Protecting the European Automobile Industry through Environmental Regulation: The Adoption of Diesel Engines[⋆]

Eugenio J. Miravete[†] María J. Moral[‡] Jeff Thurk[§]

April 23, 2014

Abstract

After Volkswagen introduced the TDI engine, the market share of diesel vehicles in Europe increased from 10% to 50% in a decade. We show that changes in consumer preferences explain most of this fast shift in demand. However, the successful diffusion of diesel engines was due to the lenient European vehicle emissions policy, which both fostered customer adoption of diesel vehicles and favored domestic automakers. Consequently, this emissions policy served as an effective non-tariff trade barrier equivalent to a 37% import tariff that cut imports in half and allowed domestic manufacturers to remain dominant in the European automobile market.

Keywords: Innovation, Non-Tariff Trade Barriers, Emission Standards, Diesel Engines, TDI Technology.

JEL Codes: O33, L62, F13.

[⋆] We thank Allan Collard-Wexler, Kenneth Hendricks, Tom Holmes, Cristian Huse, Jeff Prince, and audiences at the Universities of Colorado, ICESI, Indiana, Pontificia Universidad Católica de Chile, Texas-Austin, and the workshop on "The Economics of Low-Carbon Markets" at University of São Paulo. We are solely responsible for any errors that may still remain. Moral gratefully acknowledges funding from the Spanish Ministry of Education and Science through grant ECO2010-18947.

[†] The University of Texas at Austin, Department of Economics, 2225 Speedway Stop 3100, Austin, Texas 78712-0301; Centre for Competition Policy/UEA; and CEPR, London, UK. Phone: 512-232-1718. Fax: 512-471-3510. E–mail: *miravete@eco.utexas.edu*; http://www.eugeniomiravete.com

[‡] Facultad de Ciencias Económicas y Empresariales, UNED, Paseo Senda del Rey, 11, 28040, Madrid, Spain; and GRiEE, Vigo, Spain; Phone: +34-91-398-8930. Fax: +34-91-398-7821. E–mail: *mjmoral@cee.uned.es*; http://webs.uvigo.es/mjmoral

[§] University of Notre Dame, Department of Economics, 711 Flanner Hall, Notre Dame, IN 46556. Phone: 574-631-3083, E–mail: *jthurk@nd.edu*; http://www.nd.edu/ jthurk/

1 Introduction

Since the establishment of the General Agreement on Tariffs and Trade (GATT) in 1947, reducing barriers to trade has become an important focus of academics and policy-makers alike. The result has been dramatic reductions in import tariffs around the world. As negotiation lowered the effectiveness of tariffs as policy tools, however, it also increased the degree to which governments choose to use other domestic policies as a mechanism towards, in the words of Adam Smith, "beggaring all their neighbours."[1] Motivated by this observation, we study the effectiveness of domestic policy towards redistributing sales and profits from foreign to domestic firms when traditional trade policy tools (*i.e.*, tariffs) are not available. Rather than attempting to characterize this relationship across multiple industries, we choose instead to focus on a specific and economically important industry – European automobiles. In particular, we study the introduction of the turbo-charged, direct injection diesel (TDI) engine by Volkswagen in 1989 and the role of European environmental regulation towards both fostering customer adoption and creating a non-tariff trade barrier to defend the domestic industry from foreign competition.

Volkswagen's introduction of the TDI engine proved to be a significant product innovation for the automobile industry. These engines are quiet, durable, and reliable without the black smoke and smell previously attributed to diesel engines. Relative to gasoline engines, they also deliver superior torque and are 20 to 40% more fuel efficient. Despite these attractive characteristics, however, customer adoption of the diesel was not instantaneous. In Europe, diesel car sales increased from 10% of new car sales at the beginning of the 1990s to over 50% by the end of the decade. In the United States, however, diesels never caught on. Why did diesels become popular in Europe and not in the United States? The usual explanation references Europe's sustained policy of heavy fuel taxation which provides incentive for drivers to consider purchasing more fuel efficient vehicles.

In this paper we offer a different explanation – one popular among automobile manufacturers but overlooked by economists. We argue that historically high fuel prices created demand for fuel efficient vehicles in Europe and likely incentivized Volkswagen to develop the TDI. The increasing popularity of diesel vehicles in Europe, however, is largely thanks to Europe's emissions policy designed to be lenient on the vehicle emissions produced by diesel engines. This policy, therefore, provided an opportunity for European drivers to become acquainted with these new diesel engines during the early stages of diffusion and facilitated their popularity in later years. Further, by encouraging the sales of diesel vehicles – a product largely produced by European firms – it also

[1] Adam Smith, *The Wealth of Nations* (1776), Book IV, Chapter III (Part II): "On the extraordinary Restraints upon the Importation of Goods of almost all kinds from those Countries with which the Balance is supposed to be disadvantageous."

provided domestic automakers a comparative advantage over foreign firms and acted as a non-tariff trade barrier.

We use Spanish automobile registration data detailed by fuel engine type to estimate two oligopoly models of horizontally differentiated products; one for the early adoption stage of 1992-1993 and another for the mature 1999-2000 market. In each Bertrand-Nash equilibrium, heterogeneous price responses for different products are linked to demographics and product attributes while the profit-maximization conditions identify marginal costs and markups. This empirical strategy enables us to evaluate whether consumer preferences, particularly related to diesel vehicles, evolved over time.[2] Further, we can quantify the potential effects of changes in the emission policy on sales, profits, prices, markups, and imports – an empirical approach similar to the demand decomposition and counterfactual analysis employed by Chaudhuri, Goldberg and Jia (2006) on alternative patent protection levels of pharmaceuticals in India.

Complicating the analysis is the fact that the 1990s was a period of significant change for the industry so many factors could have contributed to the increasing popularity of diesel vehicles. Our results indicate that changes in preferences associated with observable and unobservable product characteristics, growth in personal income, and the large increase of products offered explain most of growth of aggregate industry profits over the period. Other elements such as import tariff reductions, mergers, or changes in production costs add little or nothing to explain the change in sales and profits during that decade. Furthermore, the increasing profitability of the industry was almost entirely captured by the firms who invested in diesel vehicles – European automakers. Foreign automakers, on the other hand, experienced relatively modest increases in sales and profits presumably because they largely chose not to invest in developing their own diesel models.

We show that the increasing popularity of diesel vehicles was indeed driven by changes in consumer preferences towards these models and that, as a consequence, the diesel segment became an important component of the industry, representing 52% of sales and 58% of profits in year 2000. In the popular sedans segment (*e.g.*, Volkswagen *Passat*), diesel market penetration exceeded 70% by the end of the decade. Interestingly, the diffusion of diesel vehicles is much faster than the lengthy adoption processes documented in many other industry studies.[3] For example, Manuelli and Seshadri (2014) argue that the very slow diffusion of tractors can be explained by

[2] The fact that Spain is a relatively small market within Europe limits our ability to address when a particular model is introduced as automobile models are introduced in several national markets in Europe simultaneously. It is thus reasonable to assume that decisions of introducing any particular model were not driven by the particularities of the Spanish market and thus we can ignore dynamic product positioning decisions. Therefore, focusing on the Spanish case allows us to identify elements driving the demand for automobiles while not having to address industry supply decisions related to whether or when to introduce any particular diesel or gasoline model.

[3] Greenwood (1997) documents the slow diffusion of both steam and diesel locomotives; Oster (1982) the basic oxygen furnaces for steel mills; and Rose and Joskow (1990) the coal-fired, steam-electric high-pressure generation.

their continued expected improvement.[4] The fast diffusion of diesel automobiles during the 1990s appears to indicate that Volkswagen's TDI was a major breakthrough of better quality than almost any minor improvement that followed in the last quarter century. Thus, TDI made diesel technology much more attractive to consumers and in retrospect they gained little from waiting, which in part may explain the fast pace of adoption of diesel automobiles. The other reason that might explain this fast adoption is that due to the generality of the technology (*e.g.*, Bresnahan 2010) other automakers offered their own diesel models, therefore making them more affordable and attractive to European customers. Thus, despite the successful commercialization of TDI, Volkswagen failed to capture most of the associated innovation rents. Consequently, reverse engineering and alternative engine innovations likely promoted the fast introduction of models equipped with diesel engines by other European competitors – in particular Peugeot – and thus limited the profits of Volkswagen to only about 30% of the potential innovation rents.

This analysis of the successful diffusion of diesel vehicles in Europe does not say why something similar did not happen in the United States or other markets.[5] We argue that the choice of U.S. regulators to impose stricter nitrogen oxide (NO_x) emissions standards than their European counterparts can account for this since vehicles equipped with diesel engines produce more NO_x emissions than those equipped with gasoline engines. Rather than investing to redesign their diesel engines to meet these stringent emission standards, Volkswagen and Mercedes chose to stop selling their diesel models in the U.S. market in 1993 and 1994, respectively, precisely at the time of the implementation of the U.S. emission standards mandated by the Clean Air Act Amendments. This suggests that the imposition of the these emission standards amounted to a *de facto* ban of diesel vehicles in the U.S. market. But why would American regulators choose such a stringent NO_x emissions policy when doing so would hinder any viable commercialization of diesel automobiles in the United States? This is likely due to a combination of historically low fuel prices in the U.S. and a constituency of American drivers who were still haunted by the poor performance of diesel vehicles sold in the early 1980s.[6] The resulting minuscule share of U.S. diesel sales in the early 1990s did not justify the investment required to develop diesel engines capable of meeting the new emissions standards.

Of course, it is unclear what would have happened if an American-style NO_x emission policy had been implemented in the early stages of the diffusion of diesels in Europe. Given

[4] This argument was first put forward by Schumpeter (1950, p.98) and later formalized by Balcer and Lippman (1984).

[5] Besides Europe, diesel vehicles have only spread significantly in the Indian market. See Chug, Cropper and Narain (2011).

[6] See `http://www.autosavant.com/2009/08/11/the-cars-that-killed-gm-the-oldsmobile-diesel/` for an overview of how badly GM's retrofitted gasoline engines delivered poor performance when running on diesel fuel in the late 1970s and early 1980s and how such experience conformed the negative views of Americans on diesel vehicles for many years.

the evidence of the American automobile market and the fact that NO_x scrubbing technology could not meet those stringent standards for another two decades, we think it is reasonable to assume that such a policy would have led to the effective disappearance of diesel vehicles from the European automobile market. Under this assumption, the effects on the industry would have been significant – sales shrink by 10%, prices increase between 4% (domestic) and 6% (imports) due to less variety, industry profits decrease 14%, and the composition of sales shifts towards less fuel efficient vehicles as the CAFE average decreases from 45.56 to 40.49 miles per gallon.[7] These aggregate statistics mask an important asymmetry, however, as not all firms are worse off. While the profits of European manufacturers fall 19%, non-European automakers see their market share roughly double and profits grow by 50 percent. We view this evidence that the emissions policy employed by European regulators not only promoted the diffusion of diesel vehicles, but also provided European automakers a comparative advantage and acted as a non-tariff trade barrier – limiting imports of foreign vehicles while increasing the profitability of domestic manufacturers.

Our model predicts that the equivalent import tariff of this trade barrier is substantial: 37% for the Spanish sample employed in our estimation. Extrapolating our model to the entire region provides an even starker result as a 56% import tariff would be required to limit the market share of vehicle imports to the average market penetration in Europe during the 1990s (8.6%). These results are important as they provide evidence that in a world with ever more free trade agreements, national policies such as environmental regulations might be used as a tool to favor local manufacturers over competitive imports, *e.g.*, Ederington and Minier (2003).

We test the robustness of our results by considering several alternative environments. First, we consider intermediate counterfactuals where sales of diesel vehicles are increasingly restricted, initially to European firms, then German manufacturers, then only Volkswagen, and finally no firm produces diesels. Thus, we evaluate the consequences of increasingly stringent emission policies by measuring their impact, as predicted by our model, relative to the market outcome under the actual, less stringent European policy. Second, we test whether allowing firms to retrofit their diesel vehicles with a NO_x scrubbing technology (a technology which did not exist in 2000) alters our results and find little quantitative effects as even small retrofitting expenses make diesel vehicles prohibitively expensive to consumers. Finally, we show that while the favorable tax treatment of diesel fuel in Europe does encourage sales of diesel vehicles, its overall effect, less than 5% of the market, is significantly smaller than any of the evaluated emissions policies.

[7] For the American reader these figures may seem exceedingly high, *e.g.*, the average fuel economy in 2008 for new cars and light trucks the U.S. was only 26.4 miles per gallon. However, the reported European mileage is in line with the common average consumption in Europe. It corresponds to 5.81 and 5.16 liters per 100km, respectively. There are two reasons that explain this large difference. First, European automobiles are smaller and more fuel efficient. Second, the way fuel consumption is measured in Europe exacerbates this difference as it only accounts for highway driving at a constant speed of 90km/h rather than the 40/60 U.S. mix of highway and city driving.

Our work is related to the empirical literature on innovation and customer adoption of durable goods (*e.g.*, Carranza 2010, Goettler and Gordon 2011, Gowrisankaran and Rysman 2012) which estimate the mechanics of customer adoption using dynamic models and detailed data on consumer purchases. Unfortunately, our data is not conducive to this empirical approach since the introduction of new automobiles occurs less frequently than most consumer goods (*e.g.*, digital cameras, computer processors, camcorders) and their replacement also takes longer – frequently exceeding the length of our sample. We instead use an approach similar to the one employed by Berry and Jia (2010) and compare the estimated equilibria at the early adoption stage (1992-1993) and the mature market (1999-2000). This approach both generates reasonable estimation results and is sufficient to decompose the effects on sales, profits, prices, markups, and imports from changes in the emission policy versus other factors.

Our work also builds on the literature related to the interaction of domestic policy and international trade. The seminal contribution here is Bhagwati and Ramaswami (1963) who address the substitutability between domestic policy and import tariffs. More recent works (*e.g.*, Staiger 1995, Bagwell and Staiger 2001, Deardorff 1996, Thurk 2014) take a more game theoretic approach and show that countries can use their domestic policies to extract rents from the rest-of-the-world leading to a suboptimal aggregate outcome. Our work builds on these papers by being, to the best of our knowledge, the first application of equilibrium models commonly used in empirical industrial organization to provide evidence of rent-seeking by countries using domestic policy. Moreover, our calculation of the tariff equivalence of the environmental regulation considered here provides evidence that domestic policy can be an effective replacement for traditional trade barriers such as import tariffs.

The paper is organized as follows. In section 2, we describe differences between environmental regulations in the United States and Europe, discuss the new TDI technology, and analyze in detail the features of the Spanish automobile market during the 1990s. Section 3 describes the equilibrium model of discrete choice demand for horizontally differentiated products to be estimated. Section 4 reports the estimation results, summarizes the main findings, and shows that the generality of the TDI technology erodes Volkswagen's profits substantially. Section 5 identifies the degree to which changes in demand, supply, and market structure can explain changes in the European automobile industry, particularly in relation to the diffusion of diesel vehicles. Section 6 evaluates counterfactuals associated to different emission standards where sales of diesel vehicles are increasingly restricted; the market configurations of complying with the NO_x emission standards at increasingly higher retrofitting costs; and the tariff-equivalence estimate of the non-tariff barrier component of the lenient European NO_x emission standards. We also show that the heavier European fuel taxation is not sufficient to explain the massive shift in the composition of sales, from gasoline to diesel, during the 1990s. Finally, Section 7 concludes.

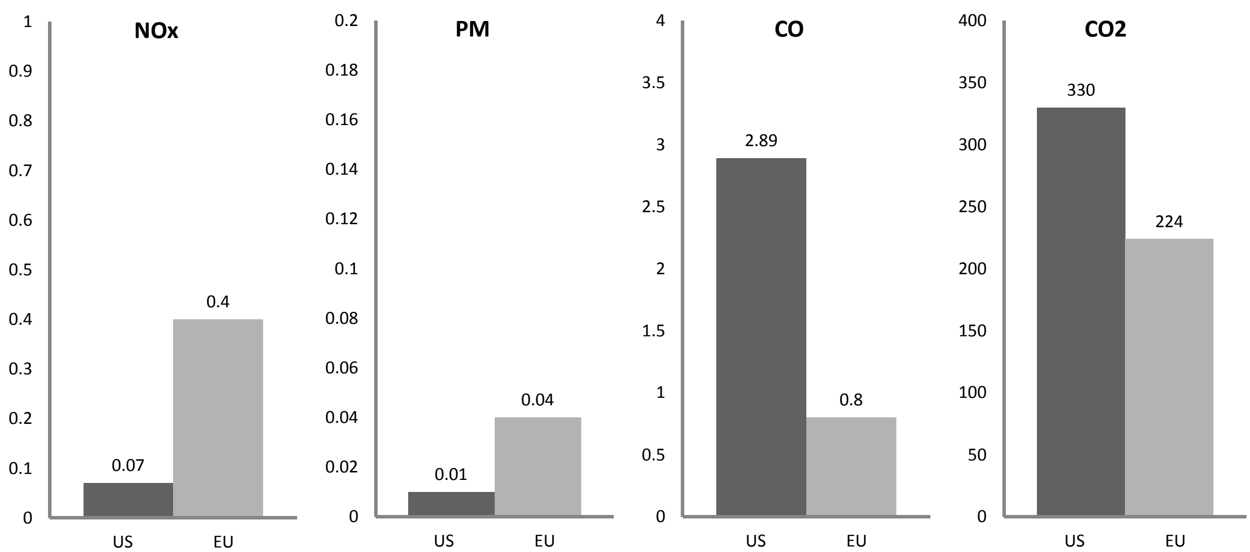
2 Data

In this section we first document the difference in emission standards in Europe and the United States. We then describe the TDI innovation and the fast diffusion of diesel engines in Europe and the features of the Spanish automobile market that we use for our empirical analysis.

2.1 Vehicle Emissions Standards in the United States and Europe

Figure 1 illustrates the differences in emissions standards between the United States and Europe in the year 2000.[8] In the United States, the approval of the 1990 Clean Air Act Amendments (CAAA) directed the U.S. Environmental Protection Agency (EPA) to, among many other things, reduce acid rain produced by nitrogen oxide (NO_x) and sulfur dioxide (SO_2). The EPA, therefore, chose a policy largely aimed at power generating plants which set emission reduction goals (Title IV-A) and established a cap-and-trade system (Title V), but it also translated into an ever more stringent NO_x emission standards for light-duty vehicles (Title II-A).

Figure 1: Europe and U.S. Emissions Standards



Source: www.dieselforum.org. All statistics are for the year 2000 and are in grams per mile. "NOx" refers to nitrogen oxide limits; "PM" to particulate matter; "CO" carbon monoxide; and "CO2" carbon dioxide.

European regulators took a different approach and chose a less stringent NO_x emission standard. While in 1994 U.S. Tier 1 standard allowed NO_x emissions of 1 gram per mile (g/mi),

[8] European authorities set NO_x and particulates matter (PM) standards for each vehicle while U.S. authorities set at a fleet-wide limit. As for CO and CO_2 emissions, these depend on fleet average fuel consumption standards and are reported in Figure 1 as realized fleet-wide levels. See Section IV of the 2001 report: "Demand for Diesels: The European Experience. Harnessing Diesel Innovation for Passenger Vehicle Fuel Efficiency and Emissions Objectives" available at www.dieselforum.org.

the Euro I standard was 1.55g/mi. By year 2000, the U.S. policy allowed only 0.07g/mi while the Euro III standard set the NO_x emission level at a far less demanding 0.4g/mi level. The differences between the U.S. and European standards are significant for automobiles since reducing NO_x emissions is much harder for diesel engines as the three-way catalytic converters used in gasoline engines cannot cope with the high concentrations of NO_x generated by diesel engines (*e.g.*, Canis 2012). The fast diffusion of diesel vehicles in the 1990s likely also enabled European authorities to choose more stringent CO_2 emission standards than the United States.

These differences proved crucial for diesel vehicles as most produced emissions that were acceptable in Europe but in violation of standards established by the EPA. According to Stewart (2010), the NO_x emissions level of the least polluting diesel model available in Canada, the Volkswagen *Jetta* (known as *Bora* in Europe), was 0.915 and 0.927g/mi for the 1991 and 1997 year models, respectively. This indicates that the NO_x emissions standards imposed by the EPA were indeed binding constraints for diesel vehicles since even the cleanest diesel models barely met the 1994 U.S. emission standards and would have generated NO_x emissions thirteen times greater than the 2000 limit. Only in 2010 did the EPA finally address the issue of NO_x emissions from diesel vehicles by requiring the installation of an urea-based selective catalytic reduction that injects an aqueous solution into the vehicles' exhaust stream to "scrub" NO_x emissions. Since then, automakers have introduced more diesel models into U.S. market, including those states that adhere to the even more demanding California emission standards.

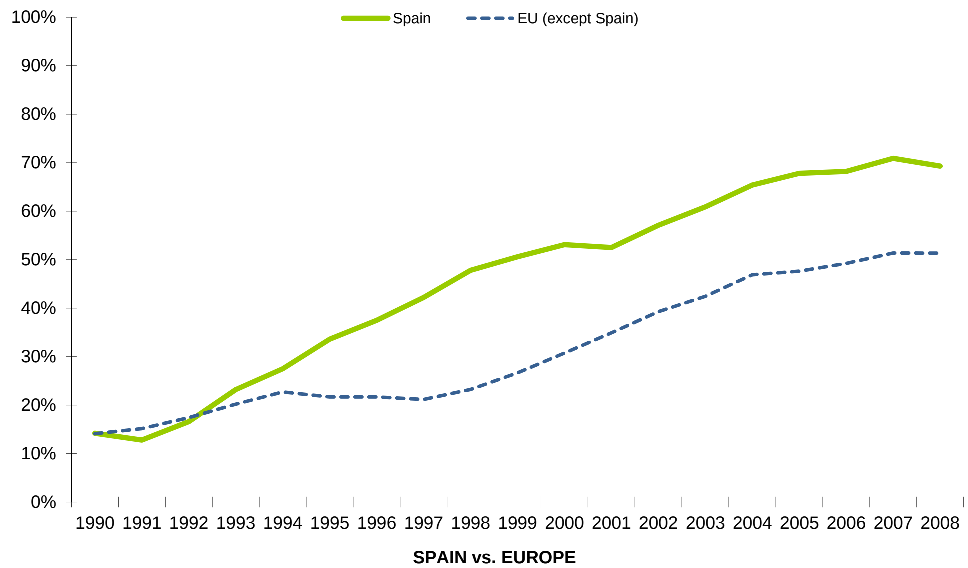
2.2 The European Market for Diesel Automobiles

Diesel technology has powered ships, trains, heavy machinery, as well as light trucks and automobiles for over a century.[9] In 1989, Volkswagen introduced the TDI technology in its 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 allows for greater engine performance while providing more torque at low r.p.m. than alternative gasoline engines. They are also credited with being more durable and reliable.[10] In addition, during the 1990s, engineers figured out how to build lighter diesel engines and powered very small models with this alternative fuel. Following this major technological breakthrough, Europeans massively embraced diesel automobiles, with their

[9] In the late 19th 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 the development of the engine for trucks and automobiles possible. The first diesel vehicles sold commercially where the 1933 Citroën Rosalie and the 1936 Mercedes-Benz 260D.

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

Figure 2: Diesel Penetration in Europe and Spain



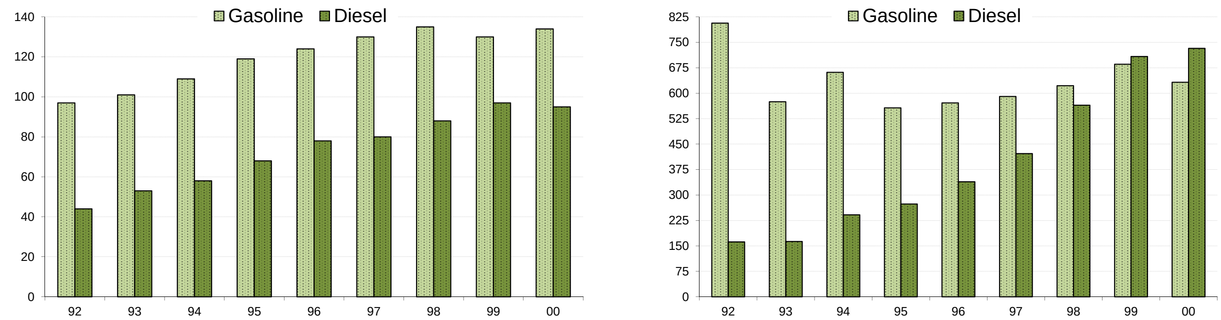
Source: *Automobile Registration and Market Share of Diesel Vehicles:* "ACEA European Union Economic Report," December 2009.

market share growing from as little as 10% to sometimes over 70% of annual sales as shown in Figure 2. High fuel cost and a favorable tax treatment of diesel fuel certainly favored the adoption of this new technology. Also, the fact that diesel pumps are available in every gas station eases access to refueling stations. Finally, long-term subsidization of diesel fuel in Europe led automobile manufacturers to sell diesel models well ahead of the introduction of the TDI. Therefore, at the time of the TDI innovation, it was easy to find mechanics trained to service these vehicles, thus reducing the cost of buying a diesel.

2.3 Evolution of Automobile Characteristics in Spain

Our data is of yearly car registrations by model and fuel engine type in Spain between 1992 and 2000. After excluding a few models, mostly luxury vehicles with extremely small market shares, our sample is an unbalanced panel comprising 99.2% of all car registrations in Spain during the 1990s. Spain was the fifth largest automobile manufacturer in the world during the 1990s and also the fifth largest European automobile market after Germany, France, the United Kingdom, and Italy. Figure 2 demonstrates that the adoption of the TDI in Spain followed a similar trend as the rest of Europe. The analysis of the Spanish automobile market can thus be viewed as approximately representative for the European diffusion of diesel vehicles during the 1990s.

Figure 3: Automobile Models and Sales by Year and Fuel Type



(a) Models Available (b) Sales (thousands of vehicles)

Figure 3 captures the dynamics governing the automobile industry in Spain during the 1990s. Notice that by 1992, manufacturers already offered 44 diesels out of 141 models sold. Such a rapid introduction of diesel models just three years after the commercialization of the TDI may hint at automobile manufacturers fearing business stealing much more than the consequences of cannibalizing the sales of their own gasoline models. It also suggests the inability of VOLKSWAGEN to prevent imitation of the TDI by the competition. Notice also that the number of models available grew significantly, both in the gasoline and the diesel segments. The effective entry of Asian manufacturers during the early 1990s contributed increased the number of gasoline models by about 30%, thereby increasing competition in this segment.[11] Gasoline models were still, at the end of the decade, more numerous than diesel vehicles but diesel models were always abundant enough to give consumers a real choice among competing technologies. Since the entry of new models should reduce markups, consumers benefit from both an increase in variety and lower prices.

Table 1 summarizes the features of vehicles sold in the Spanish automobile market and their evolution during the 1990s. Overall, diesel vehicles are about 10% heavier than similar gasoline versions. Diesel and gasoline versions of a particular model have the exact same size although the latter are lighter. Since European vehicles are smaller than those sold in the U.S., they use smaller engines that have less horsepower but also more fuel efficient. Diesel models have 15% to 20% less horsepower than gasoline vehicles and are between one and two thousand Euros more expensive.

Overall, sales of automobiles are 46% higher at the end of the decade, from 968,334 to 1,364,687 units sold annually. However, sales of gasoline models were essentially identical in 1993 and 1995, about 573,000, despite the 1994 scrappage program, when they temporarily increased by 15%. Since then, sales of gasoline models increased at a steady pace, between 3% and 10% a year until 1999 but they never reached the 1992 peak level again. The evolution of sales of diesel automobiles is starkly different. Initially in 1992, they only represented 16% of total sales. After the scrappage programs were implemented, they grew at rates between 13% and 25% a year between

[11] Asian imports include DAEWOO, HONDA, HYUNDAI, KIA, MAZDA, MITSUBISHI, NISSAN, SUZUKI, and TOYOTA.

Table 1: Car Model Characteristics Across Engine Types

ENGINE	MODELS	SHARE	PRICE	C90	SIZE	HPW
1992-1993						
EU: DIESEL	93	18.9	12.6	4.5	74.0	31.4
EU: GASOLINE	148	76.6	11.5	5.4	71.7	40.9
NON-EU: DIESEL	4	0.2	14.4	5.3	80.9	29.2
NON-EU: GASOLINE	50	4.4	14.1	5.8	76.8	44.0
ALL	295	100.0	11.8	5.3	72.4	39.2
1999-2000						
EU: DIESEL	153	49.8	16.0	4.6	76.2	31.4
EU: GASOLINE	170	38.4	14.7	5.7	73.2	38.6
NON-EU: DIESEL	39	2.5	16.9	5.5	82.1	31.1
NON-EU: GASOLINE	94	9.3	13.5	6.1	75.2	40.9
ALL	456	100.0	15.3	5.2	75.1	35.0

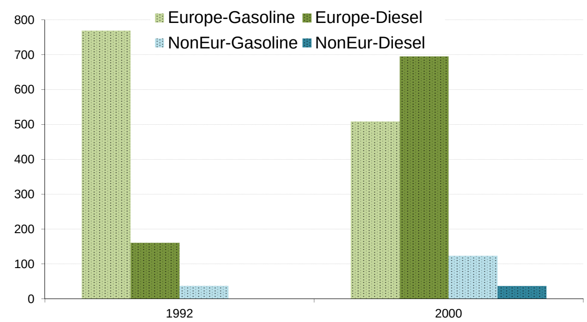
Statistics weighted by relevant quantity sold. PRICE is denominated in the equivalent of thousands of 1994 Euros and includes tariffs. C90 is the fuel consumption in liters to cover 100 km at a constant speed of 90 km/h on highway conditions. SIZE is length×width measured in square feet. HPW is the performance ratio of horsepower to thousand pounds of weight.

1994 and 1999 depending on segments. Thus, by the end of the decade diesels represented 54% of the market, as they grew from 161,667 to 732,334 units sold in years 1992 and 2000, respectively.

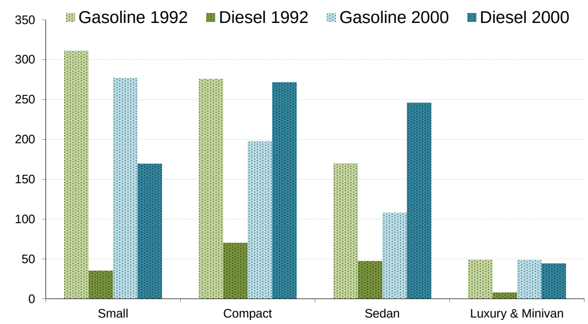
For this new technology to succeed as it did, diesel vehicles need to be seen as desirable in many ways, and not only regarding fuel economy. Diesel vehicles consume 20%-40% less fuel than gasoline models, leading to savings of about 35% in the cost of driving. However, relative fuel savings were reduced in the second half of the 1990s. Gasoline price increased by 50% in real terms between 1992 and 2000 (half of the increase taking place in year 2000) while the price of diesel fuel increased by 56% during the same period. Thus, the relative price of diesel and gasoline prices change little across our two samples.

All vehicles became larger during the decade but diesels made some inroads in the smaller segments as technology allowed building smaller diesel engines. Diesel vehicles also became more powerful to compensate the increase in weight associated to diesel engines and the increase in size. On the contrary, performance —the HP to WEIGHT ratio— of gasoline models almost universally worsened over the decade as vehicles became larger and heavier. All these hints at diesel vehicles becoming better products capable of attracting the interest of many drivers. Diesel engines are also reputed for high torque, excellent reliability, and longer durability than gasoline engines. These are unobservable features that could also be favorably compared against the increased weight and lower power of diesel vehicles. The change in the distributions of these automobile characteristics is shown in Figure W.2 in the Web Appendix.

Figure 4: Automobile Sales by Segment, Fuel Type, and Geographic Origin



(a) Sales by Year (thousands of vehicles)



(b) Sales by Segment (thousands of vehicles)

Figure 4 completes our description of the drastic changes in the Spanish automobile market. Figure 4 (a) shows how the production pattern of European manufacturers is turned upside down in just a few years. A quarter of a million fewer gasoline vehicles were sold by the end of decade while the production of diesel models increased by over half a million units, almost quadrupling production earlier in the decade.

Still diesel demand became sufficiently large by the end of the decade that Non-European automakers[12] began introducing their own diesel models. Since they had not invested in the technology earlier, their diesel models incorporated engines purchased from European automakers.[13] Figure 4 (b) further explores the transformation of sales at the car segment level.[14] Notice that only in the SMALL segment are sales of gasoline models larger than their diesel counterparts by 2000. Even in the LUXURY and MINIVAN segment niches, diesels are on par with gasoline vehicles. The largest transformation happens in the COMPACT and SEDAN segments where sales of gasoline vehicles plummet while sales of diesels quintuplicate within few years.

In our estimation we account for three additional issues that change during the 1990s: increasing personal income, import duties, and the ownership structure of the European automobile industry. When estimating the model we modify both the incomes of consumers to account for growth in the Spanish economy and the marginal cost equation to control for the differentiated

[12] CHRYSLER is the only non-Asian imported brand. Thus, we use the terms "Asians" or "non-Europeans" when referring to imports. CHRYSLER sold its production facilities to PEUGEOT in 1978 and since then the few models sold in Europe are imported from the United States. On the contrary FORD and GM are considered European manufacturers. FORD has 12 manufacturing plants and has been continuously present in Europe since 1931. GM entered the European market in 1911, acquired the British brand Vauxhall and the German Opel in the 1920s and today operate 14 manufacturing facilities in Europe.

[13] See Busser and Sadoi (2004, Footnote 2). Demand for diesel vehicles in their countries of origin was so small that Asian manufacturers acquired engines from other European firms as a less costly way to satisfy local European demand rather than investing in the development of diesel engines from scratch.

[14] Other than the LUXURY segment, which also includes sporty cars, 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.

import taxation faced by manufacturers depending on their national origin. Similarly, we also control for the corresponding ownership structures at the beginning and end of the decade when defining the multi-product first-order profit maximization conditions of the equilibrium model to be estimated. Our counterfactual analysis, therefore, can also evaluate the role of changes in these factors on the equilibrium outcome, in particular as related to the diffusion of diesel vehicles. See Table A.1 in Appendix A for further details on import tariffs and mergers in the European automobile industry during the 1990s.

3 An Equilibrium Oligopoly Model of the Automobile Industry

Our estimation approach follows Berry and Jia (2010). We estimate two static equilibrium, discrete choice oligopoly models of horizontally differentiated products put forward by Berry, Levinsohn and Pakes (1995) and now used widely. The idea is to take two snapshots of a market that is evolving quickly and combine the parameters of the two estimations to quantify the effect of the different components of the model.

Consumer i derives an indirect utility from buying vehicle j at time t that depends on price and characteristics of the car:

$$\begin{aligned} &u_{ijt} = x_{jt}\beta^*_{it} - \alpha^*_{it} p_{jt} + \xi_{jt} + \epsilon_{ijt}\,, \\ &\text{where } \; i = 1, \ldots, I_t; \quad j = 1, \ldots, J_t; \quad t = \{1992 - 1993, 1999 - 2000\}\,. \end{aligned} \tag{1}$$

This Lancasterian approach makes the payoff of a consumer depend on the set of characteristics of the vehicle purchased, which includes a vector of n observable vehicle characteristics x_{jt} as well as others that remain unobservable for the econometrician, ξ_{jt}, plus the effect of unobserved tastes of consumer i for vehicle j, ϵ_{ijt}, which is assumed i.i.d. extreme value distributed. We allow for individual heterogeneity in response to vehicle prices and characteristics by modeling the distribution of consumer preferences over characteristics and prices as multivariate normal with a mean that shifts with consumer attributes:[15]

$$\begin{pmatrix} \alpha^*_{it} \\ \beta^*_{it} \end{pmatrix} = \begin{pmatrix} \alpha_t \\ \beta_t \end{pmatrix} + \Pi_t D_{it} + \Sigma_t \nu_{it}\,, \quad \nu_{it} \sim N(0, I_{n+1})\,. \tag{2}$$

Consumer i in period t is characterized by one unobserved and a d vector of observed demographic attributes, D_{it} and ν_{it}. In our case, we allow the estimate of the slope and intercept of demand to vary with per capita income. Π_t is a $(n+1) \times d$ matrix of coefficients that measures

[15] Random coefficients generates correlations in utilities for the various automobile alternatives that relax the restrictive substitution patterns generated by the Independence of Irrelevant Alternatives property of the logit model.

the effect of income on the consumer valuation of automobile characteristics, *e.g.*, average valuation and price responsiveness. Similarly, Σ_t measures the covariance in unobserved preferences across characteristics. We decompose the deterministic portion of the consumer's indirect utility into a common part shared across consumers, δ_{jt}, and an idiosyncratic component, μ_{ijt}. These mean utilities of choosing product j and the idiosyncratic deviations around them are given by:

$$\delta_{jt} = x_{jt}\beta_t + \alpha_t p_{jt} + \xi_{jt} \, , \tag{3a}$$

$$\mu_{ijt} = \begin{pmatrix} x_{jt} & p_{jt} \end{pmatrix} \times \left(\Pi_t D_{it} + \Sigma_t \nu_{it} \right) \, . \tag{3b}$$

Consumers choose to purchase either one of the J_t vehicles available or $j = 0$, the outside option of not buying a new car with zero mean utility, $\mu_{i0t} = 0$. We therefore define the set of individual-specific characteristics leading to the optimal choice of car j as:

$$A_{jt}\left(x_{\cdot}, p_{\cdot t}, \xi_{\cdot t}; \theta\right) = \left\{ \left(D_{it}, \nu_{it}, \epsilon_{ijt}\right) | u_{ijt} \geq u_{ikt} \quad \forall k = 0, 1, \ldots, J_t \right\} \, , \tag{4}$$

with θ summarizing all model parameters. The extreme-value distribution of random shocks allows us to integrate over the distribution of ϵ_{it} to obtain the probability of observing A_{jt} analytically. The probability that consumer i purchases automobile model j in period t is:

$$s_{ijt} = \frac{\exp\left(\delta_{jt} + \mu_{ijt}\right)}{1 + \sum\limits_{k \in J_t} \exp(\delta_{kt} + \mu_{it})} \, . \tag{5}$$

Integrating over the distributions of observable and unobservable consumer attributes D_{it} and ν_{it}, denoted by $P_D(D_t)$ and $P_\nu(\nu_t)$, respectively, leads to the model prediction of the market share for product j at time t:

$$s_{jt}(x_t, p_t, \xi_t; \theta) = \int_{\nu_t} \int_{D_t} s_{ijt} dP_{D_t}(D_t) dP_{\nu_t}(\nu_t) \, , \tag{6}$$

with s_{0t} denoting the market share of the outside option.[16]

The industry is characterized by multi product automobile manufacturers behaving as oligopolistic, non-cooperative, profit maximizers. We assume that marginal costs depend linearly on observable model characteristics z_{jt} and some unobservable characteristics summarized by ω_{jt}:

$$\ln(mc_{jt}) = z_{jt}\gamma_t + \omega_{jt} \, . \tag{7}$$

[16] 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 to 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 of the decade and accelerated growth of the second half. Thus, our outside option accounts for both the yearly automobile sales and the increasing total number of households. In the estimation we use the values of 0.92 and 0.94 for s_0 in 1992 and 1993, respectively and 0.89 for the mature market in 1999-2000.

For each time period, first-order conditions of profit maximization are a nonlinear function of market shares $s_{jt}(x_t, p_t, \xi_t; \theta)$ of each model, their retail prices, and markups:[17]

$$\frac{p_{jt}}{1+\tau_{jt}} = mc_{jt} + \underbrace{\Delta_t^{-1}(p, x, \xi; \theta) s_{jt}(p, x, \xi; \theta)}_{b_{jt}(p,x,\xi;\theta)} . \tag{8}$$

where τ_{jt} is the year-specific import duty applicable to each model, if any; $b_{jt}(\cdot)$ is the vector of equilibrium markups; $s_{jt}(\cdot)$ is the vector of market share estimates for each vehicle-year pair; and $\Delta_t(\cdot)$ is the ownership matrix with elements:

$$\Delta_{rjt}(x_t, p_t, \xi_t; \theta) = \begin{cases} \partial s_{jt}(x_t, p_t, \xi_t; \theta)/\partial p^{\tau}_{jt}, & \text{if products } \{r, j\} \text{ produced by the same manufacturer}, \\ 0 & \text{otherwise}. \end{cases} \tag{9}$$

where p^{τ}_{jt} is the price chosen by the firm not including any applicable import tariffs paid by the consumer.[18] The cost equation then becomes:

$$\ln(mc_{jt}) = \ln\left[\frac{p_{jt}}{1+\tau_{jt}} - b_{jt}(p, x, \xi; \theta)\right] = z_{jt}\gamma_t + \omega_{jt} . \tag{10}$$

4 Estimation

Estimation is now standard and described in detail in Berry et al. (1995, §6). For each year t we first compute δ_{jt}. (Berry et al., 1995, Appendix I) shows that the vector of mean product valuations $[\delta_{jt}]$ is a contraction mapping which can be computed recursively given consumer preferences $[\beta_t, \Pi_t, \Sigma_t]$ over characteristics $[x_{jt}]$ and prices $[p_{jt}]$ as well as the empirical distribution of vehicle market shares $[s_{jt}]$. Instrumental variable regression estimation of equation (3a) then produces a vector of consistent unobservable product characteristics estimates $[\xi_{jt}]$.[19] Next we solve for the implied markups $[b_{jt}]$ and combine these with our guess of $[\gamma_t]$ in (10) to recover the cost side unobservable $[\omega_{jt}]$. Finally we interact the optimal instruments with the vector of $[\xi_{jt}\ \omega_{jt}]$ to obtain θ_t for each sample period by generalized method of moments estimation. As we described below, we considered several combinations of instruments, a large variety of initial conditions, and several convergence criteria to ensure that our estimates are robust.

[17] The complete derivation of these general first-order conditions is available in Berry et al. (1995, §3).

[18] This treatment of the import tariffs is consistent with how duties are applied in practice. Since the consumer pays the import tariff, foreign firms choose p^{τ}_{jt} but consumers face retail price $p_{jt} = (1 + \tau_{jt})p^{\tau}_{jt}$.

[19] On the need for instrumenting and robustness of results regarding instruments and convergence criteria, see the discussion in Section 4.2.

4.1 Parameter Identification

Variation in prices conditional on similar product characteristics identifies the product price elasticities while cross-price elasticities are identified by differential changes in prices & quantities across products with similar characteristics. Variation between product characteristics and sales pins down the mean utility parameters (β) so diesel market share conditional on other product characteristics identifies consumer preferences for diesel engines (β_{DIESEL}). The interaction between product characteristics (*e.g.*, price) and distribution of demographics identifies the interaction coefficients (Π). The Bertrand-Nash equilibrium plus variation in price elasticities conditional on product characteristics identifies marginal costs (γ). Finally, variation across time identifies changes in the point estimates.

4.2 Instruments and Robustness

The need for instrumenting arises from the fact that observed prices reflect the effect of unobservable product characteristics. Thus, p_{jt} and ξ_{jt} are not orthogonal and simple ordinary least squares regression of (3a) will produce biased estimates. Automobile prices are then commonly instrumented with their product characteristics, sums of these characteristics for other models produced by the same firm, as well as those of competitors. The idea is that these product characteristics are exogenous, at least in the short run, and help determine the nature of competition and the ability of firms to charge a higher or lower markup depending on the product positioning of competitors. Adding cost characteristics account for cost shifters that also influence pricing.

Using all product characteristics is known to easily lead to serious multicollinearity problems, *e.g.*, Berry et al. (1995, §5). Thus we only use HPW and FUEL as demand instruments while ln HP and ln WEIGHT are used to instrument for cost shifts.[20] We also include their averages for other models produced by the firm and competitors, respectively.[21] Demand instruments are averaged separately for vehicles with different fuel engine types as suggested by Bresnahan, Stern and Trajtenberg (1997). As for supply, we average them across market segments. In addition, we also include the percent of year 2000 firm profits attributable to diesel engines to instrument for prices in 1992-1993. This additional instrument for the early market aims at controlling for the possibility of dynamic pricing considerations, *e.g.*, lowering prices of diesel vehicles initially to favor their adoption leading to larger markups in later periods.

[20] HPW is horsepower divided by vehicle weight. FUEL is the consumer cost of driving 100km, *i.e.*, C90 times the final price of a liter of gasoline or diesel fuel. This final price includes fuel taxes.

[21] We use averages rather than sums to ease scaling problems that might appear in the estimation.

We estimated the model using this benchmark instrumentation with those obtained using other alternatives. We added DIESEL and/or SEAT as additional demand shifters and the number of products sold as another cost shifter that can account for potential economies of scope or costs differential perhaps related to the size of the distribution network of the automobile manufacturer. To address the possibility of persistence we considered the average lagged vehicle price by segment and fuel type. More interestingly, we also included a quadratic polynomial in SIZE, the characteristic not used in the averages across manufacturers, fuel types and segments. Reynaert and Verboven (2013) suggest this approach to approximate the optimal instruments of Chamberlain (1987). Estimates do not vary significantly across combinations of all these instruments, which we read as our results being quite robust to the available instruments. A second source of concern is how sensitive our results to convergence criteria and search algorithms are. Again, results appear to be quite robust.[22] Finally, our evidence appears to indicate that our estimates belong to a global rather than a local optimum.[23]

4.3 Estimation Results

We estimate our model twice. First for the earlier sample period of 1992-1993 when diesel vehicles, while widely available but not embraced by consumers. The second estimation makes use of the last two years of our sample, 1999-2000. By then, diesel sales dominated the market and we can safely assume that learning among consumers or dynamic pricing considerations are no longer relevant.

Table 2 reports the results of these two estimations. Estimates are reasonable. Drivers consistently favor vehicles with better performance, HPW, and lower fuel consumption, FUEL (Euros per kilometer). Starting with smaller cars in 1992, SIZE is positively valued early in the 1990s but not so much by year 2000, once vehicles have indeed become larger. Consumer preferences are heterogeneous regarding the size of vehicles they purchase but the increase in the dispersion of its distribution ensures that a substantial share of customers still prefer larger cars by the end of the decade. Two additional factors become significant with the passing of the 1990s. First, Spaniards

[22] We first use a non-derivative, simplex Nelder-Mead search algorithm in our estimation. A gradient-based quasi-Newton method produces very similar estimates although the final value of the objective function is slightly lower. We follow Dubé, Fox and Su (2012) and set the norm for the mean value contraction equal to 1E-14 in order to ensure convergence to consistent stable estimates. We increased it up to 1E-10 without any effect on the estimates. For a more strict 1E-16 tolerance level the computation of the inner fixed point failed to converge. As for the tolerance of the objective function we set a 1E-05 criteria, more demanding than the 1E-03 of Knittel and Metaxoglou (2013). We also estimated the model setting this tolerance level at 1E-08. Results were identical although the computation time increased substantially.

[23] We follow Knittel and Metaxoglou (2013) and generate one hundred initial guess for the (π, σ) parameters using draws from normal distributions with different dispersions. Figure W.1 in the Web Appendix shows the empirical distribution of the value of the estimated objective functions, which is highly concentrated around the value obtained in our estimation. The minimum value found in this exercise is slightly lower but significant parameter estimates are statistically identical to our benchmark case. Table W.1 in the Web Appendix summarizes these robustness checks.

Table 2: Model Estimates

Variable	1992-1993 Coefficient	1992-1993 Rob.SE	1999-2000 Coefficient	1999-2000 Rob.SE
Mean Utility (β)				
β_{CONSTANT}	-9.4491	$(1.6363)^{***}$	-18.7681	$(3.6994)^{***}$
β_{HPW}	5.3124	$(1.4274)^{***}$	7.8394	$(1.3361)^{***}$
β_{FUEL}	-5.1178	$(3.0978)^{*}$	-2.2513	$(0.8782)^{**}$
β_{SIZE}	3.5752	$(2.0849)^{*}$	-1.2612	(1.6017)
β_{SEAT}	0.5528	(0.4984)	0.9057	$(0.3406)^{***}$
β_{DIESEL}	-0.4828	(0.4618)	0.6341	$(0.3161)^{**}$
Cost (γ)				
γ_{CONSTANT}	-0.4585	$(0.1257)^{***}$	-0.2118	$(0.0782)^{***}$
$\gamma_{\ln \text{HP}}$	1.6453	$(0.2736)^{***}$	1.5691	$(0.1395)^{***}$
$\gamma_{\ln \text{SIZE}}$	1.3449	$(0.5660)^{**}$	0.3290	(0.3376)
γ_{DIESEL}	0.6744	$(0.1788)^{***}$	0.6278	$(0.0936)^{***}$
Standard Dev. (σ)				
σ_{CONSTANT}	0.8149	(1.0760)	10.6721	$(2.3585)^{***}$
σ_{SIZE}	0.7428	(1.1535)	5.9472	$(0.4080)^{***}$
Interactions (Π)				
$\pi_{Price/Income}$	-2.9857	$(0.8164)^{***}$	-2.3155	$(0.3131)^{***}$
Elasticity Statistics:				
- Sales-weighted Average	2.6		3.1	
- Median	2.4		3.1	
- Maximum	10.7		7.5	
- Minimum	1.4		1.6	
Estimation Statistics:				
- χ^2 (df)	15.95 (8)		31.86 (7)	
- Instruments	BLP, 2000 Profits		BLP	
- Observations	295		456	
- Agents	1000		1000	

Significant estimates with p-values less than 0.1, 0.05, and 0.001 are identified with ***, **, and *, respectively. For 1992-1993 instruments include the percent of year 2000 firm profits attributable to gas or diesel engines to control for dynamic considerations of early pricing decisions.

developed a taste for the only domestic brand, SEAT. This local manufacturer was acquired by VOLKSWAGEN in 1989 and as the decade progressed their models were increasingly equipped with better quality German engines. Second, and more important for our analysis, a positive perception of DIESEL vehicles developed as their share of sales increased. Regarding costs, they are increasingly higher for DIESEL engines and more powerful vehicles but there is no evidence of economies of scale.[24] Interestingly enough, the cost of manufacturing larger cars becomes negligible, something

[24] In addition to the characteristics used in the estimation reported in Table 2, we also considered the aggregate output of each model in the European market aggregating sales by model (not distinguishing by fuel type) from Belgium, France, Germany, Italy and United Kingdom to Spanish sales using Frank Verboven's data available at `http://www.econ.kuleuven.be/public/ndbad83/frank/cars.htm`. This measure of scale was never significant though, implying that automobile manufacturers enjoy Europe-wide constant returns to scale.

that may help explaining the increasing trend favoring large car sizes documented in Table 1. Our estimation results also indicates that demand is downward slopping and that it becomes steeper as time goes by (Π estimates). Although this does not necessarily mean that demand is less elastic at equilibrium prices as there are many other demand shifters described above, the elasticity estimates reported at the second lower panel indeed indicate that demand is, on average, more elastic in year 2000 than in 1992.

4.4 How Much was the TDI Worth to Volkswagen?

A natural question our model can address is whether the introduction of the TDI technology was profitable for VOLKSWAGEN. Evidently, TDI was patented, but its generality, could help others, such as PSA in the mid-nineties, to come up with successful, high performance, diesel-based, engine alternatives. A not so difficult process of reverse engineering might have allowed competitors to limit VOLKSWAGEN's ability to appropriate the rents necessary to develop the TDI engine, therefore questioning the wisdom of such innovation strategy in the first place.[25] The counterfactual analysis summarized in Table 3 leaves little room for doubt that introducing the TDI technology was a profitable decision and that indeed VOLKSWAGEN captured a significant share of the potential innovation rents.

To evaluate the profitability of TDI for VOLKSWAGEN, we make use of two counterfactuals. One considers the possibility that diesels are either not allowed by regulators, or were simply never developed by any automobile manufacturer. Under this scenario VOLKSWAGEN's profits almost double from its actual 2000 gasoline segment profits: from bn€1.5 to bn€2.9. This is the direct result of almost doubling its sales of gasoline vehicles because the price of its gasoline models remains basically unchanged. Yet, without the ability to commercialize its TDI technology, VOLKSWAGEN's total profits would be about bn€1 lower.

In order to determine how much of the innovation rents VOLKSWAGEN was able to secure, we need to evaluate another counterfactual where the TDI technology is assumed to be exclusive for VOLKSWAGEN and where competitors cannot come up with close substitutes in the diesel segment. We thus remove all 2000 diesel models other than those produced by the VOLKSWAGEN group, which now enjoys monopoly power over that market segment. Profits then become substantially larger for VOLKSWAGEN under such scenario, up to bn€5.8. Thus, the value of the innovation rents amount to bn€3, of which VOLKSWAGEN is currently capturing almost bn€1. Thus, VOLKSWAGEN is still able to keep 31% of the potential rents of the TDI innovation under a more strict patent

[25] It is the generality of this technology what allows it to be imitated and reused easily by other manufacturers, a good example of limited appropriability of profits of innovations of general purpose technologies that can be recombined and reused in other applications. See Bresnahan (2010).

Table 3: Value of TDI Technology to Volkswagen

Experiment	No Diesel	Benchmark	Monopoly
Prices (€Thousand)	19.71	19.90	20.91
- Diesel	-	19.92	20.94
- Gas	19.71	19.88	20.88
Quantity (Thousand)	497.54	630.01	828.25
- Diesel	-	371.43	491.42
- Gas	497.54	258.58	336.84
Market Share (%)	20.18	22.88	32.53
- Diesel	-	25.83	100.00
- Gas	20.18	19.66	16.39
Markup (%)	62.00	62.25	71.98
- Diesel	-	61.26	70.86
- Gas	62.00	63.21	73.07
Profit (€Million)	2,891.32	3,815.49	5,846.47
- Diesel	-	2,299.94	3,547.05
- Gas	2,891.32	1,515.55	2,299.41

Price is in the equivalent of thousands of 1994 Euros. Quantity is VOLKSWAGEN's sales in thousands of cars. "Markup" is defined as P/MC - 1. Profits are measured in the equivalent of millions of 1994 Euros. "No Diesel" denotes the counterfactual where diesel engines are not produced by any firm. "Benchmark" refers to the equilibrium in 1999 to 2000. "Monopoly" denotes the counterfactual where VOLKSWAGEN is the only manufacturer of diesel engines.

protection or less easily reusable technology.[26] One may be concerned that imitation of the TDI by competitors like MERCEDES was an important component to facilitating customer adoption of the diesel engine. Consequently, customer adoption in a world in which VOLKSWAGEN maintains its monopoly rights would likely be smaller and our estimate of the degree to which VOLKSWAGEN captured the available rents would be biased downwards. While likely true, we view the bias as minor since VOLKSWAGEN offered the majority of diesel vehicles throughout the sample and likely drove much of the change in customer preferences regarding diesel engines.

5 Main Drivers of the Diffusion of Diesel Vehicles

Once we have obtained the structural parameters we can recompute the equilibrium prices, profits, and market shares (among others) for a variety of different scenarios. In doing so we focus our analysis on years 1999-2000 to evaluate how outcomes could have changed if some elements of the model such as preferences, costs, or market conditions had been different. The idea is to use

[26] It is interesting to note that profits under this second hypothetical scenario are larger not only because of the monopoly position in the sale of diesel vehicles (up bn€1.2), but also because VOLKSWAGEN's profits associated to its increased sale of gasoline models are also larger (up m€786) as many other fuel efficient diesel vehicles of other manufacturers have now been removed from the market.

the first-order maximization conditions and recompute the equilibrium while we substitute some or all the estimated parameters for years 1999-2000 with some or all estimated parameters for the 1992-1993 sample. Counterfactuals are aimed at quantifying the relative importance of each element of the model in explaining these magnitudes. Table W.2 in the Web Appendix specifies which element is evaluated in each counterfactual and what others remain constant.

Table 4 summarizes the main results of these counterfactuals at an aggregate level: prices, profits, and market shares by engine type and geographical origin of the manufacturer.[27] Overall, the industry is deeply transformed over these few years. The share of new diesel vehicles sold increases from 19% to 52% while profits in the Spanish automobile industry more than doubled as sales increased by 61% and prices (in real terms) by 30%. There are however interesting differences between domestic and foreign automobile manufacturers: estimated demand for locally produced European vehicles is always less elastic, ensuring higher markups, regardless of whether drivers consider purchasing a gasoline or a diesel vehicle. Thus, Europeans increased the price of their gasoline and diesel models by 32% and 27%, respectively while Asian imports were still able to increase the price of diesels by 17% because of the fast growth of demand in this segment despite lacking any brand reputation. As for the price of their gasoline models, they were almost 5% lower due to the stagnation of demand for gasoline vehicles and the much increased competitive pressure in this segment as Asians introduced a large number of new models and realize important efficiency gains in this segment. Still, Asians more than doubled their market share penetration (mostly in the gasoline segment) and Europeans lost 7% market share. In year 2000, the composition of European sales was completely different with 4 diesels sold for every 3 gasoline vehicles *vs.* 1 diesel for every 4 gasoline vehicles in 1992.

The first three counterfactuals reported in Table 4 refer to changes in exogenous variables affecting demand. The "1992 Income" counterfactual recomputes the equilibrium outcome assuming all parameter estimates for the 1999-2000 sample reported on the right column of Table 2 but replacing the sampling of individuals, now using the empirical distribution of income for years 1992-1993 rather than for 1999-2000. A lower per capita income translates into lower prices (−11%) and profits (−28%) but leaves the distribution of market shares unaltered. The growth in per capita income in Spain during the 1990s is thus responsible for important price and profit increases. Notice that the effect of income growth on prices is more pronounced for gasoline models.[28]

[27] Table W.3 in the Web Appendix also includes the analysis of price markups detailed by engine type and geographical origin of the manufacturer. Table W.5 complements these results with measures of dispersion of these counterfactuals. Tables W.6 to W.8 further break down these counterfactuals by manufacturer an engine type.

[28] Further analysis at the manufacturer level in Tables W.6 and W.8 shows that income leads to large price increases among the gasoline versions of FIAT, MERCEDES, and VOLKSWAGEN. Profits increase sharply among high quality models such as BMW and MERCEDES, while for lower quality gasoline models of FIAT, PSA, and RENAULT the increase in profitability is below that of Asian manufacturers.

Table 4: Counterfactuals — Average Effects on Prices, Profits, and Market Share

	PRICE		Price (%Δ from 2000 Base Case)									
			Demand			Supply			Market Structure			
FIRM	1992	2000	1992 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
European:												
- All Models	11.7	15.4	-11.1	2.7	18.3	1.4	-10.6	-7.4	-31.5	0.6	-0.3	-3.0
- Diesel	12.6	16.0	-9.1	5.1	15.5	1.7	-8.7	-6.3	-30.0	0.7	-0.3	-
- Gas	11.5	14.6	-13.6	1.3	22.7	1.1	-12.6	-6.6	-29.4	0.5	-0.3	2.2
Non-European:												
- All Models	14.1	14.2	-11.6	7.7	22.7	1.9	-10.2	-4.0	-15.4	-	0.2	-0.7
- Diesel	14.4	16.9	-5.3	4.5	10.7	2.7	-4.0	5.4	-21.5	-	0.1	-
- Gas	14.1	13.5	-12.8	9.3	26.0	1.7	-11.4	-5.1	-11.3	-	0.2	4.6

	PROFITS		Profits (%Δ from 2000 Base Case)									
			Demand			Supply			Market Structure			
FIRM	1992	2000	1992 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
European:												
- All Models	6,074.6	13,481.1	-28.0	-46.9	-80.0	-4.4	3.0	7.0	-36.6	12.8	-0.5	-20.2
- Diesel	1,228.1	7,842.4	-28.7	-52.9	-82.8	-4.3	-0.1	-13.0	-69.7	12.7	-0.5	-
- Gas	4,846.5	5,638.6	-26.9	-38.7	-76.2	-4.4	7.3	34.7	9.5	12.8	-0.6	90.7
Non-European:												
- All Models	404.0	1,335.0	-27.2	-49.0	-27.5	-4.0	-0.5	-21.3	-75.0	-	-0.7	46.3
- Diesel	17.8	313.7	-30.7	-56.9	-17.8	-4.7	-7.9	-35.4	-94.4	-	-0.7	-
- Gas	391.2	1,021.3	-26.1	-46.6	-30.5	-3.7	1.8	-16.9	-69.0	-	-0.8	91.3

	SHARE		Market Shares									
			Demand			Supply			Market Structure			
FIRM	1992	2000	1992 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
European:												
- All Models	95.4	88.2	87.9	90.1	71.1	88.1	88.6	91.3	95.6	100.0	88.3	81.2
- Diesel	18.9	49.7	48.2	45.3	35.4	49.6	48.0	41.3	25.1	56.3	49.9	0.0
- Gas	76.6	38.4	39.7	44.8	35.7	38.5	40.6	50.1	70.5	43.7	38.5	81.2
Non-European:												
- All Models	4.6	11.8	12.1	9.9	28.9	11.9	11.4	8.7	4.4	0.0	11.7	18.8
- Diesel	0.2	2.5	2.3	1.8	7.4	2.5	2.1	1.4	0.2	0.0	2.5	0.0
- Gas	4.4	9.3	9.8	8.0	21.4	9.4	9.2	7.2	4.2	0.0	9.2	18.8

Statistics weighted by relevant quantity sold. “No Diesel” evaluates the market performance with all demand and supply estimates for the 1999-2000 sample but assuming that diesel vehicles are not available. “All” reports the results for the end of the decade assuming all demand and supply conditions and ownership structure from 1992 but models available in 2000.

The second demand counterfactual, "$\{\alpha, \beta, \sigma, \pi\}$" addresses the effects of a change of preferences as these parameters summarize the preferences of drivers as described by observable product characteristics. In computing the new equilibrium we substitute the estimated value of all these parameters in 1999-2000 with the corresponding estimates for 1992-1993. The third demand counterfactual, "$\{\alpha, \beta, \sigma, \pi, \xi\}$" adds the effect of the distribution of unobservable characteristics. This is done by matching each 1999-2000 model with a random draw of the 1992-1993 distribution of ξ conditional on fuel type and vehicle price. Comparing results to those of the "$\{\alpha, \beta, \sigma, \pi\}$" counterfactual allows us to quantify the economic importance of unobservable product characteristics of automobiles.

Change in preferences, whether driven by observable or unobservable product characteristics, has profound effects. By itself, it is responsible for nearly all the change in prices and profits, with larger effects for gasoline prices and profits from diesels. Preferences in 1992 favored the type of vehicle produced by non-European firms: fuel efficient gasoline models. Had preferences remained unchanged, including observable and unobservable product characteristics, the share of imported gasoline models would have more than doubled. The change of preferences among European drivers is thus critical to understand the limited penetration of Asians in the European automobile market. New preferences allow Europeans to avoid a substantial reduction in their combined market penetration of 17.1%, from 88.2% to 71.1%. Notice that most of this market share loss is made up by the 14.3% reduction in the share of diesel vehicles, from 49.7% to 35.4%. More important, about a 10% market share responds directly to the effect of unobservable product characteristics. This result supports the idea that demand for the new product may be subject to learning, driving experience, and other unobservable features such as reliability, durability, and high torque.

Next, we turn our attention to elements affecting the supply side of the market: phasing out of import tariffs as well as observable and unobservable costs components. Only the latter have some effect on market shares, particularly European diesel vehicles. Without considering other factors affecting costs, or perhaps the effect of learning in manufacturing diesel vehicles, these environments would be 13% less profitable and their market penetration about 8% lower. Imports might have also increased their production efficiency during the 1990s substantially. Including unobserved cost components reduces the combined market penetration of imports by 3% and profits by 21%.

The following three counterfactuals relate to other features associated to the market structure. The change in ownership structure, accounting for the multiple acquisitions documented in Table A.1 in Appendix A, has a negligible effect on market outcomes. The increase in competition due to imports has similar small effects as the tariff barrier reduction of 1992: a reduction in the markup of about 1% while the rest of variables remain essentially unchanged. It is the change

in product offering ("1992 Models"), an evaluation that overlaps with most demand and supply counterfactuals, that has the largest effects. The increase in product offerings seems to be key to explain the change in the distribution of market shares. Restricting products to those sold in 1992 the overall market shares of domestic vehicles and imports would remain unchanged. These new products also explain most of the observed price change and increase in profits during the 1990s.

Our last counterfactual ("No Diesel") is the most interesting as it identifies the contribution of diesel vehicles to the European automobile industry. In the last column of Table 4 we evaluate the effect of not allowing the sale of diesel vehicles. The counterfactual simply removes diesel vehicles from the choice set in 1999-2000 and recomputes the equilibrium using the estimated parameters for this sample while restricting agents to choose among the remaining gasoline models only. This serve as the counterfactual scenario of a world where TDI and other innovations in diesel engines never happened, or alternatively, a market configuration where environmental regulation makes diesel technology commercially not viable. While limiting sales to gasoline models increase the price of domestic gasoline vehicles by 2.2%, prices of imports raise by 4.6% once they do not have to compete with fuel efficient European models. Domestic firms increase the profitability of gasoline vehicles but overall they fall short 10% of the profits achieved with the introduction of diesel vehicles. Profits of imports however, skyrocket by almost 50% relative to year 2000 as Asians automakers do not have to sell their high cost diesels and they double their market share of their fuel efficient gasoline models characterized by low costs of production.

6 Trade Effects of Strict NO_x Emission Standards

We are now able to evaluate the main hypothesis put forward by this paper: a European NO_x emission standards similar to the policy set by the EPA to comply with the mandate of the CAAA in the early 1990s might have limited the market penetration of fuel efficient, gasoline powered, Asian automobiles by favoring the production of domestic diesel vehicles. To this end, Table 5 recomputes the market equilibrium of the Spanish market in 1999-2000 under scenarios that are increasingly more restrictive for the presence of diesel vehicles. Each one of these scenarios has a real-life counterpart either in the configuration of the industry in the U.S. or in Europe. The goal is to evaluate possible scenarios other than the complete disappearance of diesel vehicles from the market. In addition to the market outcomes that we have reported until now, we also include the Corporate Average Fuel Economy (CAFE) level resulting from each different scenario. The top panel of Table 5 reports the 1999-2000 market outcomes as a reference for all other counterfactuals.

The second panel considers the case where only European manufacturers sell diesel vehicles. A slight tightening of NO_x emission standards might have made the commercialization of Asian

Table 5: Value of Diesel Automobiles

Scenario	Models	CAFE	Price	Quantity	Markup	Share	Profits
Base (1999-2000)							
EU: DIESEL	153	51.18	16.04	1,369.82	61.60	49.75	7,842.44
EU: GASOLINE	170	41.57	14.65	1,058.30	67.91	38.43	5,638.64
NON-EU: DIESEL	39	42.85	16.93	68.33	58.84	2.48	313.70
NON-EU: GASOLINE	94	38.87	13.52	257.19	71.58	9.34	1,021.33
Only European Firms							
EU: DIESEL	153	51.17	16.09	1,398.41	61.85	50.98	8,051.09
EU: GASOLINE	170	41.56	14.70	1,079.27	68.13	39.35	5,779.73
NON-EU: DIESEL	0	-	-	0.00	-	0.00	0.00
NON-EU: GASOLINE	94	38.85	13.53	265.11	71.23	9.67	1,049.47
Only German Firms							
EU: DIESEL	57	55.51	19.73	556.96	67.66	21.74	3,996.48
EU: GASOLINE	170	41.46	14.63	1,615.87	67.13	63.08	8,571.90
NON-EU: DIESEL	0	-	-	0.00	-	0.00	0.00
NON-EU: GASOLINE	94	38.74	13.72	388.76	71.73	15.18	1,567.32
Only Volkswagen							
EU: DIESEL	40	57.29	17.95	491.42	74.11	19.30	3,547.05
EU: GASOLINE	170	41.40	14.79	1,655.21	67.49	65.00	8,886.97
NON-EU: DIESEL	0	-	-	0.00	-	0.00	0.00
NON-EU: GASOLINE	94	38.70	13.83	399.67	71.98	15.70	1,628.91
No Diesels							
EU: DIESEL	0	-	-	0.00	-	0.00	0.00
EU: GASOLINE	170	41.35	14.96	2,002.30	66.63	81.20	10,753.54
NON-EU: DIESEL	0	-	-	0.00	-	0.00	0.00
NON-EU: GASOLINE	94	38.56	14.14	463.69	73.11	18.80	1,953.34

"CAFE" is harmonic mean fuel economy (miles per gallon) as defined in the Corporate Average Fuel Economy regulation. "Price" is the sales-weighted average price faced by consumers (in thousands of 1994 Euros), including tariffs. "Quantity" is measured in millions of cars. "Profits" is measured in the equivalent of millions of 1994 Euro. "Markups" and "Share" are reported as percentages.

diesel models completely unprofitable. As Table 1 shows, Asians are not particularly competitive in this market segment. Initially, in 1992-1993, at the early stages of diffusion of the new technology, Asian manufacturers did not sell any diesel vehicles. As they became popular, they bought diesel engines directly from European manufacturers to power their many new models being introduced in the gasoline segment. This raises the question of whether Europeans were not cannibalizing some of their own sales at a huge loss.

Despite the fact that by year 2000, Asian diesel models only amounted to 2.5% of the market, European manufacturers gave up m€350 in profits for agreeing to sell diesel engines to their Asian competitors. Out of this loss, m€209 is due to direct competition from Asian diesel models running on European diesel engines while the additional m€141 results because of losses in

gasoline sales as their Asian counterparts increase their market share by appealing to fuel conscious customers, some of which might have bought inexpensive, efficient, European gasoline vehicles.

Notice however that the m€350 loss of Europeans for agreeing to sell diesel engines to Asian manufacturers exceeds the m€286 of Asian manufacturers' net profits gains in 1999-2000 under the current arrangement. In addition, in their attempt to enter every single market segment with numerous models, Asians end up self-inflicting some losses and thus sales of Asian gasoline models are 8,0000 units lower than otherwise, had they not sold diesel vehicles. Asians' cannibalization of their competitively produced gasoline vehicles is however very limited and in the end the increase in profits from selling diesel more than compensates it. European manufacturers, on the other hand, loose by selling engines to their Asian competitors unless the sales of these engines generate more than m€350 in profits.

The third panel of Table 5 addresses an scenario that resembles the current market configuration in the U.S., where only German manufacturers are selling diesel vehicles. This could represent the outcome of an even stringier NO_x emission standards that effectively exclude manufacturers such as FIAT, FORD, GM, RENAULT, and even PSA. Only the latter was able to effectively compete with VOLKSWAGEN in the second half of the 1990s and all others are less valued by drivers.[29] Our analysis should however be qualified when comparing it to the current configuration of the U.S. automobile market because while German manufacturers have a large presence in the Spanish market (a combined market share of 23.61% according to Table A.1), in the U.S. they only appeal to the smaller, higher income niche market. In the case of Spain, the fact that only German firms could commercialize diesel vehicles has an important effect because it would exclude the other leader in this segment, PSA, and other firms such as FORD, GM, and RENAULT that invested steadily in this technology while appealing to a less expensive market segment. Notice that the overall sales of diesel vehicles falls by 60% relative to the benchmark figure. Simultaneously, total sales and profits of gasoline models increase by 50%. Two other effects are worth mentioning: markups of gasoline models do not change much for excluding "low quality" diesel products from the market while German manufacturers are to increase their diesel markups by 6% in the absence of these competitors. Second, the important reduction in sales of diesel vehicles, in excess of 800,000 units, is sufficient to worsen the CAFE average by 2mpg, from 45.56 to 43.19.

The fourth panel looks at the case where VOLKSWAGEN is the only manufacturer selling diesel vehicles. Again, this resembles of the situation of the U.S. automobile market from the late 1990s to the early 2010s, when finally both BMW and MERCEDES got certified for selling cars in all 50 states, *i.e.*, meeting the even more stringent California emission standards that many other

[29] Table W.7 in the Web Appendix shows that, with the exception of PEUGEOT, the markups of diesel models of these non-German European manufacturers are higher than that of imports but still far lower than VOLKSWAGEN's markup.

states adopt. Results are very similar to the previous counterfactual. Sales of diesel vehicles reduces an additional 10% (or 2.5% market share) and VOLKSWAGEN manages to increase its markup by 7% to 74%. Not being able to purchase some of the other German diesels, most consumers turn to buy fuel efficient European gasoline models. Overall, CAFE average remains unchanged at 43.24.

The fifth and final panel evaluates the likely scenario in which the imposition of an EPA-like stringent NO_x emission standard makes producing diesel vehicles not commercially viable and they disappear from the market. Regarding fuel efficiency, CAFE average plunges to 40.49; 5mpg lower than in the benchmark case, thus dragging down any credible CO_2 emissions reduction with the technology available at that time. But in addition, notice how the market share of Asian imports increases to 18.80% and profits double in the absence of diesel vehicles. Europeans lose 7% market share, from 88.18% when selling gasoline and diesel models to 81.2% if only gasoline vehicles could be sold. Profits of European automobile manufacturers also plunge when they are not allowed to commercialize a technology in which they have a comparative advantage: profits reductions amounts to bn€2.73 a year only in Spain, or about 20% of the benchmark levels. Asian manufacturers thrived in this environment, similar to the U.S. market, as European producers had to confront a product offering made of closer substitutes to their own that in addition were far more fuel efficient and less costly to produce. While the better quality and lower cost of Asian automobile manufacturers in growing and eventually dominating the U.S. market has been extensively analyzed, we believe that we are the first to point out at the role of environmental regulations as the likely explanation of why the European market did not follow the same fate.[30]

6.1 Retrofitting Costs

It could perhaps be argued that our working assumption that the EPA's stringent NO_x standards might indeed be too drastic. We believe it is quite plausible. For many years, a technology to successfully capture NO_x emissions at the tailpipe simply did not exist. And when it finally became available, in the late 2000s, it was very expensive. By the EPA's own estimates in 2010, diesel engines could be retrofitted to comply with both EPA and California NO_x emission standards by means of a *Lean NO_x Catalyst* at an estimated cost of \$6,500 to \$10,000 per vehicle. Lean NO_xcatalysts use diesel fuel injected into the exhaust stream to create a catalytic reaction and reduce pollution. However, these catalysts still requires specific exhaust temperatures for appropriate NO_x emission control performance, and on average they reduce emissions up to a maximum of 40%. Given this limited ability to capture NO_x emissions, both BMW and MERCEDES were finally certified to be sold in all 50 states of the U.S. after equipping their new vehicles with

[30] Contrary to our findings, Huse and Lucinda (2014) show that rather than protecting domestic manufacturers, the design of the 2007 Swedish Green Car Rebate put them at a disadvantage. This is particularly true for Swedish and German vehicles.

Table 6: Retrofitting Diesel Engines to meet US Emission Standards

Scenario	Models	CAFE	Price	Quantity	Markup	Share	Profits
Benchmark							
EU: DIESEL	153	51.18	16.04	1,369.82	61.60	49.75	7,842.44
EU: GASOLINE	170	41.57	14.65	1,058.30	67.91	38.43	5,638.64
NON-EU: DIESEL	39	42.85	16.93	68.33	58.84	2.48	313.70
NON-EU: GASOLINE	94	38.87	13.52	257.19	71.58	9.34	1,021.33
Retrofitting expense of 5,000 Euros							
EU: DIESEL	153	50.86	23.07	625.17	45.24	24.04	4,323.81
EU: GASOLINE	170	41.60	14.32	1,573.08	65.12	60.49	8,019.20
NON-EU: DIESEL	39	42.33	24.08	29.05	49.97	1.12	165.43
NON-EU: GASOLINE	94	38.80	13.49	373.05	70.32	14.35	1,457.57
Retrofitting expense of 10,000 Euros							
EU: DIESEL	153	50.67	29.66	300.89	37.73	11.88	2,380.90
EU: GASOLINE	170	41.50	14.52	1,796.85	65.54	70.97	9,303.55
NON-EU: DIESEL	39	42.09	30.86	13.10	44.94	0.52	86.69
NON-EU: GASOLINE	94	38.69	13.75	420.90	71.40	16.63	1,693.02
Retrofitting expense of 20,000 Euros							
EU: DIESEL	153	50.43	42.21	81.75	30.13	3.29	786.27
EU: GASOLINE	170	41.40	14.79	1,947.06	66.22	78.37	10,307.90
NON-EU: DIESEL	39	41.93	43.92	3.16	39.27	0.13	26.06
NON-EU: GASOLINE	94	38.60	14.01	452.42	72.53	18.21	1,875.31

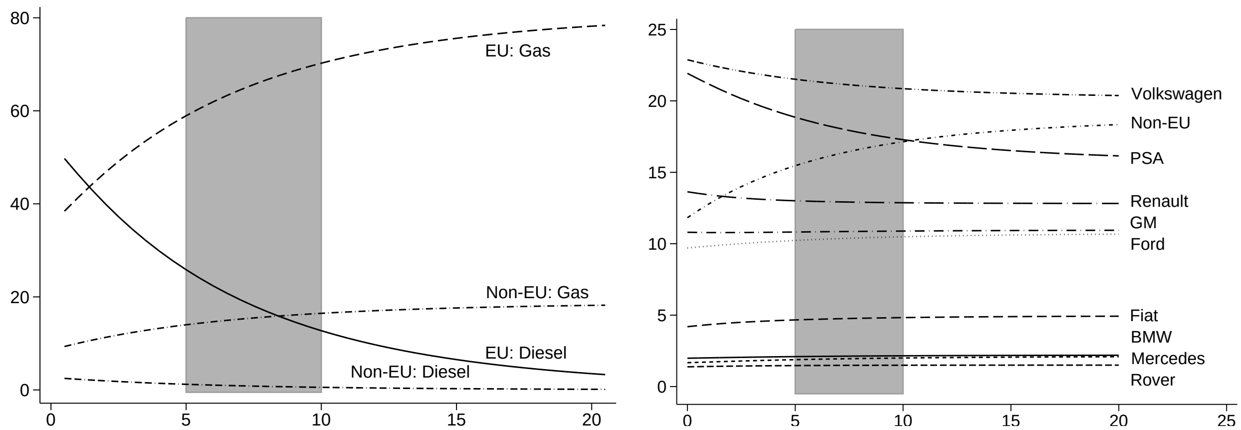
"CAFE" is harmonic mean fuel economy (miles per gallon) as defined in the Corporate Average Fuel Economy regulation. "Price" is the sales-weighted average price faced by consumers (in thousands of 1994 Euros), including tariffs. "Quantity" is measured in millions of cars. "Profits" is measured in the equivalent of millions of 1994 Euros. "Markups" and "Share" are reported as percentages. "Markups" include import duties paid by the consumer.

a *Selective Catalytic Reduction System* that injects a reductant (a urea-based solution) into the exhaust stream where it reacts with a catalyst to convert NO_x emissions to nitrogen gas and oxygen. This system is more effective, reducing NO_x emissions up to 75% but the EPA estimated that its cost ranged between $10,000 and $20,000 per vehicle in 2010.[31]

Table 6 evaluates the Spanish market configuration in year 2000 if diesel manufacturers had to comply with these emission standards and they faced retrofitting costs ranging from €5,000 to €10,000. A €5,000 retrofitting costs has dramatic effects on the automobile market configuration. Prices of diesel vehicles increase by 50% as automakers try to push consumers into higher margin gasoline models. The result is a 50% reduction in the sales and market share of European diesel vehicles as consumers switch to gasoline models produces by both European and foreign firms. Although the increase in price exceeds the €5,000 retrofitting cost, markups of diesel vehicles are cut from 62% to 45%. Overall, total profits for European firms drops by bn€1.1, which is the result

[31] On retrofitting costs see "Diesel Retrofit Devices." EPA's National Clean Diesel Campaign, 2013. `http://www.epa.gov/cleandiesel/technologies/retrofits.htm`

Figure 5: Market Shares for Different Retrofitting Costs (€1,000)



(a) By Regions (b) By Firm

of a €2.4 increase in profits from the increased sales of gasoline models and a €3.4 profit reduction from vanishing diesel sales. Profits of foreign importers increases by almost 25%. Increasing retrofitting costs to either €7,500 or €10,000 leads to similar results although the magnitudes of reduction of sales of diesels, their markup, market share, and profits are not so pronounced. Imported diesel models effectively disappear from the market and Europeans substantially reduce their model offering.

Had this technology been available in the 1990s, retrofitting costs would have been even higher. Figures 5 (a) and 5 (b) plots the results of repeating this analysis for a wider range of retrofitting costs. The shaded area highlights the retrofitting cost region of results reported in Table 6. Figure 5 (a) focuses on the impact of retrofitting on the market shares distinguishing by type of engine and geographical origin of manufacturers while Figure 5 (b) reports the combined market shares (gasoline + diesel) of each automobile group.

Notice that at a retrofitting cost of €10,000, the NO_x emission regulation has effectively reduced the diesel segment to a market niche comparable to the diesel market penetration in Europe prior to the TDI innovation. Extrapolating this result from the Spanish market we could predict that with the current retrofitting costs, diesels will most likely not become a mainstream segment in the U.S. market. The increase in production costs required to comply with environmental regulations puts them at a huge price disadvantage and consumers will opt for other, less expensive, fuel efficient vehicles. Between €7,500 and €10,000, the market share of European diesel vehicles falls below the share of gasoline imports, who grow monotonically with the retrofitting costs although the production of European gasoline models grows much faster.

The second panel of Figure 5 shows that, in terms of market shares, the only clear beneficiary of a stringent European NO_x emission policy would be foreign automobile manufacturers. Although the composition of sales changes with retrofitting costs, most European manufacturers manage to hold to their current market presence. That is not the case for the two European leaders PSA and VOLKSWAGEN. Both of them are also the largest producers of diesel vehicles in Europe and thus, having to face these large retrofitting costs erode their competitiveness and their market shares.

Therefore, given the current exorbitant cost of retrofitting diesel engines to capture NO_x emissions, we conclude that it is reasonable to expect that a stringent, EPA-like, NO_x emission standards would have effectively hindered the diffusion of diesel vehicles in Europe, particularly if such policy was enforced soon after the introduction of the TDI, at the early stages of the diffusion of the new technology.

6.2 Import Tariff Equivalence of Environmental Regulation

We have argued repeatedly that emission standards have an impact on trade. In the present case, because the favored domestic technology, diesel, is more pollutant in some dimensions, NO_x and particulate matter, than the alternative gasoline engine, European environmental inaction regarding NO_x emission standards has some trade protection value. In this section, we aim to uncover the explicit tariff value of this regulation.

Table 7 reports the counterfactuals necessary to evaluate the tariff-equivalence of the lenient European NO_x emission policy during the 1990s. Starting at the second half of the table, we first compare the 2000 benchmark with a hypothetical situation where TDI, and therefore modern diesel engines, never existed. As indicated before, the market share of Asian manufacturers jumps from 9.34% to 18.80% as they double profits and even increase the markup of their gasoline models following the disappearance of fuel efficient diesel vehicles from the market. Starting from this scenario, without diesel vehicles in the choice set, we recompute the equilibrium of our model for different import tariffs that change the relative prices of vehicles that consumers face. We repeat this analysis until the share of gasoline imports equals 11.82%, the combined share of imported diesel and gasoline automobiles sold in year 2000. We thus conclude that a 36.8% import tariff on imported automobiles would limit Asian imports and lead to a similar market outcome than not enforcing a stringent NO_x policy in the early stages of diffusion of diesel automobiles. In our final counterfactual, at the bottom of the table, we determine that it is necessary to establish a 56.4% import tariff in order to replicate the average 8.58% market share of imports in Europe during the 1990s. These are remarkable results which demonstrate how effective seemingly innocuous national policies can be in both regulating trade flows and protecting domestic industry.

Table 7: Effects of Imposing Equivalent Import Tariffs

Scenario	Models	CAFE	Price	Quantity	Markup	Share	Profits
1992 EQUILIBRIUM							
Benchmark							
EU: DIESEL	93	52.61	12.60	322.09	70.92	18.87	1,518.50
EU: GASOLINE	148	43.31	11.46	1,307.03	84.80	76.56	5,921.63
NON-EU: DIESEL	4	44.34	14.43	2.87	69.65	0.17	12.48
NON-EU: GASOLINE	50	40.74	14.06	75.18	80.03	4.40	316.88
Equilibrium without the TDI							
EU: GASOLINE	148	43.29	11.51	1,368.37	84.87	94.56	6,226.46
NON-EU: GASOLINE	50	40.71	14.14	78.78	80.37	5.44	334.72
Import Tariff of 22.6%							
EU: GASOLINE	148	43.28	11.51	1,370.55	84.90	95.43	6,239.26
NON-EU: GASOLINE	50	40.92	14.72	65.66	93.14	4.57	258.58
2000 EQUILIBRIUM							
Benchmark							
EU: DIESEL	153	51.18	16.04	1,369.82	61.60	49.75	7,842.44
EU: GASOLINE	170	41.57	14.65	1,058.30	67.91	38.43	5,638.64
NON-EU: DIESEL	39	42.85	16.93	68.33	58.84	2.48	313.70
NON-EU: GASOLINE	94	38.87	13.52	257.19	71.58	9.34	1,021.33
Equilibrium without the TDI							
EU: GASOLINE	170	41.35	14.96	2,002.30	66.63	81.20	10,753.54
NON-EU: GASOLINE	94	38.56	14.14	463.69	73.11	18.80	1,953.34
Import Tariff of 36.8%							
EU: GASOLINE	170	41.35	14.95	2,148.27	66.60	88.18	11,528.14
NON-EU: GASOLINE	94	39.09	16.06	288.01	109.33	11.82	1,062.68
Import Tariff of 56.4%							
EU: GASOLINE	170	41.35	14.97	2,213.80	66.78	91.42	11,916.00
NON-EU: GASOLINE	94	39.43	17.42	207.77	136.30	8.58	708.50

"CAFE" is harmonic mean fuel economy (miles per gallon) as defined in the Corporate Average Fuel Economy regulation. "Price" is the sales-weighted average price faced by consumers (in thousands of 1994 Euros), including tariffs. "Quantity" is measured in millions of cars. "Profits" is measured in the equivalent of millions of 1994 Euros. "Markups" and "Share" are reported as percentages. "Markups" include import duties paid by consumer.

At the top of Table 7 we repeat this same analysis but considering a different benchmark, 1992, when the diffusion of diesel vehicles was just starting, and where the presence of foreign automobile manufacturers in Europe was still rather limited, just a 4.40%. In such an environment European automobile manufacturers kept over 95% of the market and excluding the development of TDI and early adoption of diesel essentially leaves market shares unchanged: the market share of imports increases only by 1% but European profits shrank by more than bn€1 as profitable diesels

are no longer sold and the available models do not suffice segment the market sufficiently. In this environment, a 22.6% import tariff is necessary to reduce the market share of imports just by 1% to bring it back to the level of the 1992 benchmark. Thus, even in the early stages of diffusion of the new technology, the lenient European NO_x emission standards was substantial: more than double the explicit 10.3% tariff set by European authorities against automobile imports.

6.3 The Ineffectiveness of Fuel Taxes as a Non-Tariff Barrier

The usual explanation for why diesels are popular in Europe cites the region's historical policy of heavy fuel taxation which provides the right incentive for drivers to consider purchasing more fuel efficient vehicles, including diesels.[32] If true, fuel taxes should promote the diffusion of diesel engines and should also play a role in protecting the European auto industry. In Table 8, we test this hypothesis by computing equilibrium prices, quantities, profits, and imports assuming European regulators had chosen similar fuel taxes as employed by American regulators.[33]

Table 8 reveals significant aggregate effects since the liter-equivalent fuel tax for gasoline and diesel in the United States are 26% and 42% of those in Europe, respectively.[34] Since consumers favor more fuel efficient cars (Table 2), imposing U.S. fuel taxes increases overall sales by 5.1% as more consumers decide to purchase a new car rather than the outside good. As average price is relatively unchanged, the increase in sales drives a 4.7% increase in total profits.

We also see that the composition of the fuel taxes has important distributional effects as relatively high taxes for diesel fuel in the U.S. makes these vehicles less popular – the share of new cars equipped with diesel engines falls from 52.2% to 45.4%. Further, the total quantity sold for diesel decreases 8.6% compared to a 20.1% increase for gasoline models. Prices and margins change little so the large change in quantity sold again translates to a significant change in profits as income from diesel vehicles decrease 8.8% compared to a 21.3% increase in profits for vehicles equipped with a gasoline engine. The shift in composition also has modest environmental implications since the increased popularity in vehicles with gasoline engines decreases the CAFE mileage standard from 45.57 to 44.64 miles per gallon. that changing fuel taxes has small implications for European

[32] Linn (2014) shows that current differences in market penetration of diesel across national markets in Europe are better explained by heterogeneous tastes for demand for fuel economy rather tan by differential vehicle or fuel taxation.

[33] Recall that fuel efficiency product characteristic (FUEL) incorporates for both mileage and the cost of fuel, including fuel taxes. In the benchmark estimation, FUEL uses the European fuel tax rates based on engine type. In the policy experiment, we aggregate variation in US state fuel taxes for diesel and gasoline by computing the volume-weighted average for each and use these taxes to modify FUEL.

[34] The per liter fuel taxes for diesel and gasoline in Europe in the 1999-2000 period were €0.357 and €0.516, respectively (source: *Agencia Tributaria*). The volume weighted average fuel taxes in the United States for diesel and gasoline were €0.150 and €0.136, respectively (source: *American Petroleum Institute*). All taxes are in 1994 Euros.

Table 8: Imposing US-style Fuel Taxes and Emissions Standards

Scenario	Fuel Tax	Models	CAFE	Price	Quantity	Markup	Share	Profits
EU: DIESEL	1.00	153	51.18	16.04	1,369.82	61.60	49.75	7,842.44
EU: GASOLINE	1.00	170	41.57	14.65	1,058.30	67.91	38.43	5,638.64
NON-EU: DIESEL	1.00	39	42.85	16.93	68.33	58.84	2.48	313.70
NON-EU: GASOLINE	1.00	94	38.87	13.52	257.19	71.58	9.34	1,021.33
ALL	1.00	456	45.57	15.29	2,753.64	64.89	100.00	14,816.12
US Fuel Taxes								
EU: DIESEL	0.42	153	51.05	16.05	1,249.68	61.44	43.18	7,142.36
EU: GASOLINE	0.26	170	41.34	14.95	1,264.81	67.25	43.70	6,801.81
NON-EU: DIESEL	0.42	39	42.40	17.02	64.41	58.85	2.23	297.19
NON-EU: GASOLINE	0.26	94	38.26	13.84	315.48	71.26	10.90	1,275.18
ALL	0.33	456	44.64	15.35	2,894.37	64.99	100.00	15,516.54

"Fuel Tax" is the average fuel tax (normalized by the European fuel tax for each type) in 2000. "CAFE" is harmonic mean fuel economy (miles per gallon) as defined in the Corporate Average Fuel Economy regulation. "Price" is the sales-weighted average price faced by consumers (in thousands of 1994 Euros), including tariffs. "Quantity" is measured in millions of cars. "Profits" is measured in the equivalent of millions of 1994 Euro. "Markups" and "Share" are reported as percentages.

automakers relative to stringent NO_x emissions standards. These results indicate that the fuel taxes employed by European regulators do indeed promote diesel vehicles, about $124,000$ units sold, though the effect is small, less than 5% of the market.

Finally, market share and profitability changes little for foreign firms when we impose US fuel taxes suggesting that the fuel taxes chosen by European regulators play an insignificant role in promoting the domestic auto industry. Of the €700 million additional in profit generated by the lower fuel taxes, profits for foreign firms increase €237.3 million – a 17.8% increase over the benchmark and roughly one-third of the incremental profits generated by the industry under the new fuel tax policy. European automakers capture the residual €463.1 million amounting to a 3.4% increase in profits. MERCEDES and BMWare big beneficiaries of the new fuel taxes as profits for these firms increase 16.5% and 13.0%, respectively. The change in fuel prices have relatively minor effects on PSA and VOLKSWAGEN, however, as profits for these firms only increase 0.8% and 1.0%, respectively.

7 Concluding Remarks

Our analysis of the diffusion of diesel automobiles in Europe during the 1990s characterizes the very rich dynamics of an industry that evolved in a very different manner than its American counterpart. At the beginning of of the 1990s, Asian automakers flooded both the U.S. and European markets

with new fuel efficient gasoline models increasing competitive pressure on the segment where they had a comparative cost advantage. Rather than compete in this segment, European automakers invested heavily in the development of fuel efficient diesel engines – a market segment for which they had the necessary know-how and technological advantage.

For this European strategy to succeed, consumers had to embrace this new product. Our analysis of the Spanish market during the 1990s shows that consumer preferences did indeed change as consumers developed a taste for diesel vehicles in a relatively short period of time. The introduction of TDI was indeed a success as the models equipped with diesel engines exceeded 50% of the market while diesels amounted to over 70% of the most popular automobile models in Spain by the end of the decade. The fast growth of the diesel segment was only possible because of vigorous competition among European manufacturers. Thus, we show that the development of diesel engines by other European firms dissipated 70% of the potential innovation rents that VOLKSWAGEN could have captured had it remained the sole manufacturer of diesel vehicles. The remaining 30%, about bn€1 a year in the Spanish market alone, was enough to profit from commercialization of this new technology.

A common explanation of why Europeans purchase smaller and more fuel efficient cars is that fuel taxation is higher in Europe than in the U.S. While this might be true, we show that it does not explain the massive adoption of diesel vehicles within a decade. We rather point at the lenient European environmental policy towards NO_x emissions as being a key strategic complement for European manufacturers to succeed in their attempt to build a domestic fuel efficient alternative against Asian imports. Applied early in the adoption of this new technology, EPA-like NO_x emission standards would have aborted any meaningful diffusion of diesels in Europe.

The European NO_x emission standards not only allowed domestic automakers the necessary time for drivers to learn and embrace this new technology but also acted as a powerful non-tariff trade barrier against foreign imports, reducing their market penetration from 18.8% to 11.8% by the turn of the century. We use our model to show that the tariff equivalence of this non-tariff trade barrier ranges from 22.6% in 1992 to 36.8% in 2000 – both significant figures. Extrapolating this exercise to the entire European region reveals an even starker result as an import tariff of 56.4% would be required to limit imports to the average European import share in the 1990s (8.6%). This is, to the best of our knowledge, the first use of a structural equilibrium model of demand and industry oligopoly pricing to evaluate the trade effects of non-tariff trade barriers. We show that in an increasingly global economy, governments can effectively use national policies, including environmental regulations, to protect domestic industries when traditional trade policies are no longer available.

References

Bagwell, K. and R. W. Staiger (2001) "Domestic Policies, National Sovereignty and International Economics Institutions," *Quarterly Journal of Economics*, Vol. 116, pp. 519–562.

Balcer, Y. and S. A. Lippman (1984) "Technological Expectations and Adoption of Improved Technology," *Journal of Economic Theory*, Vol. 34, pp. 292–318.

Berry, S., J. Levinsohn, and A. Pakes (1995) "Automobile Prices in Market Equilibrium," *Econometrica*, Vol. 63, pp. 841–890.

Berry, S. and P. Jia (2010) "Tracing the Woes: An Empirical Analysis of the Airline Industry," *American Economic Journal: Microeconomics*, Vol. 2, pp. 1–43.

Bhagwati, J. and V. K. Ramaswami (1963) "Domestic Distortions, Tariffs, and the Theory of Optimum Subsidy," *Journal of Political Economy*, Vol. 71, pp. 44–50.

Bresnahan, T. F. (2010) "General Purpose Technology," in B. H. Hall and N. Rosemberg eds. *Handbook of the Economics of Innovation*, Vol. II, New York, NY: North-Holland.

Bresnahan, T. F., S. Stern, and M. 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.

Busser, R. and Y. Sadoi (2004) "Japanese Automobile Makers in Europe and the Organization of the Supply System," in R. Busser and Y. Sadoi eds. *Production Networks in Asia and Europe. Skill Formation and Technology Transfer in the Automobile Industry*, New York, NY: Taylor & Francis.

Canis, B. (2012) "Why Some Fuel-Efficient Vehicles Are Not Sold Domestically," report to congress, Congressional Research Service.

Carranza, J. E. (2010) "Product Innovation and Adoption in Market Equilibrium: The Case of Digital Cameras," *International Journal of Industrial Organization*, Vol. 28, pp. 604–618.

Chamberlain, G. (1987) "Asymptotic Efficiency in Estimation with Conditional Moment Restrictions," *Journal of Econometrics*, Vol. 34, pp. 305–334.

Chaudhuri, S., P. K. Goldberg, and P. Jia (2006) "Estimating the Effects of Global Patent Protection in Pharmaceuticals: A Case Study of Quinolones in India," *American Economic Review*, Vol. 96, pp. 1477–1514.

Chug, R., M. L. Cropper, and U. Narain (2011) "The Cost of Fuel Economy in the Indian Passenger Vehicle Market," *Energy Policy*, Vol. 39, pp. 7174–7183.

Deardorff, A. V. (1996) "An Economist's Overview of the World Trade Organization," Working Paper 388, Research Seminar in International Economics, University of Michigan.

Dubé, J.-P., J. T. Fox, and C.-L. Su (2012) "Improving the Numerical Performance of Static and Dynamic Aggregate Discrete Choice Random Coefficients Demand Estimation," *Econometrica*, Vol. 80, pp. 2231–2267.

Ederington, J. and J. Minier (2003) "Is Environmental Policy a Secondary Trade Barrier? An Empirical Analysis," *Canadian Journal of Economics*, Vol. 36, pp. 1371–154.

Goettler, R. L. and B. R. Gordon (2011) "Does AMD Spur Intel to Innovate More?" *Journal of Political Economy*, Vol. 119, No. 6, pp. 1141–1200.

Gowrisankaran, G. and M. Rysman (2012) "Dynamics of Consumer Demand for New Durable Goods," *Journal of Political Economy*, Vol. 120, pp. 1173–1219.

Greenwood, J. (1997) *The Third Industrial Revolution: Technology, Productivity, and Income Inequality*, Washtington, DC: AEI Press.

Huse, C. and C. Lucinda (2014) "The Market Impact and the Cost of Environmental Policy: Evidence from the Swedish "Gree Car Rebate."," *Economic Journal*, Vol. 124, p. forthcoming.

Knittel, C. R. and K. Metaxoglou (2013) "Estimation of Random Coefficient Demand Models: Two Empiricists' Perspective," *Review of Economics and Statistics*, Vol. 95, p. forthcoming.

Linn, J. (2014) "Explaining the Adoption of Diesel Fuel Passenger Cars in Europe," Mimeo, Resources for the Future.

Manuelli, R. and A. Seshadri (2014) "Frictionless Technology Diffusion: The Case of Tractors," *American Economic Review*, Vol. 104, No. 4, pp. 1368–1391.

Oster, S. (1982) "The Diffusion of Innovation among Steel Firms: The Basic Oxygen Furnace," *Bell Journal of Economics*, Vol. 13, pp. 45–56.

Reynaert, M. and F. Verboven (2013) "Improving the Performance of Random Coeffcients Demand Models: the Role of Optimal Instruments," *Journal of Econometrics*, Vol. 178, p. forthcoming.

Rose, N. L. and P. L. Joskow (1990) "The Diffusion of New Technologies: Evidence from the Electric Utility Industry," *RAND Journal of Economics*, Vol. 21, pp. 354–373.

Schumpeter, J. A. (1950) *Capitalism, Socialism, and Democracy*, New York, NY: Harper & Row, 3rd edition.

Staiger, R. W. (1995) "A Theory of Gradual Trade Liberalization," in A. V. Deardorff, J. A. Levinsohn, and R. M. Stern eds. *New Directions in Trade Theory*, Ann Arbor, MI: The University of Michigan Press.

Stewart, S. J. (2010) "Collection of PM Emission Data from In-Use Light-Duty Diesel and Gasoline Vehicles,"Technical report, British Columbia Clean Air Research Fund Final Report, Pacific Vehicle Testing Technology, Ltd.

Thurk, J. (2014) "The Effects of Coordinating National Patent Policies," Mimeo, University of Notre Dame.

Appendix

A Spanish Data Sources

To control for household income distribution a thousand individuals are sampled each year from the *Encuesta Continua de Presupuestos Familiares* (Base 1987 for years 1992-1997 and Base 1997 for years 1998-2000) conducted by INE, the Spanish Statistical Agency.[35] Fuel prices were also obtained from INE. In real 1994 euro-equivalent denominations per liter, these are 0.445, 0.488, 0.565, and 0.695 for diesel and 0.580, 0.628, 0.737, and 0.875 for gasoline, for years 1992, 1993, 1999, and 2000, respectively.

Table A.1: Automobile Groups: 1992 vs. 2000

	Year 1992			Year 2000		
Automaker	Gasoline	Diesel	Owner	Gasoline	Diesel	Owner
ALFA ROMEO	5,038	64	ALFA ROMEO	2,941	3,983	FIAT
AUDI	16,689	1,982	VOLKSWAGEN	15,273	24,184	VOLKSWAGEN
BMW	17,855	1,906	BMW	13,683	15,838	BMW
CHRYSLER	1,243	–		5,941	2,389	
CITROËN	68,890	36,851	PSA	46,420	111,694	PSA
DAEWOO	–	–		25,201	–	
FIAT	35,677	5,733	FIAT	30,557	17,967	FIAT
FORD	121,140	17,468	FORD	55,268	57,013	FORD
HONDA	4,805	–		8,782	1,072	
HYUNDAI	2,704	–		30,150	3,590	
KIA	–	–		9,778	1,387	
LANCIA	11,117	905	LANCIA	2,206	2,126	FIAT
MAZDA	3,064	–		2,205	1,480	
MERCEDES	9,352	4,129	MERCEDES	13,953	10,684	MERCEDES
MITSUBISHI	3,041	–		3,660	1,013	
NISSAN	16,010	905		17,855	21,971	
OPEL	110,286	11,099	GM	66,488	75,418	GM
PEUGEOT	61,323	35,494	PSA	55,371	92,496	PSA
RENAULT	147,907	27,448	RENAULT	76,925	99,360	RENAULT
ROVER	15,255	425	ROVER	10,173	8,491	ROVER
SAAB	1,551	–	SAAB	1,867	2,424	GM
SEAT	85,773	11,787	VOLKSWAGEN	58,072	109,447	VOLKSWAGEN
SKODA	724	–	SKODA	5,003	10,385	VOLKSWAGEN
SUZUKI	2,058	–		3,250	486	
TOYOTA	4,425	–		16,827	3,584	
VOLKSWAGEN	50,561	5,471	VOLKSWAGEN	47,125	50,296	VOLKSWAGEN
VOLVO	10,179	–	VOLVO	7,379	3,566	FORD

Sales of vehicle by manufacturer and fuel type. "Owner" indicates the name of the automobile group with direct control on production and pricing. Those without a group are all non-European manufacturers and given their smaller size will be grouped under the NON-EU label later in the analysis.

For the estimation of the equilibrium random coefficient discrete choice model of Table 2 we distinguish between prices paid by consumers and those perceived by manufacturers. On the

[35] See `http://www.ine.es/jaxi/menu.do?L=1&type=pcaxis&path=/t25/p458&file=inebase` for a description of these databases in English.

demand we build a data set using 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.

Until Spain ended its accession to the European Union transition period in 1992, it was allowed to charge import duties on European products. Similarly, import duties for non-European products converged to European levels. European imports paid tax duty of 4.4% in 1992, and nothing thereafter. Non-European manufacturers had to pay 14.4% and 10.3%, respectively.

The other relevant factor that changes during the 1990s is the ownership structure of automobile firms. During this decade FIAT acquired ALFA ROMEO and LANCIA; FORD acquired VOLVO; and GM acquired SAAB. BMW acquired ROVER in 1994 but sold it (with the exception of the "Mini" brand) in May 2000 so these are treated as separate firms. Table A.1 describes the ownership structure at the beginning and end of the decade.

B Computing Domestic Automobile Prices

We provide computational details for the procedures we employ to find the profit-maximizing prices under each policy experiment. Each firm f produces some subset $\mathcal{F}_t^f$ of the $j = 1, \ldots, J$ automobile brands in each period t and chooses a vector of pre-tariff prices $\{p_{j,t}^{\tau}\}$ to solve:

$$\max_{\{p_{jt}^{\tau}\}} \sum_{j \in \mathcal{F}_t^f} \left(p_{jt}^{\tau} - c_{jt} \right) \times M_t s_{jt}(p_{jt}) \,, \tag{B.1}$$

where we have assumed that the consumer pays the import duty. The final price facing the consumer (p_{jt}) is defined as $p_{jt}^{\tau} \times (1 + \tau_{jt})$ where τ_{jt} is the import tariff (if applicable). The firm's first-order condition associated with profit maximization in period t is given by:

$$s_{jt}(p_t) + \sum_{r \in \mathcal{F}_t^f} (p_{rt}^{\tau} - c_{rt}) \times \frac{\partial s_{rt}(p_t)}{\partial p_{rt}^{\tau}} = 0 \,. \tag{B.2}$$

Optimality requires that Equation (B.2) hold for all products sold in period t. We express the set of firm f first-order conditions in matrix notation as:

$$s(p_t) + \Omega(p_t) \times (p_t^{\tau} - c_t) = 0 \,, \tag{B.3}$$

where an element of the matrix Ω is defined as:

$$\Omega_{jr} = \begin{cases} \dfrac{\partial s_{jt}(p_t)}{\partial p_{rt}^{\tau}} \,, & \text{if } \{j, r\} \subset \mathcal{F}_t^f \,, \\ \\ 0 & \text{otherwise} \,. \end{cases} \tag{B.4}$$

For a given vector of period t marginal costs c_t, we find the fixed point to the system of equations defined in Equation (B.3) numerically. To this end, define the following operator in period t as:

$$T(p_t) = c_t - \Omega^{-1}(p_t) \times s(p_t)\,, \tag{B.5}$$

where the equilibrium prices are such that $p' = T(p)$. When $\|p' - p\|_\infty$ is sufficiently small, then the first-order condition defined in Equation (B.3) necessarily holds and p' contains the set of profit-maximizing retail prices in each market.

C Additional Results

Table C.1: Car Model Characteristics Across Engine Types

ENGINE	MODELS	SHARE	PRICE	C90	SIZE	HPW	MC	ε_p
1992-1993								
EU: DIESEL	93	18.9	12.6	4.5	74.0	31.4	7.8	2.7
EU: GASOLINE	148	76.6	11.5	5.4	71.7	40.9	6.8	2.5
NON-EU: DIESEL	4	0.2	14.4	5.3	80.9	29.2	8.6	3.0
NON-EU: GASOLINE	50	4.4	14.1	5.8	76.8	44.0	8.3	2.9
ALL	295	100.0	11.8	5.3	72.4	39.2	7.1	2.6
1999-2000								
EU: DIESEL	153	49.8	16.0	4.6	76.2	31.4	10.3	3.1
EU: GASOLINE	170	38.4	14.7	5.7	73.2	38.6	9.3	3.0
NON-EU: DIESEL	39	2.5	16.9	5.5	82.1	31.1	10.8	3.4
NON-EU: GASOLINE	94	9.3	13.5	6.1	75.2	40.9	8.3	3.0
ALL	456	100.0	15.3	5.2	75.1	35.0	9.8	3.1

Statistics weighted by relevant quantity sold. PRICE is denominated in the equivalent of thousands of 1994 Euros and includes tariffs. C90 is the fuel consumption in liters to cover 100 km at a constant speed of 90 km/h on highway conditions. SIZE is length×width measured in square feet. HPW is the performance ratio of horsepower to thousand pounds of weight. MC is based on estimates from Table 2. Similarly, ε_p reports the average price elasticity estimate in absolute value.

Web Appendix – Not for Publication

Table W.1: Robustness – Convergence

Alternative	Matlab / Tolerance	Objective Function
Algorithm:		
Ours: Nelder-Mead (simplex)	fminsearch.m	40.98
Quasi-Newton (gradient)	fminunc.m	41.09
Contraction Mapping:		
Less Demanding	1E-10	40.98
Ours (Dubé et al. (2012))	1E-14	40.98
More Demanding	1E-16	Not Converged
Objective Function:		
Less Demanding (Knittel and Metaxoglou (2013))	1E-03	40.98
Ours	1E-05	40.98
More Demanding	1E-08	40.98

Figure W.1: Distribution of Objective Function Estimates

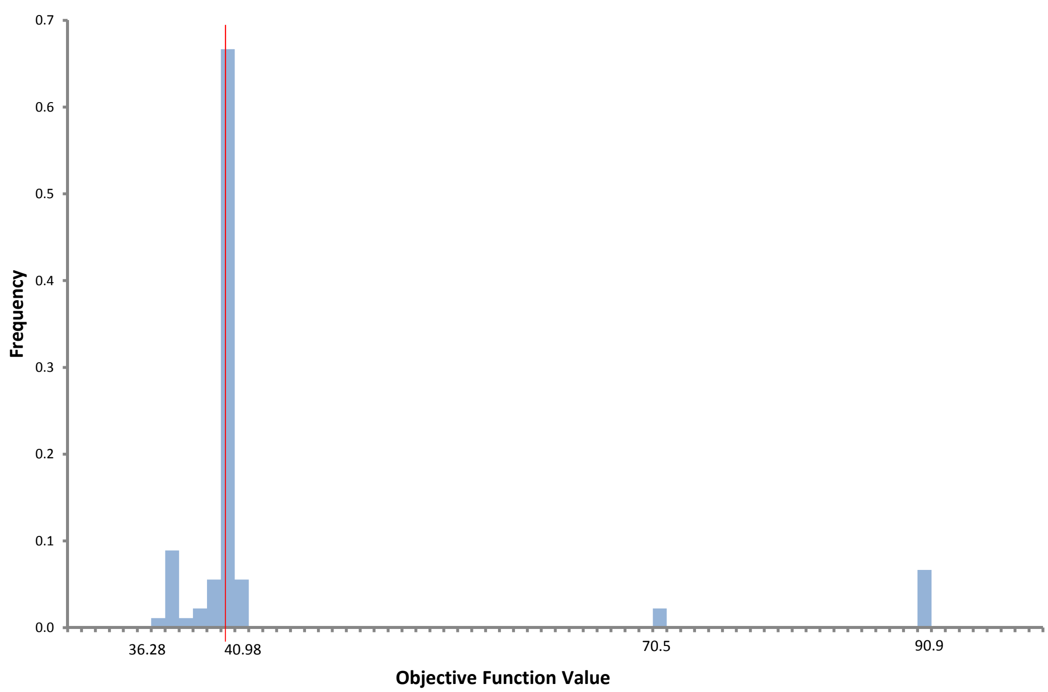
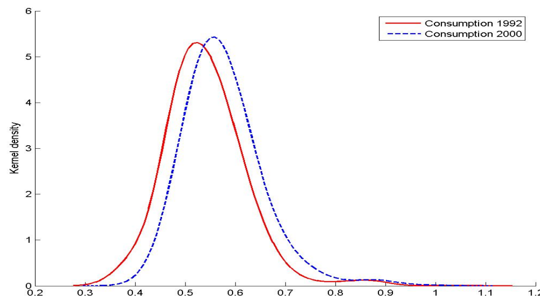
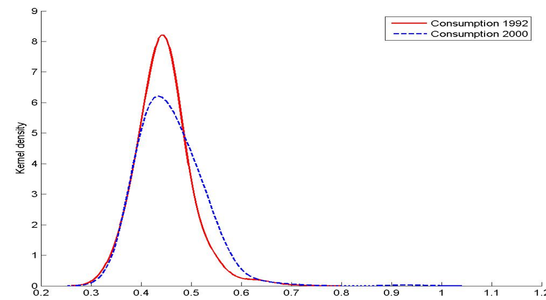


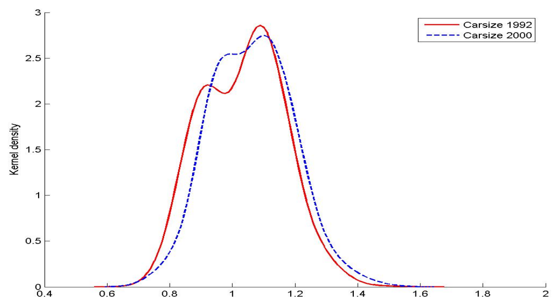
Figure W.2: Change in the Distribution of Automobile Attributes



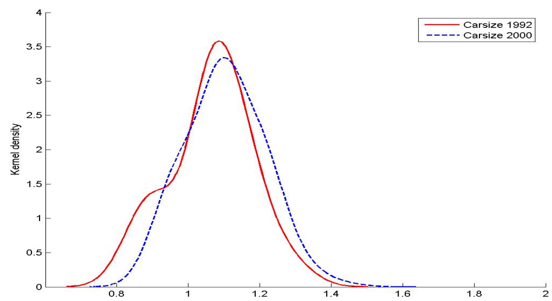
(a) Gasoline: Mileage



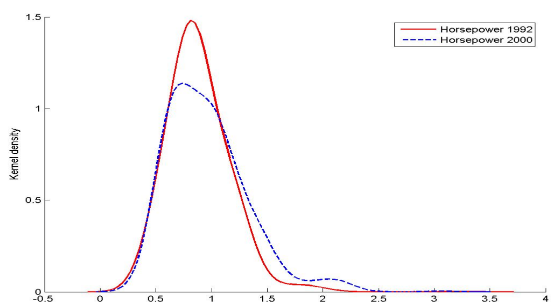
(b) Diesel: Mileage



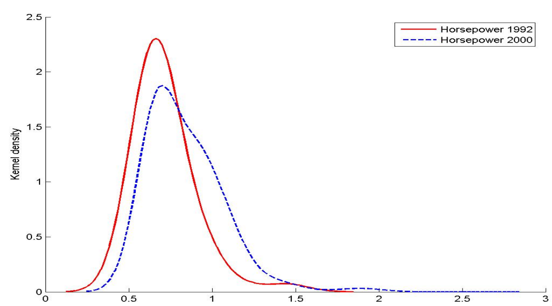
(c) Gasoline: Car Size



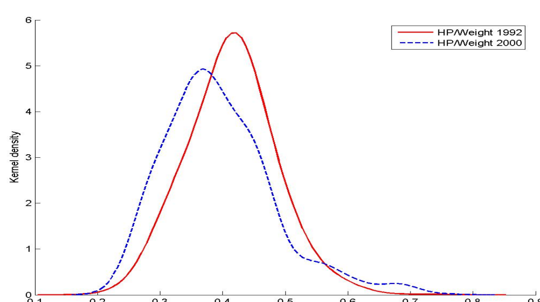
(d) Diesel: Car Size



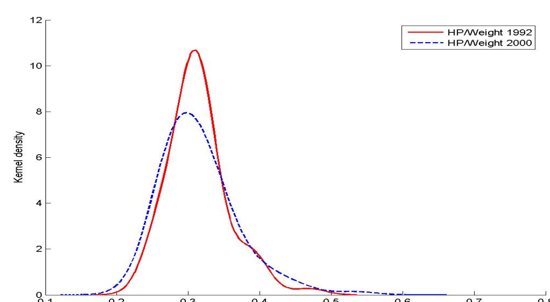
(e) Gasoline: Horsepower



(f) Diesel: Horsepower



(g) Gasoline: Horsepower/Weight



(h) Diesel: Horsepower/Weight

Table W.2: Components for the Counterfactual Experiments

	Demand			Supply			Market Structure			
Experiment	Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\xi\}$	Tariffs	$\{\gamma\}$	$\{\omega\}$	Models	Owners	Imports	Diesel
1992 Income	**1992**	2000	2000	2000	2000	2000	2000	2000	Yes	Yes
$\{\alpha,\beta,\sigma,\pi\}$	2000	**1992**	2000	2000	2000	2000	2000	2000	Yes	Yes
$\{\alpha,\beta,\sigma,\pi,\xi\}$	2000	**1992**	**1992**	2000	2000	2000	2000	2000	Yes	Yes
Tariffs	2000	2000	2000	**1992**	2000	2000	2000	2000	Yes	Yes
$\{\gamma\}$	2000	2000	2000	2000	**1992**	2000	2000	2000	Yes	Yes
$\{\gamma,\omega\}$	2000	2000	2000	2000	**1992**	**1992**	2000	2000	Yes	Yes
1992 Products	2000	2000	2000	2000	2000	2000	**1992**	2000	Yes	Yes
1992 Owners	2000	2000	2000	2000	2000	2000	2000	**1992**	Yes	Yes
No Imports	2000	2000	2000	2000	2000	2000	2000	2000	**No**	Yes
No Diesel	2000	2000	2000	2000	2000	2000	2000	2000	Yes	**No**

"1992" denotes the 1992-1993 sample and "2000" the 1999-2000 sample.

Table W.3: All Counterfactuals — Average Effects

	1999-2000 Base Case			Price (%Δ from Base Case)									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	1992 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
European:													
- All Models	88.2	323	15.4	-11.1	2.7	18.3	1.4	-10.6	-7.4	-31.5	0.6	-0.3	-3.0
- Diesel	49.7	153	16.0	-9.1	5.1	15.5	1.7	-8.7	-6.3	-30.0	0.7	-0.3	-
- Gas	38.4	170	14.6	-13.6	1.3	22.7	1.1	-12.6	-6.6	-29.4	0.5	-0.3	2.2
Non-European:													
- All Models	11.8	133	14.2	-11.6	7.7	22.7	1.9	-10.2	-4.0	-15.4	-	0.2	-0.7
- Diesel	2.5	39	16.9	-5.3	4.5	10.7	2.7	-4.0	5.4	-21.5	-	0.1	-
- Gas	9.3	94	13.5	-12.8	9.3	26.0	1.7	-11.4	-5.1	-11.3	-	0.2	4.6

	1999-2000 Base Case			Price-Cost Markup									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	MARKUP	1992 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
European:													
- All Models	88.2	323	64.4	55.6	71.6	65.8	63.1	81.7	85.7	67.8	65.3	63.8	66.6
- Diesel	49.7	153	61.6	53.5	65.5	63.8	60.4	75.6	72.2	60.9	62.6	61.1	-
- Gas	38.4	170	67.9	58.2	77.8	67.7	66.6	88.9	96.9	70.3	68.8	67.4	66.6
Non-European:													
- All Models	11.8	133	53.1	45.7	70.3	66.1	51.9	69.9	74.4	44.6	-	53.3	56.9
- Diesel	2.5	39	44.0	38.7	55.7	55.3	43.0	49.9	47.5	40.0	-	44.1	-
- Gas	9.3	94	55.6	47.3	73.7	69.8	54.3	74.6	79.8	44.9	-	55.7	56.9

	1999-2000 Base Case			Profits (%Δ from Base Case)									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PROFIT	1992 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
European:													
- All Models	88.2	323	13,481.1	-28.0	-46.9	-80.0	-4.4	3.0	7.0	-36.6	12.8	-0.5	-20.2
- Diesel	49.7	153	7,842.4	-28.7	-52.9	-82.8	-4.3	-0.1	-13.0	-69.7	12.7	-0.5	-
- Gas	38.4	170	5,638.6	-26.9	-38.7	-76.2	-4.4	7.3	34.7	9.5	12.8	-0.6	90.7
Non-European:													
- All Models	11.8	133	1,335.0	-27.2	-49.0	-27.5	-4.0	-0.5	-21.3	-75.0	-	-0.7	46.3
- Diesel	2.5	39	313.7	-30.7	-56.9	-17.8	-4.7	-7.9	-35.4	-94.4	-	-0.7	-
- Gas	9.3	94	1,021.3	-26.1	-46.6	-30.5	-3.7	1.8	-16.9	-69.0	-	-0.8	91.3

Statistics weighted by relevant quantity sold. Markups defined as Price/MC - 1 where Price excludes tariffs. "No Diesel" evaluates the market performance with all demand and supply estimates for the 1999-2000 sample but assuming that diesel vehicles are not available. "All" reports the results for the end of the decade assuming all demand and supply conditions and ownership structure from 1992 but models available in 2000.

Table W.4: All Counterfactuals — Market Shares (%)

		Demand			Supply			Market Structure			
ENGINE	BASE	1992 Income	$\{\alpha, \beta, \sigma, \pi\}$	$\{\alpha, \beta, \sigma, \pi, \xi\}$	1992 Tariffs	$\{\gamma\}$	$\{\gamma, \omega\}$	1992 Models	No-Imports	1992 Owners	No-Diesel
- All Models	88.2	87.9	90.1	71.1	88.1	88.6	91.3	95.6	100.0	88.3	81.2
- Diesel	49.7	48.2	45.3	35.4	49.6	48.0	41.3	25.1	56.3	49.9	0.0
- Gas	38.4	39.7	44.8	35.7	38.5	40.6	50.1	70.5	43.7	38.5	81.2
Non-European:											
- All Models	11.8	12.1	9.9	28.9	11.9	11.4	8.7	4.4	0.0	11.7	18.8
- Diesel	2.5	2.3	1.8	7.4	2.5	2.1	1.4	0.2	0.0	2.5	0.0
- Gas	9.3	9.8	8.0	21.4	9.4	9.2	7.2	4.2	0.0	9.2	18.8
BMW-Dsl	2.0	1.4	1.7	1.7	1.8	1.5	0.7	1.1	2.1	1.9	0.0
BMW-Gas	2.0	1.2	1.4	1.3	1.8	1.7	3.0	1.8	2.5	2.0	2.2
FIAT-Dsl	3.1	3.0	2.7	14.6	3.0	3.2	2.6	4.5	3.4	3.1	0.0
FIAT-Gas	5.4	6.2	5.0	11.5	5.4	5.6	6.8	7.2	6.9	5.3	5.0
FORD-Dsl	8.4	8.4	8.5	7.5	8.3	7.9	6.8	11.1	9.0	8.5	0.0
FORD-Gas	11.1	11.0	11.8	9.0	11.0	11.0	9.7	15.9	14.0	11.2	10.7
GM-Dsl	10.4	10.5	10.3	5.4	10.3	10.7	11.1	8.2	11.1	10.3	0.0
GM-Gas	11.2	10.9	12.3	5.0	11.1	11.7	11.2	14.5	14.1	11.1	11.0
MERCEDES-Dsl	1.4	1.0	1.2	2.1	1.3	1.2	1.9	1.9	1.5	1.4	0.0
MERCEDES-Gas	2.0	1.3	1.7	1.5	1.8	1.9	7.7	1.7	2.5	2.0	2.1
NON-EU-Dsl	4.8	4.5	3.9	17.4	4.7	4.3	3.4	0.8	0.0	4.7	0.0
NON-EU-Gas	19.6	19.8	15.2	37.5	19.6	18.5	12.6	5.7	0.0	19.3	18.8
PSA-Dsl	28.6	29.4	29.7	11.2	28.4	29.5	32.1	41.7	29.7	28.3	0.0
PSA-Gas	14.7	15.5	15.7	6.4	14.8	14.9	13.6	13.9	18.0	14.6	15.7
RENAULT-Dsl	14.3	14.9	13.6	4.7	14.2	14.6	16.4	17.4	15.1	14.1	0.0
RENAULT-Gas	12.9	13.0	13.1	4.8	12.9	12.6	9.2	15.7	16.1	12.8	12.8
ROVER-Dsl	1.3	1.2	1.4	5.3	1.2	1.3	1.2	0.5	1.4	1.3	0.0
ROVER-Gas	1.5	1.3	1.4	5.6	1.4	1.5	1.0	3.6	1.9	1.5	1.5
VOLKSWAGEN-Dsl	25.8	25.8	27.1	30.3	26.8	25.8	24.0	12.7	26.8	26.4	0.0
VOLKSWAGEN-Gas	19.7	19.8	22.4	17.5	20.2	20.5	25.3	20.1	24.0	20.1	20.2
Outside Option	89.35	90.62	94.95	97.71	89.47	89	89.01	90.02	89.56	89.34	90.46

At the bottom panel market shares based on the engine category. Statistics grouped by by ownership group: GM: OPEL and SAAB; VOLKSWAGEN: AUDI, SEAT, and SKODA; FIAT: ALFA ROMEO, LANCIA, and FIAT; FORD: FORD and VOLVO; PSA: CITROËN and PEUGEOT; and NON-EU: CHRYSLER, DAEWOO, HONDA, HYUNDAI, KIA, MAZDA, MITSUBISHI, NISSAN, SUZUKI, and TOYOTA.

Table W.5: All Counterfactuals — Dispersion of the Distribution

	1999-2000 Base Case			Percent of Products with an Increase in Price relative to the Benchmark									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	92 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	92 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	92 Models	No-Imports	92 Owners	No-Diesel
European:													
-All Models	88.2	323	15.4	0.0	50.8	45.5	92.6	20.4	35.3	-	67.2	50.5	63.5
-Diesel	49.7	153	16.0	0.0	45.1	42.5	92.2	0.0	58.8	-	68.0	47.7	-
-Gas	38.4	170	14.6	0.0	55.9	48.2	92.9	38.8	14.1	-	66.5	52.9	63.5
Non-European:													
-All Models	11.8	133	14.2	0.8	87.2	88.0	100.0	30.8	69.9	-	-	100.0	93.6
-Diesel	2.5	39	16.9	2.6	92.3	94.9	100.0	5.1	82.1	-	-	100.0	-
-Gas	9.3	94	13.5	0.0	85.1	85.1	100.0	41.5	64.9	-	-	100.0	93.6

	1999-2000 Base Case			Percent of Models with a Markup Increase relative to the Benchmark									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	92 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	92 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	92 Models	No-Imports	92 Owners	No-Diesel
European:													
-All Models	88.2	323	46.3	0.0	50.8	45.5	91.6	95.4	82.0	-	67.2	50.5	63.5
-Diesel	49.7	153	45.1	0.0	45.1	42.5	92.2	100.0	65.4	-	68.0	47.7	-
-Gas	38.4	170	47.8	0.0	55.9	48.2	91.2	91.2	97.1	-	66.5	52.9	63.5
Non-European:													
-All Models	11.8	133	43.7	0.8	87.2	88.0	93.2	96.2	64.7	-	-	100.0	93.6
-Diesel	2.5	39	38.1	2.6	92.3	94.9	100.0	100.0	53.8	-	-	100.0	-
-Gas	9.3	94	45.2	0.0	85.1	85.1	90.4	94.7	69.1	-	-	100.0	93.6

	1999-2000 Base Case			Percent of Products with an Increase in Profit relative to the Benchmark									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	92 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	92 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	92 Models	No-Imports	92 Owners	No-Diesel
European:													
-All Models	88.2	323	11,074.9	0.9	0.3	35.3	10.2	50.5	55.7	-	100.0	3.1	100.0
-Diesel	49.7	153	6,465.4	0.0	0.0	34.6	7.8	85.0	30.1	-	100.0	3.3	-
-Gas	38.4	170	4,609.5	1.8	0.6	35.9	12.4	19.4	78.8	-	100.0	2.9	100.0
Non-European:													
-All Models	11.8	133	1,192.3	6.0	0.8	63.2	41.4	30.8	21.8	-	-	0.0	100.0
-Diesel	2.5	39	283.1	0.0	0.0	69.2	17.9	69.2	15.4	-	-	0.0	-
-Gas	9.3	94	909.3	8.5	1.1	60.6	51.1	14.9	24.5	-	-	0.0	100.0

Statistics weighted by relevant quantity sold. Markups defined as Price/MC - 1 where Price excludes tariffs. “No Diesel” evaluates the market performance with all demand and supply estimates for the 1999-2000 sample but assuming that diesel vehicles are not available. “All” reports the results for the end of the decade assuming all demand and supply conditions and ownership structure from 1992 but models available in 2000.

Table W.6: Firm Level Counterfactuals — Prices

				Price (%Δ from Base Case)									
	1999-2000 Base Case			Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	92 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	92 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	92 Models	No-Imports	92 Owners	No-Diesel
BMW-Dsl	2.0	6	31.9	-5.3	-7.2	6.9	4.4	-16.4	9.7	0.0	-11.4	0.0	0.0
BMW-Gas	2.0	8	36.7	-5.0	-5.6	-1.1	4.6	-13.7	-17.3	0.5	7.6	0.0	0.4
FIAT-Dsl	3.1	27	15.7	-6.0	4.8	14.2	4.5	-13.2	-2.1	0.0	-1.9	0.1	0.0
FIAT-Gas	5.4	30	11.0	-10.7	10.0	45.6	3.9	4.4	-26.5	0.9	-1.0	0.2	5.3
FORD-Dsl	8.4	15	15.6	-6.3	3.6	19.9	4.4	-9.1	4.2	0.0	4.4	-0.2	0.0
FORD-Gas	11.1	21	13.9	-8.1	1.7	27.1	4.0	-1.7	-4.6	0.9	30.2	0.1	4.7
GM-Dsl	10.4	13	14.9	-6.2	3.7	21.0	4.5	-10.8	-3.6	0.0	-21.6	0.1	0.0
GM-Gas	11.2	18	13.7	-6.7	1.7	29.0	4.4	-1.3	-16.2	0.9	29.0	0.1	3.6
MERCEDES-Dsl	1.4	11	33.8	-8.0	-5.5	0.4	4.0	-13.4	-27.1	0.0	-44.0	0.0	0.0
MERCEDES-Gas	2.0	12	36.2	-18.7	-16.5	3.7	1.8	5.5	-36.1	0.5	-34.1	0.1	2.6
NON-EU-Dsl	4.8	39	16.9	-5.4	-1.0	7.7	3.9	-10.4	9.3	0.0	-2.5	0.1	0.0
NON-EU-Gas	19.6	94	13.5	-11.8	4.2	23.2	2.8	0.1	0.5	0.8	14.1	0.2	6.1
PSA-Dsl	28.6	22	15.2	-6.9	2.4	6.6	4.4	-10.3	-4.8	0.0	-3.7	0.0	0.0
PSA-Gas	14.7	18	12.5	-6.7	2.6	21.9	4.3	-0.5	-11.8	0.0	5.5	0.0	0.4
RENAULT-Dsl	14.3	10	13.5	-6.4	2.5	27.2	4.5	-8.1	-9.4	0.0	1.5	0.0	0.0
RENAULT-Gas	12.9	12	12.6	-5.5	2.7	18.2	4.7	-2.6	-6.5	0.5	-15.4	0.0	2.4
ROVER-Dsl	1.3	9	18.5	-5.6	-1.9	2.8	4.6	-14.9	2.1	0.0	16.8	0.1	0.0
ROVER-Gas	1.5	10	15.9	-5.6	-2.7	2.9	4.6	-8.7	4.7	0.7	17.8	0.1	2.3
VOLKSWAGEN-Dsl	25.8	40	16.8	-8.3	4.6	6.3	0.0	-8.3	-1.9	0.0	-16.0	-1.2	0.0
VOLKSWAGEN-Gas	19.7	41	15.0	-10.9	-1.2	20.2	0.1	5.2	-20.8	1.0	-25.3	-1.3	3.7

Statistics weighted by relevant quantity sold. Markups defined as Price/MC - 1 where Price excludes tariffs. “No Diesel” evaluates the market performance with all demand and supply estimates for the 1999-2000 sample but assuming that diesel vehicles are not available. “All” reports the results for the end of the decade assuming all demand and supply conditions and ownership structure from 1992 but models available in 2000.

Table W.7: Firm Level Counterfactuals — Markups

	1999-2000 Base Case			Markup (%)									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	92 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	92 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	92 Models	No-Imports	92 Owners	No-Diesel
BMW-Dsl	2.0	6	26.7	22.2	25.6	23.4	27.2	29.6	26.5	22.1	26.6	26.7	0.0
BMW-Gas	2.0	8	25.5	20.2	23.2	22.6	26.0	28.2	29.0	24.8	25.4	25.5	25.5
FIAT-Dsl	3.1	27	37.6	33.1	40.6	39.4	38.4	39.9	44.2	36.7	37.2	37.6	0.0
FIAT-Gas	5.4	30	47.1	39.5	55.0	44.7	48.0	49.3	69.5	48.8	46.6	47.2	48.5
FORD-Dsl	8.4	15	39.4	34.4	42.2	39.3	40.3	41.3	42.4	42.8	39.7	38.9	0.0
FORD-Gas	11.1	21	43.2	37.5	48.8	42.1	44.1	44.8	49.0	44.6	43.5	42.6	44.6
GM-Dsl	10.4	13	42.0	36.6	44.4	40.6	42.9	45.2	46.4	41.9	42.2	42.0	0.0
GM-Gas	11.2	18	44.6	38.9	49.1	40.1	45.5	46.2	57.0	43.9	44.8	44.7	45.6
MERCEDES-Dsl	1.4	11	26.5	22.7	25.3	24.4	27.2	29.2	34.2	21.7	26.4	26.5	0.0
MERCEDES-Gas	2.0	12	27.4	24.5	27.1	22.8	28.3	27.3	37.4	17.4	27.3	27.4	27.2
NON-EU-Dsl	4.8	39	38.1	33.5	43.5	41.6	38.8	40.2	40.3	33.9	0.0	38.2	0.0
NON-EU-Gas	19.6	94	45.2	38.0	54.3	49.4	45.8	47.6	56.6	37.0	0.0	45.3	46.5
PSA-Dsl	28.6	22	49.4	43.3	48.2	47.1	50.3	53.9	55.1	46.9	50.5	49.4	0.0
PSA-Gas	14.7	18	55.1	48.0	57.3	47.2	55.8	58.0	67.1	54.0	56.5	55.1	51.7
RENAULT-Dsl	14.3	10	45.3	39.5	49.4	42.1	46.2	47.9	51.4	41.0	45.9	45.4	0.0
RENAULT-Gas	12.9	12	47.3	41.0	52.2	46.2	48.1	49.3	55.9	46.9	47.9	47.3	47.8
ROVER-Dsl	1.3	9	34.3	29.9	36.2	35.9	35.2	37.0	36.1	31.1	34.0	34.4	0.0
ROVER-Gas	1.5	10	36.4	31.5	40.8	40.8	37.3	38.4	37.7	35.8	35.9	36.5	37.2
VOLKSWAGEN-Dsl	25.8	40	47.3	41.3	45.0	44.9	48.3	50.5	54.4	42.3	48.5	46.0	0.0
VOLKSWAGEN-Gas	19.7	41	52.3	45.5	54.0	45.6	53.7	52.5	75.4	50.8	53.6	51.1	51.0

Statistics weighted by relevant quantity sold. Markups defined as Price/MC - 1 where Price excludes tariffs. "No Diesel" evaluates the market performance with all demand and supply estimates for the 1999-2000 sample but assuming that diesel vehicles are not available. "All" reports the results for the end of the decade assuming all demand and supply conditions and ownership structure from 1992 but models available in 2000.

Table W.8: Firm Level Counterfactuals — Profits

	1999-2000 Base Case			Profit (%Δ from Base Case)									
				Demand			Supply			Market Structure			
FIRM	SHARE	MODELS	PRICE	92 Income	$\{\alpha,\beta,\sigma,\pi\}$	$\{\alpha,\beta,\sigma,\pi,\xi\}$	92 Tariffs	$\{\gamma\}$	$\{\gamma,\omega\}$	92 Models	No-Imports	92 Owners	No-Diesel
BMW-Dsl	2.0	6	185.2	-48.4	-63.3	-76.7	-9.7	88.7	-64.3	-78.9	13.1	-0.5	-
BMW-Gas	2.0	8	195.8	-56.4	-73.2	-82.8	-11.3	51.6	56.8	-23.7	12.1	-0.4	116.7
FIAT-Dsl	3.1	27	185.9	-25.3	-51.5	54.5	-3.5	24.8	-24.6	-57.1	13.5	-0.7	-
FIAT-Gas	5.4	30	231.2	-14.6	-37.6	2.3	-0.9	-21.0	54.3	32.0	13.7	-0.8	84.8
FORD-Dsl	8.4	15	516.8	-23.6	-43.3	-72.4	-3.0	6.8	-24.0	-65.2	14.4	-0.6	-
FORD-Gas	11.1	21	579.5	-20.6	-33.6	-66.3	-2.5	-15.9	14.5	38.8	13.9	-0.6	96.9
GM-Dsl	10.4	13	635.4	-22.1	-47.4	-85.7	-3.1	10.7	-6.3	-77.8	13.5	-0.7	-
GM-Gas	11.2	18	600.6	-20.6	-36.8	-83.7	-2.7	-13.0	24.2	20.3	13.3	-0.7	93.9
MERCEDES-Dsl	1.4	11	133.1	-50.2	-67.0	-66.6	-10.6	82.4	-8.5	-37.7	12.8	-0.4	-
MERCEDES-Gas	2.0	12	180.7	-55.3	-66.5	-81.1	-12.0	39.0	180.7	41.0	12.1	-0.4	113.6
NON-EU-Dsl	4.8	39	283.1	-25.1	-55.7	18.3	-0.7	4.9	-42.9	-94.3	-	-0.7	-
NON-EU-Gas	19.6	94	909.3	-18.9	-49.6	-9.1	0.4	-14.9	-26.2	-67.4	-	-0.8	97.1
PSA-Dsl	28.6	22	1,980.1	-21.8	-50.6	-91.2	-3.5	9.0	-2.0	-59.1	12.6	-0.6	-
PSA-Gas	14.7	18	828.8	-15.5	-41.9	-85.9	-2.1	-17.5	18.4	-10.6	12.5	-0.7	92.2
RENAULT-Dsl	14.3	10	837.8	-18.8	-49.0	-90.1	-2.3	4.5	-4.7	-64.1	13.6	-0.7	-
RENAULT-Gas	12.9	12	667.4	-17.0	-37.6	-85.9	-1.7	-16.4	-7.8	18.3	13.8	-0.8	93.8
ROVER-Dsl	1.3	9	85.2	-30.3	-41.9	16.7	-4.6	24.5	-18.2	-88.2	13.5	-0.6	-
ROVER-Gas	1.5	10	80.7	-24.4	-37.7	60.2	-3.5	2.8	-7.2	118.7	13.3	-0.6	101.4
VOLKSWAGEN-Dsl	25.8	40	1,906.0	-24.8	-48.3	-70.9	4.3	14.9	-16.6	-86.3	12.7	-0.2	-
VOLKSWAGEN-Gas	19.7	41	1,244.7	-22.1	-42.8	-71.9	3.0	-14.2	63.8	-7.5	12.2	-0.3	95.4

Statistics weighted by relevant quantity sold. Markups defined as Price/MC - 1 where Price excludes tariffs. “No Diesel” evaluates the market performance with all demand and supply estimates for the 1999-2000 sample but assuming that diesel vehicles are not available. “All” reports the results for the end of the decade assuming all demand and supply conditions and ownership structure from 1992 but models available in 2000.