Faculdade de Economia,
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Texto para Discussão

Série Economia

TD-E 01 / 2012

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

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

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May 2012

Abstract

This paper quantifies the effects of the Swedish green car rebate (GCR), a program to reduce oil dependence and greenhouse gases emissions. We estimate the demand for automobiles in the Swedish market and construct the counterfactual of no-GCR to estimate the effects of the program. We find the GCR to have increased the market shares of green cars by 4.6 percentage points and its cost to be about USD 100/tonCO2, thus 5 times the price of an emission permit. Since regular (fossil) fuels receive a stricter treatment than alternative (renewable) ones we also simulate a counterfactual in which they are treated in equal terms. We find the cost of such a program to be 2.5 percent lower than that of the GCR. We also quantify the effect of fuel arbitrage on the cost of the GCR: since the main green cars in Sweden are FFVs (flexible-fuel vehicles), which can seamlessly switch between (high-CO2) gasoline and (low-CO2) ethanol, fuel choice is another dimension policymakers need to account for – the cost of CO2 savings increases by over 8 (20) percent if 25 (55) percent of FFV owners drive on gasoline instead of ethanol. Finally, and at odds with political economy arguments that the GCR was designed to benefit local manufacturers, we show that (together with high-end German brands) Swedish carmakers lost market shares due to the GCR's design.

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.

*__Preliminary and incomplete – Please do not cite or distribute.__ We thank Tobias Olsson for making data available and Alexandra Lindfors and Martin Roxland for research assistance.

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1 Introduction

Road transport is responsible for 20 percent of the CO2 emissions generated by fuel consumption worldwide. With the growth of emerging economies, transport fuel demand 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, while passenger cars are responsible for about 12 percent of the overall emissions, this share is a much higher 19 percent in Sweden (as compared to 20 percent for the US), for the country has one of the most fuel-devouring car fleets in 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 technologies for the transportation sector. (See Parry, Walls and Harrington 2007 for a discussion of the importance of alternative fuels.)

The Swedish Green Car Rebate The Swedish Green Car Rebate (GCR), which was introduced in April 2007, thus prior to the global economic crisis, was put forth with two main objectives, namely promote the reduction of GHG (greenhouse gases) emissions of newly-registered cars and reduce oil dependence. These aims were to be achieved through a 10,000 SEK rebate paid to private individuals purchasing environmentally friendly cars, or *green cars*.[2]

A key feature of the GCR is its reliance on alternative (renewable) fuels to achieve its aims.[3] The GCR defined a green car according to which fuels it is able to operate and on how much CO2 it emits: while cars able to run only on *regular fuels* – 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, gas and electricity) were given a more lenient treatment (details of which below). In contrast with other markets, see e.g. Sallee (2010) for a survey, the GCR has affected a substantial fraction of the car market: from its introduction in 2007 to 2008, the number of green car models available on the market increased from 73 to 120, of which 54 were alternative ones.[4] On the demand side, green cars commanded a 25 percent market share among newly-registered cars, two-thirds of which were able to run on renewable fuels.

Empirical Strategy This paper investigates economic and environmental aspects of the Swedish GCR. To do so, we construct a unique registration-based dataset for the Swedish car market with car models disaggregated up to the fuel segment level, e.g. high- vs. low-emission gasoline version of a model. To quantify the impacts of the Swedish GCR we estimate a structural model for the Swedish car market. Building on it we are able to examine counterfactuals to the actual policy and assess their effects on the car market. First, we examine the counterfactual of no environmental

[1] The 1994 EEA Treaty which created the European Economic Area 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] The rebate corresponds to roughly 6 percent off of the price of a new VW Golf 1.6. With the SEK/USD exchange rate at 6.984 (7.650) at the inception (end) of the program, the rebate was in the range USD 1,300-1,500.

[3] While countries such as France and Germany established an explicit ceiling for emissions to qualify for the program, the US has put forth a scrappage scheme; Sweden in turn combined an emission threshold with renewable fuels. See http://ec.europa.eu/environment/air/transport/road.htm for an overview of the European framework and http://www.cars.gov/ for details of the US scrappage program. Note also that in the US the emission requirement is replaced with a (roughly equivalent) fuel economy one.

[4] For perspective, Beresteanu and Li (2011) document 15 hybrid models available on the US market in 2007.

policy. That is, we examine what would have happened in the counterfactual of no environmental policy at all. 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. Whereas the former needed to satisfy an arguably stringent requirement to qualify as green cars, the latter received a more lax treatment by the program. As a result, we assess what would have happened had one treated regular and alternative fuels in a symmetric manner. That is, in this counterfactual only vehicles emitting no more than 120 gCO2/km do qualify for the rebate.
We assess the following aspects of the GCR. First, we focus on the environmental side of the GCR. Metrics according to which such a policy can be assessed include the extent to which it was able to tackle GHG emissions, i.e. CO2 emission savings, and at which cost. Our strategy is to combine our estimates of CO2 savings implied by the policy with its cost in order to obtain the cost per ton of CO2 emissions saved; these are then compared to the cost of similar programs in the US, to the price of European emission permits and to the social cost of carbon.

Second, we investigate the impact of the policy on overall market shares of carmakers as well as their market shares disaggregated by fuel segment. In particular, we examine to which extent – if at all – local manufacturers Saab and Volvo benefited from the policy. This is important because governments may design policies in order to benefit local *vis-à-vis* foreign producers and boost local employment, R&D and exports. Hosting two carmakers, Sweden is highly dependent on the automobile industry, which is key to employment, investments, exports and R&D in the country. In fact, 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). Having originated in Sweden, Volvo and Saab were taken over by US carmakers, thus becoming brands within global car 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 of the local brands was still performed in Sweden, so much so that both are still considered local brands by Swedish consumers.

Finally, we assess the impact of the asymmetric treatment enjoyed by regular and alternative vehicles in terms of both environmental and market effects. That is, we examine in which way the skew of the GCR towards renewables altered market outcomes and what would have been the cost of a symmetric version of the program whereby only vehicles emitting no more than 120 gCO2/km would be classified as green cars and qualify for the rebate.

Main Findings Our first set of findings relate to the environmental consequences of the GCR. By computing counterfactuals for an alternative scenario without the rebate, on the environmental side our results indicate a decrease in lifetime CO2 emissions of about 427.5 thousands tons for the vehicles sold during the GCR. Weighed against the costs of the rebate, this implies that the cost of the GCR was 706 SEK per ton of saved CO2. This amounts to USD 100 using the average SEK/USD exchange rate, thus lower than estimates obtained for the US market of USD 177 by Beresteanu and Li (2011) and at the lower end of results in the range USD 91-288 obtained by Li, Linn and Spiller (2011). The cost of CO2 savings can also be compared to the prices of emission rights and to the social cost of carbon (SCC) – at about five times the cost of CO2 emission permits or the value of the SCC, the estimates do not lend support to the view that the program was cost-effective.[5](By making such a statement one is of course implicitly abstracting from the

[5]Emission rights were illiquid instruments during the period the GCR was in place. End-of-quarter spot prices were EUR 10.83, 13.13, 13.14 and 12.36 per tonne of CO2 for each quarter in 2009. At the then prevailing SEK/EUR exchange rates, this would imply prices 118.53, 142.37, 134.23 and 126.88 SEK, respectively. The SCC is estimated to be EUR 15 (about 150 SEK) per ton of CO2 (in 2005 prices) (Interagency Working Group on Social Cost of

desired long term objective to increase the acceptance for green cars, whose market share has increased by 4.6 percentage points due to the program.)

Accounting for the fact that a non-trivial share of FFV owners switches between gasoline and ethanol based on their relative prices results in non-trivial increases in the cost of the program. If gasoline usage among FFV owners is 25 (55) percent, the cost of CO2 savings increases by 8 (20) percent to 764 (846) SEK as compared to 706 SEK in the benchmark.

The asymmetric treatment enjoyed by regular as compared to alternative fuels resulted in high-emission diesel and especially gasoline vehicles suffering increased competition from low-emission regular vehicles and (high-emission) FFVs, all of which are eligible for the 10,000 SEK rebate. The main brands losing out from the rebate were Swedish carmakers Volvo and Saab as well as (high-end) German carmakers Audi, BMW and Mercedes. On the other hand, value brands such as Peugeot, Kia, Skoda (as well as VW, which has a broad product line) benefited the most from the program. Moreover Ford, the legacy player in the FFV segment, did particularly well in this fuel segment.

Removing the asymmetric character of the GCR would result in savings of about 2.5 percent in the cost of CO2 savings but – most importantly – would not avoid the issues stemming from fuel arbitrage. In short, adoption of the FFV technology as the main technology to high-emission gasoline and vehicles introduces fuel choice as a dimension policymakers have to account for. Moreover, imposing a 120 gCO2/km threshold across the board would essentially benefit high-end German and Swedish brands while worsening the prospects of both VW and Ford. Thus, there is no evidence that the Swedish GCR did benefit the local brands.

Contribution and Related Literature This paper contributes to the burgeoning literature on the impact of policies directed towards the automobile market with the aim to either stimulate the economy or promote the adoption of fuel-efficient vehicles. The use of a structural model allows to combine alternative policies targeting the new car market and fuel tax policies.

To our knowledge, this is the first attempt to investigate a green car policy with a broad impact on the automobile market and skewed towards renewables. In contrast to what happens in North America, the Swedish policy affected a substantial portion of the market, so much so that the share of registered vehicles not targeted by the program dropped from nearly 100 percent prior to its inception to roughly 75 percent in less than two years after its introduction. What is more, the Swedish GCR pushed strongly for renewable fuels, with the result that FFVs, the leading alternative green car, commanded a market share of 16 percent of new vehicle registrations already in 2008. Combined, all fuel segments benefiting from the GCR commanded a market share of about 25 percent of the Swedish market.

The focus on alternative fuels makes the paper relate to the literature between fuel and car markets and on the one focusing on renewable fuels. In the case of the former, the evidence is that consumer reaction is surprisingly slow (Borenstein 1993). This finding can be attributed to the fact that the dominant automobile engine is typically captive and/or there is no fueling infrastructure available for non-standard fuels. As opposed to what happens in markets such as the US, where Corts (2010) documents a low market penetration of ethanol due to the lack of fueling infrastructure, 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 swiftly, effectively arbitraging across fuels (gasoline and ethanol). This is consistent with micro-level evidence from Brazil, where fuel arbitrageurs are estimated to be 60 percent among FFV owners (Salvo and Huse 2012); market-level evidence for Sweden points that the share of FFV owners who arbitrage across

Carbon 2010; Aldy, Krupnick, Newell, Parry and Pizer 2010).

fuels to be in the range 46-77 percent (Huse 2012). It is then important to account for the fact that a fraction of motorists might switch between fuels in the calculation of CO2 savings and their associated costs.

Three papers are closely related to ours, namely Chandra, Gulati and Kandlikar (2010), Beresteanu and Li (2011) and Li, Linn, and Spiller (2011).[6] Whereas Chandra et al (2010) and Beresteanu and Li (2011) look at the Canadian and US programs to promote the adoption of hybrid electric vehicles (HEVs), respectively, Li et al (2011) evaluates the US "Cash-for Clunkers" program.[7] 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, the cost of the programs is substantial.[8] This finding may hold due to the fact that these programs typically target a small share of the market: for instance, Beresteanu and Li (2011) document that the highest market share commanded by HEVs in their sample is 2.15 percent of total registrations in 2007, the last year in their dataset.[9]

The paper is structured as follows. Section 2 describes the institutional background and the rebate scheme. Section 3 describes the data, while Section 4 presents the structural model and its results. Section 5 reports results of policy experiments and the final section concludes.

2 Institutional Background

Despite being smaller than markets such as the French and German ones, 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.[10] 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 EU 18 countries (the original EU 15 plus Hungary, Lithuania and Slovenia) Sweden consistently appeared at the bottom of the CO2 emission 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 In early 2007 the Swedish government introduced a program intended to promote renewable fuels and oil independence. The Green Car Rebate (GCR), which was passed in Parliament and announced to the public in March 2007, effectively starting in April 2007, consisted of a 10,000 SEK (amounting to about USD 1500 using the average SEK/USD

[6]Knittel (2009) is another related paper which calibrates the cost of CO2 for the Cash-for-Clunkers program.

[7]Given its environmental objectives, the Swedish GCR is close in spirit to the former.

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

[9]While we focus on the whole car market, other studies have examined either a single hybrid model or the hybrid market niche. Gallagher and Muehlegger (2007) estimate the effect of state and local incentives, rising gasoline prices, and environmental ideology on hybrid vehicle sales; Kahn (2008) studies the effect of environmental preferences on the demand for green products; Sallee (2008) studies the incidence of tax credits for the Toyota Prius and documents that consumers capture the significant majority of the benefit from tax subsidies.

[10]The numbers presented involve all registered passenger cars, thus including those owned by private individuals, businesses and government.

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, which requires 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 in late 2006 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 comply with certain emission criteria (see SFS 2007). Cars are divided into two categories: regular and alternative fueled cars. Cars running on fossil fuels, referred to as *regular fuels*, qualify as green cars if their CO2 emissions are below 120 g/km.[11] Cars able to run on fuels other than gasoline and diesel, referred to as *alternative fuels*, qualify as green cars if their consumption lies below the energy equivalent of 9.2 l/100 km gasoline or 9.7 m3/100 km of gas (typically CNG); electric cars are considered green if their consumption lies below 37 kWh/100 km. The main alternative fuel cars are flexible-fuel vehicles (FFVs), which are able to run on any combination of ethanol and gasoline. This allows FFV owners to arbitrage between these fuels comparing their prices to their energy contents.[12]

In contrast to the US market, emission thresholds in Sweden apply to individual cars rather than to a brand-level sales-weighted average as in the CAFE standard. Moreover, 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]

The Swedish Passenger Car Market The overall number of brands and models on the Swedish market increases during the sample period and 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.[14]

TABLE 2 ABOUT HERE

The main alternative fuel in Sweden is ethanol, a fuel available in over half of all fueling stations in the country. The ethanol sold in Sweden is a mixture of 85 percent ethanol and 15

[11]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.

[12]According to the Swedish Environmental Protection Agency (2008), one liter of ethanol contains about 26% less energy than one liter of gasoline.

[13]Although the thresholds defining regular and alternative fuel cars are 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 about 220 gCO2/km (for perspective, the 2012 Porsche 911 Carrera emits 205 gCO2/km). See also 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/100 corresponds to 10.87 *kpl* or 25.54 *mpg*.

[14]While at odds with, e.g. Li, Timmins and von Haefen (2009), this is consistent with findings in Sallee and Slemrod (2011) for North America and EFTE (2009) for the European market. The latter documents decreases in CO2 emissions in the range 17-27 percent for a sample of models while either fixing or increasing their engine horsepower *within a two-year period*.

percent gasoline in which the gasoline works as a lubricant and helps starting the engine.[15] 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 the possibility to seamlessly switch between gasoline and ethanol may explain the swift adoption of FFVs, not to mention the availability of a well-developed ethanol retail network.

Table 2 also reports that, starting from only 2 models marketed in 2004 (two versions of the Ford Focus), the number of FFVs increased to 18 in 2007, 44 in 2008 and 66 in 2009. 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 gas 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 expensive by consumers.

FIGURE 1 ABOUT HERE

FFVs were the main gainers following the GCR reaching 16.1 percent of registrations in 2008, while gas and electric vehicles never commanded more than 1 percent of the market, see Figure 1. The growth in the FFV share was in large part 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 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 the light of the use of list (recommended) prices when estimating demand.[16]

3 Data

We combine a number of datasets, from administrative-based registration data to publicly-available car characteristics, fuel data and air pollutants. The details are as follows.

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

[15] During the winter the mixture contains 25 percent gasoline to avoid start-up problems at low temperatures.

[16] List prices, or MSRPs (manufacturer's suggested retail prices) in the US are set by manufacturers and are typically constant across geographic markets within a model-year. Given the difficulty in obtaining transaction prices since these are typically not readily available, MSRPs have commonly been used in the literature, see e.g. Beresteanu and Li (2011).

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, number of doors, gearbox type, weight, fuel economy (city driving, highway driving and mixed driving, with testing made under EU-determined driving cycle and expressed in liters per 100 kilometers, or 100 cubic meters per km for gas cars), CO2 emissions (measured in gCO2/km under EU-determined driving conditions and mixed driving), vehicle tax and list prices.

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).

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 segment. For a given model, yearly mileage decreases with age and is typically higher for diesel as compared to gasoline engines.
We then regress average odometer readings on the inverse of age interacted with fuel fixed-effects plus segment and model fixed-effects. We then estimate the lifetime mileage of cars disaggregated by fuel assuming a lifespan of 15 years.[17]

Inflation 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. The Appendix gives more details on the construction of the dataset.

Combining Datasets We merge characteristics and registration datasets. One important issue arising 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 datasets in that we observe sales for different fueled versions of a given model. For each combination of year-brand-model-fuel we use characteristics from the baseline version, i.e. the lowest price 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 a rich literature since 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. Individual heterogeneity

[17] The lifespan of a car can arguably be much 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.

is modeled in a way not to restrict substitution patterns *a priori*. 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. 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, engine size and brand and ξ_j are characteristics observed by the market participants but not the econometrician (such as quality, style etc). We decompose the individual coefficients as $\beta_{ik} = \overline{\beta}_k + \sigma_k v_{ki}$, where $\overline{\beta}_k$ 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. Finally, we normalize the outside good to have zero utility.

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 Linn and Klier (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). We use a set of polynomial basis functions of exogenous variables within a market segment. For a given market segment, we calculate the number of other products of the same firm and the number of firms in the same group, and the number of other products of the same producer in the same group. BST instruments implicitly assume a form of localized competition among products, and this seems consistent with anecdotal evidence from 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 economy (liters/100km, under mixed driving), road tax and price (in thousands of SEK, as of December 2009, deflated by the Swedish CPI). 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, gasoline/ethanol, gasoline/electric and gasoline/CNG) fixed-effects and interactions of fuel economy and fuel segment fixed-effects. [18] Consumer heterogeneity is introduced onto price coefficients via antithetic random draws of a standard Normal distribution.

TABLE 3 ABOUT HERE

We first compare 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).

Specification 1 features a negative and significant price coefficient of -0.0026. 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 by a fivefold as compared to its OLS counterpart. An immediate result from controlling for price endogeneity is the improved estimates of own-price elasticities, now in the range 1.4-4.2 and thus consistent with economic theory.

Introducing heterogeneity in the form of a random coefficient for price renders a price coefficient of -0.022, thus about eight times the magnitude of its uninstrumented counterpart. More importantly, it improves price elasticities: the 10th and 90th percentiles are given by 5.3 and 2.5, respectively, with a median value of 3.9. These values 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 are in line with economic theory and the literature: consumers prefer higher engine power and engine size. [19]

4.2 Supply

Model Specification 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 $\Im_f \subset \{1, ..., J\}$. Firm f chooses the prices of its products to maximize its profits according to the profit-maximization problem

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

$$\begin{aligned} s.t. \; D_j(p) &\geqslant 0, \; j \in \Im_f \\ p_j &\geqslant 0, \; j \in \Im_f \end{aligned}$$

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

[18] We have also experimented with product fixed-effects, with unsatisfactory results. This is likely to be due to the use of a single cross-sectional market, a relatively short sample period (6 model-years), frequent name changes in products and moderate product entry and exit.

[19] 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 consumers prefer Swedish and high-end German brands. French brands Renault, Peugeot and Citroen have intermediate estimates whereas brands such Daewoo, Dodge and Rover have the lowest brand estimates.

constraints for this program do not bind in equilibrium, as 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 simply 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 every product.

Estimates We adopt two estimates of marginal costs. The first one is obtained from backing-out marginal costs from the above system, as is standard in the literature. That is, we combine data on prices and product ownership with our demand estimates, so that the only unknown quantity in each of the J equations is exactly the marginal cost for product j. These terms are recovered under the maintained hypothesis of Bertrand-Nash conduct by solving the system for the vector of marginal costs.

The second one uses the backed-out marginal costs as dependent variables which are regressed on product characteristics and brand fixed-effects. Following BLP (1995), we adopt the following specification

$$ln(c_j) = w_j \gamma + \varpi_j$$

where the identifying assumption is that $E(\varpi_j | w_j, x_j) = 0$. In contrast with the demand system, this hedonic regression is essentially a reduced-form approximation to the cost structure of products in the industry.

5 Policy Experiments

5.1 Counterfactual: No Green Car Rebate

Setup We assess the impact of the GCR by computing the counterfactual of no rebate and comparing it to our benchmark results. We evaluate both environment- and market-related sides of the program. On the environmental side, we quantify CO2 emission savings induced by the program as well as their costs. To do this, we use data from the mandatory car inspections to estimate the mileage of cars, see Section 3 for details. Mileage estimates are then combined to car sales in the actual and counterfactual scenarios. The resulting difference in CO2 emissions is finally divided by the cost of the GCR.

On the market side we focus on market shares disaggregated by brand and fuel segments. That is, we are interested in how the GCR affected the different fuel segments, eg. low-emission regular vehicles, and the main brands operating in the Swedish market as well as the brands operating in each fuel segment. Following the literature we allow for carmakers to compete in prices. That is, although we also report perfect competition results for the sake of completeness we assume that carmaker's conduct is Bertrand-Nash – our estimates suggest that the differences as slight, consistent with findings in Adamou, Clerides and Zachariadis (2011) for the German market.[20]

While in the baseline specification we consider a situation in which FFV owners do not drive using gasoline, we later allow for the fact that FFVs allow their owners to arbitrage across fuels. That is, since FFVs can run on any combination of gasoline and ethanol and it is known that ethanol contains roughly 70 percent of the energy of gasoline, the no-arbitrage relation between gasoline and ethanol is $p_e \cong 0.7p_g$. Huse (2012) finds that fuel arbitrageurs are prevalent in Sweden, making roughly two-thirds of FFV owners. The consequence of fuel switching is that any savings in CO2 emissions should take fuel arbitrage into account. In what follows, we use the estimates in Huse (2012) to compute another estimate of the cost-effectiveness of the GCR.

CO2 Emission Savings Table 4 reports estimates CO2 savings based on the GCR and their associated costs. Panel A reports estimates of CO2 savings, measured in tons. At about 400 thousand tons, estimates differ marginally when considering Bertrand-Nash pricing (BNP) instead of perfect competition. They do, however, differ more substantially once fuel arbitrage by FFV owners is taken into account. This occurs because engines running on gasoline emit more CO2 than those running on ethanol (see Huse 2012 for details and an account of other pollutants). Accounting for fuel arbitrage results in a non-trivial increase in the cost of CO2 savings, especially when considering that FFVs make up a small proportion of the car fleet in Sweden. For instance, under BNP an overall increase from 0 to 25 percent in the use of gasoline results in a 6 percent decrease in the CO2 savings from 427.5 to roughly 402 thousand tons of CO2.

TABLE 4 ABOUT HERE

Panel B in Table 4 reports the associated costs of CO2 savings. As above, perfect competition and BNP yield similar estimates, with slightly lower values for the BNP estimates which, at 706 SEK corresponds to about USD 100. 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 Swedish market. In the case of BNP an overall increase from 0 to 25 percent in the use of gasoline results in an increase of about 8 percent 706 to 764 SEK – about USD 8 – in the cost of CO2 savings. When the overall use of gasoline increases to 55 percent, this cost increases some 20 percent to 846 SEK or $121 with respect to the case of no arbitrage.

Market Impact of the GCR We start by examining the effect of the GCR on the market shares of the different fuel segments. As reported in Panel A of Table 5, high-emission gasoline vehicles are the most affected by the GCR – they suffer increased competition from both low-emission gasoline

[20] Although it relies on a number of arguably heroic assumptions, the convenience of the perfect competition assumption lies on its ease of computation, since only the demand side of the model is needed. Moreover, while the assumption of flat vehicle supply curves is not realistic in the long run, it can be seen as a reasonable approximation to the short-run effects of the policy.

and diesel vehicles as well as (high-emission) FFVs. As a result, their market shares decrease by about 4.2 percentage points under BNP which are captured by the three fuel segments in similar magnitudes. The market share of high-emission diesel vehicles are also affected by the GCR, but to a lesser extent than their gasoline counterparts. Gasoline/electric and gasoline/CNG vehicles both command a low market share and are hardly affected by the program in absolute terms. All in all, green cars experienced an increase of 4.6 percentage points in the Swedish market which may be attributed to the GCR.

TABLE 5 ABOUT HERE

Panel B in Table 5 reports the effect of the GCR on brand-level market shares. The main players operating in the market are Volvo, Toyota, Peugeot, Volkswagen (VW) and Ford, all of which command a market share of more than 5 percent. Volvo, which has been the market leader in Sweden for decades, did not benefit from the GCR. In fact, our counterfactual exercise reports a 1.85 percent decrease in its market share due to the GCR, second only to Mercedes Benz. Other carmakers losing over 1 percentage point in market shares due to the program include Audi, Saab and BMW. The losses that these high-end carmakers suffered and are attributed to the GCR come from essentially two segments, namely low-emission regular vehicles and (high-emission) FFVs, besides low-end high-emission vehicles, as will be documented below. It is then no surprise that the main brands benefiting from the GCR are then the likes of Peugeot and Kia seen as value brands with a strong presence in the regular fuel market and VW, which has a strong presence in all segments, including the FFV one.

TABLE 6 ABOUT HERE

<to be completed> In Table 6 we examine brand-level market shares for the high-emission regular fuel segments. The main gainers from the GCR in the gasoline segment were value brands Skoda, Peugeot and Toyota. In fact, roughly one-third of Skoda's market share and one-fourth of Peugeot's one in this segment (1.32/3.94 and 1.08/3.97, respectively) can be attributed to the program. On the other hand, brands Volvo, Mercedes, BMW and Saab all suffered at the hands of their competitors following the rebate, which is found to be responsible for decreases of over 1 percentage point in their market shares. Value brands did also gain market share in the high-emission diesel segment, with brands Kia, Fiat and Peugeot facing increases of at least half a percentage point in their market shares and brands Toyota, Saab and Audi losing market share.

TABLE 7 ABOUT HERE

The estimates in Table 7 point to growth of over half a percentage point of Hyundai and Toyota in the low-emission gasoline and of Citroen in the low emission diesel segment. In the FFV segment Ford, the legacy player in the market was the main brand benefiting from the program with a 0.80 percentage point increase followed by far by VW, with a 0.43 percentage point increase.
of at least half a percentage point in their market shares and brands Toyota, Saab and Audi losing market share.

5.2 Counterfactual: Rebate for Low-emission Vehicles Only

Setup One controversial aspect of the GCR is the fact that alternative and regular green cars were treated asymmetrically. That is, while cars operating using regular (fossil) fuels were required to emit less than 120 gCO2/km to qualify for the rebate, those operating on alternative (renewable) fuels received a much more favorable treatment – see Section 2. In what follows we consider the counterfactual of a symmetric rebate on environmental and market variables.

One immediate effect of the asymmetric character of the GCR is that no FFV qualifies as a green car – as reported in Table 2, no single FFV emits less than 120 gCO2/km throughout our sample period. Had the GCR treated regular and alternative vehicles symmetrically, one would expect carmakers to bring to market a number of low-emission FFV models, but this is left for further research due to the complexity of such a model of firm behavior.

CO2 Emission Savings Table 8 reports cost estimates of CO2 savings achieved via a symmetric program contemplating only vehicles emitting no more than 120 gCO2/km. As before, estimates differ marginally when considering perfect competition and Bertrand-Nash pricing (BNP), with the latter estimating at 688 SEK the cost of each ton of CO2 saved, slightly less than USD 100. However, accounting for fuel arbitrage results in a sizable increase in the cost of CO2 savings, despite the small share of FFVs in the Swedish car fleet. In the case of BNP an overall increase from 0 to 25 percent in the use of gasoline results in an increase of about 8 percent from 688 to 746 SEK – about USD 8 – in the cost of CO2 savings. When the overall use of gasoline increases to 55 percent, this cost increases some 20 percent to 829 SEK (or USD 118) with respect to the case of no arbitrage.

TABLE 8 ABOUT HERE

When comparing the estimates in Tables 4 and 8, the difference between cost estimates is in the range USD 2.5-3 across the board. That is, the asymmetric program is some 2.5 percent more expensive than its symmetric counterpart. Although the difference may be arguably small, the asymmetric program does provide a transfer to consumers purchasing FFVs who may then arbitrage across fuels, that is potentially working against the very aims of the program.

Market Impact of the GCR When compared to the GCR, its symmetric counterpart tends to benefit high-emission diesel and especially gasoline vehicles, which suffer less competition from alternative vehicles, notably FFVs. As reported in Panel A of Table 9, high-emission gasoline and diesel vehicles command market shares of about 54 and 25 percent, respectively, compared to a lower 12 percent one for FFVs (from 14 percent in the original GCR, see Table 5). Surprisingly, low-emission gasoline vehicles would benefit from the asymmetric GCR, albeit by small amounts. Again, gasoline/electric and gasoline/CG vehicles command a small market share.

TABLE 9 ABOUT HERE

As above, Panel B in Table 9 reports market shares under the symmetric GCR and how they would change in comparison to the actual GCR. The main players in the market would hardly change in the symmetric case, although Volvo would command a 1.6 percentage point higher market share and both Peugeot and Toyota would command a lower one in the symmetric program. Brands Peugeot, Kia, VW and Skoda would benefit the most from the original GCR, with their market shares increasing by 1-2 percentage points.

TABLE 10 ABOUT HERE

Table 10 examines brand-level market shares for the high-emission regular fuel segments and how they would change as compared to the actual GCR. With the exception of Mercedes Benz, which appears with a 2.9 percent market share, the other main players in the gasoline segment are the same, although now Volvo surpasses Toyota as the segment leader. In the diesel segment, the main difference among the main players is that Toyota replaces Peugeot.

TABLE 11 ABOUT HERE

Table 11 reports what would happen to the fuel segments benefited by the original GCR had it treated fuels symmetrically. In the low-emission gasoline segment Toyota, Peugeot and Citroen would remain the main players, but Hyundai would lose a substantial share whereas in the diesel segment Citroen would be the one to lose out while VW and Audi's position would hardly change. In the FFV segment, Volvo and Saab would be essentially unaffected by the policy whereas VW and especially Ford would lose ground. Both carmakers have a broad product range and a well-established presence in the FFV segment which made them benefit from the program.

Concluding Remarks

This paper estimates a structural model of the Swedish car market to examine economic and environmental impacts of the Swedish green car rebate (GCR). We start by examining the market impact and the cost of CO2 emission savings by comparing the GCR with the counterfactual of no-GCR. Next, we explore the effects of the asymmetric treatment of regular (fossil-run) and alternative (renewable-run) fuel vehicles, a key feature of the GCR.

The costs of the program were substantial and comparable to those of recent US counterparts. We estimate the cost of CO2 emission savings over the lifetime of vehicles purchased via the GCR to be about USD 100/ton CO2, thus five times the price of an EU emission permit and at the lower end of estimates for the US. However, since FFVs, which enable their owners to choose the cheapest fuel between gasoline and ethanol, command a non-trivial market share of vehicles sold during the GCR, one has to account for fuel switching (or fuel arbitrage) by owners of FFVs. In fact, assuming owners of FFVs use gasoline 25 (55) percent of the time results in increases of CO2 emission savings to the order of 8 (20) percent.

The brands which benefited the most from the GCR were value brands such as Peugeot, Kia (both with gains of over 1 percentage points in quantity-based market shares) and Skoda, followed by VW (which has a broad product line), whereas the main losers were Swedish brands Saab and Volvo and high-end German carmakers Mercedes, Audi and BMW, all of which lost more than 1 percentage points in market shares. The loss in market shares by Swedish and German carmakers occurred mostly in the high-emission gasoline market segment, with low-emission gasoline, low-emission diesel and FFVs sharing the gains in roughly equal terms.

While removing the asymmetric character of the GCR would reduce the cost of CO2 emission savings by 2.5 percent (or USD 2.5-3/ton CO2 saved), such a program would benefit Swedish and high-end German brands while worsening the prospects of VW and Ford. The mechanism is simple, in that it would make FFVs less attractive than in the case of the asymmetric GCR. This can be also seen by the market shares commanded by FFVs under the asymmetric and symmetric versions of the GCR: while under the former their market shares would be as high as 14.05 percent, the counterfactual market shares of FFV under the latter would be 12.18 percent.

All in all, this paper provides two important take-aways. First, in markets with the presence of hybrids or – more generally – fuel competition, fuel switching – or fuel arbitrage – cannot be assumed away, as it may substantially increase the costs of policies. Second, and contrary to anecdotal evidence and political economy arguments, the program did neither protect nor benefit local brands Saab and Volvo.

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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: gasoline, gasoline for cars classified as green cars, diesel, diesel for cars classified as green cars, ethanol, gas and electric hybrids.

The original sales data has seven observations for each time period, region and model; one for each fuel type. A lot of the observations have a value of zero either because no cars were actually sold or because the model did not exist for that certain fuel type. We drop all the zero-observations regardless of reason.

Car characteristics, price and tax The characteristics data is on a more disaggregate level than the sales data, since it contains the characteristics by sub-models, e.g. there are 18 different Audi A3 gasoline versions. To be able to combine the characteristics data with the sales data, we have aggregated the characteristics over sub-models and the car characteristics over sub-models and time based on the baseline model, thus following the literature, e.g. BLP (1995). Both the price and the vehicle tax are kept on a yearly basis since we know the time for each car registered but not the model year. The reason for treating price and tax differently is that we found the car characteristics to vary significantly less between different model years, than was the case for price and tax. Price and tax are more related to the time of registration than to the specific year model purchased.

As a first step, we drop all sub-models that lack the main characteristics that we initially want to use in our model, namely price, tax, fuel consumption for mixed driving, carbon dioxide emission, kerb weight, number of doors, number of cylinders, cylinder volume and engine power. As a second step, we use the characteristics of the base model.

Combining sales data and characteristics When combining the sales data and the characteristics data, not all sales items found a match. For those who did not find a match, we searched the characteristics of other model groups with certain criteria, enhancing the criteria if still no match was found. First we checked for the same brand, same model and same fuel type but for the following year (since most year models are released in the prior fall); second we checked for the same brand and same fuel type for the same year; next for the same brand and same fuel type for the following year; and finally for the same fuel type the 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). To obtain our final complete set of data, we had to classify certain cars as green cars for the period prior the rebate. This was done by checking for all diesel cars with a particle filter and with a maximum carbon dioxide emission of 120 g/km and all gasoline cars with a maximum carbon dioxide emission of 120 g/km. Concerning the alternative fuel cars, (following the same definition as used for the rebate) all fall in the green car category except the electric hybrid cars from Lexus.

Fuel economy and emission data 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 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. In the calculations, we find some of the information we need to transform our gasoline based emission data into ethanol based emission data. Firstly, E85 consumption is approximately 35 percent higher than gasoline consumption, according to lab research performed on the most common car model. Secondly, carbon dioxide emissions for E85 are 688.3 g/l, regardless of whether it is 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 ($\frac{1.35 \times 688.3}{100}$). For winter months, the ethanol version used is E75, which has a higher consumption (approximately 45% higher). For these months, the carbon dioxide emmissions are multiplied by $\left(\frac{1.42 \times 688.3}{100}\right)$.

More on CO2 emissions Since our focus is on FFVs in, we describe our strategy for FFVs and gasoline-only cars. For the latter the procedure begins with a estimate of yearly mileage driven (in km), together with a measure of CO2 emissions in (g/km). For FFVs the estimates are more complex, since they depend not only on the relative emissions from using each fuel type, but also on how consumers use each fuel type. Following Huse (2012), we assume FFV owners are of one among three types: those who only use gasoline, those who only use ethanol, and those who engage in arbitrage between both fuels. We consider the the average of Scenarios 2 and 3 in that paper, which results in 15 percent of consumers purchasing only ethanol, 25 percent using only gasoline and 60 percent of arbitrageurs. Assuming that ethanol is cheaper than gasoline half of the time a FFV would have CO2 emissions equal to 55 percent of gasoline emissions ($= 25\% + 0.5 * 30\%$) and 45 percent of ethanol emissions. The paper also reports results considering only ethanol consumers and 25% of gasoline consumption.

The emission data for gas (also referred to as 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.

Mileage data The data on average distances covered are based on odometer readings from all cars inspected in Sweden and the data is collected by the Swedish Motor Vehicle Inspection Company during the yearly vehicle inspections. The data is divided into more fuel types than our data set which leads us to aggregate the data for gas cars. For gas we use the average of all different types of gas, when more than one type is available for a brand.

Potential market To go from observed quantities to observed market shares we need to define the size of the potential market for each region and time period. One way to obtain the potential market variables would be by estimating them, as suggested in Reiss and Wolak (2005). 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 (2005), this definition has some shortcomings. 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. It is however difficult to find data on the number of Swedish households divided by income. Therefore we define the market as the number of individuals (instead of households) in a region of or above the age of 20 with a yearly income of 200,000 SEK (about USD 27500) 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 Counterfactuals

<to be updated>

Impact of the rebate on aggregate sales When calculating the counterfactuals, we need an estimate 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 examine the effect of the rebate on aggregate sales by estimating the following equation:

$$\ln(sales_t) = \alpha + \phi GCR_t + z_t'\beta + v$$

where GCR represents the rebate dummy, z_t contains time fixed effects and potentially market characteristics such as the CPI and the Industrial production index by Statistics Sweden. The results are reported in Tables B1 and B2. No apparent effect of the rebate on aggregate sales is visible; we can thus use the actual market shares for the outside good when computing the counterfactuals.

TABLE B1 ABOUT HERE

TABLE B2 ABOUT HERE