar positive effect on SMALL and SEDAN diesels sold by brands with strong ties to the local Spanish market.

Contrary to our emphasis on fleet composition effects of scrapping subsidies, most researchers have worried about the effectiveness of this Keynesian policy against economic downturns. Only Greenspan and Cohen (1999) find that influencing the scrappage rate affects total automobile sales. The contribution with a more long-lasting influence though is the work of Adda and Cooper (2000), the first to show that scrappage programs increase aggregate sales only temporarily. In the long run Adda and Cooper (2000) conclude that French scrappage programs of the 1990s do not have any permanent effect. Schiraldi (2011) presents similar evidence for the Italian market in the 2000s. He addresses the effect of plans requiring longer car age to qualify for the replacement subsidy and how, in the presence of a secondary market the reduction in sales of used cars is even more persistent than the reduction of sales of new vehicles. This ineffectiveness of scrappage programs is a major indictment of a policy that is very expensive to begin with. Mian and Sufi (2010) confirm that the accelerated scrappage of 680,000 clunkers induced by the $3bn budget of the 2009 CARS program would had happened anyway, at no taxpayer cost, in just seven additional months.[1] Furthermore, Hoekstra, Puller and West (2015) confirm not only that CARS accelerated the sales of vehicles that would have taken place in the next eight months, but also that by making small and fuel efficient vehicles relatively less expensive, CARS actually reduced the overall spending on new vehicles over the same time period.

Contrasting with the limited effectiveness of CARS, we argue that the 1994-95 scrappage programs led the share of registered diesel automobiles to reach a tipping point. These two scrappage programs were implemented in Spain to overcome an economic recession that had left the Spanish automobile industry in shambles. A more fuel efficient technology, the turbo-charged, direct-injection, diesel engine (TDI), had been available for five years at the time of these policy interventions. Thus, the widespread adoption of diesels afterwards was self-propelled, and continued

[1] Similarly, Copeland and Kahn (2013) argue that CARS had only a short-lived spike effect on sales. In addition to this limited ability to increase aggregate sales Gayer and Parker (2013) criticize CARS on the basis of the high cost of the few jobs it created and for being a very inefficient and expensive policy to reduce carbon emissions.

despite the sustained increases in per capita income and fuel prices and independently of the permanent replacement subsidy of the late 1990s.[2]

CARS also included an environmental motivation that was intertwined with the goal of expanding aggregate demand to stabilize the economy in 2009. The design of the CARS program specifically linked the scrappage subsidy to the purchase of a new fuel efficient vehicle with a minimum required mileage, thus making them relatively less expensive to other automobile choices.[3] CARS also limited the value of the new car to a listed price of $45,000 and required that the traded-in vehicle did not exceed fuel economy of 18 miles per gallon. Thus, by favoring less expensive and more fuel efficient vehicles, CARS explicitly aimed at inducing the adoption of fuel efficient technologies such as hybrid engines.[4] Both, Huse and Lucinda (2016) and Li and Wei (2013) argue that restricting the set of qualifying choices reduces the effectiveness of scrappage programs in increasing demand. And yet, this program did not lead to a massive adoption of alternative fuel vehicles.

Unlike CARS, European scrappage programs of the 1990s consisted mostly of flat rebates independent of new and traded vehicle characteristics and/or income of buyers. Spanish scrappage programs in particular did not explicitly intend to shift preferences in favor of diesel models during the 1990s. They consisted of flat rebates for new car purchases that replaced sufficiently old vehicles regardless of the fuel they used, mileage they made, or income of the buyer.[5] Because of European single market rules, scrappage subsidies could not discriminate against national origin of purchased vehicles. Thus, these programs are a good proxy for an exogenous regime change to study the demand for differentiated types of engine powered vehicles. Our unique data, which details car registrations by models and type of engine in Portugal and Spain over a decade, allow us to measure not only the short term sales boosting effect of the scrappage programs but also the long term shift in consumer tastes in favor of the new diesel engines. From this perspective,

[2] Miravete, Moral and Thurk (2015) estimate a structural model of demand for this same period in Spain and show that the lenient European regulation on NO_x acted as a *de facto* trade barrier against Asian imports. Other papers that addressed diesel vehicles include Verboven (1999), who explain the price premium paid for diesel vehicles as an attempt by manufacturers to discriminate across buyers' expected driving needs; and Grigolon, Reynaert and Verboven (2014) and Munk-Nielsen (2015), who show that fuel taxation is a more effective tool than vehicle taxation driven by fuel economy, or equivalently, mileage targeted *feebates*.

[3] Linking the subsidy to the purchase of a more fuel-efficient vehicle was first contemplated in the 1997 Italian scrappage scheme, aimed at reducing emissions by encouraging purchase of newer, more fuel efficient cars. Grigolon, Leheyda and Verboven (2016) show that the environmentally targeted scrappage programs implemented in Europe during the recent financial crisis were still able to stabilize sales of automobiles in the short run.

[4] These incentives might lead to other effects such as fostering imports rather than the intended domestic production because the emissions of locally produced vehicles are not low enough, *e.g.*, see Huse and Lucinda (2014) for the case of Sweden.

[5] This is the optimal policy advocated by Beresteanu and Li (2011) as the most effective in promoting the adoption of alternative fuel vehicles.

this paper is the first to document in detail the differentiated impact of scrappage programs on the demand of automobiles running on different fuels.

Despite Spanish rebates not targeting fuel efficiency explicitly, we document that they induced heterogeneous buyer responses across fuels and market segments. These lump-sum rebates amounted to a very similar percent price discount for diesel and gasoline models in the very competitive SEDAN segment, thus fueling demand for diesel vehicles substantially. Similarly, the same flat rebate amounted to a much larger percent price reduction for SMALL vehicles than for the slightly larger COMPACT models. Our evidence thus shows that the 1994-95 Spanish scrappage programs might have induced drivers to favor SMALL diesels over COMPACT gasoline models; overall leading to a almost 50% mileage improvement. Furthermore, the impact on sales of SMALL and SEDAN diesels was larger among models produced by brands with local manufacturing plants.

The paper is organized as follows. Section 2 uses diesel market penetration data from several European countries to suggest that scrappage programs might have a positive long-term effect on the speed of diffusion of this alternative fuel technology. Section 3 briefly describes the relevant features of the new diesel engine technology, details the matching of car registrations from Portugal and Spain, and compares the diesel penetration across market segments and over time in these two countries. Section 4 reviews the different Spanish scrappage programs and evaluates their effectiveness in promoting sales of automobiles running on different fuel types. We estimate a simple treatment effects model of the scrappage programs on the sales per model both at the aggregate level and by automobile segments, document the immediate increase in sales of vehicles by segment and fuel type and discuss the wide ranging price discount induced by these flat rebate policies. Section 5 concludes.

2 Scrappage Programs and the Diffusion of Diesel Automobiles in Europe

Diesel engines have been routinely used in automobiles since the 1930s.[6] In Europe, a common fuel taxation policy adopted after the first oil crisis in 1973 did not tax diesel fuel as heavily as gasoline to protect transportation services and agriculture. Over the next fifteen years this policy lead to a slow but steady development of a 10% diesel market niche comprised of commercial and large passenger vehicles. Consequently, by the late 1980s, European drivers were familiar with the diesel technology, there was a wide network of auto-mechanics trained in diesel technology, and all gas stations sold diesel fuel; all these were important preconditions for the successful diffusion of

[6] In the late XIX Century, Rudolf Diesel designed an internal combustion engine in which heavy fuel self-ignites after being injected into a cylinder where air has been compressed to a much higher degree than in gasoline engines. However, it was only in 1927, many years after Diesel's death, that the German company Bosch built the injection pump that made possible the development of the engine for trucks and automobiles.

this alternative fuel technology. Diesel vehicles of the 1980s were however noisy, smelly, and not considered to be great performers overall. In 1989, Volskwagen introduced the TDI technology in the Audi 100 model. A TDI engine uses direct injection, where a fuel injector sprays fuel directly into the combustion chamber of each cylinder. The turbocharger increases the amount of air going into the cylinders and an intercooler lowers the temperature of the air in the turbo, thereby increasing the amount of fuel that can be injected and burned. Overall, TDI technology allows for greater engine performance while also decreasing emissions and providing more torque than alternative gasoline engines. It should also be noted that, unlike in the U.S., diesel fuel is available in almost every gas station across Europe. The new TDI prompted a fast adoption of diesel vehicles across Europe with market penetration growing from 10% to over 50% within a decade.[7]

The diffusion of diesel technology in the European automobile market is a remarkable success story that transformed the composition of European automobile fleets in little over a decade, where diesel vehicles went from accounting for less than 10% of the market in the early 1990s to well over 50% of total annual sales ten years later (and even exceeding 70% for some countries and market segments). Our goal in this paper is to measure the role of scrappage programs in fostering the widespread adoption of diesel vehicles in Europe and suggest that these programs, if appropriately timed, *may induce* permanent effects on the composition of the automobile fleet beyond any temporary quantitative impact on aggregate sales.

We now present some preliminary evidence supporting our hypothesis that scrappage programs might have long-term effects on the diffusion of diesel vehicles. We first obtained information on the timing and duration of the different scrappage programs offered in Europe during the 1990s.[8] Next, we collected information on the overall share of diesel vehicles sold in sixteen European countries between 1991 and 2008, denoted by λ. We explain the market penetration of diesel vehicles as driven by a time trend (speed of diffusion) time-varying economic variables affecting the speed of diffusion or the overall equilibrium diesel penetration level, and a treatment capturing the effect of scrappage programs on the diffusion of diesel vehicles. The estimated model is:

$$\ln\left(\frac{\lambda_{it}}{1-\lambda_{it}}\right) = \beta_0 + \delta_e \text{ECONOMIC VARIABLES} + \delta_t \text{TREND} + \delta_s \text{SCRAPPAGE}\,. \tag{1}$$

The first two columns of Table 1 report descriptive statistics of the explanatory variables that were used. The estimated regressions make use of 277 country-year observations between 1991 and 2008. The dependent variable is the logistic transformation of the market share of diesel vehicles sold each year in each country. The average diesel penetration is 29% (with a standard deviation of

[7] See the 2004 report: "Why Diesel?" from the European Association of Automobile Manufacturers (ACEA).

[8] These include Denmark, France, Ireland, Italy, Norway, and Spain and they mostly consist of flat rebates. All data sources and details of each program are included in Appendix A.

Table 1: Scrappage Programs and Adoption of Diesel Technology in Europe

	Mean	Std. Dev.	OLS Regressions			
CONSTANT			−3.3752	[12.19]	−3.3874	[12.10]
TREND	10.0000	(5.48)	0.0887	[5.63]	0.0897	[5.52]
TREATMENT	0.2763	(0.45)	0.3114	[1.89]		
SCRAPPAGE	0.0428	(0.20)			0.4165	[1.52]
AFTER SCRAPPAGE	0.2336	(0.42)			0.2914	[1.61]
GDP-PC	27.2888	(8.63)	0.0332	[4.41]	0.0333	[4.41]
FUELPRICE: GASOLINE - DIESEL	0.1753	(0.11)	2.5347	[3.90]	2.5276	[3.87]
FUELTAX: GASOLINE - DIESEL	7.6171	(4.23)	−0.0108	[0.50]	−0.0106	[0.49]
R^2			0.2550		0.2553	

Absolute-value, heteroskedastic-consistent, t-statistics are reported between brackets.

22%). Fuel prices and GDP-PC are measured in thousand U.S. dollars using PPP exchange rates while fuel taxes are measured as percentage over fuel prices. TREATMENT is a dummy variable that takes value 1 after the application of scrappage program in those countries that sponsored them. In an alternative specification we define the SCRAPPAGE dummy for periods when scrappage programs were implemented and AFTER SCRAPPAGE for those that followed the policy intervention. The latter two columns of Table 1 present the result of regressing the speed of diffusion for each country-year pair. The first regression column considers that scrappage effects on the speed of diffusion might only be temporary. The specification of the second column allows for some permanent long-term effect of scrappage programs on the speed of diffusion of diesel vehicles.

With treatment estimates that are significant at 10%, results do not reject our interpretation that demand composition changes after the implementation of a scrappage program when fuel-saving technology is being adopted. Sales of diesel vehicles appear to increase with per capita income and with gasoline being more expensive than diesel fuel, in addition to other time-varying economic variables as captured by TREND. But in addition, European scrappage programs appear to increase the speed of adoption of diesel vehicles both in the short run, as plans are offered, and in the long run, years after they ended. We thus conclude that, although not definitive, the evidence does not contradict our suggested interpretation that scrappage programs may induce qualitative long term effects on the composition of automobile fleets as we documented for the Spanish case.

The results reported in Table 1 can only be considered preliminary evidence of the scrappage programs having long-term effects on the diffusion of diesel vehicles as we only address changes in the fuel composition of sales rather than distinguishing between the differentiated effects of scrappage programs on sales of gasoline and diesel vehicles or across automobile segments. It only focuses on the effect of the diffusion of diesel vehicles despite the fact that most scrappage programs implemented in Europe did not offer subsidies conditional on the type of fuel of the newly purchased automobile. Furthermore, it is difficult to argue that policy interventions were

exogenous or non-anticipated.[9] We thus turn our attention to the analysis of the Iberian markets where Portugal can clearly be considered a good control group while exogenous policy interventions only took place in Spain repeatedly at different stages of the diffusion process.

3 Diesel Automobiles in the Iberian Markets

In this paper we make use of car registration data from Portugal and Spain during the 1990s. While in Spain several scrappage programs were implemented during this period, Portugal never resorted to this kind of policy to stimulate aggregate demand, perhaps because a large share of that stimulus would eventually end up increasing demand and creating jobs in other European countries. The different policies followed in these two neighboring countries allow us to use Portugal as a control group when evaluating the effectiveness of Spanish scrappage programs to influence the adoption of diesel vehicles.

Our data combines information from different sources. Spanish administrative registration data is collected by the *Dirección General de Tráfico*, the Spanish equivalent of a state department of motor vehicles. ANFAC (*Asociación Española de Fabricantes de Automóviles y Camiones*), the Spanish automakers association, supplied yearly registration data from 1991 to 2000 distinguishing by car model and type of fuel. We manually collected Spanish prices and automobile characteristics (horsepower, weight, length, width and fuel consumption) as reported by the automobile buying guide *Guía del Comprador de Coches*. We also obtained registration data from the Portuguese Department of Transportation, the IMT (*Instituto da Mobilidade e dos Transportes*). We manually collected Portuguese automobile prices using several issues of the buying guide *Guia do Automóvel*. Portuguese registration information also contains model characteristics which helped us to link the car models sold in the Spanish and Portuguese markets. Models sold in Portugal and Spain are technically identical.

We computed model-year sales by aggregating the yearly sales of all versions of a given model separately in Spain and Portugal. After excluding a few models with extremely small market shares, mostly luxury vehicles, our sample is an unbalanced panel comprising more than 99% of Iberian automobile sales.[10] In particular, there are 1,869 observations for Spain and 1,590 observations for Portugal. Over the decade, there are 340 models sold in Spain. All vehicles sold in Spain are

[9] The 1999 European Conference of Ministers of Transport noticed the timing and similarity of the French and Spanish programs in a side-by-side comparison of European scrappage programs of the 1990s in its publication "Cleaner Cars. Fleet Renewal and Scrappage Schemes." The program that went into effect in April of 1994 in Spain pretty much copied the design of the French program enacted in February of that same year. See Appendix A for additional details.

[10] We set a threshold of minimum yearly registrations to determine entry and exit into the database to avoid outliers in the estimation. For Spain, car models with less than 40 registrations per year (as a 2-year moving average) are removed. For Portugal this threshold is equal to 8 units by year (about the same sales per capita limit). The

available in Portugal but in a few cases not enough units are sold to be included in our final merged database. Overall we account for 184 out of 206 gasoline models and 115 out of 134 diesels for the Portuguese market. Models are grouped in market segments as they are commonly classified by the European automobile industry.[11] Finally, we also collected information on gross domestic product per capita, fuel prices and consumer price indices from the respective national statistical offices.[12] All prices are reported in the equivalent of 1994 euros.

Tables 2 and 3 summarize the features of vehicles sold during the 1990s by segment and fuel type in Portugal and Spain, respectively. Overall, diesel vehicles are between 10% and 20% heavier than similar gasoline versions depending on the product mix purchased in each country. Diesel and gasoline versions of a particular model have the exact same size (given by a car's length and width). Diesel models are 5% to 15% less powerful than gasoline vehicles but they deliver about 20% better mileage. The different mix of products sold in each country explain some of these differences in relative mileage and performance (HP/WEIGHT). Portuguese consumers purchase a substantially larger share of SMALL vehicles both in their gasoline and diesel versions but a smaller share of COMPACT cars. They also purchase fewer SEDAN, LUXURY, or MINIVAN vehicles but when they do they favor the diesel versions disproportionately.

In addition to the mean levels reported in Tables 2 and 3, Figure 1 presents the evolution of many of yearly sales-weighted characteristics over the decade distinguishing by fuel type and country. Market penetration of diesel vehicles is always higher in Spain than in Portugal. The Spanish automobile market is about 4 times larger than the Portuguese market (1 million vehicles sold *vs.* 240,000 a year, respectively) but while in the gasoline segment was 3 times larger (646,341 *vs.* 202,524) in the diesel segment it was 10 times larger (371,838 *vs.* 38,409). The share of diesels grew in both countries as a result of a steady reduction of gasoline vehicle sales. But in the Spanish case, sales of diesels surpassed gasoline by the end of the decade while in Portugal sales of diesels never reached 30% of the market.

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market shares of vehicles excluded from the samples are extremely low: 0.004% for Spain and 0.003% for Portugal, on average, during the 1990s.

[11] Our car segments follow the "Euro Car Segment" definition described in Section IV of "Case No. COMP/M.1406 - Hyundai/Kia." *Regulation (EEC) No. 4064/89: Merger Procedure Article 6(1)(b) Decision.* Brussels, 17 March 1999. CELEX Database Document No. 399M1406. The only exception is the LUXURY segment that also includes sporty cars.

[12] We also collected other macro variables such as as growth rate and population from OCDE, and interest rate from Eurostat, but they turned out not to be significant in our analysis and did not include them in the final results included in the paper.

Table 2: Portuguese Automobile Market by Segment and Type of Fuel: 1991–2000

GASOLINE:	SHARE	MODELS	PRICE	FCOST	KM/L90	HP	LENGTH	WIDTH	WEIGHT
ALL	100.00	103	16,320	4.33	18.70	83	155	65	2,123
SMALL	59.21	24	11,941	4.06	19.93	67	146	63	1,907
COMPACT	27.59	25	19,489	4.57	17.74	98	163	67	2,331
SEDAN	10.40	26	26,433	4.92	16.50	118	174	67	2,593
LUXURY	2.07	27	44,900	5.45	14.81	166	178	68	2,948
MINIVAN	1.10	4	25,231	5.42	14.95	101	166	68	2,720
DIESEL:	SHARE	MODELS	PRICE	FCOST	KM/L90	HP	LENGTH	WIDTH	WEIGHT
ALL	100.00	57	24,067	2.49	22.28	79	164	66	2,507
SMALL	30.98	10	14,720	2.27	24.44	59	146	63	1,996
COMPACT	22.67	14	22,775	2.49	22.30	77	162	67	2,467
SEDAN	34.43	19	29,623	2.54	21.85	91	177	68	2,803
LUXURY	6.30	10	53,370	2.93	19.01	123	188	70	3,234
MINIVAN	7.27	6	27,749	3.20	16.47	94	178	71	3,438

SHARE is the average market share of each market segment by fuel category between 1991 and 2000. MODELS reports the average number of models available for consumers to choose from each year. All other variables are sales weighted averages for the same period. PRICE is the price of automobiles measured in the equivalent of 1994 euros; FCOST is the fuel cost in 1994 euros of driving 100 kilometers on a highway; KM/L90 reports the distance driven with one liter of fuel on a highway at a constant speed of 90 kilometers per hour; HP denotes horsepower; LENGTH and WIDTH are measured in inches and WEIGHT in pounds.

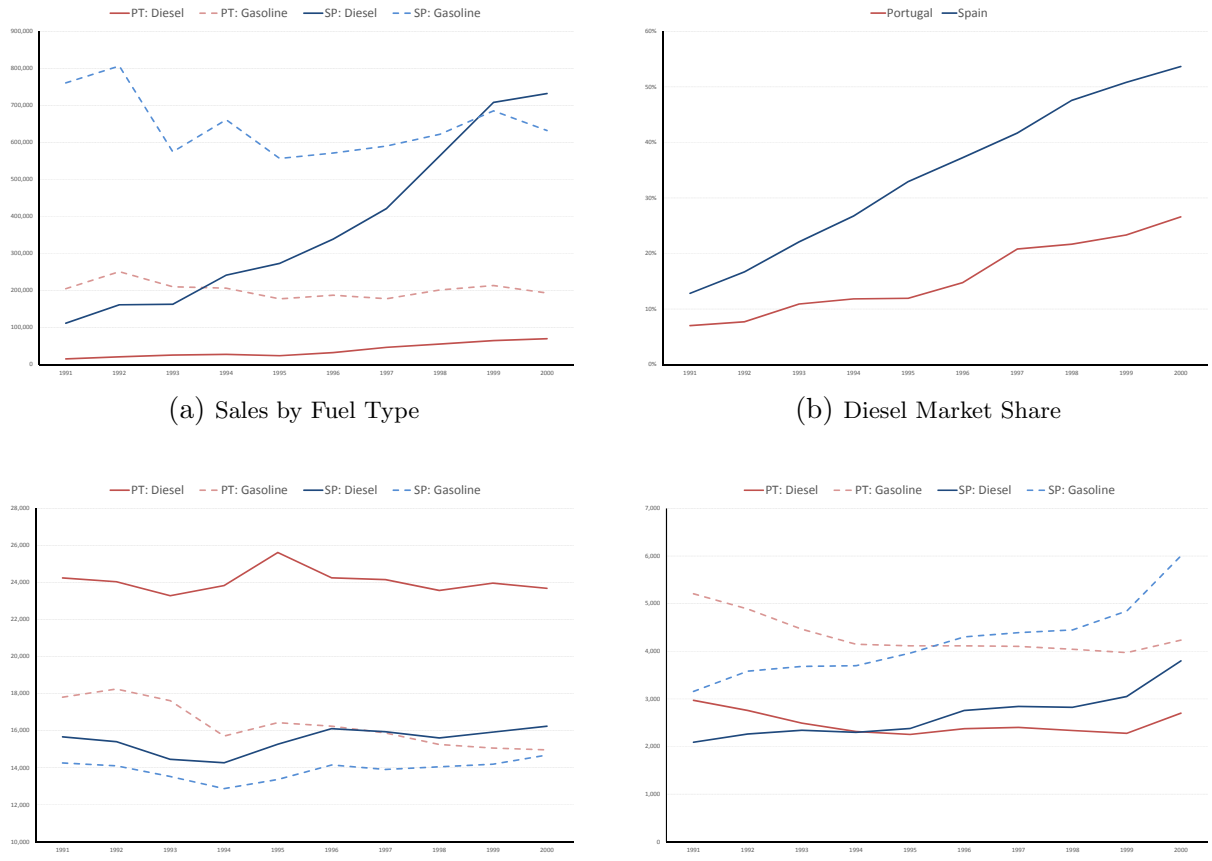
Table 3: Spanish Automobile Market by Segment and Type of Fuel: 1991–2000

GASOLINE:	SHARE	MODELS	PRICE	FCOST	KM/L90	HP	LENGTH	WIDTH	WEIGHT
ALL	100.00	117	13,907	4.21	18.14	89	159	65	2,227
SMALL	44.19	25	9,836	3.83	19.95	65	146	63	1,900
COMPACT	31.34	25	14,057	4.28	17.82	96	163	67	2,305
SEDAN	18.16	28	18,579	4.59	16.62	114	175	67	2,621
LUXURY	5.33	32	29,506	5.34	14.34	155	182	69	2,969
MINIVAN	1.32	9	21,459	5.52	13.82	119	173	70	3,070
DIESEL:	SHARE	MODELS	PRICE	FCOST	KM/L90	HP	LENGTH	WIDTH	WEIGHT
ALL	100.00	71	15,485	2.66	21.97	76	163	66	2,442
SMALL	24.69	12	10,674	2.41	24.28	61	146	63	2,023
COMPACT	39.92	19	14,204	2.66	22.00	73	162	66	2,409
SEDAN	29.56	21	18,700	2.77	21.11	85	174	68	2,686
LUXURY	3.34	13	34,947	3.11	18.77	131	188	70	3,282
MINIVAN	2.74	9	23,684	3.48	16.84	98	176	71	3,414

SHARE is the average market share of each market segment by fuel category between 1991 and 2000. MODELS reports the average number of models available for consumers to choose from each year. All other variables are sales weighted averages for the same period. PRICE is the price of automobiles measured in the equivalent of 1994 euros; FCOST is the fuel cost in 1994 euros of driving 100 kilometers on a highway; KM/L90 reports the distance driven with one liter of fuel on a highway at a constant speed of 90 kilometers per hour; HP denotes horsepower; LENGTH and WIDTH are measured in inches and WEIGHT in pounds.

The main differences between the Spanish and Portuguese markets is the much higher price of vehicles in Portugal, not the relative fuel cost of driving, which on average remains unchanged.[13] Diesels are, on average, 50% more expensive than gasoline vehicles in Portugal but only 11% more expensive in Spain. Furthermore Figure 1 (c) shows that this price difference appears to increase over time in Portugal but remains constant in Spain. The different cost of acquisition might explain the lower market penetration of diesel vehicles in Portugal but fails to explain the rapid growth of sales of diesels in Spain. The hypothesis that we evaluate in the following section is that scrappage programs are partially responsible for the long-run growth in the sales of diesels.

Figure 1: Adoption of Diesels in Portugal and Spain



(a) Sales by Fuel Type

(b) Diesel Market Share

(c) Car Prices by Fuel Type

(d) Fuel Cost of Driving

[13] It is well documented the heavy taxation of automobile sales in Portugal, 40% *vs.* 15% in Spain. Fortunately for our purposes, such policy did not change substantially during the 1990s. See pages 37, 73, and Figure 4 in page 150 of Degryse and Verboven (2000).

4 Scrappage Programs and the Diffusion of Diesel Automobiles in Spain

In the midst of a severe recession, the Spanish government enacted two automobile scrappage plans in 1994 in order to stimulate aggregate demand by increasing sales in the largest and most important industry of the Spanish economy, which had lost 20% of its employees between 1992 and 1994. The first scrappage plan, *Renove I*, remained active between April and October of 1994 and it offered €600s for any purchase that replaced an automobile ten years or older. The second plan, *Renove II*, in effect between October 1994 and June 1995 was less generous, offering €480 per automobile that replaced another seven years or older.[14] These scrappage programs were intended to be a one-time intervention. However, starting in April of 1997, the Spanish government offered a permanent scrappage subsidy under *Plan Prever* with identical conditions to *Renove I*. This permanent subsidy policy remained unchanged until the end of 2003, when it was modified to include larger explicit incentives for vehicles with better mileage. The impact of the *Prever* program might only be more limited because of the reduced pool of older vehicles that had already been replaced between 1994 and 1995. But whether it had a positive effect on the diffusion of diesel vehicles is still an open empirical question.

In 1994, when the scrappage programs were implemented, sales of gasoline models increased by 86,706 units relative to total sales of 574,896 automobiles sold the previous year, *i.e.*, 15%. Sales of diesel vehicles increased by 78,497 while diesel sales only amounted to 163,140 units in 1993, *i.e.*, an impressive 48% increase. Figure 1 (a) clearly shows that these policy interventions increased the sales of gasoline models only temporarily while sales of diesels appear to start growing faster from that moment on. The scrappage schemes certainly accelerated this process but, by how much? How much larger was the long term effect relative to the short term effect of these programs? Do diesels grow in later periods only because of the establishment of the permanent scrappage subsidy of *Prever*?

In order to address these questions, Table 4 presents a series of reduced form regressions to evaluate the average treatment effects of the different Spanish scrappage programs on the demand for vehicles using fuel engines relative to the control group of Portuguese sales where scrappage programs were absent.[15] In addition to price, income, fuel prices, time trends, a diesel dummy,

[14] The average subsidy of the first, more generous program amounted to about 4.89% for gasoline and 4.40% for diesel vehicles. These percent subsidies are comparable to most other European scrappage programs of the 1990s but are far more modest than the subsidies of the CARS program.

[15] Given the aggregate nature of our time series our results will be valid if we can assume that the average change in sales per model in Spain (treated group) in the absence of scrapping subsidies (treatment) is equal to the observed average change in sales per model in Portugal (control). This assumption known as *Parallel Paths*, *e.g.*, Angrist and Krueger (1999, §2), implies that differences between the sales per model in Portugal and Spain in the absence of scrapping subsidies in Spain are time-invariant. Appendix B shows that we can rule out pre-treatment trend differentials between the treated and control groups. Results confirm that in our case the Parallel Path assumption is reasonable and supported by our data.

and their interactions, we also include indicators for periods when the scrappage programs and permanent subsidies were offered. We also include model fixed effect dummies to control for all time-invariant observable and unobservable product characteristics. Our econometric specification is as follows:

$$\begin{aligned}
\ln(\text{SALES}/1000) = {} & \alpha + \beta_P \ln(\text{PRICE}) + \beta_{PD}[\ln(\text{PRICE}) \times \text{DIESEL}] + \beta_F \ln(\text{FUELPRICE}) \\
& + \beta_I \ln(\text{GDPPC}) + \beta_{IS}(\ln(\text{GDPPC}) \times \text{SEGMENT}) \\
& + \gamma_T \text{TREND} + \gamma_D \text{DIESEL} + \gamma_{DT}(\text{DIESEL} \times \text{TREND}) \\
& + \delta_{SR} \text{CFC} + \delta_{SRD}(\text{DIESEL} \times \text{CFC}) \\
& + \delta_{LR}(\text{LATE} \times \text{SP}) + \delta_{LRD}(\text{DIESEL} \times \text{LATE} \times \text{SP}) \\
& + \theta_S \text{SUBS} + \theta_{SD}(\text{DIESEL} \times \text{SUBS}) \\
& + \theta_{DSH}(\text{DIESEL} \times \text{SUBS} \times \text{HOME}) + \theta_{DSX}(\text{DIESEL} \times \text{SUBS} \times \text{NONEU}) .
\end{aligned} \tag{2}$$

Sales of a particular model-year depend on static demand determinants (β) such as the price of the vehicle, the price of the type of fuel used, and income. We allow for different price responsiveness for gasoline and diesel vehicles. Individuals regularly driving long distances might have a strong preference for diesel vehicles as they can more easily realize fuel savings, *e.g.*, see Verboven (1999). Results of Table 4 show that demand for diesel vehicles is less elastic than for gasoline models. The positive effect of ln(FUELPRICE) reflects the increase in sales of smaller, fuel-efficient models as oil prices increase slightly during the second half of the decade. We also include interactions between the log of the income per capita, ln(GDPPC), and automobile segment indicators to allow for different size of the income effect across automobile types. All automobile segments behave as normal goods but demand for LUXURY vehicles grows four times faster with income than demand in the popular SEDAN segment. All these parameters, once we control for car model fixed effects are robust and quite stable across specifications.

Next, we consider a set of variables aiming to capture the valuation for DIESEL vehicles and its evolution over time, (γ). The interaction of TREND and DIESEL captures a potentially complex process that combines the offering of new models (always in both gasoline and diesel versions), their average valuation, and the learning associated with the diffusion of this alternative fuel technology. The effect of TREND is slightly negative, reflecting the fact that the number of models available increase substantially during the decade, from 128 to 229 in Portugal and from 129 to 229 in Spain. On average, sales of DIESEL vehicles is larger on a per model basis, and they grow over the decade as DIESEL engines become better appreciated.

The four parameters (δ) test the main hypotheses put forward by this paper, that cash-for-clunkers programs may have not only positive short-term but also long-term effects on the

Table 4: Subsidies and Scrappage Programs – Average Treatment Effects

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7		Model 8	
Static Demand Drivers:																
CONSTANT	−8.424	(0.624)***	−7.915	(0.626)***	−1.835	(1.069)*	−2.924	(1.109)***	−3.343	(1.090)***	−3.099	(1.094)***	−3.269	(1.100)***	−3.305	(1.102)***
ln(PRICE)	−0.811	(0.092)***	−0.851	(0.092)***	−2.607	(0.169)***	−2.380	(0.180)***	−1.967	(0.181)***	−1.976	(0.181)***	−1.956	(0.181)***	−1.953	(0.182)***
ln(PRICE) × DIESEL	0.099	(0.179)	−0.015	(0.436)	−0.303	(0.312)	−0.107	(0.317)	−0.937	(0.392)**	−0.881	(0.400)**	−0.851	(0.398)**	−0.854	(0.398)**
ln(FUELPRICE)	0.684	(0.251)***	0.802	(0.265)***	1.752	(0.195)***	1.700	(0.197)***	0.969	(0.234)***	0.855	(0.239)***	0.848	(0.239)***	0.849	(0.239)***
ln(GDPPC)	5.011	(0.205)***	4.970	(0.206)***	2.792	(0.336)***	2.878	(0.335)***	2.322	(0.356)***	2.219	(0.358)***	2.150	(0.357)***	2.153	(0.357)***
ln(GDPPC) × COMPACT	−0.035	(0.041)	−0.031	(0.041)	0.475	(0.411)	0.514	(0.411)	0.535	(0.407)	0.539	(0.407)	0.635	(0.405)	0.629	(0.406)
ln(GDPPC) × SEDAN	−0.811	(0.092)***	−0.851	(0.092)***	−2.607	(0.169)***	−2.380	(0.180)***	−1.967	(0.181)***	−1.976	(0.181)***	−1.956	(0.181)***	−1.953	(0.182)***
ln(GDPPC) × LUXURY	−0.560	(0.058)***	−0.542	(0.058)***	1.713	(0.387)***	1.817	(0.389)***	1.994	(0.386)***	1.995	(0.386)***	2.112	(0.385)***	2.122	(0.385)***
ln(GDPPC) × MINIVAN	−0.541	(0.054)***	−0.551	(0.053)***	0.645	(0.689)	0.610	(0.689)	0.395	(0.690)	0.360	(0.691)	0.406	(0.689)	0.368	(0.693)
Preference Change:																
TREND	−0.074	(0.010)***	−0.124	(0.012)***	−0.170	(0.012)***	−0.166	(0.012)***	−0.175	(0.012)***	−0.180	(0.012)***	−0.180	(0.012)***	−0.180	(0.012)***
DIESEL			−0.846	(0.291)***	1.858	(1.054)*	2.115	(1.059)**	2.018	(1.060)*	2.019	(1.062)*	2.669	(1.062)**	2.726	(1.065)**
DIESEL × TREND			0.141	(0.021)***	0.198	(0.023)***	0.203	(0.023)***	0.187	(0.023)***	0.189	(0.023)***	0.181	(0.023)***	0.182	(0.023)***
Spain: Cash-for-Clunkers:																
CFC							0.073	(0.078)	0.209	(0.081)***	0.206	(0.081)**	0.209	(0.081)***	0.209	(0.081)***
DIESEL × CFC							0.441	(0.131)***	0.563	(0.133)***	0.571	(0.133)***	0.571	(0.134)***	0.570	(0.134)***
LATE × SP									0.381	(0.079)***	0.236	(0.100)**	0.238	(0.100)**	0.238	(0.100)**
DIESEL × LATE × SP									0.519	(0.124)***	0.608	(0.165)***	0.600	(0.166)***	0.601	(0.166)***
Spain: Permanent Subsidy:																
SUBS											0.238	(0.100)**	0.238	(0.100)**	0.238	(0.100)**
DIESEL × SUBS											−0.120	(0.167)	−0.385	(0.174)**	−0.424	(0.179)**
DIESEL × SUBS × HOME													0.610	(0.148)***	0.648	(0.154)***
DIESEL × SUBS × NONEU															0.164	(0.215)
R^2	0.391		0.401		0.748		0.750		0.756		0.756		0.757		0.758	
Adj. R^2	0.390		0.399		0.719		0.721		0.728		0.728		0.730		0.730	
Car Model FE	No		No		Yes		Yes		Yes		Yes		Yes		Yes	

OLS estimates using a sample size of 3,459 observations. Dependent variables are log of sales per model, year, and country in thousand units. Heteroskedastic-consistent standard errors are reported in parentheses. Significant estimates with p-values less than 0.1, 0.05, and 0.01 are identified with *, **, and ***, respectively.

composition of automobile sales. Dummy variable CFC takes value 1 for years 1994-1995, when the first two scrappage programs *Renove I* and *Renove II*, initially announced as a one-time event, were offered. Estimate δ_{SR} shows that these scrappage programs were effective in increasing sales of all vehicles in the short run, a result commonly documented in the literature. Notice however that the estimate of δ_{SRD} indicates that the effect of the Spanish early cash-for-clunkers is more than double for diesel vehicles than for gasoline models. Thus, these scrappage programs were partially responsible for the widespread diffusion of diesel automobiles in Spain.

More interestingly, we also consider the possibility that the evolution of preferences is nonlinear and accelerates during the second half of the decade because of the effect of the scrappage programs. The short term effect δ_{SRD} increases the share of diesel vehicles on the roads, which through the well-known imitation, contagion, or accumulated effect of learning behind the typical S-shaped diffusion curve, translates in a faster speed of diffusion from that moment on. Parameters (γ) already captured the change of preferences, common to Portugal and Spain. Dummy variables LATE $\times$ SP identifies any Spanish observation for years 1996-2000, once the first scrappage programs were implemented and estimates δ_{LR} and δ_{LRD} identify the differential behavior of Spanish sales of gasoline and diesel models, respectively relative to Portuguese control group. Results indicate that while both sales of gasoline and diesel vehicles grow in Spain faster than Portugal after the Spanish scrappage programs where implemented, their long-term impact on diesel vehicles is three times larger than on gasoline models. Thus, we conclude that the Spanish scrappage programs of 1994-1995, at the early stage of diffusion of diesel vehicles had both a short-term and a lasting long-term effect that accelerated the rate of adoption of diesels in the Spanish market substantially relative to Portugal, where such scrappage programs were never offered, *e.g.*, see Figure 1 (a).

The remaining set of parameters (θ) report other effects on sales associated to the permanent scrappage subsidy program *Plan Prever* offered from 1997 on. Overall, the effect on gasoline models is identical to the long-term effect of the 1994-1995 cash-for-clunkers programs. The effect of permanent subsidies on sales of diesel vehicles is more nuanced as it heterogeneous depending on the subset of diesel vehicles considered. It is positive, and again three times larger than the effect on gasoline models, for brands with production facilities in Spain: CITROËN, FORD, GM, PEUGEOT, RENAULT, SEAT, and VOLKSWAGEN; it is not significant for non-european imports; and negative for other European brands such as BMW, FIAT, MERCEDES, ROVER, SKODA, and VOLVO. Thus, the permanent scrappage subsidy policy appears to favor the purchase of domestic brands. This result is somewhat similar to the home bias effect induced by scrappage programs found by Grigolon et al. (2016), although we show that given the fast growth of sales of diesels in the Spanish market, it is only significant for this type of fuel engines.

Table 5: Subsidies and Scrappage Programs – Average Treatment Effects by Segment

	SMALL		COMPACT		SEDAN		LUXURY		MINIVAN	
Static Demand Drivers:										
CONSTANT	−3.429	(2.581)	−2.027	(1.904)	−2.503	(1.811)	−2.210	(1.689)	−3.165	(4.614)
ln(PRICE)	−1.068	(0.574)*	−1.666	(0.333)***	−2.041	(0.314)***	−2.047	(0.300)***	−2.312	(0.819)***
ln(PRICE) × DIESEL	−1.283	(1.120)	−1.595	(0.855)*	−0.673	(0.705)	0.702	(0.712)	−2.186	(1.364)
ln(FUELPRICE)	1.195	(0.530)**	0.646	(0.520)	1.076	(0.493)**	0.313	(0.410)	0.640	(1.118)
ln(GDPPC)	2.909	(0.537)***	2.795	(0.439)***	3.498	(0.407)***	3.849	(0.412)***	2.727	(1.043)***
Preference Change:										
TREND	−0.150	(0.024)***	−0.165	(0.031)***	−0.208	(0.025)***	−0.191	(0.019)***	−0.132	(0.078)*
DIESEL	−0.498	(0.869)	−3.339	(1.269)***	0.058	(0.581)	−1.759	(0.687)**	0.000	(0.000)
DIESEL × TREND	0.057	(0.059)	0.180	(0.052)***	0.265	(0.041)***	0.159	(0.039)***	0.310	(0.094)***
Spain: Cash-for-Clunkers:										
CFC	0.299	(0.165)*	−0.180	(0.213)	0.180	(0.160)	0.490	(0.124)***	0.665	(0.452)
DIESEL × CFC	0.980	(0.337)***	1.569	(0.285)***	0.225	(0.248)	0.074	(0.237)	0.249	(0.494)
LATE × SP	0.138	(0.180)	0.016	(0.228)	0.094	(0.252)	0.583	(0.148)***	0.983	(0.411)**
DIESEL × LATE × SP	1.344	(0.413)***	1.515	(0.348)***	0.434	(0.385)	−0.153	(0.244)	−0.414	(0.508)
Spain: Permanent Subsidy:										
SUBS	−0.033	(0.191)	0.320	(0.230)	0.419	(0.251)*	0.266	(0.155)*	−0.022	(0.322)
DIESEL × SUBS	−0.613	(0.503)	−0.205	(0.368)	−0.705	(0.408)*	−0.458	(0.245)*	0.020	(0.430)
DIESEL × SUBS × HOME	1.041	(0.457)**	0.028	(0.325)	1.196	(0.250)***	0.070	(0.281)	0.294	(0.296)
Observations	689		814		913		800		243	
R^2	0.681		0.698		0.710		0.774		0.666	
Adj. R^2	0.642		0.659		0.677		0.747		0.572	

OLS estimates. Dependent variable is sales per model, year, and country in thousand units. All regressions include car model fixed effects. Heteroskedastic-consistent standard errors are reported in parentheses. Significant estimates with p-values less than 0.1, 0.05, and 0.01 are identified with *, **, and ***, respectively.

Scrappage subsidies in Spain amounted to a lump-sum available to anyone with a qualifying clunker. Since individual transaction data is not available we cannot identify who actually benefited from the program and thus, treatment CFC denotes a regime where a potential rebate was available for consumers effectively reducing the acquisition cost of buying a new vehicle. Table 4 included DIESEL × CFC to allow for treatment effects across fuels. Table 5 further explores the heterogeneity of treatment effect across automobile segments. We now estimate the treatment effects associated to the scrappage programs for each automobile segment separately. Results show substantial heterogeneity across automobile segments and fuel engine types. Demand for smaller vehicles is more elastic and with the exception of LUXURY vehicles, demand for gasoline models is always more elastic than their diesel alternative. Income growth favors the sale of larger vehicles and high fuel prices boosts demand for SMALL and SEDAN ones. The negative sign of TREND is significant across all segments, reflecting the fact that the number of models available grows during the decade across all segments.[16] DIESEL vehicles are not valued much, particularly for the COMPACT and LUXURY segments. However, this appreciation of diesel engines improves over the decade in all but the SMALL segment.

The 1994-1995 scrappage programs increase the demand of gasoline models in the SMALL and LUXURY segments. As for diesels, the Spanish cash-for-clunkers leads to much larger increases in sales of SMALL and COMPACT segments. This triggers similar increases for LUXURY and MINIVAN gasoline models representing about 4% of total sales in Spain. More interesting is the long term increases in SMALL and COMPACT diesels representing 23% of total sales in the Spanish automobile market. The scrappage program had a definitely more sizeable effect on small diesels than on luxurious gasoline vehicles in the long run. By contrast, the late permanent scrappage subsidy increased equally the sales of diesel and gasoline models the most popular segment, SEDAN (about 22% of the market).

Table 6: Scrappage Discounts and Additional Sales (1994-1995)

	GASOLINE				DIESEL			
	SALES	CFC SALES	%	DISCOUNT	SALES	CFC SALES	%	DISCOUNT
SMALL	577,096	101,440	17.58	25.01	124,187	47,429	38.19	23.71
COMPACT	357,426	59,405	16.62	16.89	244,733	64,057	26.17	16.84
SEDAN	219,470	30,029	13.68	12.81	121,044	67,771	55.99	11.86
LUXURY	56,702	7,822	13.79	8.48	18,657	14,982	80.30	7.24
MINIVAN	7,826	1,781	22.76	15.41	6,533	3,787	57.97	10.38

Results of simulations using Model 8 of Table 4.

[16] For instance, in Spain there were 26 SMALL models (18 gasoline and 8 diesel) in 1991, while in 2000 the number of models had grown to 49 (33 gasoline and 16 diesel). Similarly, at the beginning of the decade there were 34 SEDAN models (20 gasoline and 14 diesel) while at the end there were 52 models (28 gasoline and 24 diesel).

Table 6 makes use of estimates of Model 8 in Table 4 to simulate the overall short term sales induced by the 1994-1995 scrappage programs in Spain by fuel type and market segment. The aggregate predicted effect, 398,503 additional cars sold.[17] Notice that, relative to the distribution of cash-for-clunkers induced gasoline sales, the percentage of sales induced by the scrappage program is substantially larger for SMALL, and SEDAN diesel models. This result might occur because of preferences for vehicles in these segments among diesels but perhaps it is also reinforced by the scrappage programs. Notice that the blind flat rebate amounts to a much larger percent price discount for SMALL than for any other larger vehicle. Percent price reductions are always smaller for diesels because the price of these vehicles is always more expensive than their gasoline counterparts, *e.g.*, Figure 1 (c).

Figure 2: Percent Scrappage Savings by Segment and Fuel Type

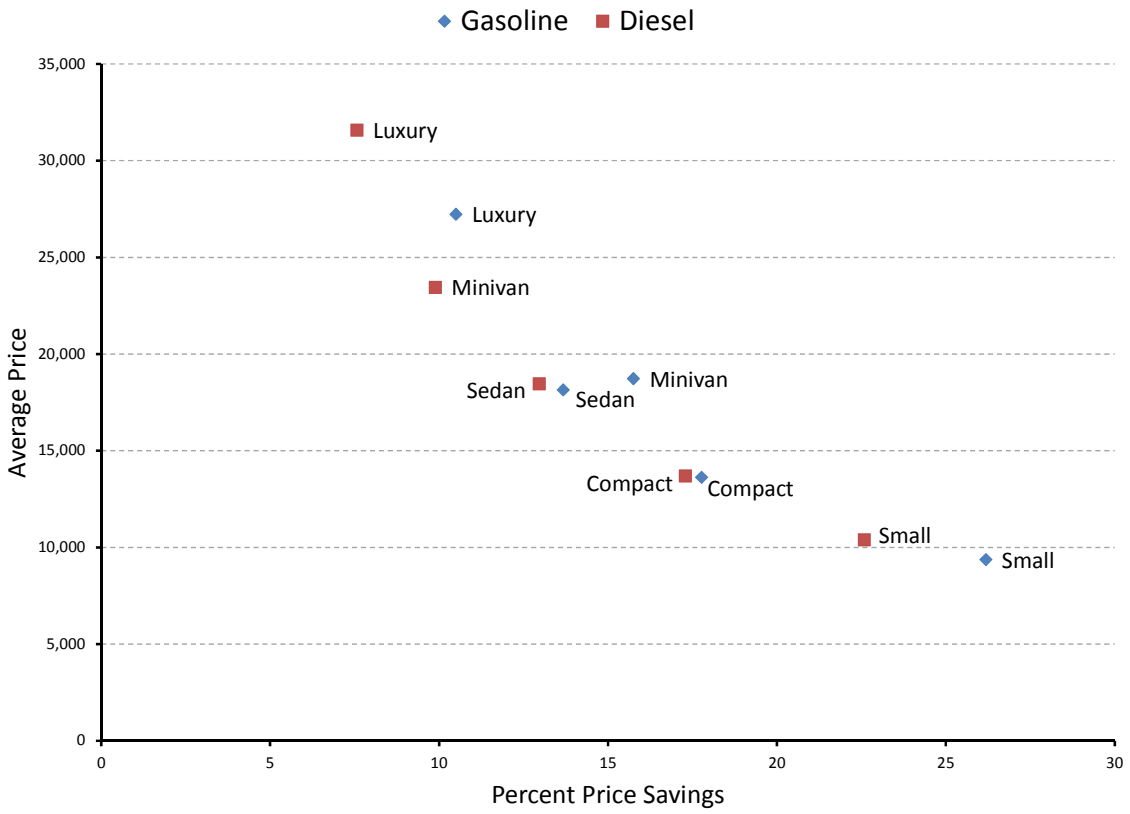


Figure 2 plot the average discount against average price by category and fuel type. The percent discount of diesels is substantially larger than for COMPACT gasoline models. It is conceivable that consumers substitute away from the latter to the former because to realize a larger percent discount. The

[17] Our estimated model generates an accurate simulation of sales under the cash-for-clunker programs. Licandro and Sempayo (1997) report that the actual number of cars benefiting from the 1994 and 1995 *Renove* plans was about 357,000 units. Splitting this prediction proportionally to the duration of each plan, predicted sales associated to *Renove I* amount to 159,401. According to the El País newspaper edition of 4 November 1994, the total number of cars sold subsidized by the *Renove I* program was 170,811.

negative sign of γ_D in Table 5 for COMPACT diesel vehicles supports this idea of substitution away towards fuel efficient and more heavily subsidized SMALL diesels. Figure 2 also shows that both prices and discounts are very similar for COMPACT and the popular SEDAN vehicles. Table 6 documents that, perhaps because of their popularity, scrapping subsidies were responsible for 56% of sales of SEDAN diesels, double the scrappage induce sales of SEDAN gasoline models already by mid 1990s.

5 Concluding Remarks

This paper shows that scrappage programs such as CARS may induce important qualitative changes on the characteristics of the automobile fleet in addition to a temporary increase in sales and the renewal of old automobiles for newer ones. While we document heterogeneous treatment effects across market segments, the larger impact of these scrappage subsidies on sales of diesel vehicles relative to gasoline models is a very robust result of our analysis that holds both in the short and long run. This is a new implication of scrappage policies that has not been documented before and that might justify its use if the induced benefits in terms of road security, emissions, or fuel consumption exceed its financial costs.

The effect of the Spanish scrappage programs of 1994 and 1995 were long lived because dynamic informational linkages such as learning or imitation exist. These dynamic effects are more important when policy interventions take place in the early stages of a process of diffusion of a new technology and the timing of these programs coincided with the early adoption of diesel vehicles. Thus, they not only increased sales of diesels more than gasoline models in the short run but also accelerated the speed of diffusion of diesels beyond the change in preferences in favor of diesel vehicles that is assumed to be common to Portugal and Spain. As a result of it, sales of diesel vehicles in Spain exceeded those of gasoline models by the end of the 1990s, far ahead of many other European countries.

Finally, because of it own very nature, an emission-blind flat rebate independent of the purchased or scrapped vehicle and/or the income of the buyer, the induced discount of vehicles is substantially larger than for any other automobile category, thus inducing some buyers to prefer them over the slightly larger gasoline COMPACT. As for the popular SEDAN segment, scrappage programs were responsible for the majority of sales of its diesel models.

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Appendix

A European Scrappage Programs

For the analysis of Table 1 we collected information on scrappage programs for sixteen European countries between 1990 and 2008 as well as sales of diesel and gasoline vehicles and other economic variables.[18] Data were obtained from the following sources:[19]

- *Automobile registration and market share of diesel vehicles:* "ACEA European Union Economic Report," December 2009.
- *Fuel prices, taxes, exchange rate, and PPP:* "Energy Prices & Taxes," IEA, several issues.
- *GDP per capita:* "World Economic Outlook," IMF, several issues.
- *Scrappage programs:* "Cleaner Cars. Fleet Renewal and Scrappage Schemes," European Conference of Ministers of Transport, 1999. In addition to the Spanish program described in the main body of the paper, the other European scrappage programs are:
  - *Denmark:* DKr 6,500 ($1,000) bonus for scrappage a car older than ten years regardless of replacement (1994 to June 1995).
  - *France:* FF 5,000 ($950) bonus (an average 6% discount) for scrappage a car older than ten years if replaced with a new model February 1994 to June 1995). A similar scheme followed with FF 7,000 for scrappage a large car and FF 5,000 for small cars, in both cases older than eight years (October 1995 to September 1996).
  - *Ireland:* £1,000 ($1,600) registration tax reduction when a ten year old car (or older) was replaced with a new one (June 1995 to December 1997).
  - *Italy:* L 1.2 to 2 million ($900-1,200) bonus for replacing an existing car. The exact bonus depended on the engine displacement of the replacement car bought (January 1997 to January 1998). A second program offered L 1.25 to 1.5 million depending on the fuel mileage of the new replacement vehicle (February to September 1998).
  - *Norway* NKr 5,000 ($800) bonus for scrappage a vehicle older than ten years regardless of replacement (1996 only).

Greece also offered a scrappage scheme from January 1991 to March 1993 to accelerate the spread of catalysed car and reducing emissions. We ignore this program and treat Greece as one of those countries that does not implement scrappage programs because while non-commercial diesel vehicles were sold in Greece starting in 1991, for environmental reasons, sales of diesel vehicles were only allowed outside the populous districts of Attiki and Thessaloniki, which explains why diesel vehicles are extremely rare in Greece even today.

[18] These countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Norway, Netherlands, Portugal, Spain, Sweden, and United Kingdom.

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B Testing the Parallel Paths Assumption

Table 7 presents the results of three regressions exploring the evolution of sales in Portugal and Spain between 1991 and 1993, *i.e.*, during the pre-treatment period of our sample. The idea of the parallel path hypothesis is to test for structural change between the control and treatment group during the pre-treatment period. Model A presents the basic specification. Following Mora and Reggio (2013), in addition to car fixed effects to account for product characteristics, we also include determinants of demand such as the price of automobiles in each market, fuel prices, and income per capita. These variables control for any predictable differential growth of sales in Portugal and Spain. Variables SPAIN and TREND control for differences in sales due to market size and the possibility of different growth paths in sales in these two countries and DIESEL × TREND allows for the possibility that the speed of diffusion is also different in Portugal and Spain. Model B tests for the effect of the scrappage treatment in the pre-treatment sample. The estimate of DIESEL × SPAIN is not significant, which suggests that the parallel path hypothesis is correct if we were to study the overall effect of the scrappage subsidies on sales of diesel vehicles. Model C adds DIESEL × SPAIN × TREND to account for different growth paths in the sales of diesels. The corresponding estimate is not significant either. Overall, Models B and C support our assumption of parallel paths and our interpretation that the sudden and long term increase in sales of diesels in Spain are caused by the scrappage programs of 1994 and 1995.

Table 7: Parallel Paths in Pre-Treatment Samples

	Model A		Model B		Model C	
CONSTANT	3.029	(2.385)	3.275	(2.339)	3.080	(2.299)
ln(PRICE)	−2.809	(0.500)***	−2.659	(0.500)***	−2.656	(0.499)***
ln(FUELPRICE)	0.289	(0.535)	−0.335	(0.385)	−0.504	(0.417)
ln(GDPPC)	2.482	(0.785)***	2.098	(0.734)***	2.183	(0.720)***
TREND	−0.115	(0.103)	−0.136	(0.077)*	−0.133	(0.076)*
SPAIN	−0.269	(0.345)	−0.381	(0.346)	−0.473	(0.350)
DIESEL × TREND	0.212	(0.105)**	0.217	(0.105)**	0.158	(0.148)
DIESEL × SPAIN			0.402	(0.298)	0.211	(0.413)
DIESEL × SPAIN × TREND					0.103	(0.132)
Observations	793		793		793	
R^2	0.538		0.541		0.542	
Adj. R^2	0.534		0.537		0.537	

OLS estimates using the 1991-1993 pre-treatment sample for both Portugal and Spain. Endogenous variable are sales per model, year, and country in thousand units. All regressions include car model fixed effects. Heteroskedastic-consistent standard errors are reported in parentheses. Significant estimates with p-values less than 0.1, 0.05, and 0.01 are identified with *, **, and ***, respectively.