

# Qualitative Effects of “Cash-for-Clunkers” Programs<sup>\*</sup>

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## Abstract

“Cash-for-Clunkers” programs are credited with increasing automobile sales only temporarily. We analyze the Spanish automobile market during the 1990s to argue that such policy interventions may induce permanent qualitative effects by shifting the demand towards fuel efficient vehicles, thus changing the composition of the automobile fleet in the long run. Between 1994 and 2000 the market share of diesel automobiles increased from 27% to 54%. Sales of diesel vehicles after the Spanish government sponsored two scrappage programs was more important across most popular market segments. As diesel vehicles became mainstream they also became closer substitutes to gasoline models.

**Keywords:** Scrappage Programs, Fuel Efficiency, Diffusion of New Durable Goods, Diesel Engines, TDI Technology.

**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 whose impact on sales of new automobiles and fuel savings are yet to be determined. About 680,000 vehicles were replaced at a taxpayer cost of \$3bn, or over \$4,000 apiece on average. While Greenspan and Cohen (1999) find that influencing the scrappage rate affects total sales, following the influential work of Adda and Cooper (2000), the common wisdom among economists is that scrapping programs only influence aggregate sales temporarily but that in the long run they do not have any permanent effect. Thus, Mian and Sufi (2010) document that the accelerated scrappage of clunkers induced by CARS would had happened anyway, at no cost, in just seven additional months.

However, there are potential reasons to sponsor cash-for-clunkers programs other than just stimulating aggregate demand. For instance, European scrappage programs of the 1990s were aimed at increasing road security by reducing the average age of automobile fleets. Hence, if it could be argued that the benefits of some induced externalities such as reduced emissions may offset the financial cost of the programs.<sup>1</sup> This motivation appears to have guided the design of the CARS programs, which specifically linked the scrappage subsidy to the purchase of a new fuel efficient car with a minimum required mileage.<sup>2</sup> 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 18 miles per gallon. Thus, by favoring less expensive and more fuel efficient vehicles, CARS could prove an effective policy to induce the adoption of fuel efficient technologies such as hybrid engines.

Our goal in this paper is to suggest that scrappage programs *may induce* permanent qualitative effects on the composition of the automobile fleet beyond any temporary quantitative

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<sup>1</sup> Changes in consumer behavior may reduce the size of these externalities. The “rebound effect” reduces potential fuel savings as miles driven increase when individuals purchase more fuel efficient vehicles. See Hahn (1995).

<sup>2</sup> 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.

impact on aggregate sales. In particular we present evidence consistent with scrappage programs having the effect of shifting demand in favor of new fuel efficient diesel engines during the 1990s in Spain. We argue that the permanent impact of scrappage programs is likely to operate through a demonstration effect that makes evident the effectiveness and quality of the new technology to hesitant or uninformed consumers. In a process similar to the adoption of hybrid corn documented by Griliches (1957), demand shifts towards the new fuel efficient automobiles well after the scrappage program expired as consumers update their beliefs regarding the quality and performance of the new diesel technology.

We cannot evaluate the long-term effectiveness of the 2009 CARS program in the U.S. yet. Instead, we provide evidence from similar experiences in Europe using aggregate information on diesel vehicle registrations. The analysis of the Spanish case uses detailed automobile registration information, including make and model by type of engine of sold vehicles. Thus, our analysis of the Spanish automobile industry in the 1990s can be understood as documenting a representative case of the impact that scrappage subsidies had on the dramatic technological transformation of the European automobile industry, something that might shed light on the prospect of success of fuel efficiency policies considered elsewhere in changing consumers' tastes in favor of fuel efficient automobiles.<sup>3</sup> 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 accounted 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). We argue in this paper that a *properly timed* scrappage program may be key in shifting the taste of consumers in favor of alternative fuel automobiles.

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<sup>3</sup> There are several parallel features between the U.S. today and Spain in the 1990s regarding the automobile industry. The Spanish market in the 1990s was far from marginal: it was then the fifth largest in the world measured by output and the second largest single contributor to GDP, as well as the largest exporter of the country. Furthermore, and similar to CARS, two scrappage programs were introduced partly to overcome a recession that was, relative to the U.S. today, even more severe in terms of unemployment as it exceeded 24% of the Spanish labor force in 1994.

Two scrappage programs were implemented in 1994 to overcome an economic recession that had left the Spanish automobile industry in shambles. Interestingly, a more fuel efficient technology, namely, the turbocharged, direct-injection, diesel engine (TDI) had been available for five years at the time of the policy intervention.<sup>4</sup> Our unique data, which details car registrations by models and type of engine, 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.

In combination with the economic recession that favored the purchase of smaller cars, the two scrappage programs enacted in Spain in 1994 led the share of registered diesel automobiles to reach a tipping point. Thus, its widespread adoption afterwards was self-propelled, and continued through changes in fuel prices and increase in per capita income that followed during the second half of the 1990s. From this perspective, this paper is the first to document in detail the differentiated impact of scrappage programs on the demand of different types of automobiles. The different market penetration of different market segments at the time of the policy intervention helps us to weakly identify the effect of the scrapping program separately from the change in preferences behind the diffusion of the new technology. To back up our interpretation of the results obtained using Spanish data we also make use of more aggregated data of several countries to document that European scrapping programs appear to have a similar long-lasting effects in increasing the market share of diesel automobiles despite being implemented at different moments in time in each county with essentially the same set of models available to all of them.

Many interesting results arise. First, we show that the effectiveness of the subsidy in shifting demand in favor of fuel efficient diesel engines is not immediate. It rather spreads over several years following the termination of the scrappage programs. More importantly, the program appears to have long-lasting effects if enforced during the very early stages of diffusion of the new technology.

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<sup>4</sup> Scrappage programs did not explicitly intend to shift preferences in favor of diesel models. Leaders in diesel manufacturing produced these models mostly in other European countries but they could not be discriminated against because of European single market rules. Thus, these programs are a good proxy for an exogenous regime change to study the demand for differentiated types of engine powered vehicles.

Second, we document that better mileage or low diesel prices are not the only reasons why consumers end up favoring diesel models. Non-observable characteristics such as durability and reliability of diesel engines may have played a positive role in the adoption of this new technology. Third, we show that consumer tastes evolve so that gasoline and diesel models become closer substitutes.

The paper is organized as follows. Section 2 briefly describes the relevant features of the new diesel engine technology, its major improvements, and its widespread adoption in Spain and Europe during the decade of the 1990s. Section 3 reviews the two cash-for-clunkers programs enacted in Spain in 1994 and evaluates the effectiveness of these programs in promoting sales of automobiles and changing the preference of consumers for different types of engines. 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 and type of fuel engine. This section also documents that, overall, other European scrappage programs also lead to a steady state increase in the share of diesel vehicles sold. Section 4 presents the results of an equilibrium discrete choice model of demand for automobiles that distinguishes between diesel and gasoline versions of these vehicles in order to identify whether unobserved characteristics in addition to better fuel mileage help explaining the adoption of this new technology. In Section 5 we estimate an equilibrium oligopoly model to show that as time goes by diesel engine vehicles become far more responsive to the prices of gasoline models and as result both types of vehicles become closer substitutes. Section 6 concludes.

## 2 TDI Technology

Diesel engines have been routinely used in automobiles since the 1930s. In the 1980s diesel automobiles were noisy, smelly, and overall not considered to be great performers. In 1989, Volkswagen introduced the TDI technology in the Audi 100 model.<sup>5</sup> A TDI engine uses direct injection, where a

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<sup>5</sup> 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.

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.<sup>6</sup>

In Europe, an explicit policy to reduce dependence on foreign oil prompted governments to subsidize diesel fuel for decades, which led to a slow but steady increase in the sales of diesel automobiles in Europe during the 1990s, helping consumers to learn the advantages of diesel technology. The overall effect on fuel saving is however unclear as better fuel efficiency may lead to an increase in the average miles driven per vehicle. Johannsson and Schipper (1997) estimate that the elasticity of travel to fuel price in the early 1990s was  $-0.3$  in Europe. Goldberg (1998) estimates such elasticity to be  $-0.2$  or less in the U.S. conditional on the choice of vehicle.<sup>7</sup>

After excluding few models, mostly luxury vehicles, with extremely small market shares, our sample is an unbalanced panel with 1,869 observations that includes 340 models (206 with gasoline engines and 134 diesel models) comprising 99.2% of the car registrations in Spain during the 1990s. Models are grouped in market segments as they are commonly classified by the European automobile industry. The only exception is the LUXURY segment that also includes sporty cars.<sup>8</sup>

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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.

<sup>6</sup> See the 2004 report: "Why Diesel?" from the European Association of Automobile Manufacturers (ACEA). It should also be noted that, unlike the U.S., diesel fuel is available in almost every gas station across Europe.

<sup>7</sup> TDI models were not introduced immediately in the U.S., where in addition to low gasoline prices, European manufacturers needed to obtain an emission certification by the U.S. Environmental Protection Agency, a hurdle that frequently took several years to clear. Carbon dioxide emissions per mile are only slightly lower (about 5%) for diesel than for gasoline engines. Regarding emissions, diesel fuel is clearly less pollutant only if we also take the refining process into account as it requires less energy than gasoline. Thus, the popular insistence on clean diesel may actually lead to an increase in emissions per mile as authorities set a low-carbon, low-sulfur content for diesel fuel, which requires substantially more energy (and emissions) to be refined. On this neglected issue, see Schipper, Marie-Lilliu and Fulton (2002, p.337).

<sup>8</sup> 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. Appendix A details the numerous sources we employ to build our data set.

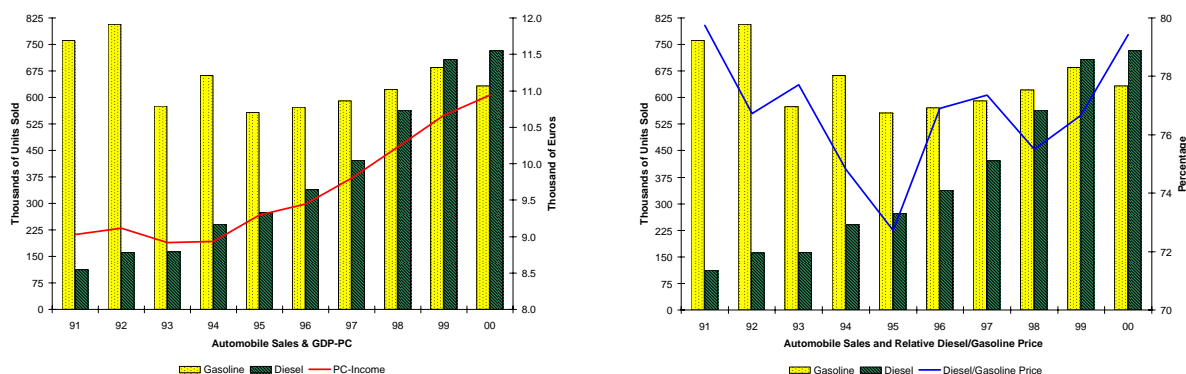
**Table 1: Spanish Automobile Market by Segment and Type of Fuel: 1991–2000**

GASOLINE:	SALES	MODELS	PRICE	FCOST	KM/L90	HP	LENGTH	WIDTH	WEIGHT
ALL	646,340	118	13,025	3.99	18.43	89.14	158.65	65.43	2,227
SMALL	282,750	26	9,212	3.63	20.08	65.40	146.09	63.25	1,900
COMPACT	204,270	26	13,181	4.05	17.94	95.75	162.64	66.56	2,305
SEDAN	117,930	28	17,428	4.34	16.72	114.36	174.69	67.32	2,621
LUXURY	35,190	33	27,693	5.06	14.56	155.45	181.69	69.35	2,970
MINIVAN	6,208	9	20,059	5.23	14.08	118.83	172.52	69.59	3,071
DIESEL:	SALES	MODELS	PRICE	FCOST	KM/L90	HP	LENGTH	WIDTH	WEIGHT
ALL	371,840	71	14,518	2.52	22.25	76.02	162.64	66.14	2,442
SMALL	91,422	12	9,993	2.29	24.45	61.22	146.48	63.05	2,023
COMPACT	144,480	19	13,341	2.52	22.12	72.98	161.54	66.47	2,409
SEDAN	116,040	21	17,525	2.62	21.30	85.48	174.34	67.51	2,686
LUXURY	10,696	13	32,781	2.93	18.96	131.21	187.54	70.07	3,282
MINIVAN	9,198	10	22,103	3.30	17.08	97.52	176.28	71.32	3,414

SALES indicate the average yearly vehicle registration 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 kilometers traveled with one liter of fuel driving at a speed of 90 kilometers per hour on a highway; HP denotes the horsepower; LENGTH and WIDTH are measured in inches and WEIGHT in pounds.

Table 1 summarizes the features of vehicles sold during the 1990s by segment and fuel type. Overall, diesel vehicles are about 10% heavier than similar gasoline versions. Diesel and gasoline versions of a particular model have the exact same size. Since European vehicles are smaller than those sold in the U.S. market, they use smaller engines that are less powerful but also more fuel efficient. Diesel models are 15% to 20% less powerful than gasoline vehicles. They were also between 1,000 and 2,000 euros more expensive. Why did Spanish (as well as other European) consumers embrace this more expensive, less powerful technology? Fuel economy is the obvious reason. Table 1 shows that diesel vehicles consume 20% less fuel than gasoline models, leading to savings of about 35% in the cost of driving. However, diesel engines are also reputed for high torque, excellent reliability, and longer durability than gasoline engines. All those unobservable features could be favorably compared against the increased weight and lower power of diesel vehicles. Table 1 also describes the features of different market segments by type of engine. Within segments the same

**Figure 1: Price and Income Effects on Sales**

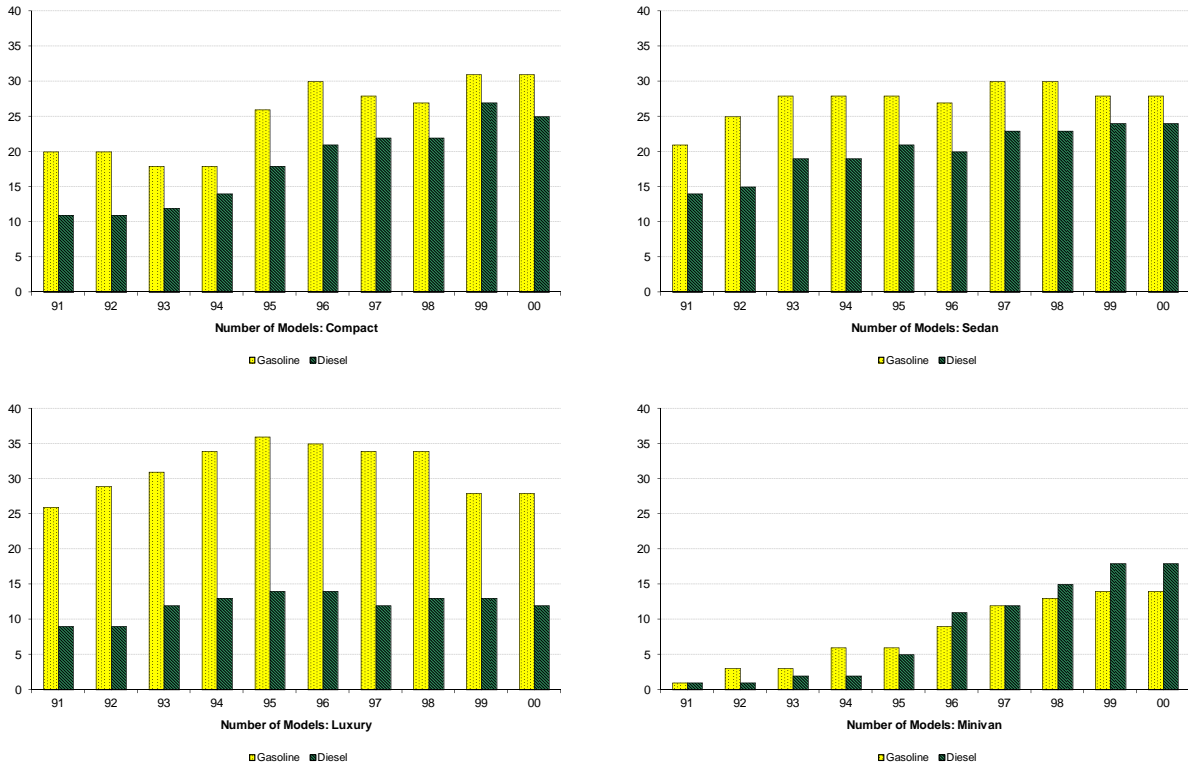


features discussed before hold: diesel vehicles are essentially of identical size to gasoline models although they are heavier, less powerful, and priced at a premium.

Figure 1 illustrates how market conditions relate to the demand of automobiles with different engine types. Notice that diesel automobiles cannot be considered an inferior good. Income per capita grew in Spain rapidly during the second half of the 1990s and sales of diesel vehicles outpaced the growth of per capita income, GDP-PC. Sales of gasoline models were essentially identical in 1993 and 1995 despite the 1994 scrappage program, when they temporarily increased by 15%. Sales of gasoline models increased at a steady pace, between 3% and 10% a year until 1999 but they never reached the sales level of 1992 again. The evolution of sales of diesel automobiles is starkly different. Initially in 1991, they only represented 12.82% of total sales. After the scrappage programs were implemented, they grew at an explosive rate of almost 50% a year, which stabilized at rates between 13% and 25% a year between 1994 and 1999 depending on segments. Thus, by the end of the decade diesel automobiles represented 53.66% of the market.

Figure 2 shows the heterogeneity of initial conditions across different market segments at the time of the policy intervention. There were many diesel models available in the COMPACT and SEDAN segments, which may reflect a an ongoing trend in favor of this technology. On the contrary, the number of LUXURY and MINIVAN models only grew significantly after the implementation of the

Figure 2: Diesel vs. Gasoline Models



scrappage programs, perhaps suggesting that supply follows a substantial increase in demand. Our economic analysis will distinguish among the different segments in order to account for the relative availability of diesel models as well as for the intensity of competition.

### 3 Segment-Specific Effects of Cash-For-Clunkers Programs

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.<sup>9</sup> These plans were also aimed at increasing road safety by reducing the average age of the

<sup>9</sup> It has been estimated that the Spanish cash-for-clunkers programs induced the sale of an additional 120,000 vehicles, or about 13% of the Spanish market in 1994. See Licandro and Sempayo (1997).

automobile fleet.<sup>10</sup> The first scrappage plan remained active between April and June of 1994 and it offered between 500 and 600 euros for any purchase that replaced an automobile seven years or older. The second plan, in effect between October 1994 and March 1995 was less generous, offering 480 euros per automobile that replaced another ten years or older.<sup>11</sup>

Figure 3 shows the evolution of sales over the 1990s in Spain by market segments distinguishing by type of engine. It shows how the increase in automobile demand goes hand in hand with a significant change in its composition, and how dynamics is different in each market segment.<sup>12</sup> It is however important to remark that these scrappage programs were not aimed at inducing sales of diesel vehicles but only to boost automobile sales in general. Furthermore the policy was not anticipated either. 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.<sup>13</sup> Thus, it can be ruled out that diesel benefited from this program beyond the individual decisions of buyers, as the incentive they received was the same regardless of the type of fuel of the replacement vehicle. Similarly, since the program was announced just weeks before being offered, we can ignore the possibility of individuals delaying the purchase of a vehicle in order to take advantage of the benefits of the scrappage scheme. Therefore, these scrappage schemes may have accelerated the adoption of diesel engine vehicles although such an effect was not intended by policymakers.

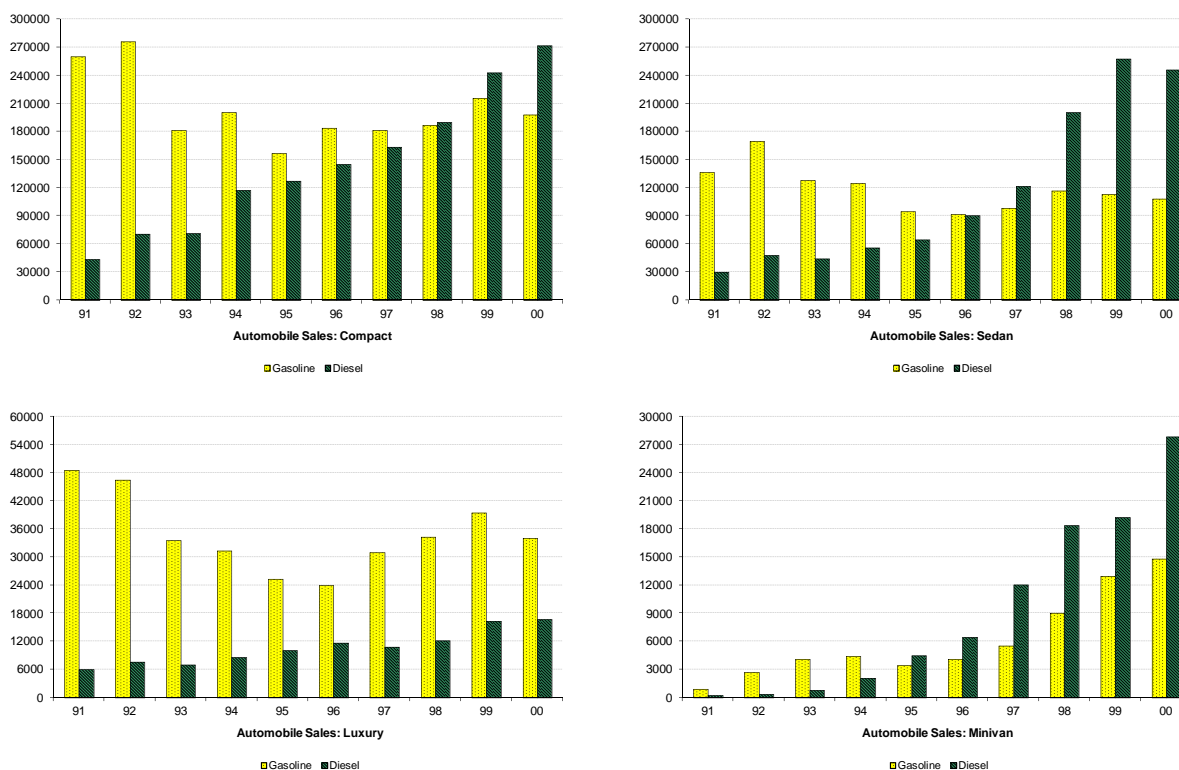
In 1994, when the scrappage programs were implemented, sales of gasoline models increased by 86,706 units relative to total sales of 574,896 automobiles sold the previous year, *i.e.*, 15%. Sales of diesel vehicles increased by 78,497 while diesel sales only amounted to 163,140 units in 1993, *i.e.*,

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<sup>10</sup> The Spanish automobile fleet was very old following a long period of slow economic growth and high unemployment. By 1995, 30% of the automobile fleet was 10 years or older. Moral (1998) estimates that the scrappage plans increased 2.13% the de-registration rate of vehicles seven years or older. This is a substantial increase relative to the 1993 de-registration rates of 3% for automobiles of this age group.

<sup>11</sup> Relative to the average price of automobiles in 1994 reported in Table 1, the 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. The lowest subsidy of \$3,500 represented a minimum 7.78% of the price of the new vehicle if consumers bought the most expensive model allowed by the program, with a price tag of \$45,000. Larger subsidies,

Figure 3: Diesel vs. Gasoline Sales



an impressive 48% increase. It could be argued that after this big immediate increase in the sales of diesel vehicles, the uncertainty regarding the quality of the new technology dissipated and sales of diesel models took off steadily. The growth is particularly visible in the SEDAN and MINIVAN segments with market shares rising almost up to 70%. 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?

up to \$4,500 were possible and since most automobiles sold were much more modestly priced, therefore leading to a substantially larger percent subsidy per vehicle than in the Spanish case.

<sup>12</sup> We did not include the SMALL segment in Figure 3. Potential savings are smaller for already fuel efficient small gasoline vehicles. Furthermore, developing ultralight diesel models took longer and sales of diesel powered SMALL vehicles only speeded up at the end of the 1990s.

<sup>13</sup> 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.” See Appendix B for additional details.

In order to address these questions Table 2 presents a series of reduced form regressions to evaluate the differentiated effect of the 1994 scrappage programs on the demand for vehicles using different fuel engine types after we control for other relevant economic information.<sup>14</sup> The variable of interest is the yearly sales of each model distinguishing by type of fuel. The top of Table 2 measures the average effect of the scrappage programs in a regression that includes segment, manufacturer fixed effect (non-reported), fuel dummies, an average treatment effect, D94-00, and some economic variables such as income per capita, GDP-PC, price of the vehicle, PRICE, and price of the corresponding fuel, FUELPRICE. Our econometric specification is as follows:

$$\begin{aligned}
 \ln(\text{SALES}/1000) = & \alpha_0 + \alpha_s \text{SEGMENT} + \alpha_m \text{MANUFACTURER} + \alpha_e \text{ECONOMIC VARIABLES} \\
 & + \alpha_d \text{DIESEL} + \alpha_t \text{D94-00} + \alpha_{tt} \text{TREND} \\
 & + \alpha_{dt} \text{DIESEL} \times \text{D94-00} + \alpha_{dtt} \text{DIESEL} \times \text{TREND}.
 \end{aligned} \tag{1}$$

In equation (1), D94-00 is a dummy variable that identifies observations from 1994 to 2000. In order to obtain a differentiated treatment effect by fuel type we also include  $\text{DIESEL} \times \text{D94-00}$ . Thus, treatment effects are measured relative to the average sales per gasoline model in the period 1991-1993. We also include a time trend, TREND, and its interaction with fuel type,  $\text{DIESEL} \times \text{TREND}$ , in an attempt to capture the possibility of exogenous factors shifting the demand of gasoline and diesel vehicles in a different manner. This may be due, for instance, to some exogenous learning about the quality of these vehicles. Finally, in addition to including segment fixed effects, we repeat the analysis of the impact of the 1994 scrappage programs within each segment in order to better account for the documented heterogeneous behavior of sales across automobile categories.

Results indicate that relative to the corresponding gasoline version, sales per model of diesel vehicles are substantially smaller within every automobile segment (negative estimate of  $\alpha_d$ ). This

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<sup>14</sup> In another study of the automobile industry, Busse, Silva-Risso and Zettelmeyer (2006) quantify the treatment effect of counterfactual promotions on retail car prices.

Table 2: Scrappage Programs – Average and Dynamic Treatment Effects

	ALL	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN
CONSTANT	-4.8572 (1.30)	-8.0734 (0.90)	5.5927 (0.67)	-5.9325 (0.96)	-10.2380 (1.91)	5.8601 (0.44)
COMPACT	0.6608 (11.39)					
SEDAN	0.4943 (9.54)					
LUXURY	-0.4631 (5.53)					
MINIVAN	-0.9827 (11.70)					
TREND	-0.0547 (0.62)	-0.0951 (0.45)	0.0909 (0.48)	0.0432 (0.28)	-0.1828 (1.35)	0.0182 (0.07)
DIESEL	-1.3599 (6.66)	-1.4557 (2.97)	-1.8041 (4.27)	-1.9896 (5.73)	-0.8611 (2.66)	-0.8517 (1.44)
D94-00	-0.0897 (0.54)	-0.1590 (0.41)	-0.1889 (0.50)	-0.1428 (0.53)	-0.0059 (0.03)	0.1891 (0.33)
DIESEL × D94-00	0.5024 (2.41)	0.7659 (1.46)	0.6426 (1.46)	0.2503 (0.74)	0.5988 (1.91)	1.2883 (2.07)
DIESEL × TREND	0.1123 (3.63)	0.0077 (0.10)	0.1107 (1.72)	0.2110 (4.04)	0.0393 (0.79)	0.0838 (1.19)
ln(PRICE)	-1.2129 (8.51)	1.5504 (3.88)	-0.9693 (2.02)	-1.5813 (4.56)	-1.9420 (10.73)	-2.8413 (6.36)
ln(GDP-PC)	3.3751 (1.84)	1.4182 (0.32)	-1.7654 (0.44)	4.2071 (1.39)	7.1481 (2.68)	1.4168 (0.22)
ln(FUELPRICE)	-0.2416 (0.42)	0.0887 (0.07)	-0.6013 (0.51)	-1.2046 (1.19)	0.3295 (0.35)	0.4937 (0.46)
$R^2$	0.4911	0.4196	0.4658	0.5398	0.4419	0.5000
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	ALL	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN
CONSTANT	-4.6282 (1.23)	-7.0688 (0.78)	4.5737 (0.54)	-5.6727 (0.91)	-10.0651 (1.87)	7.7928 (0.54)
COMPACT	0.6619 (11.40)					
SEDAN	0.4937 (9.52)					
LUXURY	-0.4648 (5.54)					
MINIVAN	-0.9830 (11.70)					
TREND	-0.0303 (0.31)	0.0187 (0.08)	-0.0046 (0.02)	0.0795 (0.48)	-0.1615 (1.08)	0.0968 (0.31)
DIESEL	-1.3564 (6.31)	-1.4621 (2.80)	-1.8439 (4.16)	-1.9878 (5.41)	-0.8795 (2.56)	-0.8082 (1.32)
D94-95	-0.1021 (0.61)	-0.2147 (0.54)	-0.1440 (0.38)	-0.1602 (0.58)	-0.0175 (0.08)	0.1355 (0.22)
D96-00	-0.1845 (0.81)	-0.5855 (1.08)	0.2004 (0.40)	-0.2882 (0.74)	-0.0803 (0.25)	-0.1042 (0.13)
DIESEL × D94-95	0.5037 (2.41)	0.7658 (1.46)	0.6457 (1.46)	0.2534 (0.75)	0.5965 (1.88)	1.2418 (1.95)
DIESEL × D96-00	0.5841 (1.89)	1.1302 (1.43)	0.2482 (0.39)	0.3571 (0.68)	0.6143 (1.24)	1.5398 (2.06)
DIESEL × TREND	0.0999 (2.17)	-0.0467 (0.40)	0.1697 (1.82)	0.1947 (2.44)	0.0368 (0.48)	0.0459 (0.49)
ln(PRICE)	-1.2093 (8.48)	1.5769 (3.93)	-0.9878 (2.05)	-1.5837 (4.56)	-1.9382 (10.66)	-2.8291 (6.23)
ln(GDP-PC)	3.2184 (1.73)	0.6934 (0.15)	-1.1066 (0.27)	4.0203 (1.32)	7.0154 (2.60)	0.4021 (0.06)
ln(FUELPRICE)	-0.3289 (0.56)	-0.3620 (0.25)	-0.2924 (0.24)	-1.3359 (1.28)	0.2367 (0.24)	0.3548 (0.31)
$R^2$	0.4047	0.4182	0.4649	0.5379	0.4394	0.4944
Observations	1,869	360	432	473	438	166
Models	340	64	82	81	72	41
Firm Dummies	27	19	22	26	20	17

*OLS* estimates. Endogenous regressors are sales per model and year in thousand units. Absolute, heteroskedastic-consistent t-statistics are reported in parentheses. All regressions also include (non-reported) MANUFACTURER fixed effects. Variables PRICE and GDP-PC are measured in the equivalent of thousands of 1994 euros while FUELPRICE is measured in euros. Segment dummies add up to zero in the estimation that includes all segments. Thus, the estimate for the SMALL dummy is 0.2907 for the average treatment specification and 0.2922 for the dynamic treatment model.

is particularly true for COMPACT and SEDAN vehicles. However, the scrappage program tends to reverse this effect in the long run (positive estimate of  $\alpha_{dt}$ ). The program has no significant effect on the demand of gasoline vehicles (insignificant estimate of  $\alpha_t$ ) but it shifts the long term demand of diesel cars by an average of 28.03%, *i.e.*,  $1000 \times \exp[\alpha_t + \alpha_{dt}] = 1,510.89$ , over the average sales per diesel model according to Table 1:  $371,838/69 = 5,389$ . The overall effect of other exogenous shifts on the demand for diesel vehicles captured by the interaction DIESEL  $\times$  TREND is smaller:  $1000 \times \exp[\alpha_{dtt}] = 1,118.85$ , *i.e.*, a 20.76% increase in demand for diesel vehicles in the long run. Thus, the long term effect of the scrapping program is about 35% larger than the growing trend in favor of diesel vehicles.

Evaluating the scrapping program by market segment hints at it having the potential effect of facilitating consumers to update their beliefs about the quality of new products only. The largest effect of the program concentrates on the LUXURY and MINIVAN segments, with very low sales and models available at the time of the intervention. It is likely that in these cases, the increase in sales may trigger a self-sustaining shift in demand towards diesel models as customers of these segments become aware of the performance of these vehicles after their sales suddenly surge. In contrast, it is the secular trend favoring demand for diesel vehicles what matters for the vastly more popular COMPACT and SEDAN segments, which amounts to over sixteen times the sales of LUXURY and MINIVAN vehicles at the time of the policy intervention. This evidence is consistent with the idea that once products are known by customers, scrapping programs add little to induce long-lasting effects beyond the ongoing change in preferences.

Vehicles can always be considered normal goods, *i.e.*, positive estimate of GDP-PC, although income only has a strong, significantly positive effect on the demand for LUXURY vehicles. FUELPRICE has no significant effect on the demand of any kind of vehicles but demand for almost all segments are downward slopping with respect to their own PRICE. The larger and more expensive a vehicle is, the more elastic the corresponding demand is. The only counterintuitive results of

Table 2 is the positive own vehicle price effect on the demand for SMALL cars. Most popular SMALL vehicles are locally manufactured. Thus, the positive price effect may just reflect the market power of domestic brands due to loyalty to local brands and the convenience of having an extensive network of dealers.

The effect of the Spanish “cash-for-clunkers” programs of 1994 need not be instantaneous if the alluded dynamic informational linkages exist. Dynamic effects are more important when policy interventions take place in the early stages of a process of diffusion of a new technology. Thus, we decompose the treatment dummy D94-00 into the short run impact effect dummy D94-95 (when the programs were implemented) and the average long run effect of D96-00.

Results reported at the bottom of Table 2 provide a richer picture of the influence that the two scrapping programs had on the diffusion of diesel automobiles. It can be concluded that these programs had no effect on the sales of gasoline models either in the short or the long run as dummies D94-95 and D96-00 are both non-significant. Results regarding diesel automobiles are quite different. The overall effect of the scrappage programs as captured by  $\text{DIESEL} \times \text{D94-95}$  and  $\text{DIESEL} \times \text{D96-00}$  are positive, implying an immediate 27.72% shift in demand but an average 27.67% longer term demand increase. Again, both effects are particularly important for the LUXURY and MINIVAN segments while the exogenous long term 20.50% yearly rate increase in demand drives the sales growth of the popular COMPACT and SEDAN segments.<sup>15</sup>

Overall, Table 2 documents an important shift in consumer preferences towards diesel automobiles in Spain during the 1990s although with marked heterogeneity across different automobile segments. The effect of scrappage policies is radically different for gasoline models (no effect) and for diesel vehicles (large positive effect). The program appears to have been most successful

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<sup>15</sup> This is a simplified version of the dynamic treatment effect estimator of Laporte and Windmeijer (2005). We also estimated a version of the model with differentiated yearly effects and obtained similar results. Including yearly dummies makes the estimation of nonlinear model presented below in Section 5 unfeasible. The reported specification at the bottom of Table 2 are more easily comparable with those of the rest of the paper.

in promoting demand in the LUXURY and MINIVAN segments while the increase in sales of popular COMPACT and SEDAN segments follows a long term trend in preferences favoring the new technology. The limited fuel savings and performance of very light diesel engines may explain the lack of any significant effect of the scrappage programs on sales of SMALL vehicles as well as the absence of any secular shift in preferences towards the new technology among buyers of these tiny cars.

### 3.1 Robustness of the Effects of Scrappage Programs

It might be argued that the results reported in Table 2 capture the effects of a different data generating process: it could well be the case that the scrappage programs only had the documented transient effects on sales and that the change in demand in favor of diesel vehicles obeyed *only* to a change of preferences already on its way when the scrappage plans were first implemented in 1994. There is some truth to this as we find that the impact of the program is not that important for those market segments where diesel technology was more widely spread. Still, the fact that temporary sales effect suddenly make the share of diesel vehicles surge may induce consumers to update their perception of the new technology, thus leading to a self-sustained growth of demand for diesel vehicles in the long run. This is most apparent in the LUXURY and MINIVAN segments of our sample, where diesel vehicles were far from popular at the time of the policy intervention.

To distinguish between these two alternative interpretations we should pool our Spanish data with data from a similar country with the same initial composition of the automobile fleet, but who never implemented a comparable scrappage program.<sup>16</sup> This analysis would only be valid only under the assumption that Spaniards and other European citizens have the same preferences for diesel vehicles, something that might be true if the control group was a southern European country. This is because the performance of diesel vehicles is different in colder climates.

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<sup>16</sup> Automobile car registration for the 1990s is available for other European countries, *e.g.*, see Goldberg and Verboven (2001), but unfortunately such information is not detailed by fuel engine type.

In the absence of ideal data we turn our attention to secondary sources of information to evaluate whether, in general, scrappage programs have a positive effect on the composition of automobile demand across Europe. The analysis is valid as model offerings are basically the same across European countries. The different timing at which the scrappage plans are implemented in each country allows us to separately identify the effect exogenous changes in preferences (common to all countries) and the effect of the scrappage programs.

Thus, we first obtained information on the timing and duration of the different scrappage programs offered in Europe during the 1990s.<sup>17</sup> Next, we collected information on the overall share of diesel vehicles sold in sixteen European countries between 1991 and 2008, denoted by  $\lambda$ . In addition we also collected measures of GDP-PC for each country as well as relative prices of fuel and relative fuel taxation, all of which may play a potential role in the demand of different fuel type vehicles. Table 3 presents the result of regressing the speed of diffusion for each country-year pair on these economic variables in a similar manner to the estimation of equation (1), *i.e.*, distinguishing between average treatment effect of the scrappage program and the alternative scenario of an impact effect different from the long term consequences of program:

$$\ln\left(\frac{\lambda_{it}}{1 - \lambda_{it}}\right) = \beta_0 + \delta_e \text{ECONOMIC VARIABLES} + \delta_t \text{TREND} + \delta_s \text{SCRAPPAGE}. \quad (2)$$

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. 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. Exogenous factors also add to the adoption of diesel vehicles, but as in our analysis of the Spanish market, their effect captured by the estimate of TREND are smaller than the treatment

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<sup>17</sup> All data sources and details of each program are included in Appendix B.

**Table 3: 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	

Regressions make use of 277 country-year observations between 1991 and 2008. The endogenous 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 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. Alternatively we define the SCRAPPAGE dummy for periods when scrappage programs were implemented and AFTER SCRAPPAGE for those that followed the policy intervention. Absolute-value, heteroskedastic-consistent, t-statistics are reported between brackets.

effects of scrappage programs. 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.

## 4 Diesel vs. Gasoline Automobiles

We have established that Spanish scrappage programs appear to have induced long term effects on the composition of the automobile fleet, favoring the adoption of new fuel efficient diesel technology. Because of the timing and effectiveness of scrappage programs, evidence suggests that substitution is coming from the outside option and old used gasoline cars. In order to account for the role of the outside option and to fully characterize the demand for vehicles with different engine types, this section estimates a discrete choice model of demand for differentiated products. Estimation of this model using disaggregate registration data by make, model, and engine type allows us to evaluate whether the demand for diesel automobiles depends only on their better mileage or

if, alternatively, diesel engines possess some other unobservable features that become valued by potential customers as they learn about this new engine technology. Hence, we estimate a nested logit discrete choice demand model. We later generalize the possible substitution patterns among vehicles by estimating a more flexible equilibrium model that incorporates the supply side of the industry and their pricing behavior in Section 5. That estimation accounts for the endogeneity of unobserved features of diesel vehicles that may lead to endogeneity of their (higher) prices. We will use these estimates to describe the evolution between the substitution among vehicles with different fuel types during the 1990s.

#### 4.1 Nested Logit Demand Estimation

In this section we assume a nested logit demand specification similar to Goldberg (1995) but including only one nest level distinguishing between gasoline and diesel models. As documented before, diesel engines are introduced in all market segments although sales patterns vary substantially across these groups and it is conceivable that individuals compare alternative models from different segments and the performance of gasoline and diesel engines in each one of them ahead of her purchase decision. Thus, defining nest groups to accommodate those predefined segments may lead to unrealistic substitution patterns, and in general, to a misspecified model. Section 5 addresses these concerns with the estimation of an automobile demand and firm pricing model without substitution pattern restrictions. Still, the use of a nested logit model is useful because engine types characterize well defined groups of vehicles with common unobserved features whose effects on demand we are interested in studying.<sup>18</sup> We therefore write a demand function as in Berry (1994, eq. (28)):

$$\ln(s_j) - \ln(s_0) = x_j\beta - \alpha p_j + \sigma \ln(s_{j|g}) + \xi_j, \quad (3)$$

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<sup>18</sup> The idea that unobservable characteristics that are highly correlated with the type of engine justifies the use of a nested logit specification is similar to the argument recently given by Gramlich (2008, p.12).

where index  $j$  denotes the model of the vehicle;  $g$  is the group indicator  $g \in [\text{GASOLINE}, \text{DIESEL}]$ ;  $x_j$  is the vector of observable characteristics of model  $j$ , and  $p_j$  its price. The price of vehicles  $p_j$  includes sales tax and import duties (if any). The market share of model  $j$  is indicated by  $s_j$  while  $s_{j|g}$  denotes the share of model  $j$  in its corresponding engine group. As it is customary in the estimation of discrete choice models of demand, we ignore the possibility of households buying used automobiles and thus,  $s_0$  represents the market share of the outside option of not buying a new car. As for vehicle characteristics we include a measure of performance, HP/WEIGHT, fuel efficiency, KM/L90, size, LENGTH  $\times$  WIDTH, as well as segment dummies and type of engine. Finally we include GDP-PC and FUELPRICE plus the average effect of the scrappage plans by engine type.

The outside option is far from constant during the 1990s. The fast growth of the Spanish economy during the second half of the 1990 triggered important immigration that amounted about 10% of the local population in little over five years. Sales of automobiles varied widely with the economic cycle with marked differences between the recession of the first half and accelerated growth of the second. Thus, our outside option accounts for both the yearly automobile sales and the increasing total number of households. Starting in 1991, the values of  $s_0$  that we employ in our estimation are: 0.93, 0.92, 0.94, 0.93, 0.93, 0.93, 0.92, 0.91, 0.89, and 0.89, respectively.

Table 4 presents the estimates of three specifications of the nested, instrumental variable, logit demand model, *IV* hereafter. Model I is the simplest logit structure, without distinguishing by type of engine. The other two specifications assume that households first decide whether to purchase a diesel or gasoline engine and then choose the model within the corresponding group. For these nested models, not only the price  $p_j$  but also the share of its model  $j$  in group  $g$ ,  $s_{j|g}$ , are endogenous as the price and market share of a particular vehicle are determined partly by its unobserved characteristics. In Model II  $p_j$  is treated as exogenous (and therefore enters as one of the instruments as well). Model III treats both  $p_j$  and  $s_{j|g}$  as endogenous. To address these endogeneity problems we follow Berry, Levinsohn and Pakes (1995), BLP hereafter, in selecting

**Table 4: Multinomial and Nested Logit Demand Estimation**

	Model I		Model II		Model III	
CONSTANT	-15.8700	(6.61)	-6.5070	(14.26)	-6.3610	(20.88)
HP/WEIGHT	2.2740	(1.11)	0.4797	(1.57)	0.4943	(2.03)
KM/L90	0.2002	(3.03)	0.0275	(2.22)	0.0141	(3.01)
LENGTH $\times$ WIDTH	-0.1730	(0.13)	0.0191	(0.18)	0.2445	(2.12)
COMPACT	0.1238	(0.36)	0.0281	(1.10)	-0.0190	(0.84)
SEDAN	-0.4254	(1.13)	-0.0390	(0.93)	-0.0479	(1.37)
LUXURY	-0.7659	(1.73)	0.0111	(0.23)	-0.0190	(0.54)
MINIVAN	1.0040	(0.84)	0.3331	(1.55)	0.1094	(1.44)
FUELPRICE	-0.3955	(0.79)	-0.7734	(12.17)	-0.7529	(13.51)
GDP-PC	0.4705	(3.40)	0.3618	(15.87)	0.3581	(16.24)
DIESEL	-1.2480	(3.57)	-1.8980	(54.10)	-1.8590	(56.01)
D94-95	-0.1633	(1.15)	-0.1910	(5.49)	-0.1897	(5.57)
D96-00	-0.4052	(2.07)	-0.4394	(8.28)	-0.4265	(8.09)
DIESEL $\times$ D94-95	0.3083	(1.00)	0.9150	(22.28)	0.9491	(36.86)
DIESEL $\times$ D96-00	0.6646	(2.07)	1.5950	(30.06)	1.6320	(52.96)
TREND	-0.0808	(1.37)	-0.0025	(0.18)	-0.0020	(0.15)
PRICE	-0.0206	(0.66)	-0.0022	(1.24)	-0.0076	(2.46)
$\ln(s_{j g})$			0.9481	(46.50)	0.9547	(62.33)
SER	1.470		0.174		0.155	
SARGAN	161.50		10.78		10.61	
$[df; \chi^2_{0.99}(df)]$	[8; 20.09]		[7; 18.48]		[7; 18.48]	
No. inelastic demands	1, 835		1, 390		23	
( $\pm 2$ s.e.'s)	(1, 133 - 1, 869)		(592 - 1, 869)		(0 - 292)	
<i>LV: I vs. II, III</i>			41.1056		41.1033	
<i>LV: II vs. III</i>					7.5608	

*IV* estimates. Absolute, heteroskedastic-consistent t-statistics are reported in parentheses. PRICE is measured in thousands of 1994 euros. LENGTH and WIDTH are measured in inches/100; HP/WEIGHT is measured as horsepower per 10 pounds of weight. The number of observations is 1,869 and the number of automobile models is 340. SER indicates the standard error of the regression,  $[e'e/(n - k)]^{1/2}$ , where  $e$  is the prediction error,  $n$  denotes the number of observations, and  $k$  is the number of parameters estimated, respectively. SARGAN is the test of overidentifying restrictions of Sargan (1958), which is distributed as a  $\chi^2$  with  $df$  degrees of freedom.

valid instruments. Since vehicles can easily be grouped by an observable feature, fuel type, we also follow Bresnahan, Stern and Trajtenberg (1997) and limit our attention to the characteristics of rivals' models of the same fuel type in defining instruments consisting on vehicle characteristics such as HP/WEIGHT, KM/L90, the corresponding fuel price, plus market segment and year dummies, and a constant. We also include the number of other models sold by the same manufacturer regardless of the type of engine and the sum of their HP/WEIGHT and KM/L90; LENGTH  $\times$  WIDTH in levels and its sum for and a dummy variable indicating whether air conditioning is included as a default option for Models II and III; and WEIGHT/LENGTH  $\times$  WIDTH for Model III only.

Models I and II are misspecified as they predict inelastic demands for a very large percentage of models. Berry et al. (1995, §7.3) argue that this result is inconsistent with profit maximization in markets with product differentiation and market power. The logit structure of Model I is not flexible enough to address the numerous unobserved features of vehicles. Addressing *only* the endogeneity of  $s_{j|g}$  in Model II reduces the number of inelastic demands down to 450 from the 1,178 cases of Model I, a substantial reduction that highlights the importance of fuel engine type in conforming individuals' decisions about which vehicle to purchase. Once we instrument for both  $s_{j|g}$  and  $p_j$  in Model III we reduce the number of inelastic demands just to 26 out of 1,869 cases.

Relative to treatment effects reported in Table 2, estimates in Table 4 address the endogeneity of  $p_j$ , with estimates of LENGTH  $\times$  WIDTH and PRICE become larger and significant. The bottom of Table 4 reports the test of non-nested hypotheses of Lavergne and Vuong (1996). A value above (below) the critical value of 1.96 ( $-1.96$ ) means that the row model is worse (better) than the column model. For instance, the value of  $LV = 31.83$  favors Model II over Model I with its restrictive substitution pattern. Model III, which addresses the endogeneity of vehicle prices and the choice of fuel type engine, is our preferred specification.<sup>19</sup> Overall, the need to instrument for the endogeneity of  $p_j$  and  $s_{j|g}$  points at the existence of unobservable features associated to diesel technology such as torque, reliability or durability that influence consumer decisions to purchase a vehicle and allow automakers to charge higher markups for these more fuel efficient vehicles.

Estimates of Table 4 are consistent with the evidence presented in Section 3. Consumers prefer less expensive, larger, more powerful, and more fuel efficient automobiles. Demand increased with income, and diesel models were on average less valued than gasoline vehicles although they benefited from a sudden effect of the scrapping program (estimate of DIESEL  $\times$  D94-95) as well as a larger long term effect (estimate of DIESEL  $\times$  D96-00).

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<sup>19</sup> Following Jaumandreu and Moral (2008), we base our test statistics for the non-nested test on the consistent first-stage GMM estimates.

## 5 Market Evolution

The demand analysis of the previous section as well as those of Busse, Knittel and Zettelmeyer (2009) and Li, Timmins and von Haefen (2009) ignore the competitive effects that any change in regulation or change in fuel taxation may have on the demand of vehicles with different fuel efficiency levels, so that they may end up overestimating the effect of environmental policies. If emission standards are tightened as it recently happened in the U.S., we should not ignore the fact that the increased demand for fuel efficient vehicles will also increase the markups that manufacturers could charge to popular models while substantial incentives will be offered to sell gas guzzlers. On the margin, some households will trade a less efficient automobile at a discount over an efficient one at a premium.<sup>20</sup>

In order to address this issue, this section estimates of a random coefficient discrete choice demand for automobiles with unrestricted substitution patterns embedded in an equilibrium oligopoly model of price competition with horizontally differentiated products. Since sales and characteristics of models change over time, we can then use the estimates of this model to document how cross-price responsiveness of gasoline and diesel models evolved during the 1990s taking into account the corresponding pricing adjustments of manufacturers to a changing demand. We adopt the same specification of this model described in Berry, Levinsohn and Pakes (1999, §3). The utility of individual  $i$  from purchasing product  $j$  is:

$$u_{ij} = x_j\beta + \xi_j - \alpha_i p_j + \sum_k \sigma_k x_{jk} \nu_{ik} + \varepsilon_{ij}, \quad j = 1, \dots, J, \quad (4)$$

where  $j = 0$  with  $u_{i0} = 0$  denotes the outside option of not purchasing a vehicle and its normalized payoff, respectively. Vector  $\beta$  captures the mean effect of observed characteristics  $x_j$  on demand

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<sup>20</sup>Goldberg (1998) and Gramlich (2008) take into account this competitive side effect with the estimation of equilibrium models.

while  $\xi_j$  measures the mean effect of unobservable characteristics common to all consumers. Individual taste parameter  $\nu_{ik}$  is identically and independently distributed (iid) with a standard normal distribution and thus parameter  $\sigma_k$  identifies the variance of consumers' taste for characteristic  $k$ . The idiosyncratic taste parameter  $\varepsilon_{ij}$  is iid with a multivariate extreme value distribution. Finally, the price effect of demand  $\alpha_i$  is assumed to vary with individual income  $y_i$ :

$$\alpha_i = \frac{\alpha}{y_i}, \quad (5)$$

where  $y_i$  will take the value of different 100 random draws per calendar year from the empirical distribution of family income in Spain during the 1991–2000 sample period.

In the equilibrium approach taken in this section, multiproduct automobile manufacturers behave as non-cooperative profit maximizing oligopoly firms. We thus need to account for the supply side, which is particularly important in the present case because manufacturers face a substantial change of preferences in a relatively short period of time and thus they will be forced to realign the markups of the different models they sell. Failure to control for this competitive effect will result in an overestimation of the demand shift towards fuel efficient diesel models. Thus, we assume that marginal costs depend linearly on observable model characteristics  $z_j$  and unobservable characteristics summarized by  $\omega_j$ :

$$\ln(mc_j) = z_j\gamma + \omega_j. \quad (6)$$

Among these characteristics we include the log of HP and log of WEIGHT; plus a DIESEL dummy to account for possible cost differences in producing the new engine; a TREND to account for exogenous efficiency gains; and an indicator of whether the automobile is not manufactured in Europe in order to capture any cost advantage that non-European manufactures may enjoy. We also include  $\ln(Q_{EU})$ , the aggregate output of each model in the European market as one of the characteristics influencing the level of marginal cost, and which effectively capture whether

manufacturers enjoy Europe-wide increasing, constant, or decreasing returns to scale. Including this variable we acknowledge that the Spanish market is not the relevant framework for automobile manufactures to make production decisions. These multinationals build each model in different plants across Europe regardless of the demand of the specific country where they are located.<sup>21</sup>

Let denote by  $\theta = (\alpha, \beta', \sigma')$ , the vector of all parameters to be estimated. First order conditions of profit maximization is a nonlinear function of market shares  $s_j(p, x, \xi; \theta)$  of each model, their prices and markups. In matrix form:<sup>22</sup>

$$\frac{p}{1 + \tau_j} = mc + b(p, x, \xi; \theta) = mc + \Delta^{-1}(p, x, \xi; \theta)s(p, x, \xi; \theta), \quad (7)$$

where  $\tau_j$  is the year-specific import duty of each model;<sup>23</sup>  $b(\cdot)$  is the vector of equilibrium markups;  $s(\cdot)$  is the vector of market share estimates of each vehicle; and  $\Delta(\cdot)$  is a  $J \times J$  matrix with elements:

$$\Delta_{rj}(p, x, \xi; \theta) = \begin{cases} \frac{\partial s_r(p, x, \xi; \theta)}{\partial p_j}, & \text{if } r, j \text{ produced by the same firm,} \\ 0 & \text{otherwise.} \end{cases} \quad (8)$$

Combining (6) and (7) the cost equation becomes:

$$\ln(mc_j) = \ln \left[ \frac{p}{1 + \tau_j} - \Delta^{-1}(p, x, \xi; \theta)s(p, x, \xi; \theta) \right] = z_j\gamma + \omega_j. \quad (9)$$

Table 5 reports the GMM estimates of this equilibrium model. Results are intuitive. Drivers prefer less expensive vehicles (negative effect of PRICE); high performance (large HP/WEIGHT); and larger ones (significant positive LENGTH  $\times$  WIDTH). Consumers are, on average, not sensitive to

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<sup>21</sup> Appendix A describes how we construct the measure of European output for each model, which automobile prices we employ in the demand and cost equations, and estimation details leading to the results of Table 5.

<sup>22</sup> A complete derivation of these general first order conditions is available in Berry et al. (1995, §3).

<sup>23</sup> During the early 1990s Spain ended the transition phase of its accession to the European Union, which required the phasing out of import duties from other E.U. countries by 1993. Non-European vehicles still faced an import duty aligned with the common European trade policy. See Appendix A for more details.

**Table 5: BLP: Equilibrium Model Estimates**

	Means		$\sigma$ 's	
<i>Demand-side Parameters (<math>\beta</math>'s):</i>				
CONSTANT	-10.9400	(16.72)		
HP/WEIGHT	3.2010	(6.17)		
KM/L90	-0.0439	(0.86)	0.1337	(4.55)
LENGTH $\times$ WIDTH	1.5360	(3.35)		
DIESEL	-3.1990	(2.22)	2.8430	(3.18)
D94-95	-0.3167	(1.01)		
D96-00	-1.3730	(4.99)		
DIESEL $\times$ D94-95	0.0457	(0.05)		
DIESEL $\times$ D96-00	2.1630	(3.05)		
TREND	2.6960	(6.83)		
<i>Price Effect (<math>\alpha_i</math>):</i>				
PRICE	-2.2030	(8.54)		
<i>Cost-side Parameters (<math>\gamma</math>'s):</i>				
CONSTANT	-2.3630	(1.13)		
ln(HP)	1.1270	(4.76)		
ln(WEIGHT)	0.4640	(1.19)		
ln( $Q_{EU}$ )	-0.3199	(2.92)		
DIESEL	0.3712	(2.15)		
TREND	0.0708	(0.79)		
NON-EUROPEAN	-0.1645	(2.81)		

GMM estimates. Absolute, consistent t-statistics are reported in parentheses. PRICE is measured in thousands of 1994 euros. All other variables are defined in Table 1 and Table 4. The number of observations is 1,869 and the number of automobile models is 340.

fuel efficiency when buying an automobile (non-significant mean value of the estimate of KM/L90), although there is sufficiently heterogeneity in the population regarding mileage as the associated  $\sigma$  estimate is significant.<sup>24</sup> Consumers are also heterogeneous in their perception of the quality of DIESEL vehicles although the vast majority of them considered gasoline engines as being of higher quality before and even during the implementation of the scrappage programs (non-significant DIESEL  $\times$  D94-95). However, DIESEL models become the preferred engine option for most consumers after the scrappage programs were implemented (large positive DIESEL  $\times$  D96-00).

<sup>24</sup> Notice that we only report two random coefficients,  $\sigma$ 's out of the potential seven demand parameters. Our estimation did not restrict the sign of these  $\sigma$ 's. When included in the estimation all others became negative, although they never were significant. We thus decide to exclude them from our final estimation. See Appendix A for estimation details.

On the supply side it appears that the automobile industry enjoys economies of scale when European-wide output is considered (negative  $\ln(Q_{EU})$ ). More powerful cars are more expensive to produce (positive  $\ln(HP)$ ), as well as the recently introduced DIESEL models. Finally, NON-EUROPEAN manufacturers have a slight cost advantage over local automakers (negative NON-EUROPEAN).<sup>25</sup>

## 5.1 Substitution Patterns

In addition to incorporate the supply side into the estimation, the main advantage of BLP is that substitution patterns among the different models are not restricted. Thus, for instance, it would be possible that the closest substitute to a particular diesel model is a slightly larger but comparably expensive gasoline vehicle. This is something that the econometric specification (3) and estimates of Table 4 cannot fully accommodate. This section analyzes two issues: the size of the substitution patterns of vehicles within the predetermined market segments relative to the substitution across segments, and the temporal evolution of the substitution between gasoline and diesel vehicles by segments. The former will help us determine whether substitution across fuels is stronger than across segments and the latter will inform us about the diffusion of the new product, confirming that sales of diesel follows the replacement of old gasoline vehicles.

Table 6 reports the sales-weighted cross-price elasticities among vehicles of a segment with respect to price variations of vehicles of all segments *of the alternative fuel* for year 1996. Diesel and gasoline vehicles are always substitutes although buyers of diesel vehicles respond more to changes in the price of gasoline models than *vice versa*. Other than MINIVAN, vehicles of the same segment are generally closer substitutes than across segments (the values of the elasticities along the diagonal are generally larger than any of the other estimates reported), which vindicates the substitution pattern imposed in Model III of Table 4. There are some remarkable exceptions

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<sup>25</sup> NON-EUROPEAN, is an indicator of whether the make of a vehicle is not manufactured in Europe. These are Daewoo, Honda, Hyundai, Kia, Mazda, Mitsubishi, Nissan, Suzuki, Toyota, and Chrysler.

**Table 6: Elasticities of Substitution Between Segments (1996)**

GASOLINE:	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN
SMALL	0.0327				
COMPACT	0.0209	0.0330			
SEDAN	0.0127	0.0208	0.0198		
LUXURY	0.0024	0.0044	0.0044	0.0038	
MINIVAN	0.0015	0.0026	0.0026	0.0020	0.0013
DIESEL:	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN
SMALL	0.0423				
COMPACT	0.0505	0.0550			
SEDAN	0.0398	0.0447	0.0352		
LUXURY	0.0106	0.0133	0.0115	0.0132	
MINIVAN	0.0051	0.0061	0.0051	0.0054	0.0015

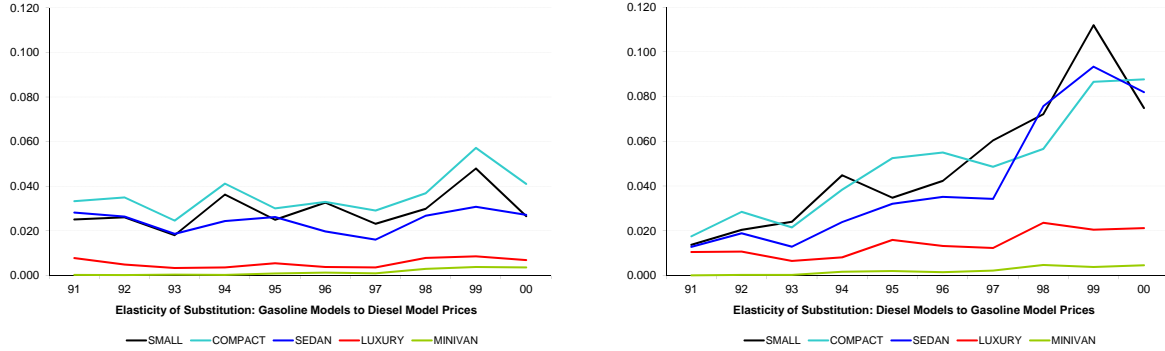
Each row indicates the elasticity of all models of a particular segment with price variations of models of the alternative fuel in different segments (columns).

though. One involves the SMALL diesel segment. If the corresponding gasoline models become more expensive, consumers will substitute away in favor of COMPACT diesel models rather than a SMALL diesel model. Given the better fuel efficiency of diesel vehicles the choice at the bottom of the market is between very small gasoline vehicles and a slightly larger diesel model.

During the 1990s sales of diesel vehicles became more and more common until they exceeded 50% of total sales by the end of the decade. This fast diffusion of the diesel engine will likely alter the substitution patterns among models with different engine types as time passed. Figure 4 illustrates the evolution of these elasticities over the 1990s. Table 7 presents the elasticities of models of given segment with respect to a simultaneous price change in all vehicles with the alternative fuel engine. We report these estimates for three years at the beginning, middle, and end of our sample.

With the exception of niche segments (LUXURY and MINIVAN) diesel models become much more responsive to prices of gasoline vehicles in the second half of the decade. Gasoline models only become slightly more responsive to changes in prices of diesel vehicles at the end of the decade and overall within-segment cross-price elasticities remain much more stable over time. This indicates that buyers of diesel vehicles are more price sensitive than those who purchase gasoline models.

**Figure 4: Elasticities of Substitution by Segments and Fuel Type**



This asymmetric pattern of cross-price substitution is consistent with the idea of consumer learning of the quality of the new technology. The introduction of diesel models does not affect the cross-price responsiveness of those consumers who still prefer gasoline vehicles. This group may include customers that are uninformed about the new TDI technology or those high income customers or infrequent drivers for which potential savings of buying a diesel are nil. On the contrary, those price sensitive, intensive drivers, and informed customers do substitute away from gasoline vehicles if they become more expensive. Moreover, this response is larger as time goes by and thus sales of diesel vehicles likely follows replacement of old gasoline models.

**Table 7: Elasticities of Substitution Within Segments (Selected Years)**

GASOLINE:	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN
1992	0.0261	0.0350	0.0264	0.0049	0.0002
1996	0.0327	0.0330	0.0198	0.0038	0.0013
2000	0.0266	0.0411	0.0272	0.0069	0.0036
DIESEL:	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN
1992	0.0204	0.0285	0.0189	0.0107	0.0003
1996	0.0423	0.0550	0.0352	0.0132	0.0015
2000	0.0749	0.0877	0.0820	0.0212	0.0046

The upper half of the table reports the sum of elasticities of substitution of all gasoline models of each segment relative to price changes of all diesel models in the same segment. The bottom half is defined accordingly for diesel vehicles when prices of all corresponding gasoline models in the same segment change.

## 6 Concluding Remarks

This paper has documented empirically 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. Our analysis has shown that the effects of scrappage programs led to a sustained increase in the sales of diesel automobiles in Spain, which grew from 13% market share in 1991 to 54% in year 2000, and reaching 68% of the market in the popular SEDAN segment.

The paper documents three sets of findings. First, scrapping programs are potentially more decisive in changing the long run composition of demand if the policy intervention takes place in the early stages of the diffusion of the new technology. Second, there are important unobserved product features of the new technology that drive the demand for the new product. This is relevant because inducing an immediate increase in sales of the new product may help hesitant or uninformed consumers to learn about its quality. And third, drivers of fuel efficient vehicles are more cross-price sensitive than those who prefer gasoline models.

The successful Spanish program led to long-term increase in sales of diesel vehicles with less generous incentives than the recent U.S. CARS program. However, the analysis of this paper shows that results should be evaluated in the long run and that the size of the program is less important than its timing. Of course only when sufficient time has passed, and with the appropriate data it will be possible to confirm that CARS was able (or not) to significantly shift demand in favor of smaller fuel efficient vehicles in the U.S.

## References

- Adda, Jérôme and Russell W. Cooper (2000) “Baladurette and Jupette: A Discrete Analysis of Scrapping Subsidies,” *Journal of Political Economy*, Vol. 108, pp. 778–806.
- Berry, Steven (1994) “Estimating Discrete-Choice Models of Product Differentiation,” *RAND Journal of Economics*, Vol. 25, pp. 242–262.
- Berry, Steven, James Levinsohn, and Ariel Pakes (1995) “Automobile Prices in Market Equilibrium,” *Econometrica*, Vol. 63, pp. 841–890.
- (1999) “Voluntary Export Restraints on Automobiles: Evaluating Strategic Trade Policy,” *American Economic Review*, Vol. 89, pp. 400–430.
- Bresnahan, Timothy F., Scott Stern, and Manuel Trajtenberg (1997) “Market Segmentation and the Sources of Rents from Innovation: Personal Computers in the Late 1980,” *RAND Journal of Economics*, Vol. 28, pp. S17–S44.
- Busse, Meghan R., Jorge Silva-Risso, and Florian Zettelmeyer (2006) “1000 Cash Back: The Pass-Through of Auto Manufacturer Promotions,” *American Economic Review*, Vol. 96, pp. 1253–1270.
- Busse, Meghan R., Christopher R. Knittel, and Florian Zettelmeyer (2009) “Pain at the Pump: How Gasoline Prices affect Automobile Purchasing in New and Used Markets,” Working Paper 15590, NBER.
- Dubé, Jean-Pierre, Jeremy T. Fox, and Che-Lin Su (2009) “Improving the Numerical Performance of BLP Static and Dynamic Discrete Choice Random Coefficients Demand Estimation,” Mimeo, University of Chicago.
- Goldberg, Pinelopi K. (1995) “Product Differentiation and Oligopoly in International Markets: The Case of the U.S. Automobile Industry,” *Econometrica*, Vol. 63, pp. 891–951.
- (1998) “Effects of the Corporate Average Fuel Efficiency Standards in the U.S.,” *Journal of Industrial Economics*, Vol. 46, pp. 1–33.
- Goldberg, Pinelopi K. and Frank Verboven (2001) “The Evolution of Price Dispersion in the European Car Market,” *Review of Economic Studies*, Vol. 68, pp. 811–848.
- Gramlich, Jacob P. (2008) “Gas Prices and Endogenous Product Selection in the U.S. Automobile Industry,” Mimeo, Yale University.
- Greenspan, Alan and Darrel Cohen (1999) “Motor Vehicle Stocks, Scrappage, and Sales,” *Review of Economics and Statistics*, Vol. 81, pp. 369–383.
- Griliches, Zvi (1957) “Hybrid Corn: An Exploration in the Economics of Technological Change,” *Econometrica*, Vol. 25, pp. 501–522.
- Hahn, Robert W. (1995) “An Economic Analysis of Scrappage,” *RAND Journal of Economics*, Vol. 26, pp. 222–242.
- Jaumandreu, Jordi and María J. Moral (2008) “Identifying Behaviour in a Multiproduct Oligopoly: Incumbents’ Reactions to Tariff Dismantling,” Mimeo, Universidad Carlos III de Madrid.
- Johannsson, Olof and Lee Schipper (1997) “Measuring Long-Run Automobile Fuel Demand: Separate Estimations of Vehicle Stock, Mean Fuel Intensity, and Measured Annual Driving Distances,” *Journal of Transport Economics and Policy*, Vol. 31, pp. 277–292.

- Knittel, Christopher R. and Konstantinos Metaxoglou (2008) “Estimation of Random Coefficient Demand Models: Challenges, Difficulties, and Warnings,” Mimeo, University of California-Davis.
- Laporte, Audrey and Frank Windmeijer (2005) “Estimation of Panel Data Models with Binary Indicators when Treatment Effects Are Not Constant Over Time,” *Economics Letters*, Vol. 88, No. 3, pp. 389–396.
- Lavergne, Pascal and Quang H. Vuong (1996) “Nonparametric Selection of Regressors,” *Econometrica*, Vol. 64, pp. 207–219.
- Li, Shanjun, Christopher Timmins, and Roger H. von Haefen (2009) “How Do Gasoline Prices Affect Fleet Fuel Economy?” *American Economic Journal — Economic Policy*, Vol. 2, pp. 113–137.
- Licandro, Omar and Antonio R. Sempayo (1997) “Los Efectos de los Planes Renove y Prever Sobre el Reemplazo de Turismos,” *Economía Industrial*, Vol. 314, pp. 129–140.
- Mian, Atir F. and Amir Sufi (2010) “The Effects of Fiscal Stimulus: Evidence from the 2009 “Cash for Clunkers” Program,” Mimeo, UC Berkeley and University of Chicago Booth School of Business.
- Moral, María. J. (1998) “La Retirada de Automóviles en España: Una Aplicación de los Modelos de Duración,” *Investigaciones Económicas*, Vol. 22, pp. 225–258.
- Sargan, John D. (1958) “The Estimation of Economic Relationships Using Instrumental Variables,” *Econometrica*, Vol. 26, pp. 393–415.
- Schipper, Lee, Céline Marie-Lilliu, and Lew Fulton (2002) “Diesels in Europe,” *Journal of Transport Economics and Policy*, Vol. 36, pp. 305–340.

## Appendix

### A Data Sources and Estimation Details

For the estimation of the equilibrium random coefficient discrete choice model of Table 5 we distinguish between prices paid by consumers and those perceived by manufacturers. On the demand we use prices and vehicle characteristics as reported by *La guía del comprador de coches*, ed. Moredi, Madrid. We select the price and characteristics of the mid-range version of each model, *i.e.*, the most popular and commonly sold. Regarding prices for the cost-side equation, we control for the differentiated import taxation faced by manufacturers depending on their origin. European imports paid tax duty of 8.7% in 1991, 4.4% in 1992, and nothing thereafter. Non-European manufacturers had to pay 18.8%, 14.4%, and 10.3%, respectively.

Our specification assumes costs to vary with European rather than with Spanish sales only. We use Frank Verboven’s data available at <http://www.econ.kuleuven.be/public/ndbad83/frank/cars.htm> to add sales from Belgium, France, Germany, Italy and United Kingdom to Spanish sales (not distinguishing by type of fuel). To capture scale effects we define total european sales,  $\ln(Q_{EU})$ , as the logarithm of the ratio of the aggregate sales of these six countries over the average of those sales over the years that each particular model is sold in Spain.

Initial cost parameters are the result of an instrumental variable hedonic regression of manufacturers’ perceived prices on characteristics and the European output. The 20 instruments include nine year dummies, NON-EUROPEAN, DIESEL (which in the supply side is considered exogenous as it depends on the overall potential demand across Europe and not only Spain), and BLP instruments on a CONSTANT,  $\ln(HP)$ , and  $\ln(WEIGHT)$ . Initial estimates of the price coefficient ( $\alpha$ ) and standard deviations ( $\sigma$ ’s) are randomly chosen. To control for household income distribution 100 individuals are sampled each year from the *Encuesta Continua de Presupuestos Familiares* (Base 1987 for years 1991-1997 and Base 1997 for years 1998-2000) conducted by INE, the Spanish Statistical Agency.<sup>26</sup> Sampling 100 individuals each year over a decade allows us to capture the important growth in income per capita that took place in Spain, mostly, during the second half of the 1990s.

We first run 2,000 iterations using the Nelder-Mead simplex direct search algorithm and then switch to the quasi-Newton method of Broyden-Fletcher-Goldfarb-Shanno that approximates the Hessian by computing the gradient at different steps of each iteration. Following Dubé, Fox and Su (2009) we set a tolerance of  $10^{-10}$  for the inner loop contraction mapping and a  $10^{-5}$  convergence criteria for the GMM objective function. Convergence always occur in fewer than 100 iterations after the simplex method reached its 2,000 iteration limit. To mitigate the risk of multiplicity of local minima raised by Knittel and Metaxoglou (2008) we use several random initial conditions on the nonlinear parameters of the model. Estimation always converges to the same estimates.

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<sup>26</sup> See <http://www.ine.es/jaxi/menu.do?L=1&type=pcaxis&path=/t25/p458&file=inebase> for a description in English of these databases.

## B European Scrappage Programs

For the analysis of Table 3 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.<sup>27</sup> Data were obtained from the following sources:<sup>28</sup>

- *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 scrapping a car older than ten years regardless of replacement (1994 to June 1995).
  - *France*: FF 5,000 (\$950) bonus (an average 6% discount) for scrapping 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 scrapping 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 scrapping 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.

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