The Market Impact and the Cost of Environmental Policy: Evidence from the Swedish Green Car Rebate*

Cristian Huse† Claudio Lucinda‡

March 2013

Abstract

This paper quantifies the effects of the Swedish green car rebate (GCR), a program to reduce oil dependence and greenhouse gas emissions in the automobile industry. We estimate the demand for automobiles in the Swedish market and simulate counterfactual policies to assess different program dimensions. Our most conservative estimates find the GCR to have increased the market shares of "green cars" by 5.5 percentage points and its cost to be about \$109/tonCO2 saved, thus 5 times the price of an emission permit. Since the main green cars in Sweden are FFVs (flexible-fuel vehicles), which can seamlessly switch between (high-CO2 emissions) gasoline and (low-CO2 emissions) ethanol, fuel choice is another dimension policymakers need to consider – once fuel arbitrage is accounted for, the cost of CO2 savings increases by over 16 percent if 50 percent of FFV owners drive on gasoline instead of ethanol. Moreover, the GCR design was detrimental to Swedish carmakers, which lost substantial market share due to the policy. As the GCR gives vehicles able to operate on alternative (renewable) fuels a favorable treatment as compared to those operating only on regular (fossil) ones, we also consider a counterfactual in which they are treated equally. Our findings suggest that consumers would have switched to the FFV technology even without the rebate.

JEL Classification: H23, H25, L11, L62, L71, L98, Q42, Q48.

Keywords: CO2 emissions; Ethanol; Environmental policy; Flexible-fuel vehicles; Fuel economy; Green Car; Governmental policy; Greenhouse gases; Renewable fuels.

*We thank Tobias Olsson for making data available, Alexandra Lindfors and Martin Roxland for research assistance, and participants at the SBE Meeting, the SSE Empirical Micro and REAP-MOITA workshops for feedback. We are also indebted to Nikita Koptyug, Henrique Pacini and Heleno Pioner (REAP-MOITA discussant) for comments. The usual disclaimer applies.

†Stockholm School of Economics. Email address: cristian.huse@sse.edu. Web: http://cristianhuse.webs.com. Correspondence address: Stockholm School of Economics, Box 6501, 113 83 Stockholm, Sweden. Phone: + 46 8736 9167.

‡University of São Paulo (FEA-RP). Email address: claudiolucinda@fearp.usp.br. Correspondence address: Av. Bandeirantes, 3900, Monte Alegre, 14040-900, Ribeirão Preto-SP, Brazil. Phone: + 55 16 3602 4971.

1 Introduction

Road transportation is responsible for 20 percent of the CO2 emissions generated by fuel consumption worldwide. With the growth of emerging economies, fuel demand for transportation needs is set to grow by 40 percent and the number of passenger cars worldwide is set to double to almost 1.7 billion by 2035 (IEA 2011a, 2011b). Within the European Union, passenger cars are responsible for about 12 percent of the overall emissions. This share is a much higher 19 percent in Sweden, and close to the 20 percent estimated to hold for the US market, as the country has one of the most fuel-devouring car fleets on the continent (Commission of the European Communities 2007). Reducing emissions from passenger cars is thus essential for Sweden to meet EU-wide environmental goals.[1] In practice – especially when gasoline taxes are difficult to sustain on political grounds – this essentially involves increasing fuel economy standards of the means of transport and/or investing in alternative fuels and transportation technologies (Parry, Walls and Harrington 2007).

This paper examines the effect of regulation on the Swedish new passenger car market. Specifically, it evaluates the effect of the Swedish Green Car Rebate (GCR) on CO2 emissions savings, their costs (both total costs and cost per ton of saved CO2) as well as the market shares of the different brands operating in this market. The Swedish automobile industry is responsible for substantial amounts of employment, investment, exports and R&D in the country.[2] As a result, one may argue that –on top of environmental concerns– a policy such as the GCR could have been tailored to benefit domestic producers, either because of the economic importance of the industry or due to the fact that regulators are likely to be captured by businesses during regulatory design (Laffont and Tirole 1991, Boyer and Laffont 1999). Thus, this paper also examines to which extent domestic carmakers benefited from its design, if at all.

The Swedish Green Car Rebate The Swedish Green Car Rebate (GCR) is one among a number of policies designed to incentivize the purchase of fuel-efficient vehicles worldwide amid the ever growing concern with GHG and the quest for oil independence.[3] The GCR, which consisted of a 10,000 SEK rebate paid to private individuals purchasing new environmentally friendly – or *green* – cars.[4] Two features distinguish the GCR from similar policies elsewhere. First, in contrast with related policies elsewhere which have typically not been applied widely enough to affect a large fraction of the new vehicle market (Sallee 2011a), the GCR was broad in that green cars commanded a 25 percent market share among newly-registered cars already in 2008, as compared to the 2.15 percent commanded by HEVs in the US after a similar policy (Beresteanu and Li 2011).

[1] The 1994 EEA Treaty originally set a target of 120 gCO2/km by 2005 (later relaxed to 130 gCO2/km by 2012) and aimed at cutting carbon emissions by 20 percent by 2020 compared to the levels of 1990. For perspective, Sweden's fleet does lag behind most EU 25 countries when it comes to average CO2 emissions; these are lower only than those of Estonia and Latvia (EFTE 2009).

[2] Having originated in Sweden, Volvo and Saab were taken over by US carmakers, thus becoming brands within conglomerates Ford and GM, respectively. The change in corporate control did not change the fact that the bulk of activities such as design, engineering and manufacturing was still performed in Sweden, so much so that both are still considered local brands by Swedish consumers. Out of a population of 9 million, some 120,000 are employed by the automobile industry, which is responsible for over 10 percent of Swedish exports (BIL Sweden 2010).

[3] Subsidies were awarded to hybrid and electric vehicles in the US and Canada; China and Brazil reduced sales tax; scrappage programs were launched in the US and a number of European countries in 2008 and 2009. Given its design, the policy we study is closer in spirit to the US hybrid subsidy.

[4] The rebate amounts to 6 percent off of the price of a new VW Golf 1.6, being in the range $1,300-1,500. In what follows we use a SEK/$ exchange rate of 7 unless mentioned otherwise.

On the supply side, the number of green car models available on the Swedish market increased from 73 to 120 already in 2008 – for perspective, Beresteanu and Li (2011) document 15 hybrid models available on the US market in 2007.[5]

Second, the GCR relies on *alternative* (renewable) fuels to achieve its aims. Anecdotal evidence suggests that the skew towards renewables was inspired by Brazil, whose CO2 emissions per unit of fuel consumption in road traffic are 20 percent below the world average due to the use of ethanol (IEA 2011a), although getting the support of the Swedish Green Party is sometimes also mentioned as an explanation for this policy feature.[6] The GCR defined a green car according to which fuels it is able to operate on and on how much CO2 it emits: while cars able to run only on *regular* (fossil) fuels (such as gasoline and diesel) were considered green cars provided they emitted no more than 120 gCO2/km, those able to run on alternative fuels (ethanol, electricity, and gas – which we call CNG hereafter) were given a more lenient treatment roughly equivalent to 220 gCO2/km. As a result, 54 among the 120 green cars marketed in 2008 were alternative ones and two-thirds of the new green cars registered in 2008 were able to operate using renewable fuels. Among these, the dominant ones are FFVs (flexible fuel vehicles), which seamlessly operate using any combination of ethanol and gasoline. While the first FFV dates back to the early 1900s – the Ford Model T was able to operate on gasoline, kerosene and ethanol– it was only in the 1980s that vehicles able to operate using renewable fuels took center stage, in the Brazilian market. However, since the technology was based on captive ethanol vehicles, consumers were effectively locked-in and suffered due to fuel shortages, which eventually resulted in the demise of the captive ethanol technology in the country.[7] The FFV technology currently in operation was introduced some 15 years ago and is available mostly in Brazil, the US and Sweden.

Empirical Strategy We quantify the impacts of the Swedish GCR by estimating a structural model for the Swedish car market and examining a number of counterfactuals to the actual policy. To do so we use a unique registration-based data set for the Swedish car market with car models disaggregated at the fuel segment level which we combine with product characteristics, fuel and mileage data.

In our analysis, we focus on both environmental and market effects of alternative policies. On the environmental side we quantify CO2 emission savings as well as their cost. On the market side, we focus on market shares of different fuel segments and brand market shares. This allows to evaluate the role of the skew towards renewables and how the program affected different car manufacturers.

We consider three counterfactuals. First, we assess the overall impact of the GCR by considering a scenario with no environmental policy. Next, we address a key feature of the GCR, namely the asymmetric treatment of vehicles running on regular as compared to those running on alternative fuels. That is, we assess what would have happened had one treated regular and alternative fuels in a similar way by letting only vehicles emitting no more than 120 gCO2/km be classified as

[5]In the Swedish market, product introduction in the FFV and low-emission segments typically occurs via the introduction of new variants (versions) of existing models.

[6]While countries such as France and Germany established an emission ceiling in their programs, the US has put forth a scrappage scheme; Sweden combined an emission threshold with renewable fuel requirements. See http://ec.europa.eu/environment/air/transport/road.htm for an overview of the European framework. Note also that in the US the emission requirement is replaced with a (roughly equivalent) fuel economy one.

[7]The New York Times (1989) reports in late 1989 how *"taxi fleets have started to glide to a halt, as many as two-thirds of Rio's service stations have closed their alcohol [ethanol] pumps, (...) a 400-car alcohol line blocked traffic on the Rio-Sao Paulo highway"* and mentions a 40 percent shortfall in ethanol supplies expected for early 1990.

green cars and thus qualify for the rebate. Finally, we examine what would have happened had all carmakers decided to turn their captive gasoline cars into FFVs to benefit from the program. This is a scenario consistent with what has happened in the mid-2000s in the Brazilian market, where all major carmakers producing in the country decided to phase out captive gasoline vehicles in favor of FFVs. Since the FFV technology piggybacks on the gasoline one, and the estimated cost to turn a captive gasoline car into a FFV is $100-200 (and decreasing, thanks to the downward trend in the prices of electronics, see Anderson and Sallee 2011), this scenario is arguably less extreme than it looks at first glance.

Main Findings On the environmental front, the results indicate that the GCR resulted in a decrease in lifetime CO2 emissions of about 493.2 thousand tonCO2 for the vehicles sold during the period in which the policy was in place. This implies a cost of 760 SEK/tonCO2 (or $109), thus lower than the $177 obtained by Beresteanu and Li (2011) and at the lower end of results in the range $91-288 obtained by Li, Linn and Spiller (2011) for the US market.[8]

Accounting for the fact that a substantial share of FFV owners switches to the cheapest between gasoline and ethanol results in non-trivial cost increases. For instance, if gasoline usage among FFV owners is 50 percent, CO2 savings decrease by 14 percent and their costs by 16 percent as compared to the benchmark, reaching 883 SEK or $126. That is, the FFV technology makes fuel choice an additional dimension regulators have to take into account when designing policy.

Removing the asymmetry of the GCR would result in lower CO2 savings but also a lower cost, in both absolute and relative terms. Importantly, since such a policy would not contemplate FFVs, fuel arbitrage does not affect the cost of the policy.

Finally, in a scenario where carmakers were to fully replace their captive gasoline models with FFVs, CO2 savings would increase substantially, but at a high total cost for the taxpayer: this alternative policy would result in a roughly fivefold cost increase as compared to the GCR. However, the high share of FFVs compounded with fuel switching would easily make the program very expensive also in relative terms, e.g. if 50 percent of FFV owners arbitrage across fuels, the cost of the program would be 36 percent above those of the actual GCR.

On the market front, the first counterfactual highlights that high-emission vehicles, especially those running on gasoline, suffered an ever increasing competition from fuel segments benefiting from the GCR; these include low-emission regular vehicles and (high-emission) FFVs, all of which were eligible for the rebate and jointly experienced a 5.5 percentage point increase in market shares due to the policy. As a result, the main brands losing out from the policy were Swedish carmakers Volvo and Saab as well as (high-end) German carmakers Audi, BMW and Mercedes, all with a strong presence in the high emission gasoline segment.[9]

A symmetric version of the GCR would make Saab and high-end German brands better off as compared to the actual policy. The reason why Volvo would be at the losing end under such

[8]These figures can be compared to the cost of similar programs in the US, to the price of European emission permits and to the social cost of carbon (SCC). Emission rights were illiquid instruments during the period the GCR was in place. Spot prices were in the range 118-142 SEK/tonCO2 at the end of each quarter in 2009 at the then prevailing exchange rates. The SCC is estimated to be EUR 15 (150 SEK) per tonCO2 (Aldy, Krupnick, Newell, Parry and Pizer 2010). In Sweden, policymakers distinguish between traded and non-traded goods; thus, they price CO2 emissions from fuel at 1060 SEK/tonCO2, see Mandell (2011) for a discussion. We thank Jan-Eric Nilsson for bringing up this point.

[9]In Sweden, Huse and Koptyug (2012) document that the 2007-2008 market shares of Volvo and Saab decreased from 17.42 to 12.44 percent and from 4.11 to 3.74 percent, respectively, *despite* the GCR. Since the GCR is not statistically significant at explaining total sales in the Swedish market (see the Appendix for details), this suggests that both carmakers did lose ground in the Swedish market during the period.

counterfactual is its focus on the high emission fuel segments, but such losses would be mild, amounting to less than half a percentage point. Importantly, the market share of FFVs would decrease by less than 0.4 percentage point (from 14.1 to 13.7 percent) as compared to the GCR, which suggests that consumers would have purchased FFVs regardless of the policy.

Finally, full conversion to the FFV technology would result in higher market shares for Swedish and high-end German brands as compared to the actual GCR, at least partially restoring market shares lost under the GCR. This finding once again shows how the FFV segment carved market share at the expense of high-emission gasoline vehicles.

Contribution and Related Literature We contribute to the burgeoning literature on the impact of policies targeted at the transportation sector, notably the automobile market, to promote the adoption of fuel-efficient technologies. To our knowledge, this is the first attempt to structurally investigate a green car policy with a broad impact on the automobile market and skewed towards renewables. The use of a structural model allows to assess different aspects of the policy by performing counterfactuals.

The papers most closely related to ours are Chandra, Gulati and Kandlikar (2010) and Beresteanu and Li (2011), which look at policies designed to promote the adoption of hybrid electric vehicles (HEVs) in Canada and the US, respectively, both of which are close in spirit to the GCR. Typically, the literature documents that although these programs tend to increase the market share of the market segment they promote at the expense of other ones, their cost is substantial.[10] This finding is likely to hold due to the fact that these programs typically target a small share of the market. More generally, the paper relates to early work by Berry, Kortum and Pakes (1996) quantifying the impact of policy and environmental changes on the US car market.

The paper also relates to the literature focusing on the cost of (environmental) regulation. For instance, Gollop and Roberts (1983) estimate the economic costs of sulfur dioxide (SO2) regulation in the US utility sector during the 1970s whereas Ryan (2011) estimates the cost of the 1990 Clean Air Act Amendments in the Portland cement industry.

The focus on alternative fuels connects the paper both to the literature studying the interaction between fuel and car markets and to the one focusing on renewable fuels. In the case of the former, the evidence is that consumer reactions are surprisingly slow (Borenstein 1993), a finding that can be attributed to the fact that the dominant automobile engine is typically captive and/or there is no fueling infrastructure available for alternative fuels. As opposed to what happens in markets such as the US, Sweden has a well-developed network of fueling stations where ethanol is readily available. Thus, the majority of FFV owners tends to react to fuel prices, effectively arbitraging across fuels (gasoline and ethanol) making fuel choice another dimension policymakers should take into account when designing policies (Anderson 2012, Salvo and Huse 2013).

2 Institutional Background

Despite being smaller than markets such as the French and German, the Swedish car market is comparable to larger European ones when looking at ownership on a *per capita* basis and ownership per household, as reported in Table 1.[11] At 9.5 years of age, the average Swedish car is however older and its engine larger than its French or German counterparts. What is more, among the

[10] The most conservative estimate among the above papers, by Li et al (2011), is that the ton of CO2 saved cost $91. At the other end of the spectrum, Metcalf (2008) estimates this cost to be $1700 for the US ethanol program.

[11] The numbers presented in Table 1 include all registered passenger cars, thus also including those owned by businesses and government.

EU 18 countries (the original EU 15 countries plus Hungary, Lithuania and Slovenia) Sweden consistently appeared at the bottom of the CO2 emissions ranking for years 2006-2008 (EFTE 2009). In what can be attributed to an early result of the GCR, the market share commanded by cars able to run on renewable fuels as a fraction of the fleet is the largest in Europe at almost 4 percent as of 2008 (ANFAC 2010).

TABLE 1 ABOUT HERE

The Green Car Rebate The Swedish Green Car Rebate (GCR), which was passed in Parliament and announced to the public in March 2007 and effectively starting in April 2007, consisted of a 10,000 SEK (about $1500 using the average SEK/$ exchange rate during the period) transfer to all private individuals purchasing a car classified as environmentally friendly, or *green*.

Carmakers were caught by surprise by the policy: product lines are typically launched once a year and require carmakers to plan their overall strategy well in advance. In the Swedish market, where this happens late in the fall, the product lines for model-year 2007 had been launched and were already in the middle of their production cycle. As a result, carmakers were only able to adjust their product lines to the rebate, i.e. re-engineer their vehicles, from model-year 2008.

To qualify as a green car and be eligible for the rebate, a car is to belong to the appropriate environmental class and has to comply with certain emission criteria (SFS 2007). Cars are divided into two categories: regular and alternative fueled cars. Cars running on fossil fuels (or *regular fuels*) qualify as green cars if their CO2 emissions are no greater than 120 g/km.[12][13] Cars able to run on fuels other than gasoline and diesel (or *alternative fuels*) qualify as green cars if their consumption is lower than the equivalent of 9.2 liters/100 km using gasoline or 9.7 m3/100 km using gas (typically CNG, compressed natural gas); electric cars are considered green if their consumption is no greater than 37 kWh/100 km. The difference in treatment dispensed to regular and alternative fuels becomes evident if these figures are converted to emission levels: the threshold for an alternative vehicle to be considered a green car is equivalent to about 220 gCO2/km running on gasoline.[14]

The Swedish Passenger Car Market The overall number of brands and models on the Swedish market increased during the sample period, especially following the inception of the GCR. In particular, the changes in the number of low emission models (those emitting less than 120 gCO2/km) marketed were non-trivial, increasing from 46 in 2007 to 69 in 2008 and 89 in 2009, see Table 2. These numbers suggest carmakers did react swiftly due, at least in part, to the GCR.

TABLE 2 ABOUT HERE

[12] In contrast to the US market, emission thresholds in Sweden apply to individual cars rather than to a brand-level sales-weighted average. At the equivalent of about 193 gCO2/mile, this emission threshold is already more stringent than the 250 gCO2/mile CAFE standard to take effect from 2016 in the US.

[13] Emissions of 120 gCO2/km correspond to fuel consumption of about 5 liters of gasoline or 4.5 liters of diesel per 100 km (75.7 and 84.1 mpg, respectively). Diesel cars must also have particle emissions of less than 5 mg/km, meaning that they need to have a particle filter.

[14] Although expressed in different units (gCO2/km and l/100km) the CO2 emissions and fuel efficiency measures are nearly equivalent; for vehicles marketed in Sweden, the correlation between CO2 emissions and mpg is -0.90, and the threshold for alternative fuels is equivalent to about 220 gCO2/km (for perspective, the 2012 Porsche 911 Carrera emits 205 gCO2/km). See Anderson, Parry, Sallee and Fischer (2011) and Huse (2012) for details. In what follows we use mostly units based on the metric system. That is, one *kpl* amounts to approximately 2.35 *mpg* since 1 mile equals 1.609 *km* and 1 gallon equals 3.78 liters; 9.2 liters/100km corresponds to 10.87 *kpl* or 25.54 *mpg*.

The main alternative fuel in Sweden is ethanol (E85), a fuel available in over half of all fueling stations in the country. It is a mixture of 85 percent ethanol and 15 percent gasoline in which the gasoline works as a lubricant and helps start the engine. On the Swedish market, cars able to operate on ethanol also do so on gasoline, thus being called FFVs (flexible-fuel vehicles). The price of an FFV is slightly higher than that of a comparable gasoline model, with second-hand values being roughly equivalent. FFV engines essentially piggy-back on the standard (Otto cycle) gasoline technology and offer the possibility to seamlessly switch between gasoline and ethanol may explain the swift adoption of FFVs.

Table 2 also reports that, starting from 2 models marketed in 2004 (two versions of the Ford Focus), the number of FFV models increased to 18 in 2007, 44 in 2008 and 66 in 2009, typically via the introduction of variants of existing models. The number of brands offering FFVs also increased substantially, from 1 in 2004 to 3 in 2007, 10 in 2008 and 12 in 2009. Interestingly, no FFV emits less than 120 gCO2/km. The effect of the GCR on the number of brands and models offering gas- and electric-based vehicles (which we refer to as gasoline/CNG and gasoline/electric vehicles, respectively) was much less dramatic – in the case of the former, this can be explained by the limited CNG retail network, concentrated in the southern part of the country, whereas in the case of the latter, anecdotal evidence suggests that electric vehicles are considered poor value for money by Swedish consumers.

FIGURE 1 ABOUT HERE

FFVs were the main gainers following the GCR reaching about 15 percent of registrations in 2008, while CNG and electric vehicles never commanded more than 1 percent of the market, see Figure 1. The growth in the FFV share was, to a large extent, at the expense of high-emission regular vehicles, which commanded a market share of 77.7 percent in 2008 down from a 94.7 percent in 2006. Although low-emission regular vehicles also gained market share, this was much lower than the gain experienced by FFVs.

Purchasing a Car The registration of a vehicle with The Swedish Transport Agency (Transportstyrelsen) must take place within ten working days of a change in vehicle ownership. Sweden being a small market, car dealers keep a very low inventory level, so much so that typically one has to order a car a few months in advance and make a deposit. This results in very few episodes of sales or rebates from the part of carmakers and/or dealers. This evidence is reassuring in light of the use of list prices when estimating demand.[15]

3 Data

We combine a number of data sets, from administrative-based registration data to car characteristics, mileage and fuel data. (See the Appendix for details.)

Car Registrations Car registration data is from *Vroom*, a consulting firm. The data on privately owned vehicles (i.e., those eligible for the rebate) is recorded at the monthly frequency from

[15] List prices, sticker prices or MSRPs (manufacturer's suggested retail prices) are set by manufacturers and are typically constant across geographic markets within a model-year. Given the difficulty in obtaining transaction prices, MSRPs have commonly been used in the literature, e.g. Beresteanu and Li (2011) for a recent example.

January 2004 to December 2009. An observation is a combination of month, brand, model and fuel type.

Car Characteristics Product characteristics are obtained from the consumer guides *Nybilsguiden* (New Car Guide) issued yearly by The Swedish Consumer Agency (*Konsumentverket*). For every car model available on the Swedish market the information includes characteristics such as fuel type, engine power and size, number of cylinders, weight, fuel economy (city driving, highway driving and mixed driving, with testing made under EU-determined driving cycle), CO2 emissions (measured in gCO2/km under EU-determined driving conditions and mixed driving) and list prices. We deflate the vehicle tax, car and fuel prices using the Consumer Price Index from Statistics Sweden. For car prices and vehicle tax we use the yearly average with 2009 as the base year and for fuel prices the monthly average with December 2009 as the base month.

Fuel Data We use market level data for fuels recorded at the monthly frequency at the national level. Recommended retail fuel prices for gasoline, diesel and ethanol are obtained from the Swedish Petroleum and Biofuels Institute (SPBI). These prices were deflated using the same CPI used for car list prices.

Mileage Data We use administrative data from the Swedish Motor Vehicle Inspection Company (*Bilprövningen*) on yearly average distances covered by Swedish passenger cars. For every year, we observe average odometer readings for cars of 3, 5, 7, 8 and 10 years of age disaggregated by brand, model, fuel type and body type.[16]

Combining Data sets One important issue arising when merging characteristics and registration data sets is that the former is observed at a more disaggregated level than the latter. Despite being more aggregated than car characteristics, the level of aggregation in registrations is still more refined than standard market level data sets in that we observe sales for different versions at the fuel level. For each combination of year-brand-model-fuel we use characteristics from the baseline version, i.e. the lowest priced model. Importantly, given the relatively small number of green versions (typically one or two per model), aggregation issues for these models essentially vanish.

4 Estimation

4.1 Demand

Model Specification We estimate the demand for cars using discrete choice models for market level data, following Berry (1994) and Berry, Levinsohn and Pakes (1995, BLP). The starting point is a microeconomic model of rational behavior for individual consumers (or households) which is then aggregated to generate market demands. Consumers buy at most one of the products available on the market and, if so, the one yielding the highest utility among the available products. The econometrician does not observe individual choices, only market level data, i.e. prices, quantities and a set of characteristics for each of the J products available on the market for

[16] That is, we do not observe micro level data on mileage. As a result, we are unable to estimate a joint model of vehicle choice and utilization as in, e.g., Goldberg (1998).

a number of periods (we suppress the index t below to avoid clutter). These "inside" products are indexed by $j = 1, ..., J$, and the outside good, the option to buy a used car or to not buy a car at all is represented by $j = 0$. Define the conditional indirect utility of individual i when consuming product j as

$$u_{ij} = \sum_{k=1}^{K} x_{jk}\beta^*_{ik} + \xi_j + \varepsilon_{ij},\ i = 1, ..., I;\ j = 1, ..., J$$

where x_{jk} are observed product characteristics such as horsepower and engine size while ξ_j are characteristics observed by the market participants but not the econometrician (such as quality, style etc). We decompose the individual coefficients as $\beta^*_{ik} = \beta_k + \sigma_k v_{ki}$, where β_k is common across individuals, v_{ki} is an individual-specific random determinant of the taste for characteristic k, which we assume to be Normally distributed, $(v_{1i}, ..., v_{Ki})' \sim \mathcal{N}(0, \Sigma)$, and σ_k measures the impact of v on characteristic k. Finally, ε_{ij} is an individual and option-specific idiosyncratic component of preferences, assumed to be a mean zero Type I Extreme Value random variable independent of both consumer attributes and product characteristics. Since consumers may decide not to buy a new car, the specification of the demand system is completed with an outside good yielding conditional indirect utility $u_{i0} = \xi_0 + \sigma_0 v_i + \varepsilon_{i0}$, where ε_{i0} is a mean zero individual market and time specific idiosyncratic term and v_i is an individual specific component reflecting heterogeneity in tastes.

The above estimation strategy assumes away a number of important features in the car market. First, given the coexistence of primary and secondary car markets (new and used cars), consumer and firm expectations about car and fuel prices are important factors to be taken into account when considering the car market – see Bento et al (2009) and Schiraldi (2011) for the joint modeling of these markets. Cars are moreover durable products, so current ownership of a car is likely to affect the current demand for automobiles, see Hendel and Nevo (2006) and Gowrisankaran and Rysman (2011) for ways of modeling intertemporal substitution. Our estimation approach, which is akin to recent studies such as Klier and Linn (2010) and Beresteanu and Li (2011) thus clearly represents a pragmatic modeling approximation to actual consumer choice behavior in the industry.

Identification Besides the exogenous characteristics, we use the set of "BST instruments", following Bresnahan, Stern and Trajtenberg (1997). That is, we use a set of polynomial basis functions of exogenous variables within a market segment. BST instruments implicitly assume a form of localized competition among products, and this seems consistent with anecdotal evidence for the automobile industry, characterized by a number of market niches and highly differentiated products.

Estimates We consider demand specifications with the following characteristics: engine power (measured in horsepower, HP), engine size (measured in cubic centimeters, CC), fuel consumption (liters/100km, under mixed driving), vehicle tax and price. We also include time (month), brand, market segment, fuel segment (gasoline with emissions above and below 120 gCO2/km, diesel with emissions above and below 120 gCO2/km, FFV, gasoline/electric and gasoline/CNG) fixed-effects and interactions of fuel consumption and fuel segment fixed-effects.[17] Consumer heterogeneity is introduced onto price coefficients via 500 antithetic pairs of random draws of the standard Normal distribution. (The Appendix lists a number of alternative specifications also experimented with.)

[17] We have also experimented with product fixed-effects, with unsatisfactory results. This is likely to be due to the use of a relatively short sample period, frequent name changes in products and moderate product entry and exit.

TABLE 3 ABOUT HERE

We report alternative demand estimates in Table 3. Specification 1 ("OLS") reports the estimates obtained when price is assumed to be exogenous, i.e. it is a standard OLS logit regression with market level data. Columns 2 and 3 report IV logit and RC logit estimates, respectively, using the instruments suggested by BST (1997). More specifically, we take characteristics fuel consumption and the ratio of engine power over weight and, for each market segment, we use the sum of characteristics, the sum of the squared characteristics, and the cross product of these characteristics across the other products produced by the same firm. The F-statistic of the excluded instruments of the first-stage regression of price on the exogenous characteristics and the instruments used is 31.48, thus suggesting that the instruments are not weak.

Specification 1 features a negative and significant price coefficient of -0.0026 as well as a positive and significant coefficient for HP, suggesting that consumers value vehicles with powerful engines. Road tax and fuel consumption coefficients are negative and significant. That is, consumers seem to shy away from high operating costs. Own-price elasticities are however typically less than one in absolute value, which is inconsistent with the assumption of profit-maximizing firms.

Accounting for price endogeneity as in Specification 2 results in a steeper demand curve, in that the estimated price coefficient increases a fivefold as compared to its OLS counterpart. An immediate result from controlling for price endogeneity is the improved estimates of own-price elasticities, the 10th and 90th percentiles are given by 4.2 and 1.4, respectively. HP, road tax and fuel consumption load with the same signs as before, but the magnitude of HP increases by a threefold. Finally, CC has a positive and significant estimate, suggesting that consumers favor engine size above and beyond HP.

Introducing consumer heterogeneity renders a price coefficient β_{Price} of -0.0218, thus about eight times the magnitude of its uninstrumented counterpart, and a statistically significant random coefficient σ_{Price} of 0.0060, see Specification 3. More importantly, introducing consumer heterogeneity substantially improves own-price elasticities, with the 10th and 90th percentiles given by 5.3 and 2.5, respectively. Such values imply markups in the range 19-40 percent and are in line with standard estimates for European markets using market level data. For instance, Goldberg and Verboven (2001) report elasticities in the range 3-6 in their Table 6.

The remaining estimates of Specification 3 are broadly in line with economic theory and the literature. That is, consumers value HP (engine power), engine size and a low road tax, but fuel consumption ceases to be significant once the random coefficient is introduced.[18] The estimates not reported in the interest of space exhibit largely intuitive patterns. For instance, the highest brand fixed-effect is that of Mercedes Benz (3.3), followed by Volvo and Porsche (3.1), Saab (2.8) and Audi (2.4), suggesting that consumers prefer Swedish and high-end German brands. French brands Renault, Peugeot and Citroen have intermediate estimates whereas brands Daewoo, Dodge and Rover have the lowest estimates. Moreover, in line with willingness-to-pay for vehicle size found in previous studies, larger market segment are monotonically preferred to smaller ones.

[18]It is worth stressing that we use fuel in consumption (in liters/100km) as opposed to monetary measures, e.g. miles per dollar as in BLP, obtained by combining fuel consumption (or fuel economy in mpg, say) with fuel prices. Our choice stems from two factors. First, the lack of fuel price data for ethanol and CNG in the earlier part of the sample. Second, due to the fact that, for FFV owners, this variable would depend on how they choose between gasoline and ethanol, e.g. whether they arbitrage across fuels.

4.2 Supply

We consider a standard differentiated product Bertrand-Nash pricing game on the supply side of the market. There are J products (indexed by $j = 1, ..., J$) which are produced by F firms (indexed by $f = 1, ..., F$), each of which produces a subset of products $\Im_f \subset \{1, ..., J\}$.[19] Firm f chooses the prices of its products to maximize its profits according to the profit maximization problem

$$\max_{\{p_j | j \in \Im_f\}} \sum_{j \in \Im_f} (p_j - c_j) D_j(p)$$

where c_j is the marginal cost of product j, assumed constant. Provided equilibrium prices of all products on the market are positive and all goods are sold in positive quantities (and so the constraints for this program do not bind in equilibrium, as is typically assumed in the empirical literature), the first-order conditions are given by

$$D_k(p) + \sum_{j \in \Im_f} \frac{\partial D_j(p)}{\partial p_k}(p_j - c_j) = 0$$

Product ownership is represented by the "ownership matrix" which, to each product in the market, assigns the firm producing it. Define the matrix Δ of dimension J by J and typical element

$$\Delta_{jk} = 1\{\text{both } j \text{ and } k \text{ produced by the same firm, } j, k = 1, ..., J\}$$

where $1\{.\}$ is the indicator function. Using the ownership indicators, the firm's first order condition may be rewritten as:

$$D_k(p) + \sum_{j=1}^{J} \Delta_{jk} \frac{\partial D_j(p)}{\partial p_k}(p_j - c_j) = 0, k = 1, ..., J$$

The (implicit) solution to this set of equations, $p^{NE} = (p_1^{NE}, ..., p_J^{NE})$, provides the prices at which each firm is maximizing its profits given the prices of others, and hence is the Nash equilibrium price to the game. Notice that there is one of these first-order conditions from firm f's objective function for every $k \in \Im_f$. Thus, we obtain a total of J first-order conditions, one for each product. This set of first order conditions is also re-solved in the various policy experiments, discussed below. (See the Appendix for details.)

5 Policy Experiments

5.1 Overview

In what follows we consider three counterfactuals. Counterfactual I ("No GCR") compares the actual GCR and the counterfactual of no policy. This allows to quantify the overall effects of the

[19] Although one could argue that the decision-makers are the conglomerates rather than the firms/brands, i.e., Ford and GM instead of Volvo and Saab, anecdotal evidence for the Swedish market suggests that the local brands enjoyed a substantial degree of independence, performing R&D and product design in Sweden. One event corroborating this view is that since Saab and Volvo were not keen on launching FFVs in the late 1990s, the Swedish government approached Ford with the guarantee to purchase a given number of FFVs per year if they were produced. This is precisely how the FFV version of the Ford Focus was introduced in the Swedish market.

program on both the environment and the market fronts.

Counterfactual II ("Symmetric GCR") considers the effects of a common threshold of 120 gCO2/km applied to regular and alternative fuels. One immediate effect of such a symmetric policy is that since no single FFV emits less than 120 gCO2/km (see Table 2), no FFV qualifies as a green car.[20]

Finally, Counterfactual III ("Full Adoption of FFV Technology") assesses what would have happened had all carmakers immediately decided to turn their captive gasoline cars into FFVs. Although arguably extreme, this scenario is consistent with what has happened in the Brazilian market in the mid-2000s, where all major carmakers decided to phase out gasoline vehicles in favor of FFVs. That is, conditional on buying e.g. any Volkswagen car model produced in Brazil as of 2006, a driver would acquire an FFV (Salvo and Huse 2011). In the US, carmakers have also begun equipping models with flexible fuel engines. With the ever decreasing price of electronics, the cost of turning a captive gasoline car into a FFV is $100-200 (thus less significant than those in e.g. Berry, Kortum and Pakes 1996). This scenario thus stresses a potentially perverse effect of the program whereby "too many FFVs" would qualify for the rebate and increase the total cost of the program, without necessarily using ethanol.[21]

We assess the above counterfactuals on both environmental and market aspects, namely (i) CO2 emission savings and their associated costs (in SEK/tonCO2 saved); (ii) Market shares by fuel segment; (iii) Brand market shares disaggregated up to fuel segment. Following the literature, we allow carmakers to compete in prices *à la* Bertrand-Nash throughout the analysis. In doing so we note that ours is essentially a short run analysis in that we do not account for endogenous changes in product characteristics (see, e.g. Klier and Linn 2010, for a study in such direction).

To calculate CO2 emission savings, we combine mileage estimates and fuel economy data with car sales in every scenario considered, with details presented in the Appendix. The resulting CO2 emissions are then divided by the total cost of the GCR to obtain the cost of CO2 savings.

While the baseline specification in each experiment considers a situation in which FFV owners do not drive using gasoline, we do also allow for the fact that FFVs enable their owners to arbitrage across fuels. Since a non-negligible share of FFV owners in Sweden takes advantage of fuel arbitrage and gasoline emits more CO2 than ethanol, fuel switching increases the cost of CO2 savings and fuel choice is an additional margin policymakers have to take into account when considering the design of policies.[22] Thus, besides the baseline case (i.e., no gasoline usage by FFV owners) we also report results for 25, 50 and 75 percent of gasoline usage to gauge the cost-effectiveness of the program.

---

[20] Although in this scenario one would expect carmakers to eventually bring to market a number of low-emission FFV models, we follow the bulk of the literature since at least Pakes, Berry and Levinsohn (1993) and focus on short-run effects – a thorough long-run analysis would involve setting up a dynamic model of the industry and is left for future research.

[21] In this scenario we assume away the existence of economies of scale in the adoption of FFVs in the Swedish market. As illustrated in Table 1, the Swedish market is small when compared to other European ones. For instance, market leader Volvo has consistently commanded a market share below 20 percent and the sales of FFVs in the 400,000-strong Swedish market amount to less than 80,000. For perspective, Hall (2000) finds a minimum efficient scale of about 130,000 units/year for automobile plants in the North American market.

[22] In what follows, we are mostly agnostic about what share of FFV owners actually arbitrages across fuels, simply reporting figures for shares of 25, 50 and 75 percent. Huse (2012) documents how the drop in oil prices following the 2008 recession, which was quickly passed through to domestic fuel prices, effectively making gasoline cheaper than ethanol in energy-adjusted terms, led to a drop of 73 percent in the monthly sales of ethanol and proposes a stylized structural model whereby the share of fuel switchers (arbitrageurs) among FFV owners is in the range 46-77 percent.

5.2 Environmental Effects

CO2 Savings and their Costs Table 4 reports estimated CO2 savings and the associated costs for the experiments considered.[23] The first column reports the results for Counterfactual I, which compares the GCR with the no-policy counterfactual. Assuming all FFV owners use only ethanol, the CO2 emission savings induced by the GCR are 493.2 thousand tonCO2, as reported in Panel A. Note, however, that the savings decrease once fuel switching is accounted for, i.e. CO2 savings reduce by 14 and 18 percent to 424.6 and 406.7 thousand tonCO2 if gasoline usage increases to 50 and 75 percent, respectively.

Lower CO2 savings imply an increased cost per tonCO2 saved, and this is what Panel B in Table 4 reports for Counterfactual I. While absence of fuel switching results in a cost of 760 SEK/tonCO2, or $109, accounting for fuel arbitrage results in a sizable increase in the cost of CO2 savings, even though FFVs command a relatively small share of the market: while an increase from zero to 25 percent in the use of gasoline results in an increase of about 12 percent (about $13) to 850 SEK/tonCO2, the cost can increase by 21 percent to 921 SEK (about $132) if gasoline usage increases to 75 percent.

TABLE 4 ABOUT HERE

Counterfactual II computes CO2 savings and cost estimates obtained from a symmetric version of the GCR. By not contemplating FFVs, in this counterfactual fuel arbitrage does not play a role, i.e. cost and savings are flat across different levels of gasoline usage. Note also that CO2 savings are lower than those in the actual GCR: in the absence of fuel switching, these savings are 193.8 thousand tonCO2, whereas 50 percent of gasoline usage induces savings of 192.1 thousand tonCO2. Not making FFVs eligible for the rebate results in a total cost of just 24 percent of the actual GCR.

Due to the strong presence of FFVs, Counterfactual III results in substantial CO2 emission savings when compared to the other experiments. On the other hand, fuel arbitrage becomes a key margin to be taken into consideration. In the absence of fuel switching, the emission savings amount to 3,159.8 thousand tonCO2, whereas a 50 percent of gasoline usage results in savings of a still sizable 1,474 thousand tonCO2. Although at 470.9 percent of the cost of the actual GCR the total cost of the program is substantial, at 558 SEK/tonCO2 its cost relative to emission savings is comparable to the GCR in the case of no fuel switching. However, the substantial presence of FFVs in the new car fleet induces a non-trivial cost increase once fuel arbitrage is accounted for: this cost increases to 1197 and 1704 SEK under 50 and 75 percent of gasoline usage, respectively.

The results in Table 4 show that, without accounting for fuel arbitrage, at about $109 the cost estimates of the program are comparable to the lower end of the estimates of Li, Linn and Spiller (2011) for the US, which are in the range $91-288, and roughly 40 percent lower than those of Beresteanu and Li (2011) for the US HEV program. However, these costs increase to about $126 ($132) if 50 (75) percent of FFV owners arbitrage across fuels. A symmetric version of the GCR results in both lower CO2 savings and lower costs per tonCO2 saved. The extent to which such a program would be preferred to the actual GCR depends on the objective function of the regulator. Finally, full adoption of the FFV technology by carmakers would induce substantial CO2 savings as compared to the GCR benchmark, but also substantial cost increases per tonCO2 saved once fuel arbitrage is accounted for.

[23] While the results in Table 4 are obtained under the maintained assumption of a 15-year vehicle lifetime to make easier to compare to the literature, e.g. Beresteanu and Li (2011), the results in Appendix B show that these results are qualitatively unchanged under an assumption of 25-year vehicle lifetime.

5.3 Market Effects

Fuel Segment Market Shares Figure 2a reports market shares of the different fuel segments under the GCR i.e. the actual policy. High emission gasoline vehicles command 50.7 percent of the market, well ahead of high emission diesel ones, with 24.7 percent.[24] Among the fuel segments benefiting from the GCR, the leading one is the FFV, which commands 14.1 percent, followed by low emission gasoline and diesel, with 6.68 and 3.61 percent, respectively. Gasoline/electric and gasoline/CNG vehicles both command less than 1 percent of the market and face negligible changes across counterfactuals.

Figure 2b examines the effect of abolishing the GCR on the different fuel segments. Doing so benefits mostly high emission vehicles, with the market share commanded by gasoline and diesel ones increasing by 4.89 and 0.603 percentage points (pp hereafter), respectively. The marked difference in the change in market shares comes from the fact that FFVs are closer competitors to high-emission gasoline than high-emission diesel vehicles: the FFV technology essentially piggybacks on the Otto cycle technology used by gasoline vehicles. On the other hand, abolishing the GCR would adversely affect the market shares of FFVs and low-emission vehicles (both gasoline and diesel), with decreases of 1.95, 1.91 and 1.64pp, respectively. Equivalently, the GCR shifted demand from high emission vehicles – especially gasoline ones – to FFVs and low emission ones, precisely the segments favored by the GCR.

FIGURE 2 ABOUT HERE

Figure 2c examines what would have happened had the GCR treated regular and alternative fuels symmetrically. Low emission vehicles are the main gainers in that they experienced an increase of 1.57 and 0.589pp for gasoline and diesel vehicles, respectively. The main take-away from Figure 2c is however the low impact of a symmetric version of the GCR on the share of FFVs. This finding suggests that a substantial share of consumers would have purchased FFVs regardless of the GCR, likely due to the potentially lower operating costs provided by such technology (see Huse and Koptyug 2012b for such an analysis at the micro level). As for high emission gasoline and diesel, their market shares decreased by 1.3 and 0.521pp, respectively.

Had carmakers decided to replace all their captive gasoline models with FFV versions, the dominant fuel segment would be high emission FFVs, which would command a 65.1 percent market share, as shown in Figure 2d.[25] High emission diesel vehicles would lose 6pp and command a 18.7 percent market share, followed by low emission FFVs, with 13.6 percent, and low emission diesel vehicles, with 2.4 percent. While high emission FFVs would essentially absorb the market shares of high emission gasoline and FFV vehicles (all of which are high emission) under the GCR, the main gainers according to this experiment would be low emission FFVs, which would command 7pp above the market share of low emission gasoline vehicles under the GCR. On the other hand, and as expected, diesel vehicles would lose substantial market share, especially in the high emission segment.

The results in Figure 2 suggest that the actual GCR has shifted demand from high emission vehicles to both FFVs and low emission vehicles. A symmetric version of the GCR would have

[24] In what follows, we report "inside shares", i.e. market shares sum to one, ignoring the role of the outside good for the sake of comparability across scenarios. Appendix B provides supporting evidence that the share of the outside good was unaffected by the GCR.

[25] Note that Figure 2d displays market shares instead of changes thereof. The reason for reporting this result in a different way is the introduction of the high- and low- emission FFVs fuel segments.

further increased the presence of low emission vehicles and hardly affected the one of FFVs, suggesting that the skew towards renewables – which was an essential part of the GCR – would not have been necessary, i.e. consumers would have purchased FFVs regardless. However, had carmakers adopted the FFV technology *en masse*, the main gainers would have been low emission FFVs, which would make substantial ground at the expense of diesel vehicles, both low and high emission.

Brand Market Shares Figure 3a reports the effect of the GCR on brand-level market shares. The main players operating in the Swedish market are Volvo (15.9 percent market share), Toyota (10.1 percent), Peugeot (8.34 percent) and Volkswagen (VW, 6.5 percent), with brands Ford, Hyundai, Skoda, Citroen and Audi also commanding market shares above 3 percent. Despite being more of a niche player, for having a narrow range of models, Swedish brand Saab has historically been placed among the top 10 brands in the sample period (see Huse and Koptyug 2012 for details).

Figure 3b, which reports the results of the counterfactual of no GCR, shows that both Swedish and high-end German brands are at the losing end of the policy. The main gainer under such counterfactual would be Mercedes, with a 2.5pp increase in market shares, followed by Volvo (2.28pp), Audi (1.62pp), BMW (1.26pp) and Saab (1.24pp). Swedish and high-end German brands are close competitors in the Swedish market, having a marked presence in the high-end gasoline segment. It then comes as no surprise the fact that they share the burden of the GCR. On the other hand, lower-end (or value) brands Peugeot, Kia and Skoda decrease their market shares by amounts in the range 1.0-2.19pp under the counterfactual of no GCR. As we detail below, these are brands typically offering the low-end models within the high-emission (gasoline or diesel) fuel segments.

Figure 3c shows the effect of the symmetric GCR on the overall market shares of car manufacturers. The main brands benefiting from such a policy would be Toyota, Citroen and Peugeot, all of which have a marked presence in low emission segments, whereas the main loser would be Volvo, which has a substantial presence in the FFV and high-emission segments, precisely the ones losing out from a symmetric policy.

FIGURE 3 ABOUT HERE

Figure 3d shows the effects of the full conversion to the FFV technology by all carmakers. The main gainer is Toyota (2.57pp), which is followed by high-end German brands Mercedes, Audi and BMW (1.92, 0.957 and 0.821pp, respectively), and Swedish brand Saab (1.15pp). Except for Toyota, these are among the brands most affected by the GCR, whose high emission gasoline vehicles would become FFVs and recover market share. Importantly, Volvo would experience a mild increase of less than 0.5pp in market shares. On the other hand, the main losers from Counterfactual III are brands such as VW, Skoda, Kia and Opel, with decreases in the range 1.1-1.6pp. Again, these are mostly brands which have benefited from the GCR and would lose out once all larger cars are turned into FFVs.

The findings in Figure 3 thus highlight three main features. First, the main losers following the GCR were local brands Saab and Volvo, together with high-end German brands Audi, BMW and Mercedes. Second, for most of these brands, the actual GCR is the worst scenario among the counterfactuals considered (the exception is Volvo under Counterfactual II). Finally, one way how these brands could have recovered market share would be to fully convert their gasoline models to the FFV technology.

Conclusion

This paper estimates a structural model of the Swedish car market to examine environmental and market effects of the Swedish green car rebate (GCR). its findings can be summarized as follows. First, the cost of the program was comparable to those of recent US counterparts, with an estimated cost of CO2 emission savings to be in the range $109-132/ton CO2. This amount is over five times the price of an EU emission permit and at the lower end of estimates for the US, even if the Swedish program affected the market more widely than elsewhere.

Second, Swedish and high-end German brands, all of which have a marked presence in the high emission gasoline segment, lose substantial market share as a result of the GCR. This result is at odds with the view that regulators are captured by (local) businesses.

Third, the finding that a symmetric version of the GCR has mild effects on the market share of FFVs suggests that the potentially lower operating costs provided by this technology would have been enough to attract consumers to this fuel segment, rendering the GCR unnecessary to shift demand towards vehicles able to operate on alternative fuels. Put in another way, the FFV technology would not need to be subsidized to attract consumers.

Within a context of new, hybrid, technologies such as the FFV, our fourth conclusion is that fuel choice is a key margin policymakers should take into account when designing policy. While one upside of flexible-fuel (or hybrid) technologies is the avoidance of technological lock-in, an immediate downside is that additional costs are incurred when consumers arbitrage across fuels.

Finally, full conversion to the FFV technology would have resulted in extremely high costs for the program and amplify the perverse effects of fuel arbitrage, yet allowing carmakers most severely affected by the actual policy to recover market share via the adoption of the FFV technology. Had carmakers decided to switch their captive gasoline cars to the FFV technology, the cost of the GCR would have increased by a fivefold, but without obvious improvements in terms of CO2 savings or costs thereof.

In assessing a unique policy skewed toward renewables and which affected a substantial share of the new car market, our findings highlight that policymakers ought to take into account the technologies in use in the markets they are regulating. This issue is to become ever more important as more alternative technologies, e.g. hybrid, multifuel, are brought to market in the coming years.

References

[1] ACEA (2008). The automobile industry pocket guide, Retrieved from http://www.acea.be.

[2] Environmental and Economic Effects of CO2-based Automobile Taxes in Germany. Working paper.

[3] Aldy, J., A. J. Krupnick, R. Newell, W. H. Parry and W. A. Pizer (2010). "Designing Climate Mitigation Policy", *Journal of Economic Literature* 48 (4), 903-934.

[4] Anderson, S. T. (2012). "The Demand for Ethanol as a Gasoline Substitute", *Journal of Environmental Economics and Management* 63 (2), 151-168.

[5] Anderson, S., I. Parry, J. M. Sallee, and C. Fischer (2011). "Automobile Fuel Economy Standards: Impacts, Efficiency, and Alternatives", forthcoming *Review of Environmental Economics*.

[6] Anderson, S., and J. Sallee (2011). Using Loopholes to Reveal the Marginal Cost of Regulation: The Case of Fuel-Economy Standards, *American Economic Review* 101, 1375-1409.

[7] Bento, A., L. Goulder, M. Jacobsen, and R. von Haefen (2009). "Distributional and efficiency impacts of increased U.S. gasoline taxes", *American Economic Review* 99, 667-699.

[8] Beresteanu, A. and S. Li (2011). "Gasoline Prices, Government Support, and the Demand for Hybrid Vehicles". *International Economic Review* 52(1): 161-182.

[9] Berry, S. (1994). "Estimating Discrete-Choice Models of Product Differentiation", *The RAND Journal of Economics* 25 (2), 242-262.

[10] Berry, S., S. Kortum and A. Pakes (1996). "Environmental Change and Hedonic Cost Functions for Automobiles". *Proceedings of the National Academy of Sciences*, 12731-12738.

[11] Berry, S., J. Levinsohn and A. Pakes (1995). "Automobile Prices in Market Equilibrium", *Econometrica* 63, 841-890.

[12] BEST (2009). Promoting clean cars, Project title: BioEthanol for Sustainable Transport, Project report, Retrieved from: http://www.best-europe.org/

[13] BIL Sweden (2010). Svensk Fordonsindustri Faktablad.

[14] Boyer, M. and J-J Laffont (1999). "Toward a Political Theory of the emergence of Environmental Incentive Regulation". *The RAND Journal of Economics* 30 (1): 137-157.

[15] Bresnahan, T. F., S. Stern and M. Trajtenberg (1997). "Market Segmentation and the sources of Rents from Innovation: Personal Computers in the Late 1980s", *RAND Journal of Economics* 28 (0), S17-44.

[16] Chandra, A., S. Gulati and M. Kandlikar (2010). "Green Drivers or Free Riders? An Analysis of Tax Rebates for Hybrid Vehicles", *Journal of Environmental Economics and Management* 60(2), 78-93.

[17] EFTE (2009). Reducing CO2 Emissions from New Cars: A Study of Major Car Manufacturers' Progress in 2008. Brussels, Belgium. European Federation for Transport and Environment

[18] European Energy Exchange (2009). Retrieved from: http://www.eex.com/

[19] Goldberg, P.K. and F. Verboven (2001). "The Evolution of Price Dispersion in the European car market", *Review of Economic Studies*, 68, 811-848.

[20] Gollop, F. M. and M. J. Roberts (1983). "Environmental Regulations and Productivity Growth: The Case of Fossil-Fueled Electric Power Generation". *Journal of Political Economy* 91(4), 654-674.

[21] Gowrisankaran, G. and M. Rysman (2011). "Dynamics of Consumer Demand for New Durable Goods". Working paper.

[22] Hall, George J. (2000). "Non-convex costs and capital utilization: A study of production scheduling at automobile assembly plants". *Journal of Monetary Economics* 45, 681-716.

[23] Harrington, W., I. Parry and M. Walls (2007). “Automobile Externalities and Policies”, *Journal of Economic Literature* 45, 374-400.

[24] Hendel, I. and A. Nevo (2006). “Measuring the Implications of Sales and Consumer Inventory Behavior”, *Econometrica* 74 (6), 1637-1673.

[25] Huse, C. (2012). “Fast and Furious (and Dirty): How Asymmetric Regulation May Hinder Environmental Policy”. Working paper.

[26] Huse, C. and N. Koptyug (2012). “Bailing On The Car That Wasn’t Bailed Out: Explaining Consumer Reactions to Financial Distress”. Working paper.

[27] Huse, C. and N. Koptyug (2012b). “Cars as Options? Quantifying the Value of Multifuel Technologies”, presented at the Annual Meeting of the Brazilian Econometric Society.

[28] IEA (2011a). CO2 Emissions from Fuel Combustion. Paris, France. International Energy Agency.

[29] IEA (2011b). World Economic Outlook. Paris, France. International Energy Agency.

[30] Klier, T., and J. Linn (2010). “The Price of Gasoline and New Vehicle Fuel Economy: Evidence from Monthly Sales Data”, *American Economic Journal: Economic Policy* 2 (3), 134-153.

[31] Klier, T. and J. Linn (2011). “New Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard”, forthcoming at the *RAND Journal of Economics*.

[32] Laffont, J-J. and J. Tirole (1991). “The Politics of Government Decision-Making: A Theory of Regulatory Capture”, *The Quarterly Journal of Economics* 106(4), 1089-1127.

[33] Li, S., J. Linn, and E. Spiller (2011). “Evaluating “Cash-for-Clunkers”: Program Effects on Auto Sales and the Environment”, RFF Discussion Paper 10-39-Rev.

[34] Li, S., C. Timmins, and R. von Haefen (2009). “How Do Gasoline Prices Affect Fleet Fuel Economy?”, *American Economic Journal: Economic Policy* 1, 113-137.

[35] Mandell, S. (2008). "Carbon Emission Values in Cost Benefit Analyses", *Transport Policy* 18(6) 888-892.

[36] Metcalf, G. (2008). "Using Tax Expenditures to Achieve Energy Policy Goals", *American Economic Review Papers and Proceedings* 98, 90-94.

[37] Miljöfordon.se (2009). Retrieved from: http://www.miljofordon.se

[38] Ministry of the Environment (2007). Press release: The Government introduces a green car rebate, Retrieved from: http://www.regeringen.se/sb/d/586/a/79866

[39] Ministry of the Environment (2008a). Press release: Regeringen avsätter mer pengar till miljöbilspremien, Retrieved from: http://www.regeringen.se/sb/d/119/a/101932

[40] Ministry of the Environment (2008b). Press release: Klimat- och energisatsningar i budgetpropositionen 2009, Retrieved from: http://www.regeringen.se/sb/d/119/a/110590

[41] Ministry of the Environment (2009). Press release: New green cars to be exempted from vehicle tax, Retrieved from: http://www.regeringen.se/sb/d/11760/a/122175

[42] Parry, I. W. H., M. Walls, and W. Harrington (2007). "Automobile Externalities and Policies", *Journal of Economic Literature* 45 (2), 373–399.

[43] Reiss, P. C., and F. A. Wolak (2007). Structural Econometric Modeling: Rationales and Examples from Industrial Organization. In *Handbook of Econometrics*, Vol. 6A.

[44] Ricardo, D. (1817). On the Principles of Political Economy and Taxation. In *The Works and Correspondence of David Ricardo*, ed. P. Sraffa. Cambridge: Cambridge University Press, 1951.

[45] Ryan, S. P. (2011). "The Costs of Environmental Regulation in a Concentrated Industry", forthcoming *Econometrica*.

[46] Sallee, J. (2011a). "The Taxation of Fuel Economy", in *Tax Policy and the Economy* v. 25, Editor Jeffrey R. Brown, NBER: University of Chicago Press, 1-38.

[47] Salvo, A., and C. Huse (2011). “Is Arbitrage Tying the Price of Ethanol to that of Gasoline? Evidence from the Uptake of the Flexible-Fuel Technology”, *Energy Journal* 32 (3), 119-148.

[48] Salvo, A., and C. Huse (2013). “Build it, but will they come? Evidence from consumer choice between gasoline and sugarcane ethanol”. Working paper.

[49] SFS (2005). Lag (2005:1248) om skyldighet att tillhandahålla förnybara drivmedel, Retrieved from: http://www.riksdagen.se/Webbnav/index.aspx?nid=3911&bet=2005:1248

[50] SFS (2007). Förordning (2007:380) om miljöbilspremie, Retrieved from: http://www.riksdagen.se/Webbnav/index.aspx?nid=3911&bet=2007%3A380

[51] The New York Times (1989). “Autos Cry for Alcohol; France Will Do Its Part”. Edition of 30 December 1989.

[52] The Swedish Consumer Agency (2004-2009). Nybildguiden (The New Car Guide).

[53] The Swedish Environmental Protection Agency (2008a). Index över nya bilars miljöpåverkan 2007, Retrieved from: http://www.naturvardsverket.se/

[54] The Swedish Environmental Protection Agency (2008b). Allmänhetens kunskaper och attityder till klimatförändringen (tidigare växthuseffekten), Retrieved from: http://www.naturvardsverket.se/

[55] The Swedish Petroleum Institute (2009a). Försäljningsställen av motorbränslen, Retrieved from: http://www.spi.se/fsg.asp?cboFromYr=2009&cboToYr=2009&cboCompany=<Alla>&cboCa

[56] The Swedish Petroleum Institute (2009b). Leveranser bränslen per månad, Retrieved on May 18, 2009 from: http://www.spi.se/statistik.asp?art=99

[57] The Swedish Tax Agency (2009). FAQ on vehicle tax, Retrieved from: http://www.skatteverket.se/funktioner/svarpavanligafragor/privat/fordonsskatt/allafragorochsvar.4.5cbc

[58] Trafikverket (2011). Uppdaterade reduktionsvärden för etanol- och gasfordon till bilindex. Retrieved from http://www.trafikverket.se/PageFiles/25435/nov10/04-2011_PM%20uppdaterade%20reduktionsv%C3%A4rden110308.pdf

[59] Train, K. and Winston, S. (2007). "Vehicle Choice Behavior And The Declining Market Share Of U.S. Automakers", *International Economic Review* 48(4), 1469-1496.

TECHNICAL APPENDIX TO

THE MARKET IMPACT AND THE COST OF ENVIRONMENTAL POLICY:

EVIDENCE FROM THE SWEDISH GREEN CAR REBATE

Cristian Huse and Claudio Lucinda

A Data

Sales data *Vroom* has adjusted new car registration data to better represent the cars that are actually used by an individual and that do not serve as demonstration units or alike. For a registration to be included in the data set, the vehicle has to be acquired by an individual within 30 days of the registration. The sales data is aggregated at the base model level for each fuel type, i.e. the item Audi A3 gasoline contains all versions of the A3 that are primarily driven on gasoline. We consider seven different fuel segments: high- and low-emission gasoline; high- and low-emission diesel; gasoline/ethanol (FFVs); gasoline/gas (CNG); and electric hybrids.

Vehicle characteristics The characteristics data is on a more disaggregated level than the sales data, e.g. there are 18 different Audi A3 gasoline versions. To be able to combine characteristics and sales data, we have aggregated the characteristics over sub-models based on the baseline model, thus following the literature, e.g. BLP (1995). Following the Swedish Consumer Agency definition, we define market segments according to vehicle weight, with the five segments defined by the thresholds 1100, 1250, 1400 and 1600 kg.

Combining sales data and characteristics When combining the sales data and the characteristics data, a small fraction of the observations did not have a match. We thus expanded our search as follows, checking the following manually. First, we checked for the same brand, model and fuel type for the following year, since models for a given year are released late in the prior fall. Second, we checked for the same brand and fuel type for the same year. Third, for the same brand and fuel type for the following year. Finally, for the same fuel type and same year (the standard deviation is lower within a population consisting of cars of the same fuel type but different brands than within a population of a certain brand but with different fuel types).

Fuel economy and CO2 emissions In the consumer guides, the emission data for FFVs is solely based on gasoline driving. According to The Swedish Consumer Agency (2008), there are no official emission values for ethanol driving. However, in their report on the climate effects of new cars, the Swedish Environmental Protection Agency (2008a) develops a way to calculate emission reductions. First, due to its lower energy content, E85 consumption is approximately 35 percent higher than gasoline consumption. Second, carbon dioxide emissions for E85 are 688.3 g/l, regardless of whether it made of sugar cane ethanol or sulphite pulp ethanol. Using this and the data on gasoline consumption from the guides, we can calculate ethanol consumption in l/100km (gasoline consumption*1.35) and carbon dioxide emissions in g/km (ethanol consumption*688.3/100). Thus, carbon dioxide emissions for E85 could be calculated by multiplying the gasoline consumption in l/100km by 9.29205 ($\frac{1.35\times688.3}{100}$). For winter months, the ethanol blend used is E75, which has a higher consumption (approximately 42% higher). For these months, the carbon dioxide emissions are multiplied by $\left(\frac{1.42\times688.3}{100}\right)$.

To estimate CO2 emissions, we estimate yearly mileage driven (in km), together with a measure of CO2 emissions (in g/km). For captive cars, mileage estimates are based on the results reported in Appendix C whereas for FFVs they also depend on the fraction of vehicle owners using each fuel. We consider four cases, namely 0, 25, 50 and 75 percent gasoline usage. Although we do not take a stand on which level looks more appropriate, Huse (2012) documents a 73 percent reduction in monthly ethanol sales following the 2008 oil price drop, which suggest that fuel switchers correspond to a non-negligible share of FFV owners.

The emission data for gas (CNG) is based on what is called certification gas, which is the same as fossil gas (Din Bil Stockholm/Hammarby, 2008). Carbon dioxide emissions from fossil gas are evaluated to be 2120 g/m3 whereas for biogas these are evaluated to 390 g/m3. The supply of vehicle gas in Sweden consists of both fossil gas and biogas, as well as a mixture of the two. According to Din Bil, the supply is evenly split, which is consistent with the report by the Swedish Environmental Protection Agency (2008a) which states that, in 2007, 53 percent of the vehicle gas sold was biogas and 47 percent was fossil gas. The emission data for gas cars is hence not correct since it assumes all cars are driven on fossil gas, thus the general emission levels for gas cars are exaggerated. We therefore re-estimate these to be equal to gas consumption per km*(2120*0.47 + 390*0.53), based on the numbers above.

Potential market To go from observed quantities to observed market shares we need to define the size of the potential market for each time period. One way to obtain the potential market variables would be by estimating them, as suggested in Reiss and Wolak (2007). Alternatively, one could follow the criterion used in BLP (1995), where the total number of households constitutes the potential market. According to Reiss and Wolak (2007), this definition has some shortcomings. First, not all households can afford a new car and other entities than households can purchase cars. Since we only examine car sales to individuals, only the former poses a possible problem. It is not realistic that all households can afford to purchase a new car, therefore this would overestimate the potential market. Therefore we define the market as the number of individuals (instead of households, as Sweden has a high number of single person households) above the age of 20 with a yearly income of 200,000 SEK (about $27,500) or more. These are the potential purchasers of a new car. It is however unlikely that they can consider buying a new car each month. We therefore assume that consumers generally consider buying a new car every fifth year, thereby dividing the numbers by 60.

B Mileage Regressions

We use data from the Swedish Motor Vehicle Inspection Company to estimate the average yearly kilometerage of a vehicle (measured in kilometers, km). Each observation (a combination of brand-model-segment-fuel-vintage) is weighted according to the number of subjects inspected. Our preferred specification is reported under Column 5 in table B1 and has controls for age, fuel fixed-effects, age-fuel interactions, fuel-year interactions (which captures fuel price levels at the yearly frequency) and fixed-effects for brand-model-segment, and year. Based on this specification, we then estimate the lifetime kilometerage of cars disaggregated by fuel.

TABLE B1 ABOUT HERE

Associated kilometerage estimates for Column 5 assuming a vehicle lifetime of 15 years are reported in Table B2 and are consistent with some stylized facts.[26] First, yearly kilometerage decreases with age. Second, diesel vehicles are the most heavily used vehicles whereas gasoline ones are the least heavily used. Gasoline/CNG vehicles are slightly less used than diesel ones, but more than FFVs and gasoline/electric vehicles.

TABLE B2 ABOUT HERE

[26] While Table B2 reports estimates based on a 15-year vehicle lifetime, Appendix B carries out the same analysis as in the text with a 25-year vehicle lifetime. The lifespan of a car can arguably be substantially longer, but anecdotal evidence for Sweden suggests that older cars are kept in the (affordable and widespread) country houses of the average Swedish household. Being based on the “Summer house” essentially implies that these cars will run for few weeks during summer every year.

C Counterfactuals

Impact of the rebate on aggregate sales When calculating the counterfactuals, we need an estimate of the share of the outside good. In order for us to be able to use the market shares for the outside good from the actual scenario, i.e. with the rebate, we must ensure that there is no correlation between the rebate and total sales. We follow Chandra et al (2010) and examine the effect of the rebate on aggregate sales by estimating the following equation

$$\ln(total\_sales_t) = \alpha + \phi.1\{GCR_t\} + z_t'\beta + v$$

where $1\{GCR_t\}$ represents the rebate dummy, z_t contains potential market characteristics such as the CPI and the Industrial production index by Statistics Sweden. The results are reported in Table C1. There is no evidence of an effect of the rebate on aggregate sales. Thus we use the actual market shares for the outside good when computing the counterfactuals.

TABLE C1 ABOUT HERE

Impact of the assumption of vehicle lifetime on costs and CO2 savings Following the literature, see e.g. Beresteanu and Li (2011), in the main text we performed our calculations under the assumption that vehicle lifetime is 15 years. To gauge the effect of this assumptions, we re-did our calculations under the assumptions of a 25-year lifetime – the results are reported in Table C2.

TABLE C2 ABOUT HERE

Although the results do change in quantitative terms, they are similar in qualitative terms. The alternative estimates for Counterfactuals I and II reported in Panel A are not surprising in that they show an increase in CO2 savings due to the increased lifetime of the fleet. For instance, increasing lifetime by 67 percent (25/15 years) results in an 18 percent increase in CO2 savings. The reason why the increase in savings is less than proportional than the one in lifetime is the decreasing yearly kilometerage of older vehicles (see Table B2 for the case up to 15 years). However, when it comes to Counterfactual III, notice that CO2 savings increase only if all FFV owners are assumed to drive on gasoline (0% gasoline usage) – fuel arbitrage is such that CO2 savings may indeed decrease under an extended vehicle lifetime. On the cost side, the results mirror those reported in the text in that the cost of CO2 savings decreases under Counterfactuals I and II and typically increases for Counterfactual III.

A comparison of the estimates above with those in the literature shows that the findings in the text are robust to changes in the lifetime assumption. In particular, notice that at 642 SEK (or $91.7), the cost of the program in the benchmark case (CF I with 0% gasoline usage) is almost identical to those in Beresteanu and Li (2011), with fuel arbitrage increasing such cost by up to 20 percent if gasoline usage reaches 75%.

Finally, the relative costs of Counterfactuals II and II as compared to those of Counterfactual I are also quite similar, being hardly affected by the lifetime assumption.

Computing counterfactuals In what follows we illustrate the computation of counterfactuals, always dropping the subscript t to save on notation. First, let $\Re$ be the set of vehicles contemplated by the rebate. In the actual GCR, this would correspond to (1) vehicles able to operate on alternative fuels; and (2) vehicles operating on regular fuels and emitting no more than 120 gCO2/km; in the case of the symmetric GCR this would correspond to vehicles emitting no more than 120 gCO2/km, regardless of fuel. Next, let r be the value of the rebate in real terms. Finally, define $\widetilde{p}_j = p_j - r.1\{j \in \Re\}$ as the price faced by consumers if a policy is in place.

With the above, market shares can be written as $s_j(\widetilde{p}_j, x_j, \xi_j; \theta)$ and the market demand for product j is given by $D_j(\widetilde{p}_j, x_j, \xi_j; \theta) = M.s_j(\widetilde{p}_j, x_j, \xi_j; \theta)$ where M denotes the potential market size. Profits for firm f are given by

$$\pi_f = \sum_{j \in \Im_f} (p_j - c_j)\, D_j(\widetilde{p}_j, x_j, \xi_j; \theta)$$

where $\Im_f$ denotes the sets of products produced by firm f. Note the distinction between prices $\widetilde{p}_j$ faced by consumers and prices p_j faced by firms: the former appear only as an argument of the demand function since the firms receive the latter, i.e..the rebate is a transfer from the government to consumers.

Estimating demand amounts to obtaining an estimate $\hat{\theta}$ for the parameter vector θ (from a random-coefficients logit model, see Specification 3 in Table 3) which is kept fixed when calculating the counterfactuals. For each counterfactual, we re-solve the problem of the firms following a given policy by choosing prices p_j to maximize their profits. This is done by solving the non-linear system of equations implied by the first-order conditions from the maximization problem above. The resulting prices are used together with the remaining model characteristics to obtain estimated shares. This results in the market shares per product, brand and fuel discussed in the paper.

For each vehicle sold, we combine the estimated lifetime kilometerage (see Table B2 in Appendix B for details) with information on emissions at the model level to calculate lifetime CO2 emissions. To distinguish between gasoline and ethanol use of FFVs, we proceed as discussed in Appendix A to acount for the different CO2 emissions of these fuels. Moreover, we re-calculated CO2 emissons assuming 25, 50 and 75 percent of FFV owners arbitrage across fuels. Finally, we obtain the cost of the policy per tonCO2 by dividing the total CO2 emissions of all vehicles sold by the total cost of the policy.

D Alternative Demand Specifications

We have conducted two sets of robustness checks. First, we compared our estimates based on the nested fixed-point algorithm (NFP) with alternative ones based on the MPEC algorithm (Dubé, Fox and Su 2011).[27] The results are similar to those reported in Table 3.

Second, we considered alternative specifications of the conditional indirect utility function used to estimate demand. For instance, we considered the following alternatives for the price and/or engine size coefficients:

1. $\beta^*_{Price} = \beta_{Price} + \sigma_y y_i + \sigma_{AGE} AGE_i$. Both y_i and AGE_i were draws from the income and age distributions of the Swedish population

2. $\beta^*_{Price} = \beta_{Price} + \sigma_y y_i$ and $\beta^*_{CC} = \bar{\beta}_{CC} + \sigma_{AGE} AGE_i$. In this alternative, we experimented with heterogeneity based in income for the price coefficient and heterogeneity based on age for the engine size coefficient.

3. $\beta^*_{Price} = \frac{\beta_{Price}}{y_i}$ and $\beta^*_{CC} = \beta_{CC} + \sigma v_i$. Here, v_i are draws from the Standard Normal distribution whereas y_i are draws from the income distribution (this is inspired in Berry, Levinsohn and Pakes 1999 and Beresteanu and Li 2011).

4. $\beta^*_{Price} = \frac{\beta_{Price}}{y_i} + \sigma v_i$. This is another alternative specification inspired by Berry, Levinsohn and Pakes (1999) and Beresteanu and Li (2011).

No specification was able to deliver results better than those of the ones reported in Table 3. More specifically, they were not able to capture enough heterogeneity to ensure the markups to be not monotonically decreasing with product prices. Since our market shares are quite small, given the large number of models in each time period, low heterogeneity implied not only lower percentage markups for higher priced cars, but also lower absolute markups for such automobiles, clearly at odds with what one would expect in this market.

[27] NFP settings included a convergence tolerance of 1e-13 for the contraction and 1e-6 for the optimization using the KNITRO optimizer.

E Brand Market Shares within Fuel Segments

In what follows, we decompose the changes in market shares within each of the five fuel segments for the three counterfactuals considered, so as to allow discerning gainers from losers at a more disaggregated level.

(i) High Emission Gasoline Segment Leading brands in the high emission gasoline segment under the GCR are Toyota, Volvo, VW, Peugeot and Skoda, each commanding market shares of at least 3.5 percent of the total market, see Figure E1a.

As already suggested in Figure 2b, the high emission gasoline fuel segment was hit hard by the GCR. The changes in market shares for Counterfactual I, reported in Figure E1b, show that this is the fuel segment where Swedish and high-end German brands saw their biggest losses whereas value brands saw substantial gains: abolishing the GCR would have resulted in increases of over 2pp in the market shares of Volvo and Mercedes, over 1pp for BMW and Audi and nearly 1pp for Saab, as well as decreases of at least 1pp for brands such as Skoda, Peugeot and Toyota.

FIGURE E1 ABOUT HERE

Figure E1c shows how the losses within the high emission gasoline segment, first detected in Figure 2c, were shared across brands in the case of a symmetric GCR. Overall, such losses were small and evenly spread, with only Volvo and Toyota facing decreases of over 0.1pp.

All in all, comparing the effects reported in Figures 3b and E1b lends further support to the view that Swedish and high-end German brands were at the losing end of the GCR: these losses come mostly from the high emission gasoline segment, of which FFV models (all of which are high emission vehicles in our data) are close substitutes.

(ii) High Emission Diesel Segment Volvo is the leading brand within the high emission diesel segment, commanding a 6.24 percent market share, and followed by Peugeot and VW, both of which command just over 2 percent, and far ahead of the remaining brands, see Figure E2a.

Figure E2b shows that under no policy, the main gainer would be Toyota (1.49pp), well ahead of brands Audi and Saab, both of which command about 0.4pp. The main losers are value brands Peugeot, Fiat, Hyundai and Kia, all of which would have lost about half a percentage point from the abolition of the program.

FIGURE E2 ABOUT HERE

Figure E2c shows that the high emission diesel segment is hardly affected by the symmetric GCR counterfactual: the only brand losing over 0.1pp is Volvo. Finally, Figure E2d shows how the losses in the high emission diesel segment from the counterfactual of full conversion to the FFV technology reflected on the different brands. The main loser is Volvo with a loss of 1.88pp, followed by Peugeot (0.966pp); brands Kia, Hyundai, VW and Fiat also witness a loss of at least 0.6pp in this scenario.

(iii) Low Emission Gasoline Segment The main players in this segment are Toyota, Peugeot, Hyundai and Citroen, with market shares in the range 0.9-2.82 percent of the market. Figure E3b

shows that under the counterfactual of no policy, Asian manufacturers Toyota and Hyundai are the main losers in this segment, , with a decrease of roughly 0.8pp in market shares.

FIGURE E3 ABOUT HERE

As already reported in Figure 2c, the low emission gasoline segment witnessed an increase in market share under Counterfactual II. Figure E3c shows that the main gainer was Toyota (0.649pp), followed by Peugeot (0.312pp) and Citroen (0.231pp).

(iv) Low Emission Diesel Segment The main player in the low emission diesel segment under the GCR is Citroen, which commands a market share of 1.44, well ahead of VW and Opel, both of which command about 0.5 percent, see Figure E4a. Figure E4b shows that the leadership of Citroen results essentially from the GCR – abolishing it results in a decrease of roughly 1pp for the French brand.

FIGURE E4 ABOUT HERE

Figure E4c shows that the symmetric GCR has a mild effect across brands whereas Figure E4d shows that full conversion to the FFV technology of the existing gasoline models would again have mostly hurt Citroen, which would have lost nearly 0.9pp.

(v) FFV Segment The main players in the FFV segment are Swedish brands Volvo and Saab (5.08 and 2.83 percent, respectively), followed by Ford (which introduced FFVs in Sweden), Peugeot, VW and Renault (with 2.31, 1.15, 0.911 and 0.877 percent, respectively), see Figure E5a. The counterfactual of no policy in Figure E5b shows that these brands benefited by the GCR. Next, Figure E5c shows that a symmetric version of the GCR would have mild effects across brands – only Volvo would lose more than 0.1pp. Figure E5c thus shows not only that consumers would have purchased FFVs even without the GCR –as already pointed out in Figure 2c–, but also that the brands operating within this segment would hardly be affected.

FIGURE E5 ABOUT HERE

Finally, Figure E5d shows that in a scenario of full conversion to the FFV technology, the main gainers in the high emission FFV segment would essentially be the Swedish and high-end German brands, i.e. the ones losing out from the GCR due to their strong presence in the high emission gasoline segment. On the other hand, the main losers would have been value brands such as Skoda and Peugeot, besides Toyota. These value brands would however be the main gainers in the low emission FFV segment, as reported in Figure E5e. For instance, Toyota and Peugeot would command market shares of 3.31 and 1.82 percent, respectively, compared to 2.82 and 1.17 percent in the low-emission gasoline segment under the GCR.

Tables and Figures for
"The Market Impact and the Costs of Environmental Policy: Evidence from the Swedish Green Car Rebate"
Cristian Huse and Claudio Lucinda

TABLE 1 – Descriptive Statistics of Selected European Passenger Car Markets

	Sweden	France	Germany
Passenger car fleet, millions (2008)	4.3	30.9	41.3
Passenger cars per 100 inhabitants (2008)	46.3	49.5	50.4
% Households with a vehicle (2006)	84.5	82	NA
Average car age, years (2008)	9.5	8.3	8.2
Average engine of new cars, in cc (2007)	1,964	1,680	1,863
Average power of new cars, in kw (2007)	105	80	96
% Passenger cars able to run on fuels other than gasoline and diesel (2008)	3.8	0	0.9
Share of cars ≤ 5 years (2008)	29.0%	33.4%	34.3%
Share of cars 5-10 years (2008)	31.9%	33.0%	33.0%
Share of cars > 10 years (2008)	39.1%	33.6%	33.6%

Note: This table is constructed using data from ANFAC (2010). Engine sizes are reported in cc (cubic centimeters).

TABLE 2 – Descriptive Statistics of Models Available on the Swedish Market, by Fuel Segment

		CO2 Emissions (gCO2/km)					
Fuel		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Total	Mean	210.8	210.4	205.5	197.7	198.8	191.4
	se(mean)	1.2	1.2	1.2	1.4	1.3	1.2
	Median	205	205	197	185	188	181
	1Q-3Q	175-239	172-239	167-233	159-223	161-225	155-217
	#brands	37	40	40	45	44	40
	#models	1854	1920	2101	1624	1946	2026
Total ≤ 120g	Mean	107.1	106.8	113.6	114.4	113.6	114.1
	se(mean)	3.1	2.9	0.9	1.1	0.9	0.7
	median	114.5	113	116	118	116	118
	1Q-3Q	90-118	90-116	109-119	109-119	109-116	109-119
	#brands	8	8	10	13	17	22
	#models	20	21	40	46	69	89
Gasoline	mean	218.0	218.4	215.4	210.5	212.4	205.9
	se(mean)	1.3	1.4	1.4	1.8	1.7	1.7
	median	213	211	207	194	198	193
	1Q-3Q	184-246	182-249	180-244	169-238	173-238	167-232
	#brands	37	40	40	45	43	39
	#models	1398	1417	1473	1081	1225	1195
Gasoline ≤ 120g	mean	116.3	115.3	112.1	111.1	112.1	113.1
	se(mean)	0.8	0.8	0.9	1.0	0.9	1.0
	median	116	116	111	109	109	112
	1Q-3Q	113-119	113-116	109-116	109-113	109-116	109-119
	#brands	3	2	4	5	7	12
	#models	10	8	14	10	18	36
Diesel	mean	188.8	188.1	183.0	172.3	174.8	168.4
	se(mean)	2.1	2.0	1.8	1.8	1.6	1.3
	median	185.5	187	174	162	169	160.5
	1Q-3Q	153-215	153-216	154-210	145-189	148-193	146-184
	#brands	28	28	31	32	34	35
	#models	442	491	596	513	667	748
Diesel ≤ 120g	mean	97.1	101.3	114.8	115.8	114.4	115.2
	se(mean)	1.0	1.2	1.4	1.4	4.5	5.2
	median	90	100	118	119	119	119
	1Q-3Q	90-116	90-116	115-119	116-119	114.5-119	112-119
	#brands	5	6	6	11	14	19
	#models	9	12	23	33	48	51
FFV	mean	165.0	198.0	185.4	184.4	194.2	195.1
	se(mean)	0.0	12.2	6.8	4.6	3.7	3.1
	median	165	215	172	175.5	184.5	191.5
	1Q-3Q	165-165	150-228	169-179	169-206	174-213	177-214
	#brands	1	3	3	3	10	12
	#models	2	11	17	18	44	66
FFV ≤ 120g	#models	0	0	0	0	0	0
Gasoline/CNG	mean	199.5	198.0	164.4	150.4	147.6	156.9
	se(mean)	12.4	12.2	7.9	6.3	9.7	4.5
	median	213	228	164	157	155	157
	1Q-3Q	150-231	150-215	148-183	136.5-164	138-160	144-167
	#brands	5	5	5	5	4	3
	#models	11	11	11	8	5	11
Gasoline/Electric	mean	104.0	104.0	147.8	147.8	161.8	171.3
	se(mean)	.	.	23.9	23.9	23.3	21.3
	median	104	104	147.5	147.5	185	188.5
	1Q-3Q	104-104	104-104	106.5-189	106.5-189	109-192	109-219
	#brands	1	1	3	3	3	3
	#models	1	1	4	4	5	6

Note: This table reports sample statistics of the distribution of engine CO2 emissions (measured in gCO2/km, running on gasoline or diesel) disaggregated by fuel and the number of brands and car models present in each fuel segment.

TABLE 3 – Demand Estimates

	(1) OLS		(2) IV		(3) RC Logit	
β_{Price}	-0.0026	***	-0.0114	***	-0.0218	***
	(0.00)		(0.00)		(0.00)	
β_{HP}	0.0072	***	0.0204	***	0.0243	***
	(0.00)		(0.00)		(0.00)	
β_{CC}	0.0001		0.0003	***	0.0002	*
	(0.00)		(0.00)		(0.03)	
$\beta_{Road\ tax}$	-0.0003	***	-0.0004	***	-0.0003	***
	(0.00)		(0.00)		(0.00)	
$\beta_{Fuel\ consumption}$	-0.2030	***	-0.1430	***	-0.0565	
	(0.02)		(0.02)		(0.10)	
σ_{Price}					0.0060	***
					(0.00)	
Brand FEs	Yes		Yes		Yes	
Time FEs	Yes		Yes		Yes	
Market segment FEs	Yes		Yes		Yes	
Fuel segment FEs	Yes		Yes		Yes	
Fuel consumption-fuel segment interactions	Yes		Yes		Yes	
N	13962		13962		13962	
Percentiles			Own-price elasticities			
p10	-1.0		-4.2		-5.3	
p25	-0.7		-3.1		-4.6	
p50	-0.6		-2.4		-3.9	
p75	-0.4		-1.8		-3.1	
p90	-0.3		-1.4		-2.5	

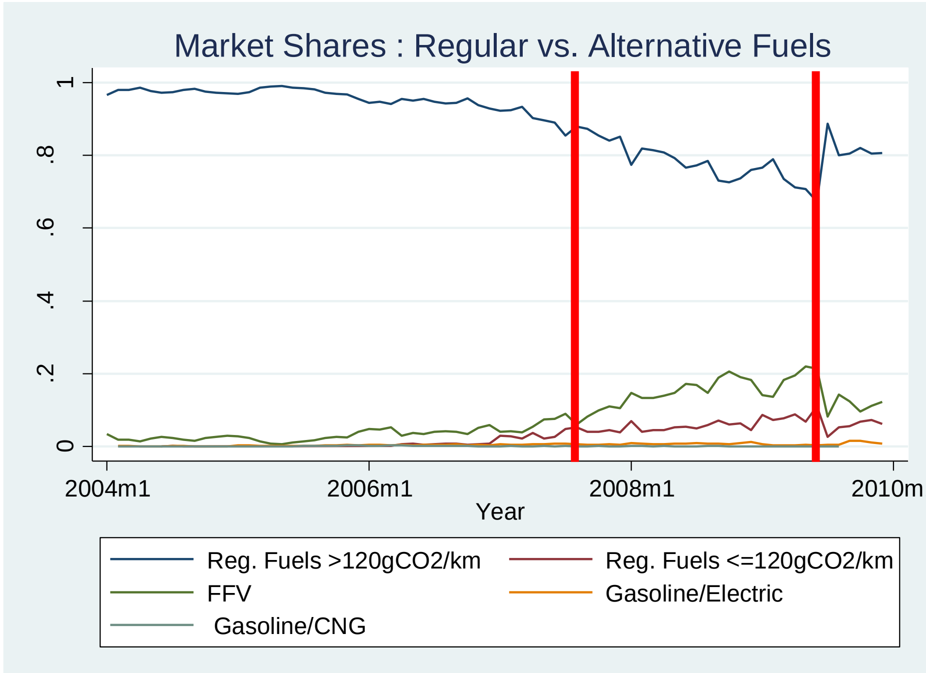
Note: Standard errors clustered by brand. * p<0.05, ** p<0.01, *** p<0.001. The value of the F-statistic of the first-stage regression is 31.48. With 5 and 13484 degrees of freedom, it is significant at the 1 percent level.

TABLE 4 – CO2 Savings and Costs of Alternative Policies

	CF I "No GCR"	CF II "Symmetric GCR"	CF III "Full FFV Adoption"
Panel A: CO2 Savings (thousands tonCO2)			
Gasoline usage			
0%	493.2	193.8	3,159.8
25%	441.0	192.5	1,878.6
50%	424.6	192.1	1,474.0
75%	406.7	191.6	1,035.6
Panel B: Cost of CO2 Savings (SEK/tonCO2 saved)			
Gasoline usage			
0%	760	465	558
25%	850	468	939
50%	883	469	1197
75%	921	470	1704
		Total Cost of Program as a Percentage of the GCR	
Percentage	--	24.0	470.9

Note: This table reports the total cost of the program in each scenario in Panel A, lifetime savings in tons of CO2 emissions induced by the different counterfactuals in Panel B and their associated costs in SEK/tonCO2 in Panel C. Results are reported for the assumption of Bertrand-Nash pricing as well as different levels of gasoline usage among FFV owners to illustrate the impact of fuel arbitrage on the program. All computations assume the lifetime of a vehicle to be 15 years. See Appendix A for details on the assumptions on gasoline usage, Appendix B for a robustness check using a 25-year lifetime assumption, and Appendix C for mileage regression results.

FIGURE 1 – Market Shares by Fuel Segment



Note: This figure depicts market shares of passenger cars sold to private individuals in the Swedish car market at the monthly frequency disaggregated by fuel segments. Vehicles running on regular fuels are split into two groups, namely high- and low-emission regular vehicles depending on whether they emit more or less than 120 gCO2/km. Vehicles able to run on alternative fuels are split into FFVs (gasoline/ethanol, or FFVs), gasoline/CNG and gasoline/electric. The figure shows the decrease in the market shares of high-emission regular vehicles and the increase in those of low-emission regular vehicles and FFVs, the leading alternative vehicle, while showing that the market shares of gasoline/CNG and gasoline/electric vehicles were essentially flat during the GCR period. The figure also suggests the existence of anticipatory effects at the (publicly announced) and of the GCR in June 2009, but no compelling evidence thereof at its start in April 2007.

FIGURE 2 – Effect of Alternative Policies on Fuel Segment Market Shares

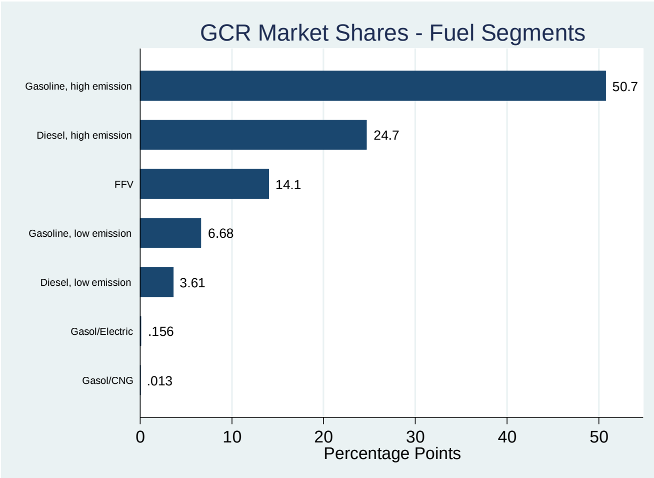


Figure 2a – GCR market shares

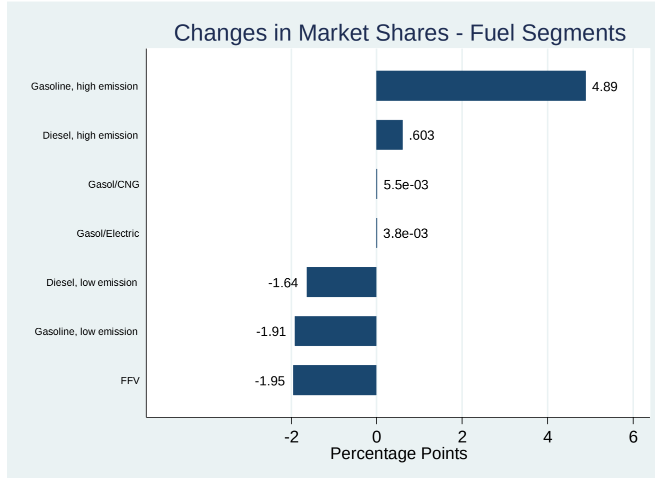


Figure 2b – Counterfactual I: No GCR vs. GCR

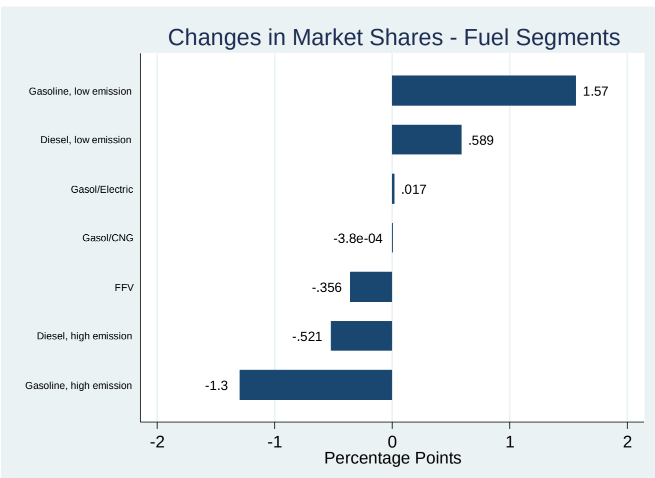


Figure 2c – Counterfactual II: Symmetric GCR vs. GCR

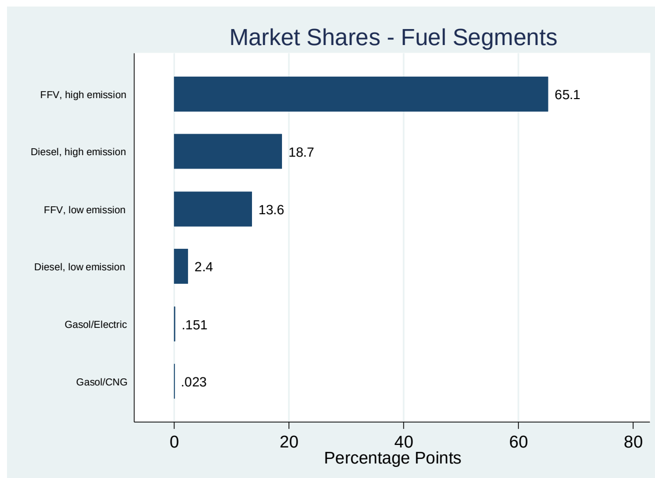


Figure 2d – Counterfactual III: Full Conversion to FFV vs. GCR

Note: This figure displays market shares under the GCR and changes in market shares at the fuel segment induced by alternative policies. Figure 2a displays market shares under the GCR (actual policy); Figure 2b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure 2c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR; Figure 2d displays market shares (instead of changes thereof) had all carmakers replaced their captive gasoline vehicles with FFVs (Note also the distinction between high- and low-emission FFVs when examining Counterfactual III). For the sake of clarity, the figure omits some brands for which (changes in) market shares were negligible.

FIGURE 3 – Effect of Alternative Policies on Brand Market Shares

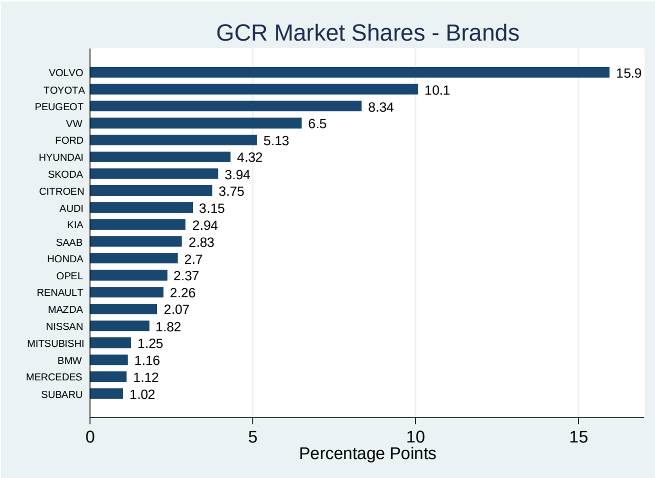


Figure 3a – GCR market shares

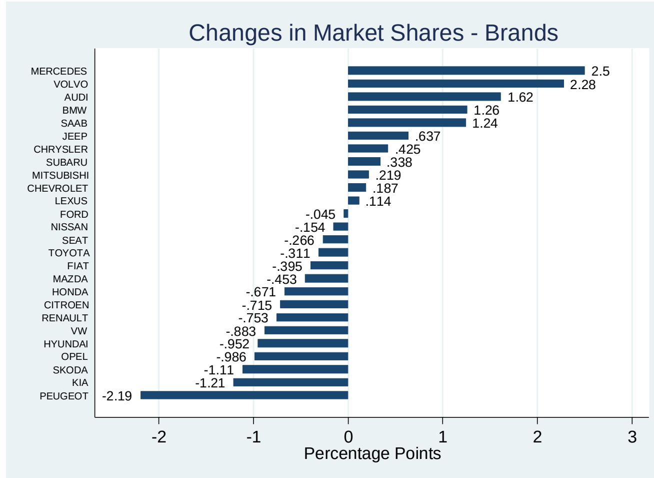


Figure 3b – Counterfactual I: No GCR vs. GCR

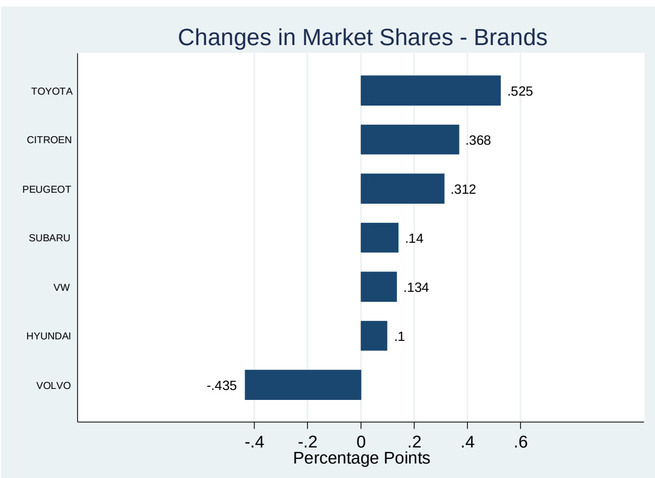


Figure 3c– Counterfactual II: Symmetric GCR vs GCR

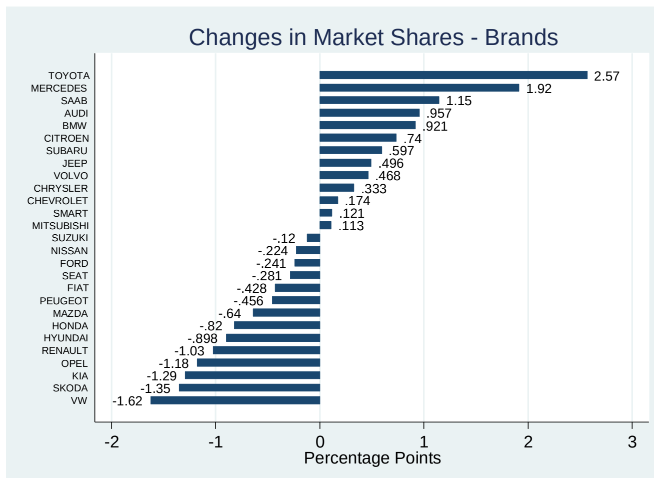


Figure 3d – Counterfactual III: Full Conversion to FFV vs GCR

Note: This figure displays brand market shares under the GCR and changes in market shares induced by alternative policies. Figure 3a displays market shares under the GCR (actual policy); Figure 3b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure 3c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR; Figure 3d displays *changes* in market shares had all carmakers replaced their captive gasoline vehicles with FFVs as compared to the GCR. For the sake of clarity, the figure omits some brands for which changes in market shares were negligible.

Tables and Figures from Appendix (Not for publication)

Table B1 – Mileage Regressions

	(1) Km/Year	(2) Km/Year	(3) Km/Year	(4) Km/Year	(5) Km/Year
Constant	19200.7***	20000.5***	17665.2***	17153.2***	17152.1***
	(220.88)	(19.39)	(22.35)	(1267.45)	(1057.17)
Fuel FEs	**Yes**	No	No	**Yes**	**Yes**
Year FEs	No	No	No	**Yes**	**Yes**
Fuel-age FEs	No	**Yes**	**Yes**	**Yes**	**Yes**
Fuel-year FEs	No	No	No	**Yes**	**Yes**
Brand-model FEs	No	No	**Yes**	**Yes**	No
Brand-model-segment FEs	No	No	No	No	**Yes**
N	2031000	2031000	2031000	2031000	2031000
R-squared	.4064	.3626	.8728	.905	.9383

Note: t-statistics in brackets, standard errors clustered by brand-fuel. * p<0.10, ** p<0.05, *** p<0.01. The full set of results is available from the authors upon request.

Table B2 – Lifetime Mileage Estimates, by Fuel

	Age of Vehicle (years)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Gasoline	16655	16158	15661	15165	14668	14171	13674	13177	12680	12183	11686	11189	10692	10196	9699	197,654
Gasoline/electric	19473	18937	18401	17865	17329	16793	16257	15721	15185	14649	14113	13577	13041	12505	11969	235,809
FFV	19621	19006	18392	17778	17163	16549	15934	15320	14706	14091	13477	12862	12248	11634	11019	229,800
Gasoline/CNG	19545	19401	19257	19113	18969	18825	18681	18537	18393	18249	18105	17961	17817	17673	17529	278,057
Diesel	25460	25068	24676	24284	23892	23501	23109	22717	22325	21933	21541	21149	20757	20365	19973	340,749

Note: Mileage disaggregated at the fuel segment based on estimates from Specification 5 in Table C1. Figures are expressed in kilometers.

Table C1 – Regression of Sales on Green Car Rebate and Market Characteristics

OLS - Dep. var: ln(total sales)	(1)
GCR dummy	-0.0124
	(-0.20)
ln(Potential Market)	0.705***
	(3.92)
ln(CPI)	-3,744
	(-1.65)
ln(Electricity Price)	-1.214***
	(-3.90)
ln(Industrial Production)	1.098***
	(5.83)
Constant	-1,309
	(-0.42)
N	73
R2	.7522

Note: t-statistics in brackets, standard errors clustered by brand-fuel. * $p<0.10$, ** $p<0.05$, *** $p<0.01$

TABLE C2 – CO2 Savings and Costs of Alternative Policies

	CF I "No GCR"	CF II "Symmetric GCR"	CF III "Full FFV Adoption"
Panel A: CO2 Savings (thousands tonCO2)			
Gasoline usage			
0%	583.6	257.7	3,353.4
25%	522.6	254.8	1,863.0
50%	503.3	253.9	1,392.4
75%	482.4	253.0	882.5
Panel B: Cost of CO2 Savings (SEK/tonCO2 saved)			
Gasoline usage			
0%	642	338	528
25%	716	341	950
50%	744	343	1271
75%	776	344	2006
		Total Cost of Program as a Percentage of the GCR	
Percentage	--	22.9	464.6

Note: This table (to be compared to Table 4 in the text) reports the total cost of the program in each scenario in Panel A, lifetime savings in tons of CO2 emissions induced by the different counterfactuals in Panel B and their associated costs in SEK/tonCO2 in Panel C. Results are reported for the assumption of Bertrand-Nash pricing as well as different levels of gasoline usage among FFV owners to illustrate the impact of fuel arbitrage on the program. All computations assume the lifetime of a vehicle to be 25 years. See Appendix A for details on the assumptions on gasoline usage and Appendix C for mileage regression results.

FIGURE E1 – Effect of Alternative Policies on Brand Market Shares within High Emission Gasoline Vehicles

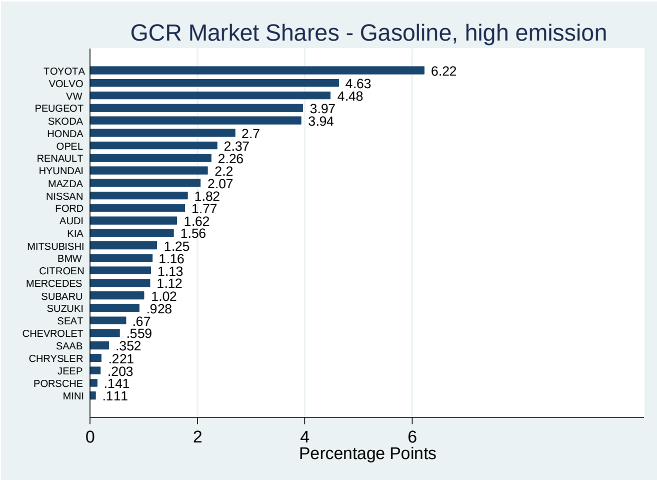


Figure E1a – GCR market shares

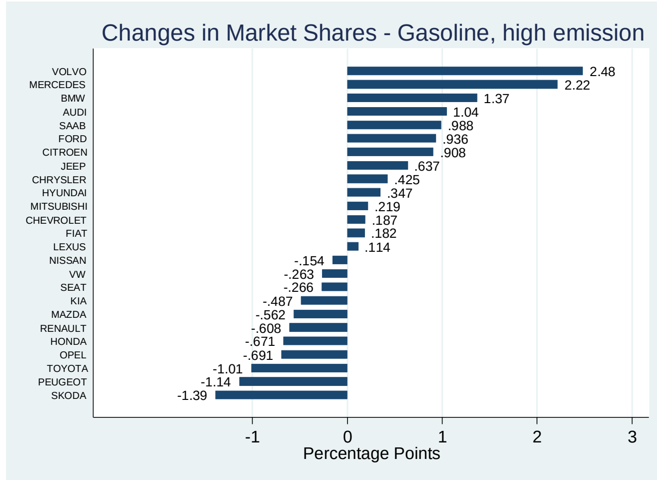


Figure E1b – Counterfactual I: No GCR vs. GCR

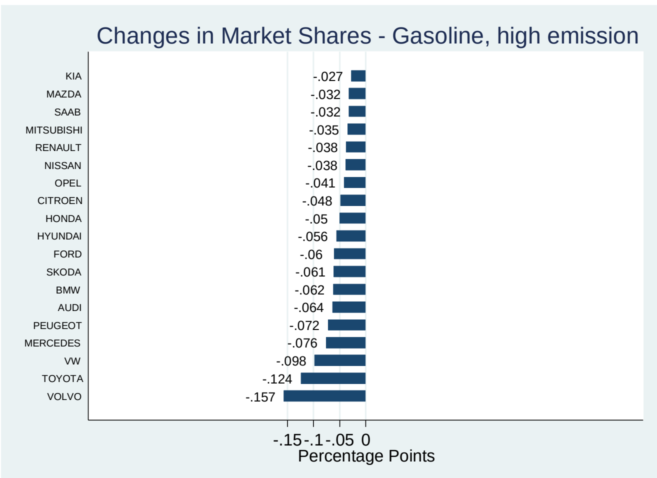


Figure E1c– Counterfactual II: Symmetric GCR vs GCR

Note: This figure displays brand market shares within the high emission gasoline segment under the GCR and changes in market shares induced by alternative policies. Figure E1a displays market shares under the GCR (actual policy); Figure E1b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure E1c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR. For the sake of clarity, the figure omits some brands for which changes in market shares were negligible.

FIGURE E2 – Effect of Alternative Policies on Brand Market Shares within High Emission Diesel Vehicles

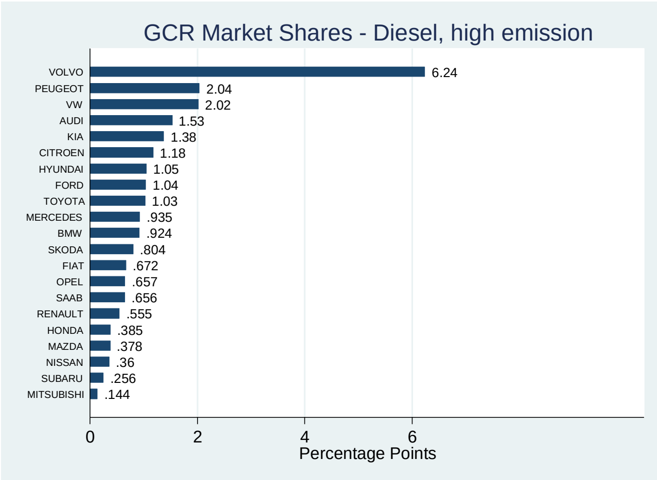


Figure E2a – GCR market shares

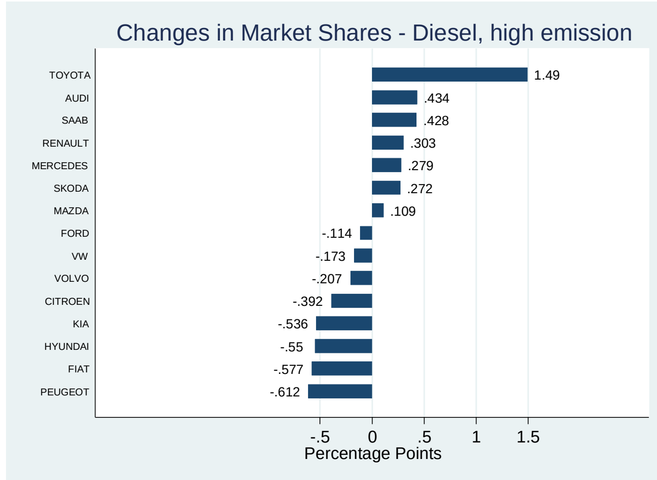


Figure E2b – Counterfactual I: No GCR vs. GCR

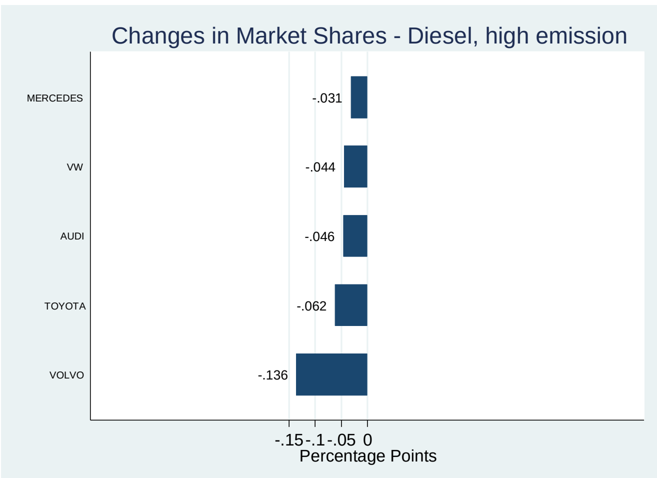


Figure E2c– Counterfactual II: Symmetric GCR vs GCR

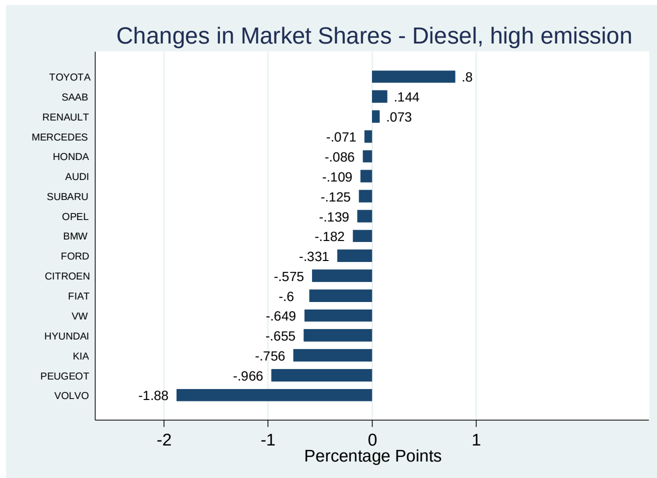


Figure E2d – Counterfactual III: Full Conversion to FFV vs GCR

Note: This figure displays brand market shares under the GCR and changes in market shares induced by alternative policies. Figure E2a displays market shares under the GCR (actual policy); Figure E2b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure E2c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR; Figure E2d displays *changes* in market shares had all carmakers replaced their captive gasoline vehicles with FFVs as compared to the GCR. For the sake of clarity, the figure omits some brands for which changes in market shares were negligible.

FIGURE E3 – Effect of Alternative Policies on Brand Market Shares within Low Emission Gasoline Vehicles

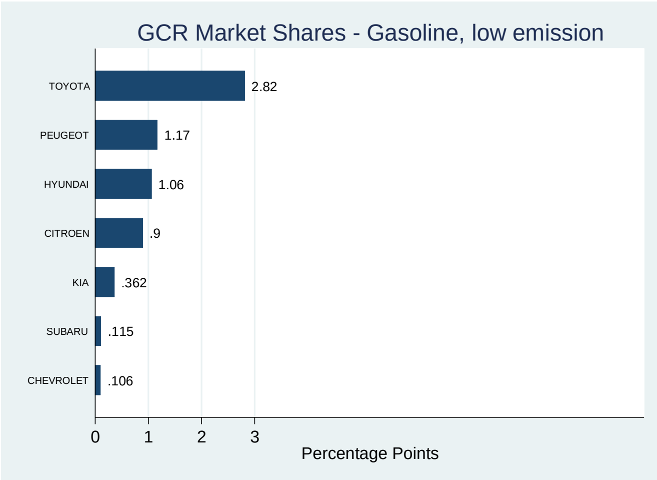


Figure E3a – GCR market shares

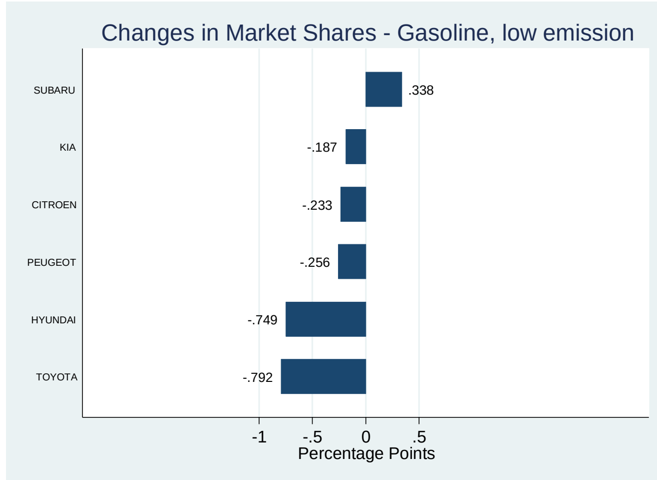


Figure E3b – Counterfactual I: No GCR vs. GCR

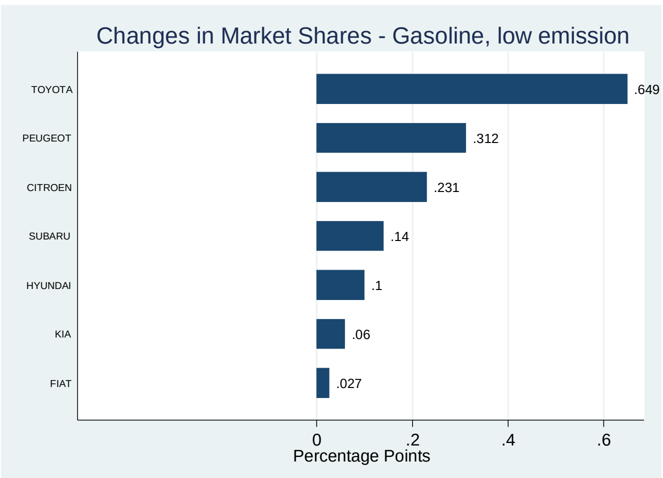


Figure E3c– Counterfactual II: Symmetric GCR vs GCR

Note: This figure displays brand market shares under the GCR and changes in market shares induced by alternative policies. Figure E3a displays market shares under the GCR (actual policy); Figure E3b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure E3c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR. For the sake of clarity, the figure omits some brands for which changes in market shares were negligible.

FIGURE E4 – Effect of Alternative Policies on Brand Market Shares within Low Emission Diesel Vehicles

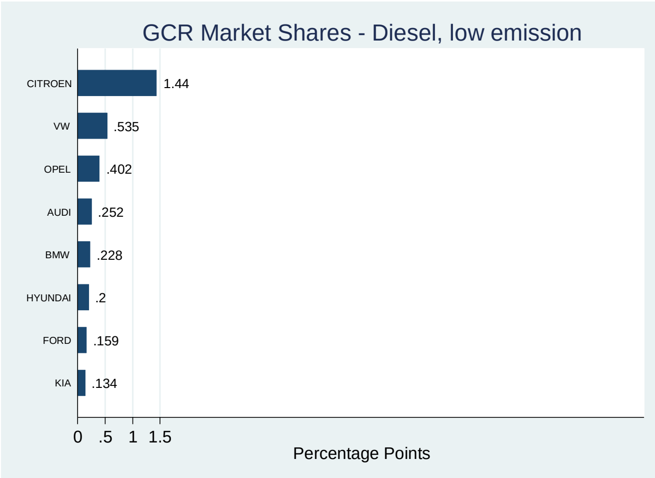


Figure E4a – GCR market shares

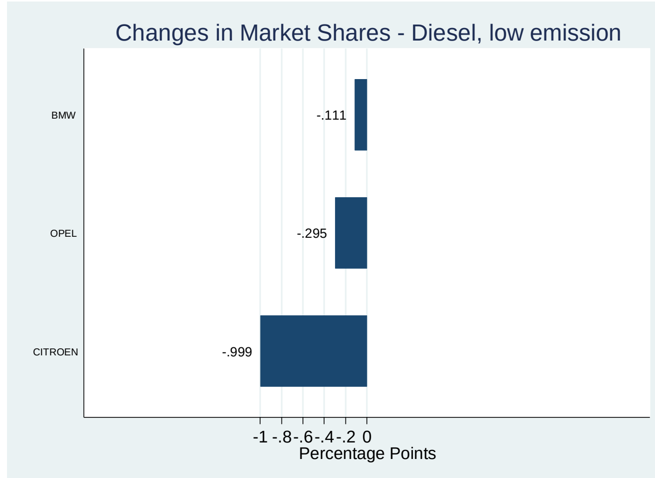


Figure E4b – Counterfactual I: No GCR vs. GCR

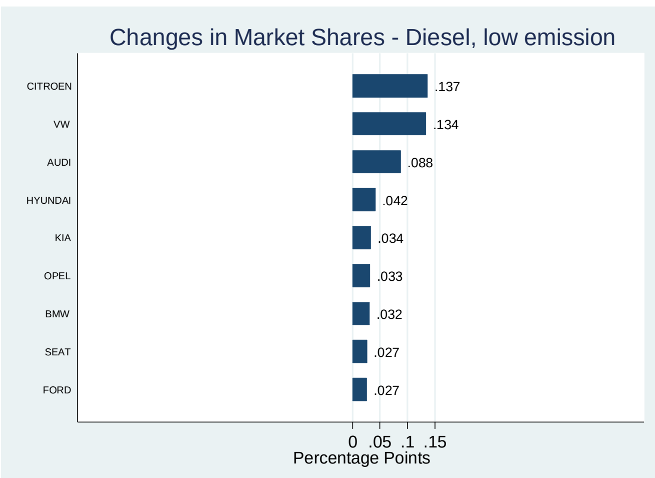


Figure E4c– Counterfactual II: Symmetric GCR vs GCR

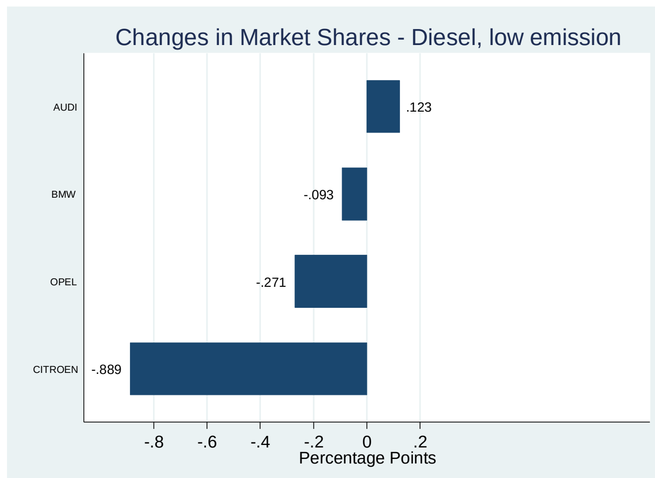


Figure E4d – Counterfactual III: Full Conversion to FFV vs GCR

Note: This figure displays brand market shares under the GCR and changes in market shares induced by alternative policies. Figure E4a displays market shares under the GCR (actual policy); Figure E4b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure E4c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR; Figure E4d displays *changes* in market shares had all carmakers replaced their captive gasoline vehicles with FFVs as compared to the GCR. For the sake of clarity, the figure omits some brands for which changes in market shares were negligible.

FIGURE E5 – Effect of Alternative Policies on Brand Market Shares within FFV Vehicles

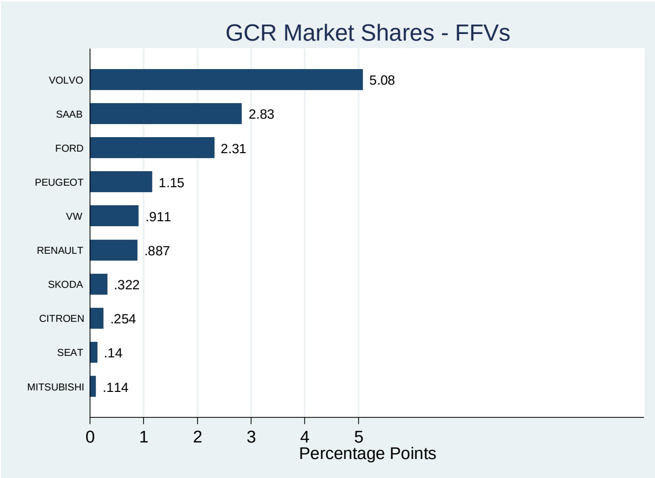


Figure E5a – GCR market shares

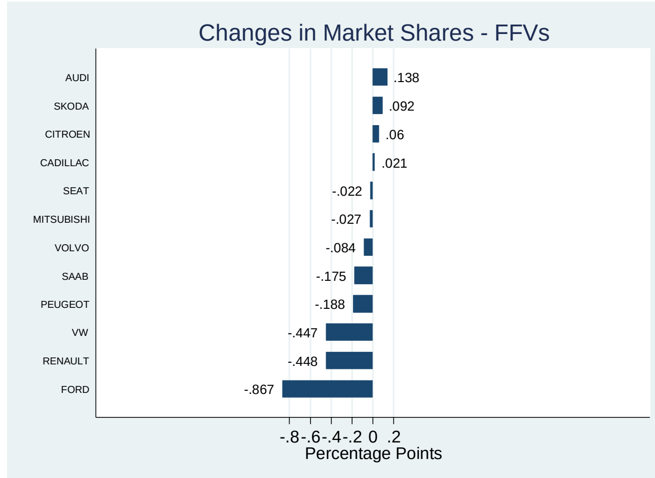


Figure E5b – Counterfactual I: No GCR vs. GCR

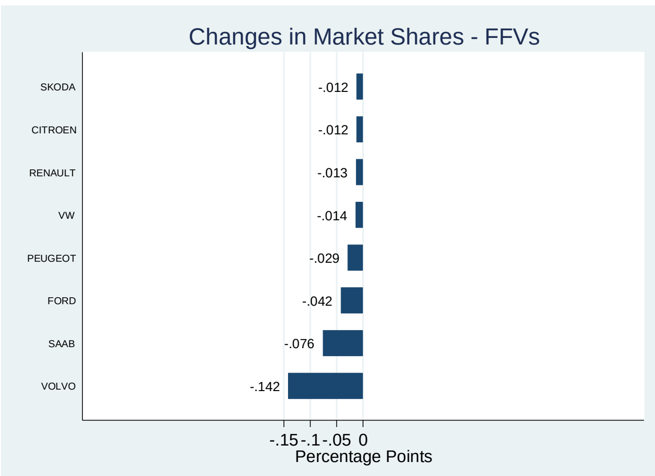


Figure E5c– Counterfactual II: Symmetric GCR vs GCR

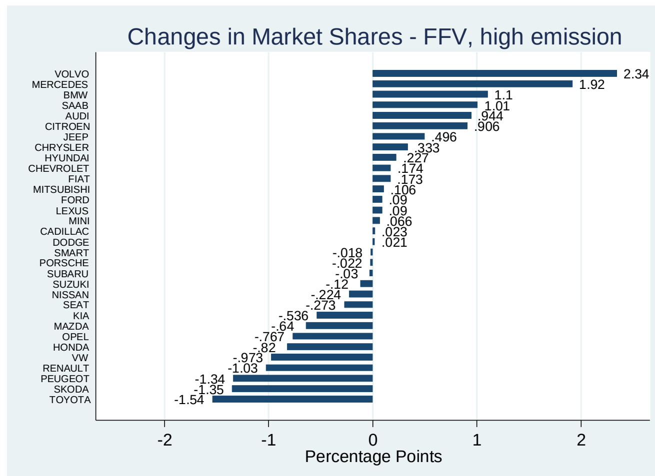


Figure E5d – Counterfactual III (a): Full Conversion to FFV vs GCR

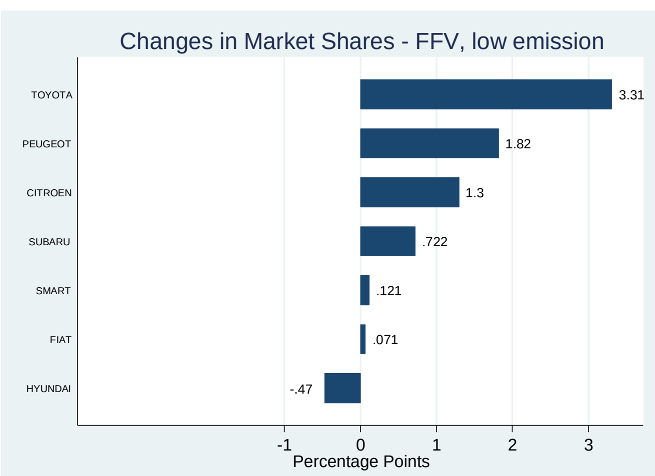


Figure E5e – Counterfactual III (b): Full Conversion to FFV vs GCR

Note: This figure displays brand market shares under the GCR and changes in market shares induced by alternative policies. Figure E5a displays market shares under the GCR (actual policy); Figure E5b displays *changes* in market shares under the counterfactual of no policy (i.e., no GCR) as compared to the GCR; Figure E5c displays *changes* in market shares under the counterfactual of a symmetric GCR as compared to the GCR; Figures E5d and E5e display *changes* in market shares of high- and low-emission FFVs had all carmakers replaced their captive gasoline vehicles with FFVs as compared to the GCR (Note also the distinction between high- and low-emission FFVs when examining Counterfactual III). For the sake of clarity, the figure omits some brands for which changes in market shares were negligible.