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Qualitative Effects of "Cash-for-Clunkers" Programs

Eugenio Miravete and Maria J. Moral

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Abstract

We document how automobile scrappage incentives similar to the '2009 Car Allowance Rebate System' (CARS) may influence drivers' tastes in favor of fuel-efficient automobiles. Between 1994 and 2000 the market share of diesel automobiles doubled after Spanish government sponsored two scrappage programs. We show that demand for diesel automobiles was not driven only by better mileage; that gasoline and diesel models became closer substitutes over time; and that automobile manufacturers reduced their markups on gasoline automobiles as their demand decreased. These programs simply accelerated a change of preference that was already on its way when they were implemented.

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

JEL Codes: L51, L62, Q28.

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1 Introduction

For decades, the automobile industry has been a major engine of growth and employment in western economies. It is not surprising that governments pay particular attention to this industry when considering Keynesian policies in order to increase aggregate demand during economic recessions. Consequently, economists have customarily measured the effectiveness of such policies by focusing on the aggregate sales effects of scrappage subsidies.[1] However, there are other potential reasons to sponsor cash-for-clunkers programs 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. Many countries also established compulsory yearly inspections to ensure a minimum maintenance level of cars. Compulsory inspection regimes increased the cost of driving older vehicles, therefore inducing their owners to replace them at an earlier age. The additional consideration that has gone into enacting the recent scrappage program in the U.S. is its effectiveness in reducing emissions by encouraging purchase of newer, more fuel efficient cars.[2]

The latest version of the cash-for-clunkers program in the U.S., the 2009 Car Allowance Rebate System (CARS), specifically linked the scrappage subsidy to the purchase of a new fuel efficient car with a minimum required mileage. It also limited the value of the new car to a listed price of $45,000 and required that the traded-in vehicle does not exceed 18 miles per gallon. Thus,

[1] Adda and Cooper (2000) evaluate the impact of such policies on the optimal replacement age of automobiles; Alberini, Harrington, and McConnell (1995) study how different requirements of the scrappage programs prompts the participation decision of owners of old cars in these cash-for-clunkers programs; Esteban (2007) analyzes the distortion that such policies have when there exists a secondary market for these durable goods and subsidies are limited to the purchase of new models; and Greenspan and Cohen (1999) and Manski and Goldin (1983) study how the scrappage rate affects total sales.

[2] Hahn (1995) evaluates the combined effect of compulsory maintenance and the 1992 cash-for-clunkers program in the U.S. while Kahn (1996) focuses on the downward trend of emissions in the U.S. during the 1990s despite the recorded increase in the total miles driven. In a classic study, Crandall and Graham (1989) address the relationship between regulating emission standards and road safety. Finally, Goldberg (1998) studies how the Corporate Average Fuel Economy Standards affect the demand for automobiles and competition among automakers. A summary of the features of the current scrappage programs across countries can be found at http://en.wikipedia.org/wiki/Scrappage_program.

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. After studying the experience of two similar programs in Spain, we conclude that while CARS will likely boost the sales of automobiles in the U.S. during 2009, it will fail to shift consumers' tastes towards smaller, more fuel efficient hybrids. The reason is not the arguably small budget of the CARS program but rather the timing of this policy intervention relative to the stage of diffusion of the new hybrid vehicles. Compared to European countries in the 1990s, hybrids represent a very low fraction of sales and U.S. customers only have a very limited selection of hybrid models to choose from. In contrast, diesel engines amounted to a substantial share of the market in Europe even before "cash-for-clunkers" programs were enacted.

For the past few decades, the United States and Europe have approached the issue of emissions in a fundamentally different way. While Europeans have taxed fuel heavily and somewhat subsidized diesel fuel, the U.S. has systematically ignored price incentives to focus on emission standards imposed on manufacturers. Interestingly, relying on standards appears not to have provided a strong enough incentive for fuel efficiency innovations in the U.S. Hybrid vehicles were introduced only in the past few years and their market share currently does not exceed 3%. In Europe, where fuel prices have remained persistently higher than in the U.S., several manufacturers introduced improved diesel engines during the 1990s (at a time of historically low oil prices) and today, this technology accounts for more than 50% of total automobile sales in Europe, thus providing significant fuel savings and emissions reductions.[3]

Despite considerable enthusiasm by environmentalists, U.S. consumers' reluctance to massively embrace hybrids or other new fuel efficient engine technologies are no different from motives

[3] It is commonly acknowledged that permanent and substantial tax increase on fossil fuels will certainly provide the right incentive for consumers to venture in adopting new fuel e�cient technologies. Parry and Small (2005) compare the taxation policies of the U.S.A. and the U.K. to evaluate the optimal level of fuel taxation and how it a�ects the emission externalities.

found behind the delay of adoption of new products. Consumers are understandably uncertain about the performance and long term reliability of the new technology, as well as the future evolution of fuel prices. These factors after all would justify, or not, the decision to be an early adopter of this new technology. Since the 1970s and until very recently, European countries applied a deliberate policy of reduced taxation on diesel fuel. In the absence of such a tax policy, governments have to resort to environmental awareness and short term scrappage programs such as CARS if they wants to influence the features of the automobile fleet. We argue in this paper that properly designed scrappage programs may succeed in changing the taste of consumers in favor of smaller, more fuel efficient automobiles. However, its timing, which was driven by macroeconomic considerations, and the limited size of the CARS program would likely mean failure to achieve such a goal.

Several factors determine the automobile model that a household purchases: disposable income, price, financing opportunities, current and future expected fuel prices, and finally acquired tastes for particular brands and styles over others. Automobiles in the U.S. market have a reputation of being larger and less fuel efficient than those of other developed countries. Low price of fuel for over two decades and low fuel taxes compared to those in other OECD countries are likely explanations for the widespread use of gas guzzlers in the U.S.[4] Given the current equilibrium in favor of large vehicles, scrappage programs need to overcome at least two hurdels to be successful. First, given their current choices, most drivers appear to have a negative opinion of smaller cars running on a relatively unknown technology. Second, any policy aimed at changing the fleet composition needs to confront the negative externality that owners of large vehicles impose on potential buyers of small ones. Early adopters of small vehicles bear an ex-ante higher risk of injury if they get involved in an accident. In both cases, the scrappage subsidy will succeed if enough customers adopt the new technology so that it leads to a self-sustaining bandwagon effect. Once the new technology has been around for a while, a sufficiently large subsidy may help tilt

[4] Two recent papers addressing the e�ect of fuel prices on the demand of new and used cars and fleet composition are Busse, Knittel, and Zettelmeyer (2009) and Li, Timmins, and von Haefen (2009), respectively.

the market towards a new equilibrium where most customers prefer smaller and more fuel efficient cars. As more people adopt the new technology, it becomes easier to change consumers' perception of what is desirable in a car. Similarly, as more customers purchase smaller cars the negative risk externality posed by large cars diminishes.

We cannot at the moment directly evaluate the effectiveness of the 2009 cash-for-clunkers program in the U.S. The program had not been fully implemented at the time when the first draft of this paper was prepared. Instead, we study the experience of similar scrappage programs in Spain during the 1990s. The reader can then approach this paper simply as documenting the experience of scrappage subsidies in a Southern European country during the 1990s. We feel not only that we document a case that is representative of similar processes in Europe during that time, our data also allow us to extract some conclusions that are valid beyond the limits of the Spanish market. The Spanish market in the 1990s was far from marginal. The automobile industry was a key sector of the Spanish economy, which is a significant parallel with the U.S. case.[5] Thus, we prefer to envision this paper as a case study where the scrappage subsidy succeeded in changing the taste of consumers in favor of fuel efficient automobiles and use the features of such policy intervention as a reference point to judge the potential effectiveness of other similar interventions, such as the 2009 U.S. CARS program.

Two scrappage programs were implemented in 1994 to overcome an economic recession that had left the Spanish automobile industry in shambles. More interesting from an empirical perspective is the fact that an alternative, more fuel efficient technology, namely, the turbocharged, direct-injection, diesel engine (TDI) had been available for five years at the time of the policy

[5] The Spanish automobile industry was the fifth largest in the world measured by output. It was 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 even more severe than the current one, with unemployment exceeding 24% of the labor force in 1994.

intervention.[6] Our data, which details car registrations by type of engine, allow us to measure not only the short term sales boosting effect of the scrappage program 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. 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. Rather it spreads over several years following the termination of the scrappage programs. Second, we document that better mileage or favorable 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.[7] Third, we show that consumer tastes evolve so that gasoline and diesel models become closer substitutes as time goes by. Consequently, producers readjust their margins to maximize profits. We therefore measure the reduction in markups charged on gasoline models as they became less popular.

Based on the analysis of the Spanish experience during the 1990s, we are skeptical about the success of the current U.S. cash-for-clunkers program beyond a temporary increase in sales. First, the relative size of the U.S. program is smaller than the Spanish one, and significantly smaller

[6] We furthermore belive that the scrapping programs did not explicitly intend to shift preferences in favor of diesel models, but only to increase total sales. Leaders in diesel manufacturing mostly produced these models 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 (natural experiment) to study the demand for di erentiated types of engine powered cars.

[7] Consequently, uncertainty about the performance of batteries and maintenance costs of hybrid cars may help explaining the delay in the adoption of those vehicles nowadays.

than the 2009 German program, thus making it less likely that it would tilt the market in favor of smaller more fuel efficient cars. Furthermore, while the subsidy per new vehicle in the U.S. is larger than any of its European counterparts, the total number of potential beneficiaries is smaller, and thus realized additional sales will likely fall short of the critical mass necessary to generate a self-sustained sales growth of hybrid vehicles. Second, the current share of hybrid cars in the U.S. is substantially smaller than that of diesel automobiles in Spain at the beginning of the scrappage programs. Third, the number of models with the hybrid option in the U.S. is far smaller than those with the diesel option in Spain. In our judgment the current US intervention is premature from the perspective of changing drivers' purchase patterns: it comes too early in the diffusion process of the hybrid technology in the U.S. market.

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 conducts a difference-in-difference (DID) analysis to evaluate the effectiveness of these programs in promoting sales of automobiles and changing the preference of consumers for different types of engines. 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. Section 5 evaluates how the scrappage program helped tipping the balance in favor of diesel engines, how diesel and gasoline versions became closer substitutes over time, and how manufacturers adjust their markups to the change in consumer preferences. Section 6 concludes.

2 TDI Technology

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. Since then, diesel technology have been used for boat, truck, train, and as heavy duty engines.

Diesel engines have also 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, 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.[8]

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.[9] In Europe, higher fuel prices and an explicit policy to reduce dependence on foreign oil led governments to subsidize diesel fuel for years, which led to a slow but steady increase in the sales of diesel automobiles in

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

[9] 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 current 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).

Europe during the 1990s, helping consumers to learn the advantages of diesel technology.[10] The overall effect on fuel saving is however unclear. 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. While emissions per mile are lower for diesel engines, better mileage and a reduced price for diesel fuel induces individuals to drive slightly more, thus potentially increasing emissions overall.[11]

We combine several data sources in building our data set. ANFAC, the Spanish association of automobile manufacturers, provides yearly registration data by model and type of fuel. Price and automobile characteristics were manually collected from *La guía del comprador de coches*, ed. Moredi, Madrid, a well known buyer guide. Automobile characteristics correspond to the mid-range version of each model since they are the most popular ones. INE, the Spanish Bureau of Statistics is the source of fuel prices, per capita income, and the number of households. After excluding some models (mostly luxury ones) with extremely small market shares, the data set is an unbalanced panel with 1,869 observations that include 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.

The rest of this section illustrates the features of the Spanish automobile market during the 1990s.[12] Table 1 summarizes the evolution of the features of vehicles sold during the 1990s. Diesel

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[10] Mayeres and Proost (2005) compare fuel taxation across Europe and argue against the favorable tax treatment of diesel fuel.

[11] Audi estimates that if one third of the automobile fleet was powered with diesel engines, the U.S. could save 1.5 million barrels of oil every day. According to the U.S. Energy Information Administration, U.S. daily consumption of motor gasoline amounts to almost 9 million barrels. It is unclear whether this estimate accounts for the "rebound" effect of increased travel due to better mileage of diesel cars.

[12] The Spanish market for diesel engines is no different from most other European markets with the exception of Scandinavian countries where diesel vehicles never reached a large market share. Schipper et al. (2002) and Verboven (2002) document the similar features of some of those markets for the first half of the 1990s.

Table 1: Spanish Automobile Market in the 1990s by Type of Fuel

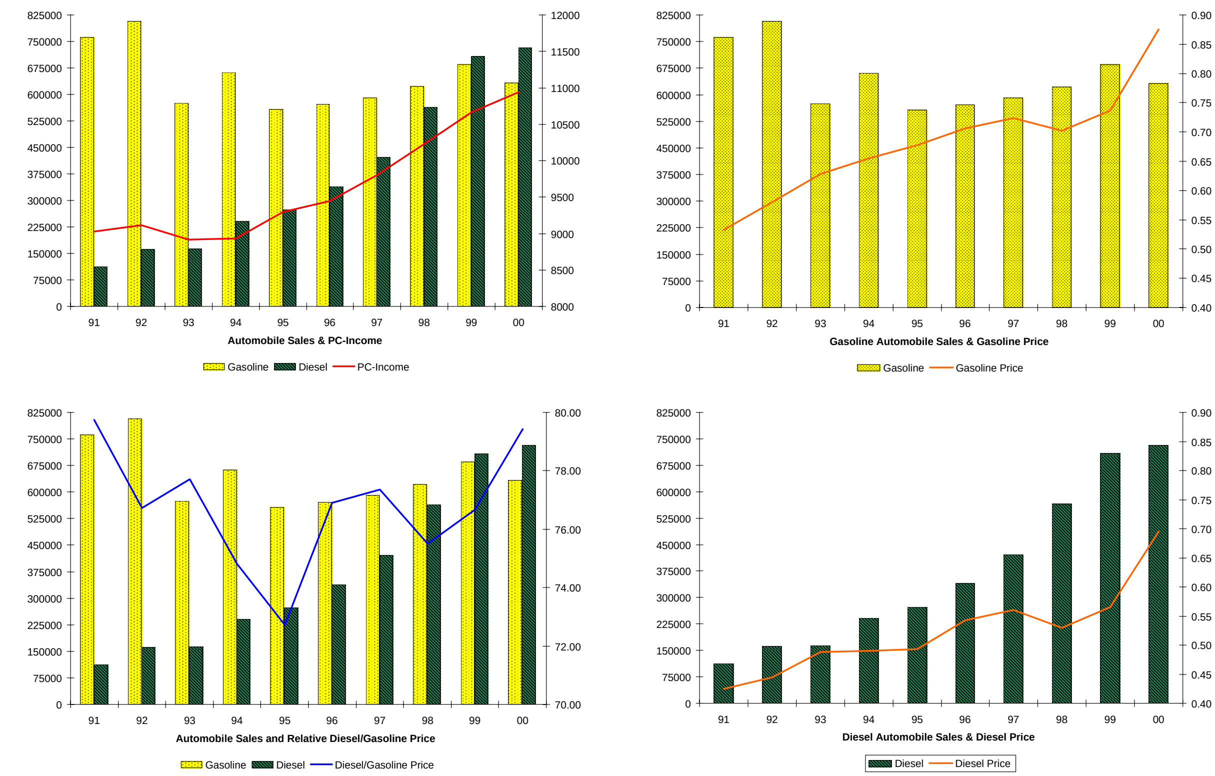
GASOLINE:	SALES	MODELS	PRICE	FCOST	FUEL90	HP	LENGTH	WIDTH	WEIGHT
1991	761,114	86	11,008	2.44	5.33	86.20	157.99	64.78	2,066
1992	806,667	97	11,227	2.85	5.41	88.38	158.63	65.00	2,100
1993	574,896	101	12,122	3.30	5.50	89.22	158.75	65.40	2,162
1994	661,602	109	12,289	3.53	5.39	85.25	157.02	65.17	2,152
1995	556,918	119	13,087	3.88	5.47	85.65	156.85	65.23	2,176
1996	571,479	124	13,668	4.16	5.43	87.34	158.18	65.41	2,242
1997	590,558	130	13,863	4.38	5.47	88.69	158.74	65.60	2,287
1998	622,279	135	14,114	4.47	5.66	90.79	159.61	65.83	2,335
1999	685,542	130	14,189	4.85	5.71	93.79	160.11	65.88	2,365
2000	632,353	134	14,679	6.00	5.76	96.05	160.64	65.97	2,382
DIESEL:	SALES	MODELS	PRICE	FCOST	FUEL90	HP	LENGTH	WIDTH	WEIGHT
1991	111,943	43	12,094	1.61	4.42	69.24	160.76	65.40	2,227
1992	161,667	44	12,270	1.80	4.45	71.63	161.84	65.59	2,266
1993	163,140	53	12,949	2.10	4.50	72.71	161.79	65.84	2,306
1994	241,637	58	13,623	2.19	4.48	71.72	161.20	65.96	2,358
1995	273,517	68	14,956	2.33	4.51	75.12	161.83	66.13	2,423
1996	339,106	78	15,563	2.66	4.52	77.03	162.51	66.29	2,479
1997	421,994	80	15,891	2.83	4.58	76.68	163.07	66.26	2,521
1998	564,706	88	15,676	2.84	4.76	79.76	163.88	66.43	2,576
1999	708,329	97	15,919	3.05	4.69	82.47	164.61	66.68	2,619
2000	732,344	95	16,239	3.80	4.59	83.86	164.88	66.81	2,646

SALES indicate the number of registered vehicles. MODELS report the total number of models available to consumers each year. All other variables are sales weighted. PRICE is the average price of automobiles measured in the equivalent of 1994 euros; HP denotes the horsepower; FUEL90 is the average fuel consumption in liters per hundred kilometers at a speed of 90 kilometers per hour on a highway; FCOST is the average fuel cost in 1994 euros of driving 100 kilometers on a highway LENGTH and WIDTH are measured in inches and WEIGHT in pounds.

vehicles are about 10% heavier than gasoline versions but both become heavier over the decade. Diesel and gasoline versions of a particular model have the exact same size.[13] Size distribution across models is similar across engine types and remains quite stable over the decade. As European vehicles are smaller than Americans, they use smaller engines and therefore are less powerful, although HP increases over the decade for heavier models. Diesel models are 15% to 20% less powerful than gasoline vehicles.

[13] A difference of means test does not allow us to reject the null hypothesis that diesel and gasoline models have the same size.

Figure 1: Price and Income Effects on Sales



Yearly sales of gasoline models declined about 17% over the decade while the sales of diesel vehicles multiplied by more than 600%, growing from a 13% market share in 1991 to 54% in year 2000. Diesel vehicles were not only less powerful, but also between 1,000 and 2,000 euros more expensive per unit. Why did Spanish (as well as European) consumers embrace this more expensive, less powerful technology?

Fuel economy is the obvious first reason to adopt this new technology. Table 1 shows that diesel vehicles consume 20% less fuel than gasoline models, leading to savings of about 35% in the cost of driving.[14] However, diesel engines are also reputed for high torque at low revolutions, excel-

[14] We adopt the European common measure for fuel economy FUEL90, *i.e.*, liters of fuel necessary to drive 100 kilometers. This fuel consumption is standarized for each model traveling at a constant speed of 90 kilometers per hour (56 miles per hour) on a highway. The U.S. mileage measure is obtained dividing 235.214583 by FUEL90. The 20% fuel savings of diesel models translates into a 25% increase in their mileage relative to gasoline vehicles. The sales weighted mileage of the gasoline models ranges from 33 miles per gallon for minivans to 47 miles per gallon for

lent reliability, and longer durability than gasoline engines, all of them unobservable characteristics in our econometric model. All those features could be favorably compared against the increased weight and lower power of diesel vehicles

Figure 1 illustrates how market conditions relate to the demand of automobiles with different engine types. The top-left diagram shows clearly that diesel automobiles cannot be considered an inferior good. Income per capita grew in Spain at a fast pace 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 also grew, although at a slower rate, after the recession ended in 1995. However, gasoline vehicles never regained the sales levels of the early 1990s. The two diagrams on the right of Figure 1 relate sales of each type of vehicle with the corresponding fuel price. Fuel prices increase steadily over the decade. At the end of the decade, diesel models exceeded the sales of gasoline versions for the first time. Interestingly, during this time, as fuel prices grew faster, sales of diesel vehicles increased (although at a lower rate particularly in years 1999 and 2000) while gasoline models stagnated or declined.

Finally, the bottom-left diagram shows the relationship between relative fuel prices and sales by type of vehicle. The price of a gallon of diesel fuel remained stable between 70% and 80% of the price of a gallon of gasoline. Interestingly, diesel is cheapest immediately after the implementation of the scrappage programs. The upward trend in the relative price of diesel and gasoline in the second half of the 1990s together with a fast growth in the sales of diesel automobiles shows that not only a cash-for-clunkers program but also some subsidization of the fuel for the new technology or reduced taxation on gasoline may be needed to reach the tipping point past which demand for the new good is self-sustained. In the Spanish case, once the bandwagon effect in favor of diesel automobiles got started, it did not stop when fuel price differences narrowed.

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compact cars, respectively. For diesel powered models, mileage ranges from 38 miles per gallon for minivans to 56 miles per gallon for compact cars, respectively.

Table 2: Segments of the Spanish Automobile Market

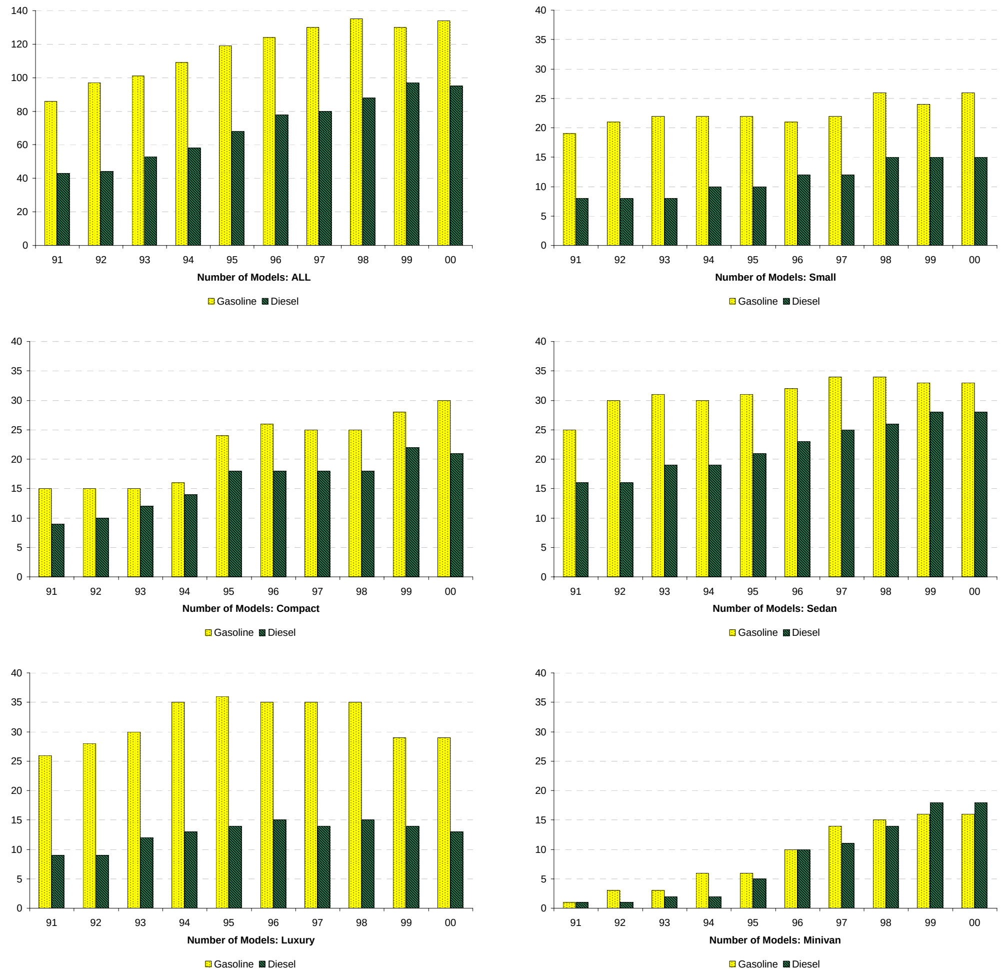
GASOLINE:	SALES	MODELS	PRICE	FUEL90	HP	LENGTH	WIDTH	WEIGHT
SMALL	2,705,031	23	9,150	5.00	64.66	145.50	63.13	1,886
COMPACT	2,053,340	22	12,786	5.56	94.32	162.07	66.46	2,282
SEDAN	1,272,976	31	16,919	6.02	113.46	174.32	67.21	2,591
LUXURY	364,910	32	26,742	6.91	151.73	180.65	69.36	2,935
MINIVAN	67,151	9	19,551	7.06	115.37	168.63	69.18	3,009
DIESEL:	SALES	MODELS	PRICE	FUEL90	HP	LENGTH	WIDTH	WEIGHT
SMALL	911,874	11	10,429	4.17	62.87	147.52	63.45	2,085
COMPACT	1,404,313	16	13,926	4.56	75.10	161.69	66.51	2,468
SEDAN	1,200,368	22	18,291	4.78	88.01	174.26	67.71	2,763
LUXURY	110,107	13	34,006	5.30	136.36	187.83	70.23	3,336
MINIVAN	91,721	8	22,564	6.11	97.74	176.06	71.27	3,558

SALES indicate the number of registered vehicles. MODELS indicate here the average number of models available to consumers. All other variables are defined as in Table 1.

Table 1 also reports the number of models available each year by type of fuel. Here is an important difference between the current U.S. market and the European market in the 1990s. At the beginning of the decade sales of diesel automobiles represented 12% of the Spanish market and there was one diesel model for every two gasoline models available to consumers. Three years later, at the time of the policy intervention, the market share of diesel automobiles had already jumped to 22% (which compares quite favourably to the current 3% share of hybrids in the total U.S. automobile market). The number of diesel models continued growing and at the end of the decade there were three diesel model for every four gasoline models available as compared to a total of only 15 hybrid models currently for sale in the U.S. market. These numbers indicate that the Spanish scrappage programs appears to be successful in changing the automobile purchase patterns of drivers because diesel vehicles were no longer a fringe market in 1994 and because consumers had a large number of products to choose from.

Table 2 describes the features of different market segments by type of engine. Within segments the same features discussed before hold: diesel vehicles are essentially of identical size to

Figure 2: Diesel vs. Gasoline Models



gasoline models although they are heavier, less powerful, and are priced at a premium. The CARS program in the U.S. may induce fuel efficiency simply by shifting consumer tastes towards smaller vehicles requiring smaller engines and consuming substantially less fuel. In Europe, vehicles were already rather small in the 1990s, and one of the reasons why the TDI technology succeeded was that it allowed the development of light small engines for the most popular market segments. Table 2 also indicates that a large number of diesel models were concentrated in the lower half of the size distribution (SMALL, COMPACT, and SEDAN). Figure 2 shows that there were many diesel models available in the COMPACT and SEDAN segments, and that their supply grew faster than in other

segments. Hence, 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 The Effects of Cash-For-Clunkers Programs in Spain

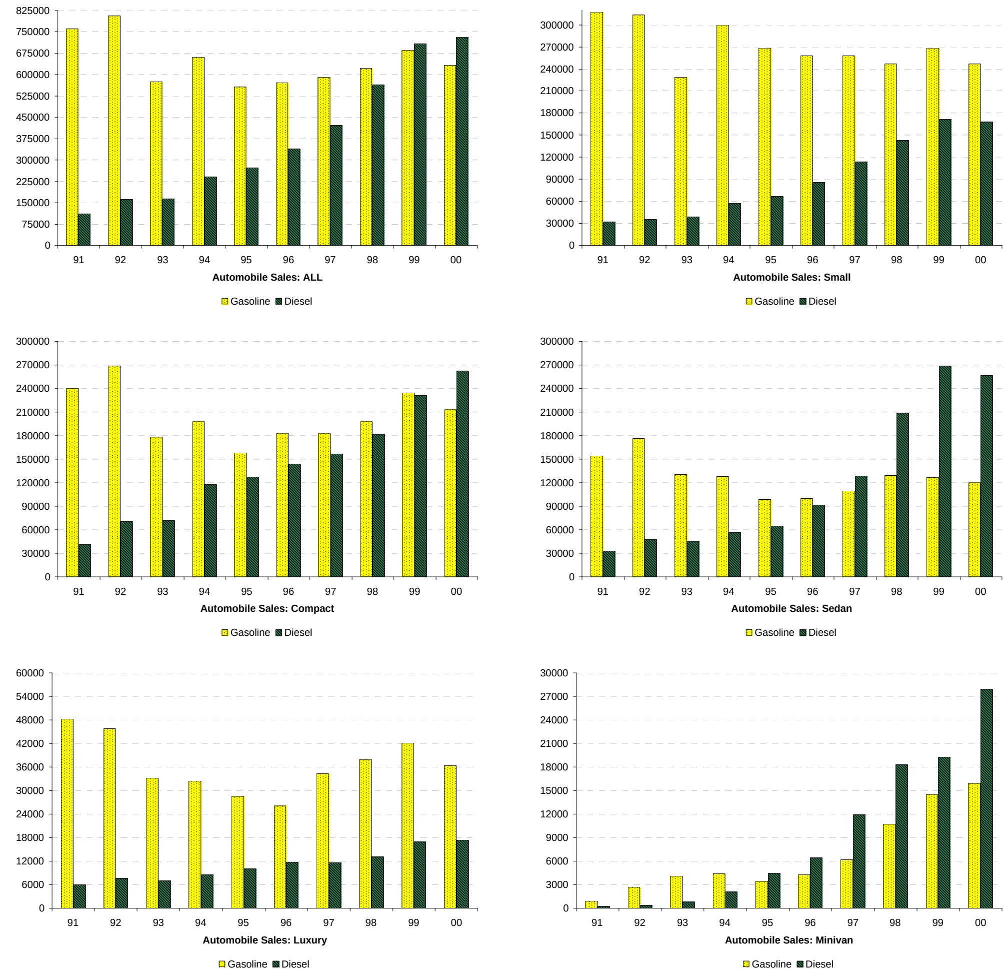
In the midst of a severe recession that pushed unemployment up to 24% of the labor force, the Spanish government enacted two automobile scrappage plans in 1994 in order to stimulate aggregate demand by increasing sales in the largest and most important industry of the Spanish economy. In addition, these plans were aimed at increasing road safety by reducing the average age of the automobile fleet.[15] 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 any 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.[16]

The increase in automobile demand goes hand in hand with a significant change in its composition. Figure 3 depicts the evolution of sales over the 1990s in Spain by market segments distinguishing by type of engine. This figure is perhaps the best illustration of a drastic change taking place in consumer preferences over the 1990s. Most likely this change of preference was already under way, but the scrappage programs certainly accelerated it. These programs were not

[15] 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.

[16] 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 figures are far more modest than the subsidies of the CARS program. The minimum 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, up to $4,500 were possible and most automobiles sold were much more modestly priced, therefore leading to a substantially larger percent subsidy per vehicle than in the Spanish case.

Figure 3: Diesel vs. Gasoline Sales



aimed at inducing sales of diesel vehicles but to boost automobile sales in general.[17] Indeed few European manufacturers were producing diesel versions in Spain, but rather in other European countries. Since the rules of the E.U. do not allow for discrimination against other European firms, these policy interventions can be understood as orthogonal to the shift in demand patterns: the acceleration of this change of preferences is therefore a side effect of these programs but not its main goal.

[17] It is 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).

Table 3: Yearly Sales Growth by Fuel Type

GASOLINE:	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN	ALL
1992	-1.16	11.79	13.94	-5.02	194.07	5.99
1993	-27.05	-33.64	-25.82	-27.51	53.56	-28.73
1994	31.01	10.82	-2.24	-2.54	7.07	15.08
1995	-10.46	-19.90	-22.84	-12.00	-22.34	-15.82
1996	-3.75	15.78	1.29	-8.71	25.29	2.61
1997	-0.01	-0.51	9.86	31.76	44.87	3.34
1998	-4.29	8.38	17.72	10.41	72.85	5.37
1999	8.52	18.60	-1.99	11.29	35.03	10.17
2000	-8.01	-8.97	-4.99	-13.82	9.74	-7.76
DIESEL:	SMALL	COMPACT	SEDAN	LUXURY	MINIVAN	ALL
1992	11.38	71.73	45.34	27.89	62.45	44.42
1993	11.03	1.94	-7.29	-9.20	102.60	0.91
1994	45.68	63.85	26.58	24.18	166.03	48.12
1995	16.36	8.62	15.29	16.21	114.84	13.19
1996	27.63	13.09	41.25	17.79	43.54	23.98
1997	33.22	8.64	40.18	-1.60	86.26	24.44
1998	25.78	16.14	62.55	13.03	53.49	33.82
1999	20.23	27.36	28.88	28.61	5.36	25.43
2000	-2.42	13.50	-4.54	2.94	44.74	3.39

Percent growth sales over previous year.

Sales of gasoline models were essentially identical in 1993 and 1995. In 1994 though, it increased 15%. Sales of gasoline models increased at a steady pace, between 3% and 10% a year until 1999 but overall they never reached the sales level of 1992 again. The aggregate however hides very diverse situations, from a slow decline of the sales of SMALL and COMPACT vehicles and stagnant sales of SEDAN, to a fast growth of sales of MINIVAN. Table 3 documents the yearly growth rates of sales by market segment and type of engine. 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 are implemented, they begin with an explosive growth rate of almost 50% a year, which stabilizes at rates between 13% and 25% a year between 1994 and 1999 depending on segment. MINIVAN grew at much faster rates but all diesel segments consistently experienced large double

digit sales growth rates. Thus, by the end of the decade diesel automobiles represented 53.66% of the market. The growth is particularly visible in the sedan and minivan segments with market shares rising almost to 70%.

The year in which 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. Sales of diesel vehicles increased by 78,497 while diesel sales only amounted to 163,140 units in 1993. This change in preferences later got a boost from a fast growth of personal income during the second half of the 1990s although there was also a counterveiling incentive of an increasingly expensive diesel fuel relative to gasoline. It could also be argued that the uncertainty around the new technology dissipated as sales of diesel models increased and more diesel models were made available to consumers. 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?

In order to address these questions Table 4 presents a series of reduced form DID regressions to evaluate the differentiated effect of the 1994 scrappage programs on the demand for vehicles using different engines after we control for other relevant economic information.[18] The variable of interest is the number of yearly sales of each model distinguished by type of fuel. The top of Table 4 measures the average effect of the scrappage programs in a regression that includes segment, manufacturer, fuel dummies, an average treatment effect, D9400, and some economic variables such as income per capita, price of the vehicle, and price of the corresponding fuel:

$$\begin{aligned} \text{SALES} = \alpha_0 &+ \alpha_s \text{SEGMENT} + \alpha_m \text{MANUFACTURER} + \alpha_d \text{DIESEL} \\ &+ \alpha_t \text{D9400} + \alpha_e \text{ECONOMIC VARIABLES}\,, \end{aligned} \tag{1}$$

[18] In another study of the automobile industry, Busse, Silva-Risso, and Zettelmeyer (2006) also make use of the DID approach to quantify the treatment e□ect of counterfactual promotions on retail car prices.

where D9400 is a dummy variable that equals one for any observation from 1994 and thereafter. In order to obtain a differentiated treatment effect by fuel type we include DIESEL×D9400. Thus, treatment effects are measured relative to the average sales per gasoline model in the period 1991-1993. Finally, to further analyze the effect of the 1994 scrappage programs we repeat the same analysis for each market segment.

Results indicate that relative to the corresponding gasoline version, sales per model of diesel vehicles are substantially smaller. This is particularly true for SMALL and COMPACT vehicles. However, the scrappage program compensates this difference, with sales of diesel vehicles increasing three times faster than the decrease in sales of gasoline models. With small variations these results hold across most segments except for MINIVAN, in which demand for both type of engines increase, and LUXURY vehicles where loss in demand for gasoline models and demand increase for diesel vehicles are both the smallest in absolute value across segments. All type of cars can be considered normal goods. Interestingly, the cross-price effect of fuel on the demand of automobiles is several times larger than the own automobile price effect. Both income and price effects are smaller in absolute value for LUXURY vehicles. There are two counterintuitive results though. First, there is a positive own vehicle price effect on the demand of SMALL cars that may be explained by the heterogeneity within this segment. SMALL domestic models, with larger distribution networks are more expensive but also better regarded by the public. The positive price effect just reflects the market power of domestic brands. Second, the positive effect of fuel price on the demand of MINIVAN may be a result of the strong demand growth of diesel versions in the second half of the 1990s, coinciding with diesel becoming relatively more expensive. Here, the positive bandwagon effect dominates the negative fuel price effect.

Evidently, the effect of the Spanish "cash-for-clunkers" programs of 1994 need not be instantaneous nor constant afterwards. Dynamic effects are more important when policy interventions like this take place in the early stages of a process of diffusion of a new technology. Thus, in order

Table 4: Scrappage Programs – Average and Dynamic Treatment Effects

	ALL		SMALL		COMPACT		SEDAN		LUXURY		MINIVAN	
CONSTANT	−8.4705	(3.14)	−23.0730	(5.12)	−3.4738	(0.65)	−19.3980	(7.05)	−2.0735	(3.16)	−1.1047	(1.47)
COMPACT	4.3569	(13.90)										
SEDAN	0.1991	(0.74)										
LUXURY	−3.4805	(16.66)										
MINIVAN	−5.1638	(22.39)										
DIESEL	−7.6092	(10.48)	−19.2970	(9.91)	−13.9830	(7.51)	−5.9655	(7.89)	−1.1645	(3.82)	−0.4435	(1.79)
D9400	−1.8444	(5.24)	−3.1654	(3.01)	−5.0484	(4.61)	−1.9098	(2.86)	−0.3176	(2.37)	0.2367	(0.77)
DIESEL×D9400	6.2606	(10.94)	7.6521	(5.54)	13.7880	(9.29)	6.1140	(12.05)	0.6712	(3.59)	1.4011	(4.61)
PRICE	−0.0642	(12.54)	2.5486	(22.99)	−0.1402	(7.03)	−0.1169	(3.19)	−0.0424	(7.46)	−0.1652	(8.30)
GDP-PC	2.0786	(9.03)	2.4623	(4.41)	2.3437	(5.24)	3.4096	(8.82)	0.5825	(3.84)	0.3576	(3.34)
FUELPRICE	−6.5126	(3.65)	−17.3300	(4.39)	−7.1371	(2.42)	−8.3928	(3.95)	−1.6724	(1.74)	1.3674	(2.53)
R^2	0.5647		0.7086		0.7266		0.6236		0.6040		0.7051	
	ALL		**SMALL**		**COMPACT**		**SEDAN**		**LUXURY**		**MINIVAN**	
CONSTANT	−42.9320	(1.26)	−98.3680	(1.16)	−150.7400	(1.36)	−51.3980	(1.80)	0.5595	(0.04)	27.8230	(1.27)
COMPACT	4.4041	(14.60)										
SEDAN	0.2227	(0.85)										
LUXURY	−3.4612	(15.83)										
MINIVAN	−5.2460	(24.33)										
DIESEL	−7.7182	(7.00)	−20.7680	(7.41)	−12.7540	(5.60)	−5.1989	(8.59)	−1.3950	(2.71)	−0.8957	(7.48)
D94	0.7043	(1.06)	2.8577	(1.71)	−0.7183	(0.38)	−0.0378	(0.05)	0.0463	(0.22)	0.3321	(0.67)
D95	−2.4093	(1.28)	−2.7376	(0.57)	−11.9970	(2.00)	−3.5861	(2.10)	0.0559	(0.07)	1.8181	(1.86)
D96	−3.0474	(1.16)	−5.1931	(0.77)	−13.8940	(1.65)	−4.1649	(1.90)	0.1847	(0.16)	2.3992	(1.69)
D97	−4.7441	(1.17)	−8.2176	(0.81)	−20.2510	(1.54)	−6.2740	(1.98)	0.4122	(0.24)	3.3166	(1.50)
D98	−7.1979	(1.31)	−14.0460	(1.03)	−27.3730	(1.51)	−8.3400	(1.83)	0.2736	(0.12)	4.7677	(1.48)
D99	−8.8096	(1.21)	−15.1950	(0.84)	−35.0200	(1.47)	−11.1200	(1.84)	0.6235	(0.21)	6.1845	(1.48)
D00	−9.5456	(1.06)	−14.9060	(0.66)	−41.5120	(1.42)	−12.9080	(1.72)	1.0286	(0.27)	7.5234	(1.48)
DIESEL×D94	2.3828	(4.08)	1.5959	(1.02)	8.7755	(4.49)	2.0195	(2.89)	0.3162	(1.73)	0.3565	(0.90)
DIESEL×D95	4.0361	(6.65)	2.9541	(1.72)	13.8980	(7.67)	3.3753	(4.07)	0.4675	(2.23)	1.0714	(2.47)
DIESEL×D96	5.1100	(8.87)	5.9290	(2.64)	12.5960	(7.60)	4.7268	(6.64)	0.7019	(3.32)	1.1271	(2.80)
DIESEL×D97	6.3015	(8.44)	7.8917	(4.23)	14.9300	(7.24)	5.9886	(8.75)	0.4846	(2.90)	1.6186	(4.20)
DIESEL×D98	7.3730	(11.83)	8.9987	(5.64)	15.3280	(7.14)	8.5409	(10.67)	0.4904	(2.35)	1.4026	(3.08)
DIESEL×D99	7.8557	(11.61)	8.9363	(5.25)	15.5810	(7.66)	10.3860	(11.40)	0.4414	(2.02)	1.1022	(3.01)
DIESEL×D00	8.8219	(12.66)	10.5670	(6.58)	18.1950	(8.63)	10.1280	(8.82)	0.7934	(3.28)	1.3977	(3.31)
PRICE	−0.0655	(11.56)	2.6012	(18.25)	−0.1351	(5.96)	−0.1077	(2.77)	−0.0426	(7.73)	−0.1736	(9.73)
GDP-PC	5.9488	(1.64)	11.4160	(1.29)	18.0690	(1.52)	6.5171	(2.14)	0.4092	(0.30)	−2.6551	(1.10)
FUELPRICE	−7.2909	(1.16)	−28.2250	(1.94)	3.0901	(0.21)	−1.1262	(0.27)	−3.6704	(1.21)	−1.6647	(0.90)
R^2	0.5728		0.7210		0.7446		0.6485		0.6080		0.7180	
Observations	1869		338		379		534		446		172	
Models	340		56		73		95		75		42	

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 MANUFACTURER fixed effects although these estimates are not reported. Variables PRICE, FUELPRICE, and GDP-PC are measured in the equivalent of thousands of 1994 euros. Segment dummies add up to zero in the estimation that includes all segments. Thus, the estimate for the SMALL dummy is 4.0883 for the average treatment specification and 4.0804 for the dynamic treatment model.

to separate the short-term from the long-term effects of these scrappage programs we compute the dynamic treatment estimator of Laporte and Windmeijer (2005). The bottom of Table 4 presents the results of a model similar to the following regression:

$$\begin{aligned} \text{SALES} = \alpha_0 &+ \alpha_s \text{SEGMENT} + \alpha_m \text{MANUFACTURER} + \alpha_d \text{DIESEL} \\ &+ \sum_{t=1994}^{2000} \alpha_t \mathbf{1}(\text{YEAR} = t) + \alpha_e \text{ECONOMIC VARIABLES}\,. \end{aligned} \tag{2}$$

We define seven dummy variables for seven consecutive years. The estimate of D94 = 1 indentifies the immediate effect of the scrappage programs on the sales per model in 1994. Similarly, the estimate of D95 = 1 identifies the effect in 1995. To allow for differentiated effects by type of fuel we interact the dummy DIESEL with these treatment effects D94, D95, ..., D00. We also repeat the analysis by automobile segment.

Results reported at the bottom of Table 4 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 almost no effect on the sales of gasoline models either in the short or the long run. The only two exceptions to this rule are MINIVAN and SMALL vehicles, whose sales increased marginally and only in immediate aftermath of the two scrappage programs. The other exception is the SEDAN segment whose demand shrunk much more in the long run than in the immediate aftermath.

Results regarding diesel automobiles are quite different. The effect of the scrappage programs is, in general, positive and several times larger in the long run than in the short run. In general the increase in demand by year 2000 is four times the immediate increase in demand for diesel vehicles right after the implementation of the programs. It is a factor of five for SEDAN vehicles and up to six for SMALL cars, the latter benefiting from the possibility of developing very small diesel engines. However, it should be noticed that the short term effect of the scrappage

plans is not significant, which could be explained by the documented initial technical difficulties of developing such small diesel engines. The only segment where short and long run effects on the demand of diesel vehicles remain constant is the LUXURY group where effects are also rather small.

Overall, Table 4 documents a very significant shift in consumer preferences towards diesel automobiles in Spain during the 1990s. The effect of scrappage policies is radically different for gasoline models (no effect) and for diesel vehicles (large positive effect). The induced increase in demand is many times larger in the long run than in the immediate aftermath of the programs. Demand for LUXURY cars remain mostly unaffected and while diesel versions exist for this segment, the increase in their sales fail to resemble the growth patterns in the rest of the segments. Given the relative large share of SMALL vehicles, the successful development of very small diesel engines probably helped the most in shifting the fleet composition. The most dramatic change in purchase pattern happened for SEDAN vehicles with demand for diesel version continually increasing after the programs ended while demand for gasoline versions plummeted right after they were implemented.

4 Diesel vs. Gasoline Automobiles

This section addresses the determinants of demand for automobiles distinguished by type of engine. As with the introduction of any new product or technology, adoption is not immediate although as the previous section has shown, it is remarkably fast for most market segments. We therefore now focus on the question whether the demand for diesel automobiles depends only on the better mileage factor . The alternative hypothesis is that diesel engines possess some other unobservable features valued by potential customers while making a purchase choice.

We will assume a nested logit demand specification similar to Goldberg (1995) but including only one nest level distinguishing between gasoline and diesel models. As documented in the previous section, 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. Still, engine types characterize well defined groups of vehicles with common unobserved features whose effects on demand we are interested in studying. Therefore we write a demand function as in Berry (1994, eq. (28)):

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

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 is its corresponding price. The price of vehicles p_j includes sales and other taxes that consumers need to pay. The market share of model j is indicated by s_j while $s_{j|g}$ denotes the share of that model in either the GASOLINE or DIESEL group.[19] As it is customary in the estimation of discrete choice demand models, 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, which we do not keep constant over the decade. There are two issues to note. First, automobile sales vary widely over the decade with a deep recession in the first half and fast economic growth in the second half. Second, the growth of the Spanish economy during the second half of the 1990 triggered an important immigration process that added millions of new residents, *i.e.*, over 10% of the local population in little over five years. Therefore, our outside option takes into account both the yearly automobile sales and the total number of households.[20] Among vehicle characteristics we include a measure of performance (HP/WEIGHT), mileage (FUEL90), and size (LENGTH × WIDTH). We also include a time trend, dummies to identify

[19] 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 given recently by Gramlich (2008, p.12).

[20] Starting in 1991, the series of s_0 is: 0.93, 0.92, 0.94, 0.93, 0.93, 0.93, 0.92, 0.91, 0.89, and 0.89, respectively.

Table 5: Multinomial and Nested Logit Demand Estimation

	Model I		Model II		Model III		Model IV	
CONSTANT	−7.1615	(17.11)	−3.3068	(56.77)	−3.7133	(60.22)	−21.3920	(3.42)
HP/WEIGHT	99.2100	(2.77)	23.4660	(8.94)	55.6800	(13.16)	1311.4000	(2.43)
FUEL90	−0.3863	(6.60)	−0.0305	(11.20)	−0.0183	(2.99)	0.4596	(1.34)
LENGTH × WIDTH	0.7512	(2.03)	0.0684	(1.86)	0.4064	(9.19)	3.4363	(2.87)
SMALL	0.7506	(8.55)	0.0677	(7.09)	0.1053	(6.32)	1.4501	(5.92)
COMPACT	0.5687	(10.32)	0.0338	(4.88)	0.0356	(4.74)	0.2696	(2.82)
LUXURY	−0.6577	(7.81)	−0.0702	(10.05)	−0.0249	(2.45)	−0.2798	(1.22)
NON-EUROPEAN							−1.6654	(15.15)
TIME TREND	0.0447	(5.59)	0.0769	(6.11)	0.0780	(5.93)	0.1131	(16.77)
DIESEL	−1.1241	(7.39)	−1.5855	(77.98)	−1.7565	(83.57)	12.5340	(1.49)
D9400	−0.6685	(7.27)	−0.5932	(9.28)	−0.6687	(8.62)	4.3005	(1.11)
DIESEL×D9400	0.8285	(8.53)	1.3127	(67.92)	1.5929	(89.19)	−12.5400	(1.43)
PRICE	−0.0192	(2.32)	−0.0012	(3.65)	−0.0112	(12.48)	−0.1767	(6.05)
$\ln(s_{j\|g})$			0.9247	(173.42)	0.9199	(103.80)	0.7161	(8.01)
SER	1.393		0.215		0.235		3.098	
SARGAN	30.74		55.39		31.87		149.10	
$[df; \chi^2_{0.99}(df)]$	[11; 24.72]		[13; 27.69]		[10; 23.21]		[10; 23.21]	
No. inelastic demands	1,847		1,857		65		4	
(± 2 s.e.'s)	(1,784 − 1,869)		(1,840 − 1,865)		(35 − 90)		(0 − 16)	
LAVERG-VUONG: Model I *vs.* II, III, IV			7.66		7.87		9.34	
LAVERG-VUONG: Model II *vs.* III, IV					10.51		−1.78	
LAVERG-VUONG: Model III *vs.* IV							−4.02	

IV estimates. The endogenous variable is always $\ln(s_j)$-$\ln(s_0)$. Absolute, heteroskedastic-consistent t-statistics are reported in parentheses. PRICE is measured in the equivalent of thousands of 1994 euros. LENGTH and WIDTH in LENGTH×WIDTH are measured in inches/100; HP/WEIGHT is measured as horsepower per 10 pounds of weight. All other variables are defined in Table 1. 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 obsrvations, and k is the number of parameters estimated, respectively. SARGAN is the two-step test of overidentifying restrictions of Sargan (1958), which is distributed as a χ^2 with df degrees of freedom. LAVERG-VUONG is the test of nonnested hypotheses of Lavergne and Vuong (1996).

market segments, type of engine, and average effect of the scrappage plans by type of engine and the national origin of vehicles.[21]

Table 5 presents the estimates of four variations of the nested instrumental variable (IV) logit demand model. Model I is the simplest logit structure, without distinguishing by type of engine. Models II and III assume that households first decide whether to purchase a diesel or gasoline engine and then choose the model within the corresponding group. Model IV is the closest

[21] NON-EUROPEAN is a dummy variable that is equal to one if the automaker did not manufacture in Europe (Daewoo, Honda, Hyundai, Kia, Mazda, Mitsubishi, Nissan, Suzuki, Toyota, and Chrysler), and zero otherwise.

to the specification of Verboven (2002) where individuals first decide which model they like and then, depending on their driving needs, they choose either the diesel or the gasoline version of such a model. Evidently, for nested models, not only the price p_j but also the share of its model j in group g, $s_{j|g}$, is also endogenous as the price and market share of a particular vehicle are determined partly by its unobserved characteristics. The different nesting specifications simply allow us to control whether these unobserved characteristics are fuel specific or not. To address these endogeneity problems we follow Berry, Levinsohn, and Pakes (1995) in selecting valid instruments. We use characteristics directly related to the model such as HP/WEIGHT FUEL90, LENGTH × WIDTH, the corresponding fuel price, plus market segment, year dummies, and a constant. We also include the number of all other models sold by the same manufacturer regardless of the type of engine, as well as the sum of their HP/WEIGHT and FUEL90 . Finally, we use as instruments the number of models and the sum of their HP/WEIGHT and FUEL90 for all models produced by rivals. For the estimation of models I to III, we follow Bresnahan, Stern, and Trajtenberg (1997) and limit our attention to the characteristics of rivals' models of the same fuel type.

Models I to III produce estimates that are consistent with the evidence presented in Section 3. They have the expected signs but are of different magnitude and significance. Consumers prefer less expensive, larger, more powerful, and more fuel efficient automobiles.[22] Demand increased over time and while diesel models were on average less valued than gasoline vehicles, the valuation of diesel engines grew significantly faster after the implementation of the scrappage programs while gasoline engines lost the favor of most drivers.

Models I and II are misspecified as they predict inelastic demand estimates for all but a handful of models. As emphasized by Berry et al. (1995, §7.3), this is inconsistent with profit maximization in markets with product differentiation and market power. The logit structure of

[22] Remember that FUEL90 is measured as liters of fuel necessary to drive 100 km on a highway at a constant speed of 90 km per hour, which is inversely related to the more common miles per gallon measure of fuel efficiency in the U.S.

Model I is not flexible enough to address the several sources of unobserved characteristics of vehicles. Model II assumes that households first decide whether to purchase a diesel or a gasoline vehicle and then choose among those of one of the subgroups. However, p_j is treated as exogenous (and therefore enters as one of the instruments as well). Model III is identical to Model II with the exception that both p_j and $s_{j|g}$ are considered endogenous. Instrumenting produces similar estimates but the number of negative price elasticities is reduced to 65 out of 1,869 cases. This is the net result of distinguishing between diesel and gasoline engines, a major source of differentiation among vehicles. The bottom of Table 5 reports the test of nonnested 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 LAVERG-VUONG = 7.66 favors Model II over Model I. Model III, our preferred specification always dominate any of the alternatives.

4.1 Engine Type as a Source of Price Discrimination

Verboven (2002) is one of the few papers to address the demand for diesel automobiles. In his framework diesel automobiles are of higher quality because of their better mileage. Although he argues that diesel models are heavier and less powerful for engines of equal size, all those differences are assumed away by focusing on a restricted sample consisting of pairs of diesel and gasoline models that are identical in every other direction. The idea is that consumers first decide what model they want and later choose whether to purchase the diesel or the gasoline version. Thus, price differences between diesel and gasoline versions could be explained as an attempt to discriminate among individuals depending on the average yearly miles driven.

For this explanation to be correct, unobserved characteristics influencing the purchase decision should be independent of the type of engine. Thus, a nesting model where individuals first decide the model taking into account all unobservable features and then choosing the type engine should fit the data better than Model III. Results of Model IV respond to this sequence

of choices although we do not limit ourselves to a sample of models for which both a diesel and gasoline version exist, because otherwise we would exclude over a third of the sample and results will certainly be biased.[23] Model III explains better the data than model IV according to the nonnested test of Lavergne and Vuong (1996), and thus, contrary to the approach adopted by Verboven (2002), a model where drivers first decide whether they will purchase a diesel or gasoline vehicle and then decide which particular model they want appears to be a better representation of the decision approach of consumers and the data generating process. Relative to Model III, results from Model IV seriously overestimate the absolute effect of performance (HP/WEIGHT), size (LENGTH × WIDTH), and (PRICE).

The main consequence of rejecting Model IV in favor of Model III is that an explanation for the differentiated pricing of diesel and gasoline versions of the same model that is based only on mileage is probably inaccurate. Model III is one where consumers buying a diesel vehicle trade off fuel efficiency for some other features of gasoline models such as speed or a larger size (for the same selling price). The mileage-only explanation of price differentials between diesel and gasoline versions also overestimates the markup and profits from introducing a more fuel efficient vehicle as diesel versions are also valued for their higher torque, durability, and reliability, something that is also better handled by Model III.

[23] Contrary to Models I to III, we need to include the NON-EUROPEAN dummy to obtain a meaningful estimate of Model IV. Non-European manufacturers only offer diesel versions in the late part of the decade. Most other estimates are not significant if we fail to include NON-EUROPEAN.

5 Adjusting Competitive Behavior to A Changing Demand

Demand analysis such as those of the previous section or those of Busse et al. (2009) and Li et al. (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, and thus they may end up overestimating the effect of environmental policies. If emission standards are tightened as it recently happened in th U.S., we should not ignore the fact that the increased demand for fuel efficient vehicles will also increase the markups that manufacturers will charge to popular models while substantial incentives will be offered to sell gas guzzlers. On the margin, some households will find profitable to purchase a less efficient automobile at a discount than an efficient one at a premium. Goldberg (1998) and Gramlich (2008) take into account this competitive side effect into the estimation of an equilibrium model.

In the setup of the present study, taking into account the supply side is important because manufacturers face an important 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 shift towards fuel efficient diesel models. Thus, we start by assuming constant returns of scale with the level of marginal cost of each model given by a function of the model observable characteristics z_j and unobservable characteristics summarized by ω_j:

$$\ln(mc_j) = z_j\gamma + \omega_j \,. \tag{4}$$

We also assume that multiproduct manufacturers behave non-cooperatively in a model of horizontal product differentiation. First order conditions of profit maximization is a nonlinear function of market shares of each model, their prices and markups. In matrix form:

Table 6: Equilibrium Model Estimates

	$\ln(s_j) - \ln(s_0)$		$\ln$(PRICE)	
CONSTANT	−2.9424	(50.44)	7.2399	(15.80)
HP; ln(HP)	−0.3711	(7.37)	1.1085	(13.16)
FUEL90	−0.0336	(5.21)	0.3305	(4.08)
ln(LENGTH × WIDTH)			2.3834	(9.32)
SMALL	0.0815	(4.03)	−0.1371	(2.92)
COMPACT	0.0826	(4.74)	−0.0523	(2.01)
LUXURY	−0.1942	(9.94)	0.1126	(3.34)
MINIVAN			0.2101	(9.20)
NON-EUROPEAN			−0.2838	(15.93)
AIR			0.1711	(9.82)
DIESEL	−1.7621	(66.02)	0.4696	(13.63)
D9400	−0.2844	(12.56)		
DIESEL×D9400	1.3720	(61.81)		
PRICE	−0.0218	(11.81)		
$\ln(s_{j\|g})$	0.9120	(99.13)		
D92			0.0252	(1.98)
D93			0.1446	(7.54)
D94			0.2552	(11.20)
D95			0.3461	(12.65)
D96			0.3968	(14.07)
D97			0.3882	(14.60)
D98			0.3541	(14.97)
D99			0.3345	(16.46)
D00			0.3455	(21.69)
GMM objective (*df*)	92.2797 (17)			
No. inelastic demands	0			

GMM estimates. Absolute, consistent t-statistics are reported in parentheses. PRICE is measured in the equivalent of thousands of 1994 euros. AIR indicates whether air conditioning is the default option. All other variables are defined in Table 1. The number of observations is 1,869 and the number of automobile models is 340.

$$p = mc + \Delta^{-1}(p, x, \xi, \alpha, \sigma, \gamma, \beta)s(p, x, \xi, \alpha, \sigma, \gamma, \beta), \quad (5)$$

which corresponds to the general formulation of Berry et al. (1995, eq. (3.3)), although since we assume a nested logit demand structure, the markup $\Delta^{-1}(p, x, \xi, \alpha\sigma, \gamma, \beta)s(p, x, \xi, \alpha, \sigma, \gamma, \beta)$ is only nonlinear in α and σ. Combining (4) and (5) the price equation is:

$$\ln\left[p - \Delta^{-1}(p, x, \xi, \alpha, \sigma, \gamma, \beta)s(p, x, \xi, \alpha, \sigma, \gamma, \beta)\right] = z_j\gamma + \omega_j\,. \quad (6)$$

Parameters are obtained by estimating jointly this pricing equation (6) with demand equation (3). At every iteration a nonlinear search determines the value of α and σ that better fulfill the moment conditions of demand and pricing equation. Then, conditional on these particular values, estimates of β are obtained from (3) and given this demand estimate, equation (6) provides estimates for γ. This procedure is repeated until convergence.

Table 6 reports the GMM estimates of this equilibrium model. PRICE includes all sales taxes in the demand equation but not in the endogenous variable of the supply relationship. Matrix z_j of characteristics affecting the marginal cost include logs of continuous regressors, segment dummies, a dummy of air conditioning as default option, type of engine, and yearly dummies. Results are intuitive: diesel versions are more expensive to produce, as are larger and more powerful vehicles. Smaller, more fuel efficient automobiles are less expensive to build. Minivans have by far the highest cost of production while non-European imports are cheaper to manufacture.[24] Cost of production increases early in the decade and stabilizes in the second half once the recession is over.

Finally, relative to Model III in Table 5 most estimates of demand have the same sign and a similar magnitude: demand is more sensitive to both the price of the automobile and the price of the corresponding fuel. The lower value of diesel models relative to gasoline ones is approximately the same as in the nested logit demand estimation. However the differences in the treatment effects associated to the scrappage programs clearly point out to important prediction biases in demand estimates of Table 5. Thus, ignoring the changes in markups would overestimate the effect of scrappage programs on the demand of diesel engines. The negative effect of these programs on the demand for gasoline models is even more dramatic.

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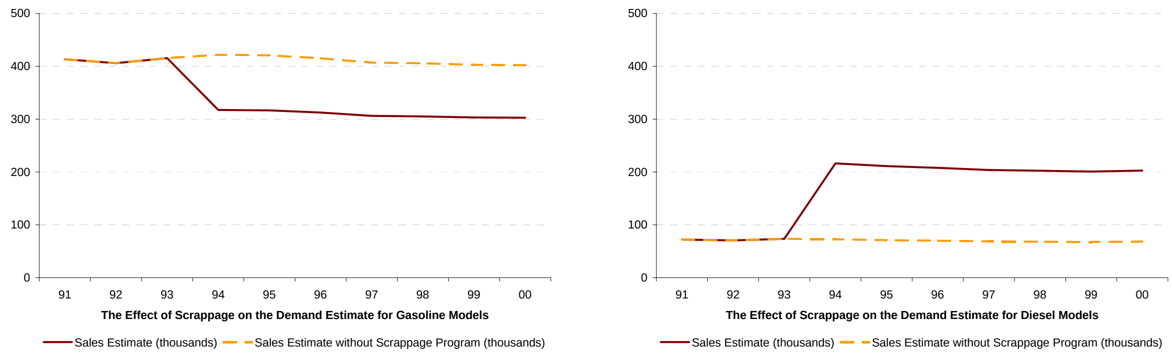
[24] The reference segment is SEDAN, however, to ease achieving convergence MINIVAN only appears on the supply equation while it is aggregated to SEDAN in the demand estimation. Minivans are frequently more expensive than many luxury models. It is a rapidly growing segment almost non-existing at the beginning of the decade and that took o rapidly with the fast economic growth during the second half of the 1990s.

Figure 4: Differentiated Impact of Scrappage Programs



5.1 Effectiveness of Scrappage Programs

Figure 4 presents the results of using these equilibrium estimates to evaluate the effectiveness of the scrappage programs once we allow for firms to determine their markups optimally depending on the scenario, *i.e.*, with policy intervention (continuous line) or without it (dashed line). This figure compares the prediction of the model based on the estimates of Table 6 with and without scrappage programs (*i.e.*, making the estimates of D9400 and DIESEL×D9400 equal to zero). These estimates are obtained after aggregating the change in sales for every model due to ignoring the scrappage programs and allowing for optimal markups. The left panel shows that the reduction in sales of gasoline models is substantial: without the scrappage program sales of gasoline models could have been 33% larger after 1993. The right panel shows that the the scrappage programs essentially doubled the sales of diesel vehicles (196%) between 1994 and 2000.

5.2 Substitution Patterns

For the rest of the analysis in this section we are going to focus on a set of six very popular automobile models for which both diesel and gasoline versions were available for most of the decade. They include the domestically produced Seat IBIZA, Ford FIESTA (both SMALL), Ford ESCORT, Opel

Table 7: Elasticities of Substitution for Selected Models by Fuel Type

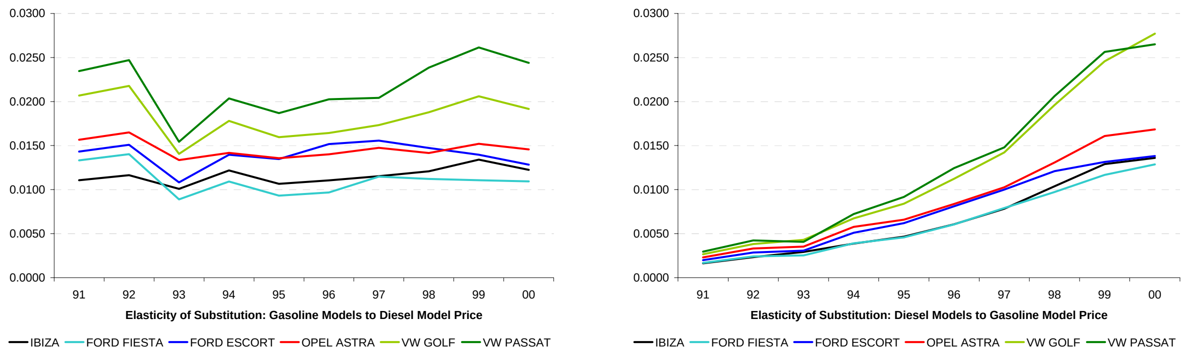
GASOLINE:	IBIZA	FIESTA	ESCORT	ASTRA	GOLF	PASSAT
1991	0.0111	0.0133	0.0143	0.0157	0.0207	0.0235
1992	0.0116	0.0140	0.0151	0.0165	0.0218	0.0247
1993	0.0101	0.0089	0.0108	0.0134	0.0141	0.0154
1994	0.0122	0.0109	0.0140	0.0142	0.0178	0.0204
1995	0.0107	0.0093	0.0135	0.0136	0.0160	0.0187
1996	0.0110	0.0097	0.0152	0.0140	0.0164	0.0203
1997	0.0115	0.0115	0.0156	0.0147	0.0173	0.0204
1998	0.0121	0.0112	0.0147	0.0142	0.0188	0.0239
1999	0.0134	0.0111	0.0140	0.0152	0.0206	0.0261
2000	0.0122	0.0109	0.0128	0.0146	0.0192	0.0244
DIESEL:	IBIZA	FIESTA	ESCORT	ASTRA	GOLF	PASSAT
1991	0.0016	0.0017	0.0020	0.0023	0.0027	0.0030
1992	0.0023	0.0024	0.0029	0.0033	0.0038	0.0042
1993	0.0029	0.0025	0.0031	0.0035	0.0043	0.0041
1994	0.0039	0.0039	0.0051	0.0058	0.0067	0.0072
1995	0.0047	0.0046	0.0062	0.0066	0.0084	0.0092
1996	0.0061	0.0061	0.0081	0.0084	0.0112	0.0124
1997	0.0078	0.0079	0.0100	0.0103	0.0142	0.0148
1998	0.0104	0.0097	0.0121	0.0131	0.0196	0.0206
1999	0.0129	0.0117	0.0131	0.0161	0.0246	0.0256
2000	0.0136	0.0129	0.0138	0.0168	0.0277	0.0265

The upper half of the table reports the sum of elasticities of substitution of each gasoline model relative to price changes in all diesel models. The bottom half of the table reports the sum of elasticities of substitution of each diesel model relative to price changes in all gasoline models.

ASTRA, and VW GOLF (all COMPACT), and VW PASSAT (SEDAN). Our goal here is to show the asymmetric sustitution pattern that these models show to changes in prices of models with the alternative engine.

The top section of Table 7 present the sum of elasticities of substitution of the gasoline versions of these six specific models to changes in prices of all diesel models available each year of the sample. The bottom of Table 7 documents the substitution of diesel models to changes in the prices of all gasoline vehicles. In general the demand for gasoline models is substantially more responsive to prices of diesel vehicles than the reverse. Only at the end of the decade are these

Figure 5: Elasticities of Substitution for Selected Models by Fuel Type



cross-price elasticities similar in magnitude. Interestingly, VW models are among the most price sensitive both in their gasoline and diesel versions. The least price sensitive are the very popular and locally produced IBIZA and FIESTA.

Figure 5 documents the very different time evolution of these elasticities. The left panel show that substitution in favor of gasoline models when diesel vehicles become more expensive remains, for the most part, quite stable over the decade, and essentially unaltered by scrappage programs, income growth, or relative fuel prices. The right panel describes a completely different situation for diesel automobiles. As they become more common, consumers are far more likely to switch towards diesel vehicles if the price of gasoline models increases. VW, the reputed manufacturer of TDI engines, particularly gains from this process.

5.3 Markup Adjustments

The very different evolution of demand for diesel and gasoline models necessarily forces manufacturers to modify their markups to accommodate this fast shift of preferences in favor of diesel engines. As we have just shown, buyers are much more likely to react by buying a diesel vehicle if gasoline models become more expensive than *vice versa*.

Table 8: Profit Markups for Selected Models by Fuel Type

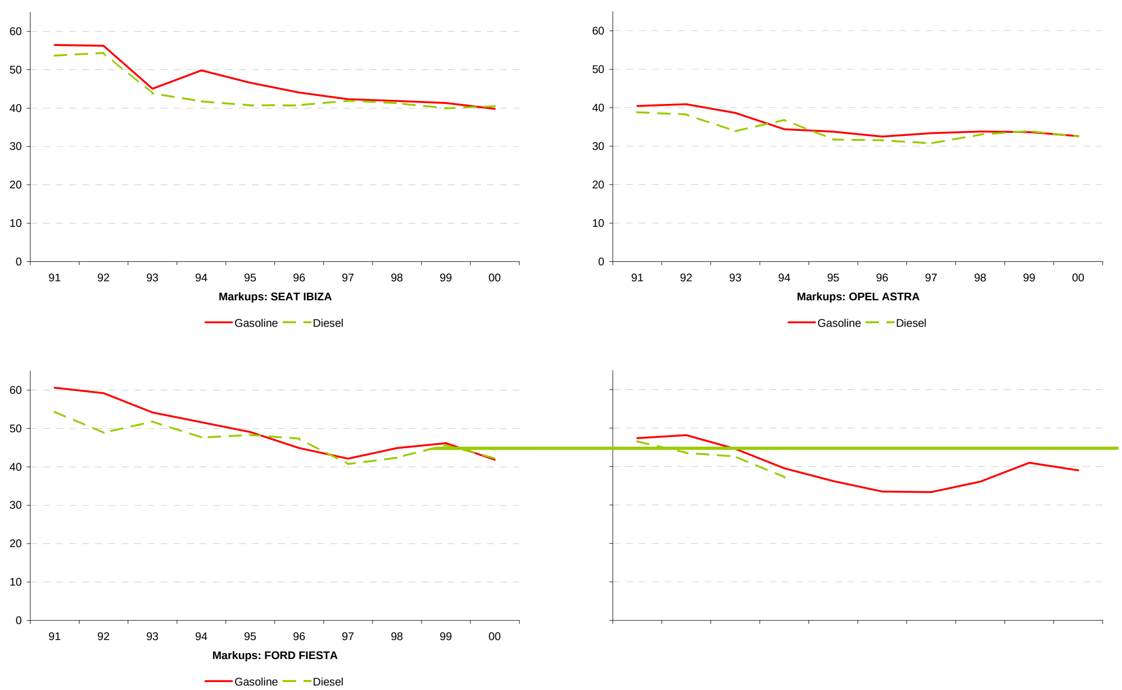
GASOLINE:	IBIZA	FIESTA	ESCORT	ASTRA	GOLF	PASSAT
1991	56.46	60.66	47.37	40.45	36.01	32.55
1992	56.26	59.23	48.16	40.89	34.28	30.99
1993	45.05	54.21	44.58	38.66	28.83	30.43
1994	49.84	51.65	39.52	34.42	26.73	24.87
1995	46.61	49.08	36.22	33.79	24.54	22.46
1996	44.08	44.90	33.51	32.50	22.96	20.74
1997	42.32	42.14	33.34	33.39	22.40	21.54
1998	41.86	44.93	36.09	33.81	21.27	20.23
1999	41.32	46.19	41.00	33.65	21.00	20.13
2000	39.82	41.88	39.00	32.60	19.21	20.08
DIESEL:	IBIZA	FIESTA	ESCORT	ASTRA	GOLF	PASSAT
1991	53.67	54.41	46.54	38.81	30.93	27.25
1992	54.42	48.87	43.52	38.26	29.26	25.79
1993	43.84	51.85	42.59	33.86	30.56	27.86
1994	41.76	47.64	37.22	36.83	27.92	24.41
1995	40.74	48.37	33.46	31.72	25.96	22.17
1996	40.76	47.35	30.22	31.56	26.16	21.22
1997	41.96	40.75	30.05	30.74	25.62	21.76
1998	41.32	42.41	32.28	33.02	24.42	19.24
1999	39.96	45.75	36.27	33.95	24.35	19.18
2000	40.53	42.19	35.95	32.48	23.84	18.74

Percent profit margin for specific models estimated using results of Table 6.

We use the estimates of Table 6 to estimate the markups of the different versions of these six popular models for each year of the sample. Table 8 present these estimates and Figure 6 show their time evolution for each specific model. Markups are much larger early in the decade. Protection against other European automakers not producing in Spain such as VW was only phased out in 1993 and quotas against non-European manufacturers was eliminated in 1996. These two important regime changes increased competition in the Spanish automobile market significantly and explain the steady reduction of all markups.

In general markups of gasoline models were larger for most models and for most of the decade but they became almost identical by the end of the decade when sales of diesel automobiles

Figure 6: Evolution of Equilibrium Markups by Fuel Type



had already exceeded gasoline sales. This reflects the initial bias towards gasoline models and the lower markups of diesel vehicles necessary to foster demand among consumers who were uncertain about the features and performance of and potential savings from diesel engines. The decline in markups due to increased competition is therefore more important for gasoline models than for diesel models: the markup of the gasoline IBIZA fell by 17% while the markup of the corresponding diesel version fell by 13%. Similar patterns are found for FIESTA (19% *vs.* 12%), ASTRA (8% *vs.* 6%), GOLF (17% *vs.* 7%), and PASSAT (12% *vs.* 9%).

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 CARS program has been criticized for being too limited. The original budget of one billion dollars in a market with 300 million customers paled with the recent German budget of 6 billion euros for a market with 85 million customers. The analysis of this paper shows qualitative effects are important, that results should be evaluated in the long run, and that the size of the program is less important than its timing.

With a revised budget of three billion dollars, a minimum of 600,000 U.S. buyers could take advantage of the CARS program. This amounts to about 6% of the expected total sales of automobiles in the U.S. during 2009, a sizable share that is achieved with a subsidy per vehicle of 15-20% of its price. By comparison, the successful Spanish program led to a larger increase in sales with less generous incentives. This result was achieved with a relatively modest subsidy per vehicle of 4% of the average final price of automobiles. If size of the program was the key issue to guarantee its success, the U.S. CARS program should certainly lead to a substantial change in the features of the active fleet of vehicles.

The most important difference between the U.S. and Spanish programs is the timing of the policy intervention relative to the diffusion path of the new, more efficient technology. Evidently governments do not choose the timing of these interventions to optimize their effect on the ongoing change of preferences but rather to respond to a macroeconomic crisis. But in 1994, when an

economic stimulus was necessary, diesel engines had already been around for decades in Spain and the new TDI technology had been available for five years. Sales of diesel automobiles amounted already to 22% market share and consumers could choose between 58 diesel and 108 gasoline models, respectively. On the contrary, today, sales of hybrids represent only 2.5% of sales in the U.S. market and consumers have only 15 models to choose from, most of them on the larger end of the distribution with the exception of the popular Toyota Prius. No matter how successful CARS is, it looks unlikely that it would succeed in tilting the market in favor of the very few fuel efficient models equipped with the hybrid technology.

Evidently, scrappage programs are just one way to induce consumers to purchase more fuel efficient vehicles. Fuel taxation and pricing of automobiles may certainly have an effect on consumers' choices. A government committed to charge high fuel prices (as in Europe) or subsidize the alternative fuel will ease the adoption of the new technology. Similarly, automakers could lower the markups of the new models during the first few years in order to attract new customers and then increase, as we have documented here, those markups as the demand for new products increase. This is best addressed in environments of dynamic competiton with horizontally differentiated products such as those of Gowrisankaran and Rysman (2009), which will allow us to evaluate among other hypotheses, how the timing of scrappage programs, or a permanent shift in fuel taxation speed up or delay the adoption of the new fuel efficient technology. That is the next project on our research agenda.

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