THE
ECONOMIC
JOURNAL

The Economic Journal, **124** (*August*), F393–F419. Doi: 10.1111/ecoj.12060 © 2013 The Author(s). The Economic Journal © 2013 Royal Economic Society. Published by John Wiley & Sons, 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA.

THE MARKET IMPACT AND THE COST OF ENVIRONMENTAL POLICY: EVIDENCE FROM THE SWEDISH GREEN CAR REBATE*

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We quantify the effects of the Swedish Green Car Rebate (GCR), a programme to reduce oil dependence and greenhouse gas emissions in the automobile industry. We find the GCR increases the market shares of 'green cars' and its cost to be \$109/ton CO_2 saved, thus five times the price of an emission permit. Since the main green cars in Sweden are flexible-fuel vehicles (FFVs), which can switch between petrol (gasoline) and ethanol, we also account for fuel choice, which increases the cost of the programme. Finally, we show that consumers would have purchased FFVs regardless of the rebate provided by the GCR.

Road transportation is responsible for 20% of the CO_2 emissions generated by fuel consumption worldwide. With the growth of emerging economies, fuel demand for transportation needs is set to grow by 40% and the number of passenger cars worldwide is set to double to almost 1.7 billion by 2035 (IEA *et al.*, 2011*a*,*b*). Within the European Union, passenger cars are responsible for about 12% of the overall emissions. This share is a much higher 19% in Sweden, and close to the 20% estimated to hold for the US market, as the country has one of the most fuel-devouring car fleets on the continent. Reducing emissions from passenger cars is thus essential for Sweden to meet EU-wide environmental goals.[1] In practice – especially when petrol (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 *et al.*, 2007).

This article 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 CO_2 emissions savings, their costs (both total costs and cost per ton of saved CO_2) 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,

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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.

[1] The 1994 EEA Treaty originally set a target of 120 g CO_2/km by 2005 (later relaxed to 130 g CO_2/km by 2012) and aimed at cutting carbon emissions by 20% 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 CO_2 emissions; these are lower only than those of Estonia and Latvia (EFTE, 2009).

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 article also examines to which extent domestic carmakers benefited from its design, if at all.

0.1 *The Swedish Green Car Rebate*

The Swedish GCR is one among a number of policies designed to incentivise 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, 2011), the GCR was broad in that green cars commanded a 25% market share among newly registered cars already in 2008, as compared to the 2.15% commanded by hybrid electric vehicles (HEVs) in the US after a similar policy (Beresteanu and Li, 2011). 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 CO_2 emissions per unit of fuel consumption in road traffic are 20% below the world average due to the use of ethanol (IEA *et al.*, 2011*a*), 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 are able to operate on and on how much CO_2 it emits: while cars able to run only on regular (fossil) fuels (such as petrol and diesel) were considered green cars provided they emitted no more than 120 g CO_2/km, those able to run on alternative fuels (ethanol,

[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 nine million, some 120,000 are employed by the automobile industry, which is responsible for over 10% 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 programmes 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% 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 seven unless mentioned otherwise.

[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 programmes, 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.

electricity and gas – which we call CNG hereafter) were given a more lenient treatment roughly equivalent to 220 g CO_2/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, which seamlessly operate using any combination of ethanol and petrol. While the first FFV dates back to the early 1900s – the Ford Model T was able to operate on petrol, kerosene and ethanol – it was only in the 1980s that vehicles able to operate using renewable fuels took centre 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.

0.2 *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 CO_2 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 us to evaluate the role of the skew towards renewables and how the programme 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 g CO_2/km be classified as green cars and thus qualify for the rebate. Finally, we examine what would have happened had all carmakers decided to turn their captive petrol cars into FFVs to benefit from the programme. 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 petrol vehicles in favour of FFVs. Since the FFV technology piggybacks on the petrol one, and the estimated cost to turn a captive petrol 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.

[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% shortfall in ethanol supplies expected for early 1990.

0.3 *Main Findings*

On the environmental front, the results indicate that the GCR resulted in a decrease in lifetime CO_2 emissions of about 493,200 ton CO_2 for the vehicles sold during the period in which the policy was in place. This implies a cost of 760 SEK/ton CO_2 (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 *et al.* (2013) for the US market.[8]

Accounting for the fact that a substantial share of FFV owners switches to the cheapest between petrol and ethanol results in non-trivial cost increases. For instance, if petrol usage among FFV owners is 50%, CO_2 savings decrease by 14% and their costs by 16% as compared to the benchmark, reaching 883 SEK or \$126. That is, the FFV technology makes fuel choice an additional dimension regulators and have to take into account when designing policy.

Removing the asymmetry of the GCR would result in lower CO_2 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 petrol models with FFVs, CO_2 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 programme very expensive also in relative terms, for example, if 50% of FFV owners arbitrage across fuels, the cost of the programme would be 36% above those of the actual GCR.

On the market front, the first counterfactual highlights that high-emission vehicles, especially those running on petrol, 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 petrol segment.[9]

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

[8] These figures can be compared to the cost of similar programmes 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/ton CO_2 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 ton CO_2 (Aldy *et al.*, 2010). In Sweden, policymakers distinguish between traded and non-traded goods; thus, they price CO_2 emissions from fuel at 1060 SEK/ton CO_2, see Mandell (2008) for a discussion. (We thank Jan-Eric Nilsson for bringing up this point.)

[9] In Sweden, Huse and Koptyug (2013) document that the 2007–8 market shares of Volvo and Saab decreased from 17.42% to 12.44% and from 4.11% to 3.74%, respectively, despite the GCR. Since the GCR is not statistically significant at explaining total sales in the Swedish market (see the online Appendices for details), this suggests that both carmakers did lose ground in the Swedish market during the period.

points (from 14.1% to 13.7%) 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 petrol vehicles.

0.4 *Contribution and Related Literature*

We contribute to the burgeoning literature on the impact of policies targeted on the transport sector, notably the car market, to promote the adoption of fuel-efficient technologies. To our knowledge, this is the first attempt to investigate structurally 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 *et al.* (2010) and Beresteanu and Li (2011), which look at policies designed to promote the adoption of HEVs in Canada and the US, respectively, both of which are close in spirit to the GCR. Typically, the literature documents that although these programmes 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 programmes typically target a small share of the market. More generally, the article relates to early work by Berry *et al.* (1996) quantifying the impact of policy and environmental changes on the US car market.

The article also relates to the literature focusing on the cost of (environmental) regulation. For instance, Gollop and Roberts (1983) estimate the economic costs of sulphur dioxide (SO_2) regulation in the US utility sector during the 1970s, whereas Ryan (2012) estimates the cost of the 1990 Clean Air Act Amendments in the Portland cement industry.

The focus on alternative fuels connects the study 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 fuelling infrastructure available for alternative fuels. As opposed to what happens in markets such as the US, Sweden has a well-developed network of fuelling stations where ethanol is readily available. Thus, the majority of FFV owners tends to react to fuel prices, effectively arbitraging across fuels (petrol and ethanol) making fuel choice another dimension policymakers should take into account when designing policies (Anderson, 2012; Salvo and Huse, forthcoming).

[10] The most conservative estimate among the above papers, by Li *et al.* (2009), is that the ton of CO_2 saved cost $91. At the other end of the spectrum, Metcalf (2008) estimates this cost to be $1,700 for the US ethanol programme.

1. 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 EU 18 countries (the original EU 15 countries plus Hungary, Lithuania and Slovenia), Sweden consistently appeared at the bottom of the CO_2 emissions ranking for years 2006–8 (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% as of 2008 (ACEA, 2010).

1.1 *The Green Car Rebate*

The Swedish 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 $1,500 using the average SEK/$ 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, that is, 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,

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 petrol and diesel (2008)	3.8	0	0.9
Share of cars ≤ 5 years (2008)	29.00%	33.40%	34.30%
Share of cars 5–10 years (2008)	31.90%	33.00%	33.00%
Share of cars >10 years (2008)	39.10%	33.60%	33.60%

Notes. This Table is constructed using data from ACEA (2010). Engine sizes are reported in cc (cubic centimetres).

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

2007). Cars are divided into two categories: regular and alternative-fuelled cars. Cars running on fossil fuels (or regular fuels) qualify as green cars if their CO_2 emissions are no greater than 120 g/km.[12,13] Cars able to run on fuels other than petrol and diesel (or alternative fuels) qualify as green cars if their consumption is lower than the equivalent of 9.2 l/100 km using petrol or 9.7 m^3/100 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 g CO_2/km running on petrol.[14]

1.2 *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 g CO_2/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.

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

Table 2 also reports that, starting from two 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 one in 2004 to three in 2007, 10 in 2008 and 12 in 2009. Interestingly, no FFV emits less than 120 g CO_2/km. The effect of the GCR on the number of brands and models offering CNG and electric-based vehicles (which we refer to as petrol/CNG and petrol/electric vehicles respectively) was much less dramatic – in the case of the former, this can be explained

[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 g CO_2/mile, this emission threshold is already more stringent than the 250 g CO_2/mile CAFE standard to take effect from 2016 in the US.

[13] Emissions of 120 g CO_2/km correspond to fuel consumption of about 5 l of petrol or 4.5 l 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 (g CO_2/km and l/100 km), the CO_2 emissions and fuel efficiency measures are nearly equivalent; for vehicles marketed in Sweden, the correlation between CO_2 emissions and mpg is −0.90, and the threshold for alternative fuels is equivalent to about 220 g CO_2/km (for perspective, the 2012 Porsche 911 Carrera emits 205 g CO_2/km). See Anderson *et al.* (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 one mile equals 1.609 km and one gallon equals 3.78 l; 9.2 l/100 km corresponds to 10.87 kpl or 25.54 mpg.

Table 2

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

		CO_2 Emissions (g CO_2/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
	No. of brands	37	40	40	45	44	40
	No. of models	1854	1920	2101	1624	1946	2026
Total ≤ 120 g	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
	No. of brands	8	8	10	13	17	22
	No. of models	*20*	*21*	*40*	*46*	*69*	*89*
Petrol	Mean	218	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
	No. of brands	37	40	40	45	43	39
	No. of models	1398	1417	1473	1081	1225	1195
Petrol ≤ 120 g	Mean	116.3	115.3	112.1	111.1	112.1	113.1
	SE (mean)	0.8	0.8	0.9	1	0.9	1
	Median	116	116	111	109	109	112
	1Q–3Q	113–119	113–116	109–116	109–113	109–116	109–119
	No. of brands	3	2	4	5	7	12
	No. of models	10	8	14	10	18	36
Diesel	Mean	188.8	188.1	183	172.3	174.8	168.4
	SE (mean)	2.1	2	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
	No. of brands	28	28	31	32	34	35
	No. of models	442	491	596	513	667	748

Table 2
(*Continued*)

Fuel		CO2 Emissions (g CO2/km) 2004	2005	2006	2007	2008	2009
Diesel ≤ 120 g	Mean	97.1	101.3	114.8	115.8	114.4	115.2
	SE (mean)	1	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
	No. of brands	5	6	6	11	14	19
	No. of models	9	12	23	33	48	51
FFV	Mean	165	198	185.4	184.4	194.2	195.1
	SE (mean)	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
	No. of brands	*1*	*3*	*3*	*3*	*10*	*12*
	No. of models	*2*	*11*	*17*	*18*	*44*	*66*
FFV ≤ 120 g	No. of models	*0*	*0*	*0*	*0*	*0*	*0*
Petrol/CNG	Mean	199.5	198	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
	No. of brands	5	5	5	5	4	3
	No. of models	11	11	11	8	5	11
Petrol/Electric	Mean	104	104	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
	No. of brands	1	1	3	3	3	3
	No. of models	1	1	4	4	5	6

Notes. This Table reports sample statistics of the distribution of engine CO_2 emissions (measured in g CO_2/km, running on petrol or diesel) disaggregated by fuel and the number of brands and car models present in each fuel segment. Figures in italics highlight the number of green car models (both regular and alternative), and the number of FFV models over time – in particular, note the growth in the number of models in the FFV segment and how no FFV model emits 120g CO2 or less.

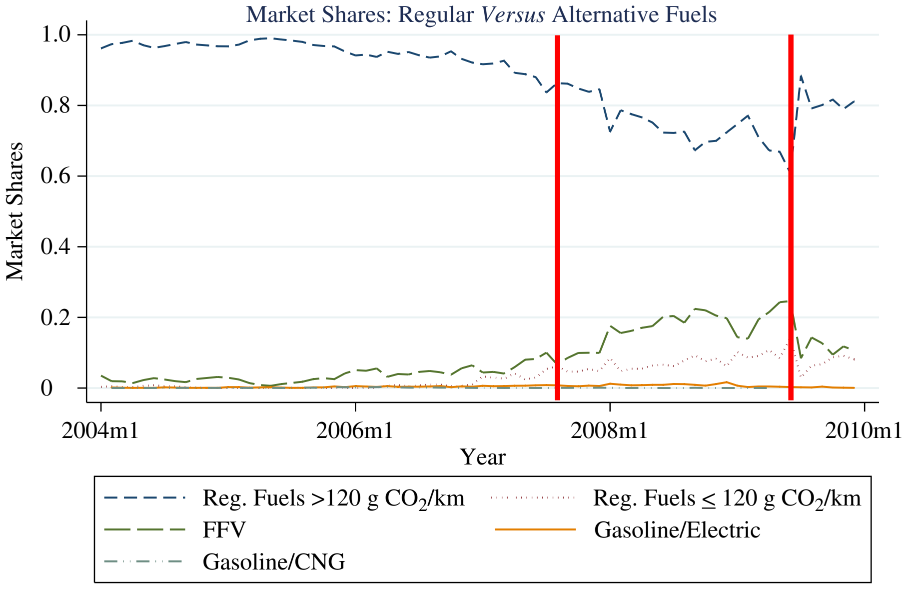


Fig. 1. *Market Shares by Fuel Segment*

Notes. 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 g CO_2/km. Vehicles able to run on alternative fuels are split into FFVs (petrol/ethanol or FFVs), petrol/CNG and petrol/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 petrol/CNG and petrol/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.

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.

FFVs were the main gainers following the GCR reaching about 15% of registrations in 2008, while CNG and electric vehicles never commanded more than 1% 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% in 2008 down from a 94.7% in 2006. Although low-emission regular vehicles also gained market share, this was much lower than the gain experienced by FFVs.

1.3. *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]

2. Data

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

2.1. *Car Registrations*

Car registration data are from Vroom, a consulting firm. The data on privately owned vehicles (i.e. those eligible for the rebate) are recorded at the monthly frequency from January 2004 to December 2009. An observation is a combination of month, brand, model and fuel type.

2.2. *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), CO_2 emissions (measured in g CO_2/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.

2.3. *Fuel Data*

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

2.4. *Mileage Data*

We use administrative data from the Swedish Motor Vehicle Inspection Company (*Bilprövningen*) on yearly average distances covered by Swedish passenger cars. For

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

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]

2.5. *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, that is, 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.

3. Estimation

3.1. *Demand*

3.1.1. *Model specification*

We estimate the demand for cars using discrete choice models for market level data, following Berry *et al.* (1995). The starting point is a microeconomic model of rational behaviour 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, that is, prices, quantities and a set of characteristics for each of the J products available on the market for a number of periods (we suppress the index t below to avoid clutter). These 'inside' products are indexed by $j = 1,\ldots, J$, 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

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

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). 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, $(v_{1i},\ldots,v_{Ki})' \sim \mathcal{N}(\mathbf{0},\boldsymbol{\Sigma})$, 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

[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 utilisation as in, for example, Goldberg (1998).

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 modelling of these markets. Cars are moreover durable products, so current ownership of a car is likely to affect the current demand for cars. 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 modelling approximation to actual consumer choice behaviour in the industry.

3.1.2. *Identification*

Besides the exogenous characteristics, we use the set of 'BST instruments', following Bresnahan *et al.* (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 localised competition among products, and this seems consistent with anecdotal evidence for the automobile industry, characterised by a number of market niches and highly differentiated products.

3.1.3. *Estimates*

We consider demand specifications with the following characteristics: engine power (measured in horsepower, HP), engine size (measured in cubic centimetres, CC), fuel consumption (l/100 km, under mixed driving), vehicle tax and price. We also include time (month), brand, market segment, fuel segment (petrol with emissions above and below 120 g CO_2/km, diesel with emissions above and below 120 g CO_2/km, FFV, petrol/electric and petrol/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 online Appendices list a number of alternative specifications also experimented with.)

We report alternative demand estimates in Table 3. Specification 1 (OLS) reports the estimates obtained when price is assumed to be exogenous, that is, 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 Bresnahan *et al.* (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

[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
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)
$\beta_{RoadTax}$	−0.0003***	−0.0004***	−0.0003***
	(0.00)	(0.00)	(0.00)
$\beta_{FuelConsumption}$	−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	13,962	13,962	13,962
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

Notes. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The value of the F-statistic of the first-stage regression is 31.48. With 5 and 13,484 degrees of freedom, it is significant at the 1% level.

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-maximising firms.

Accounting for price endogeneity as in Specification 2 results in a steeper demand curve, in that the estimated price coefficient increases 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 threefold. Finally, CC has a positive and significant estimate, suggesting that consumers favour 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 mark-ups in the range 19–40% 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.

3.2. *Supply*

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

$$\max_{\{p_j|j\in\Im_f\}} \sum_{j\in\Im_f} (p_j - c_j)D_j(p), \tag{2}$$

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 programme do not bind in equilibrium, as is typically assumed in the empirical literature), the first-order conditions are given by the following:

$$D_k(p) + \sum_{j\in\Im_f} \frac{\partial D_j(p)}{\partial p_k}(p_j - c_j) = 0. \tag{3}$$

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 $J \times J$ and typical element

[18] It is worth stressing that we use fuel in consumption (in l/100 km) as opposed to monetary measures, for example, miles per dollar as in Berry *et al.* (1995), 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 petrol and ethanol, for example, whether they arbitrage across fuels.

[19] Although one could argue that the decision-makers are the conglomerates rather than the firms/brands, that is, 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.

$$\Delta_{jk} = 1\{\text{both } j \text{ and } k \text{ produced by the same firm}, j, k = 1, \ldots, J\}, \quad (4)$$

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

$$D_k(p) + \sum_{j=1}^{J} \Delta_{jk} \frac{\partial D_j(p)}{\partial p_k}(p_j - c_j) = 0, \quad k = 1, \ldots, J. \quad (5)$$

The (implicit) solution to this set of equations, $p^{NE} = (p_1^{NE}, \ldots, p_J^{NE})$, provides the prices at which each firm is maximising 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 online Appendices for details.)

4. Policy Experiments

4.1. *Overview*

In what follows, we consider three counterfactuals. Counterfactual I (no GCR) compares the actual GCR and the counterfactual of no policy. This allows us to quantify the overall effects of the programme on both the environment and the market fronts.

Counterfactual II (symmetric GCR) considers the effects of a common threshold of 120 g CO_2/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 g CO_2/km (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 petrol 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 petrol vehicles in favour of FFVs. That is, conditional on buying, for example, 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 petrol car into a FFV is \$100–200 (thus less significant than those in e.g. Berry *et al.*, 1996). This scenario thus stresses a potentially perverse effect of the programme, whereby 'too many FFVs' would qualify for the rebate and increase the total cost of the programme, without necessarily using ethanol.[21]

[20] Although in this scenario, one would expect carmakers to bring a number of low-emission FFV models to market eventually, we follow the bulk of the literature since at least Pakes *et al.* (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% and the sales of FFVs in the 400,000-strong Swedish market amount to less than 80,000 units. For perspective, Hall (2000) finds a minimum efficient scale of about 130,000 units/year for automobile plants in the North American market.

We assess the above counterfactuals on both environmental and market aspects, namely, CO_2 emission savings and their associated costs (in SEK/ton CO_2 saved); Market shares by fuel segment; 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 Klier and Linn (2012) for a study in such a direction.

To calculate CO_2 emission savings, we combine mileage estimates and fuel economy data with car sales in every scenario considered, with details presented in the online Appendices. The resulting CO_2 emissions are then divided by the total cost of the GCR to obtain the cost of CO_2 savings.

While the baseline specification in each experiment considers a situation in which FFV owners do not drive using petrol, we 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 petrol emits more CO_2 than ethanol, fuel switching increases the cost of CO_2 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 petrol usage by FFV owners), we also report results for 25%, 50% and 75% of petrol usage to gauge the cost-effectiveness of the programme.

4.2. *Environmental Effects*

4.2.1. *CO_2 savings and their costs*

Table 4 reports estimated CO_2 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 CO_2 emission savings induced by the GCR are 493,200 ton CO_2, as reported in panel (*a*). Note, however, that the savings decrease once fuel switching is accounted for, that is, CO_2 savings fall by 14% and 18% to 424.6 and 406.7 thousand ton CO_2 if petrol usage increases to 50% and 75% respectively.

Lower CO_2 savings imply an increased cost per ton CO_2 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/ton CO_2, or \$109, accounting for fuel arbitrage results in a sizable increase in the cost of CO_2 savings, even though FFVs command a relatively small share of the market: while an increase from zero to 25% in the use of petrol results in an increase of about 12% (about \$13) to 850 SEK/ton CO_2, the cost can increase by 21% to 921 SEK (about \$132) if petrol usage increases to 75%.

[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%. Huse (2012) documents how the drop in oil prices following the 2008 recession, which was quickly passed through to domestic fuel prices, effectively making petrol cheaper than ethanol in energy-adjusted terms, led to a drop of 73% in the monthly sales of ethanol and proposes a stylised structural model whereby the share of fuel switchers (arbitrageurs) among FFV owners is in the range 46–77%.

[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, for example, Beresteanu and Li (2011), the results in online Appendix B show that these results are qualitatively unchanged under an assumption of 25-year vehicle lifetime.

Table 4

CO_2 Savings and Costs of Alternative Policies

	CF I No GCR	CF II Symmetric GCR	CF III Full FFV adoption
(*a*): CO_2 savings (thousands ton CO_2)			
Petrol usage			
0%	493.2	193.8	3,159.80
25%	441	192.5	1,878.60
50%	424.6	192.1	1,474.00
75%	406.7	191.6	1,035.60
(*b*): Cost of CO_2 savings (SEK/ton CO_2 saved)			
Petrol usage			
0%	760	465	558
25%	850	468	939
50%	883	469	1197
75%	921	470	1704
(*c*): Total cost of programme as a percentage of the GCR			
Percentage	–	24	470.9

Notes. This Table reports the total cost of the programme in each scenario in panel (*a*), lifetime savings in tons of CO_2 emissions induced by the different counterfactuals in panel (*b*) and their associated costs in SEK/ton CO_2 in panel (*c*). Results are reported for the assumption of Bertrand–Nash pricing as well as different levels of petrol usage among FFV owners to illustrate the impact of fuel arbitrage on the programme. All computations assume the lifetime of a vehicle to be 15 years. See online Appendix A for details on the assumptions on petrol usage; online Appendix B for a robustness check using a 25-year lifetime assumption; and online Appendix C for mileage regression results.

Counterfactual II computes CO_2 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, that is, cost and savings are flat across different levels of petrol usage. Note also that CO_2 savings are lower than those in the actual GCR: in the absence of fuel switching, these savings are 193,800 ton CO_2, whereas 50% of petrol usage induces savings of 192,100 ton CO_2. Not making FFVs eligible for the rebate results in a total cost of just 24% of the actual GCR.

Due to the strong presence of FFVs, Counterfactual III results in substantial CO_2 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 3,159,800 ton CO_2, whereas a 50% of petrol usage results in savings of a still sizable 1,474,000 ton CO_2. Although at 470.9% of the cost of the actual GCR the total cost of the programme is substantial, at 558 SEK/ton CO_2 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, and this cost increases to 1,197 and 1,704 SEK under 50% and 75% of petrol usage respectively.

The results in Table 4 show that, without accounting for fuel arbitrage, at about $109 the cost estimates of the programme are comparable to the lower end of the estimates of Li *et al.* (2013) for the US, which are in the range $91–288, and roughly 40% lower than those of Beresteanu and Li (2011) for the US HEV programme. However, these costs increase to about $126 ($132) if 50% (75%) of FFV owners arbitrage across fuels.

A symmetric version of the GCR results in both lower CO_2 savings and lower costs per ton CO_2 saved. The extent to which such a programme 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 CO_2 savings as compared to the GCR benchmark but also substantial cost increases per ton CO_2 saved once fuel arbitrage is accounted for.

4.3. *Market Effects*

4.3.1. *Fuel segment market shares*

Figure 2(*a*) reports market shares of the different fuel segments under the GCR, that is, the actual policy. High-emission petrol vehicles command 50.7% of the market, well ahead of high-emission diesel ones, with 24.7%.[24] Among the fuel segments benefiting from the GCR, the leading one is the FFV, which commands 14.1%, followed by low-emission petrol and diesel, with 6.68% and 3.61% respectively. petrol/electric and petrol/CNG vehicles both command less than 1% of the market and face negligible changes across counterfactuals.

Figure 2(*b*) 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 petrol 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 petrol than high-emission diesel vehicles: the FFV technology essentially piggybacks on the Otto cycle technology used by petrol vehicles. On the other hand, abolishing the GCR would adversely affect the market shares of FFVs and low-emission vehicles (both petrol and diesel), with decreases of 1.95, 1.91 and 1.64 pp respectively. Equivalently, the GCR shifted demand from high-emission vehicles – especially petrol ones – to FFVs and low-emission ones, precisely the segments favoured by the GCR.

Figure 2(*c*) 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 0.589 pp for petrol and diesel vehicles respectively. The main feature of Figure 2(*c*) 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 (2012) for such an analysis at the micro level. As for high-emission petrol and diesel, their market shares decreased by 1.3 and 0.521 pp respectively.

Had carmakers decided to replace all their captive petrol models with FFV versions, the dominant fuel segment would be high-emission FFVs, which would command a 65.1% market share, as shown in Figure 2(*d*).[25] High-emission diesel vehicles would

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

[25] Note that Figure 2*(d)* 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.

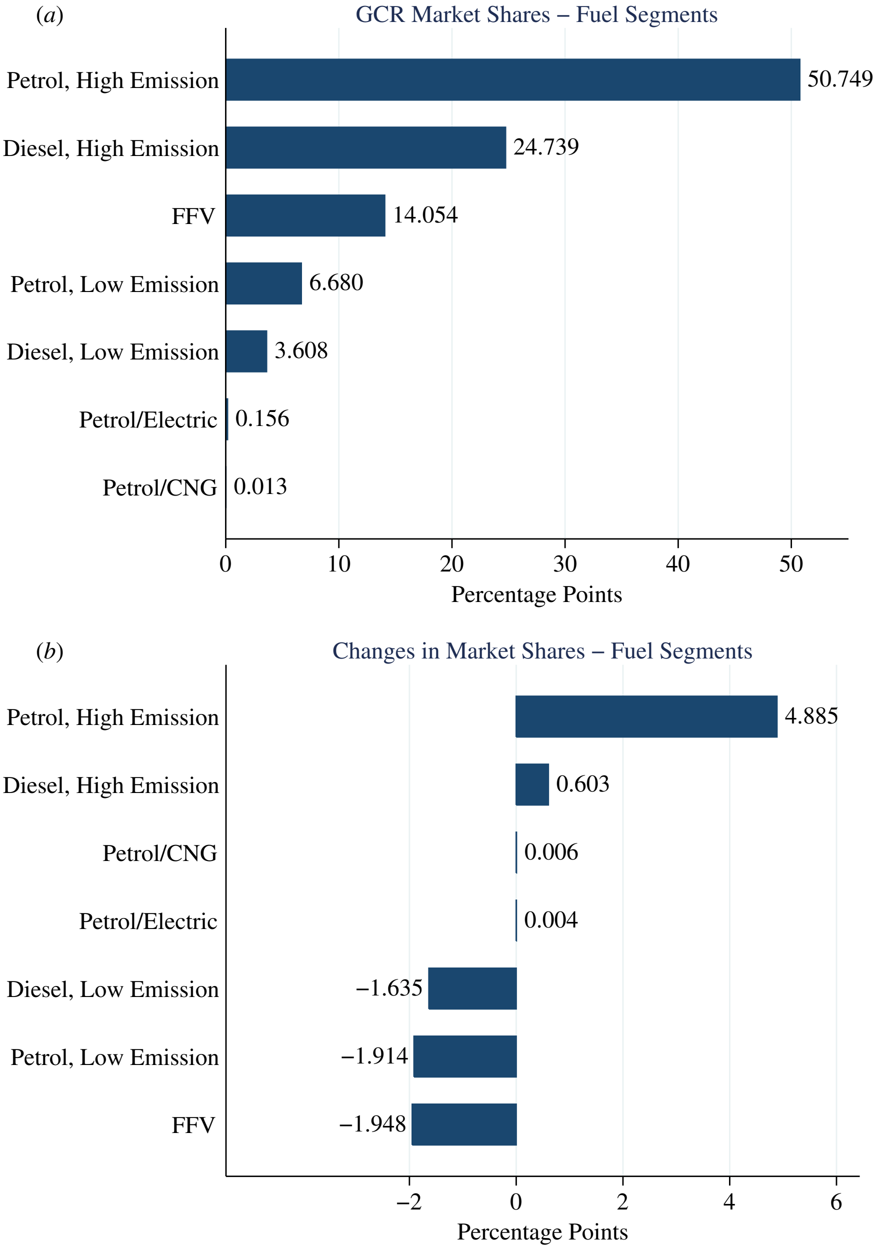
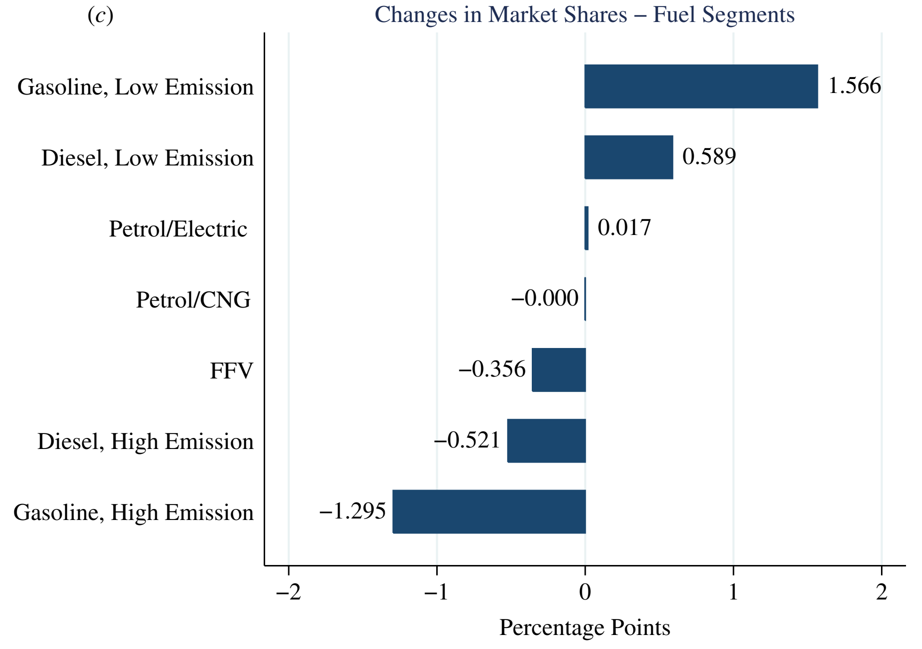


Fig. 2. *Effects of Alternative Policies on Fuel Segment Market Shares*

Notes. This Figure displays market shares under the GCR and changes in market shares at the fuel segment induced by alternative policies. (*a*) Market shares under the GCR (actual policy); (*b*) changes in market shares under the counterfactual of no policy (i.e. no GCR) as compared to the GCR; (*c*) changes in market shares under the counterfactual of a symmetric GCR as compared to the GCR; (*d*) market shares (instead of changes thereof) had all carmakers replaced their captive petrol 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.



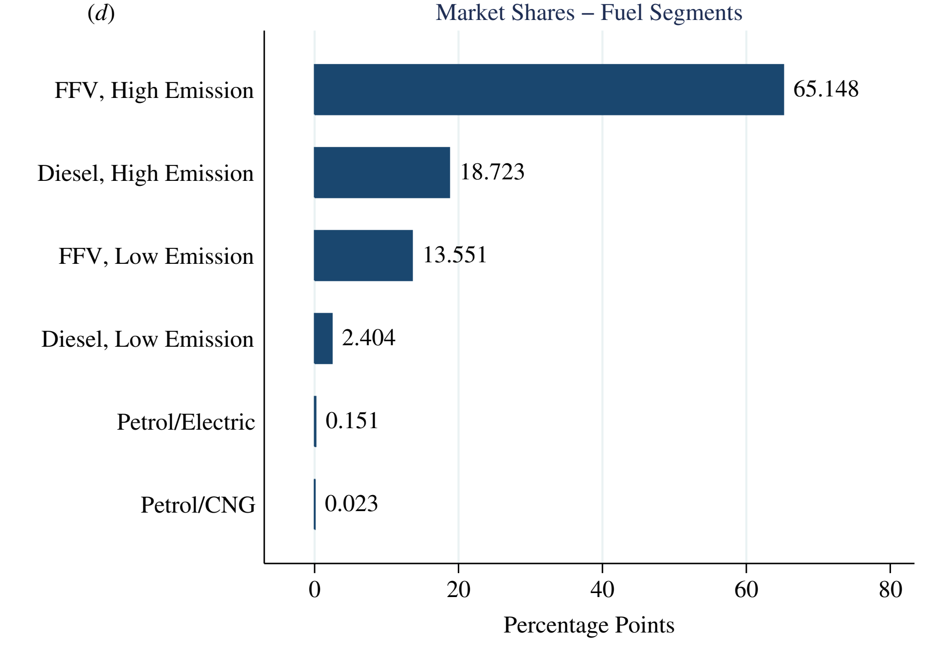


Fig. 2. *(Continued)*

lose 6 pp and command a 18.7% market share, followed by low-emission FFVs, with 13.6%, and low-emission diesel vehicles, with 2.4%. While high-emission FFVs would essentially absorb the market shares of high-emission petrol 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 7 pp above the market share of low-emission petrol 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 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, that is, 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.

4.3.2. *Brand market shares*

Figure 3(*a*) reports the effect of the GCR on brand-level market shares.[26] The main players operating in the Swedish market are Volvo (15.9% market share), Toyota (10.1%), Peugeot (8.34%) and Volkswagen (VW, 6.5%), with brands Ford, Hyundai, Skoda, Citroen and Audi also commanding market shares above 3%. 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 (Huse and Koptyug, 2013).

Figure 3(*b*), 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 2.5 pp increase in market shares, followed by Volvo (2.28 pp), Audi (1.62 pp), BMW (1.26 pp) and Saab (1.24 pp). Swedish and high-end German brands are close competitors in the Swedish market, having a marked presence in the high-end petrol segment. It then comes as no surprise 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 1.0–2.19 pp under the counterfactual of no GCR. As we detail below, these are brands typically offering the low-end models within the high-emission (petrol or diesel) fuel segments.

Figure 3(*c*) 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(*d*) shows the effects of the full conversion to the FFV technology by all carmakers. The main gainer is Toyota (2.57 pp), which is followed by high-end German brands Mercedes, Audi and BMW (1.92, 0.957 and 0.821 pp respectively) and Swedish brand Saab (1.15 pp). Except for Toyota, these are among the brands most affected by

[26] Given the large number of brands operating in the Swedish market, for the sake of clarity we omit from Figure 3 and the Figures in the online Appendices those brands with the smallest market shares or with the smallest changes in market shares in the counterfactuals. The full set of results is available from the authors upon request, or from the replication files available at the Economic Journal webpage.

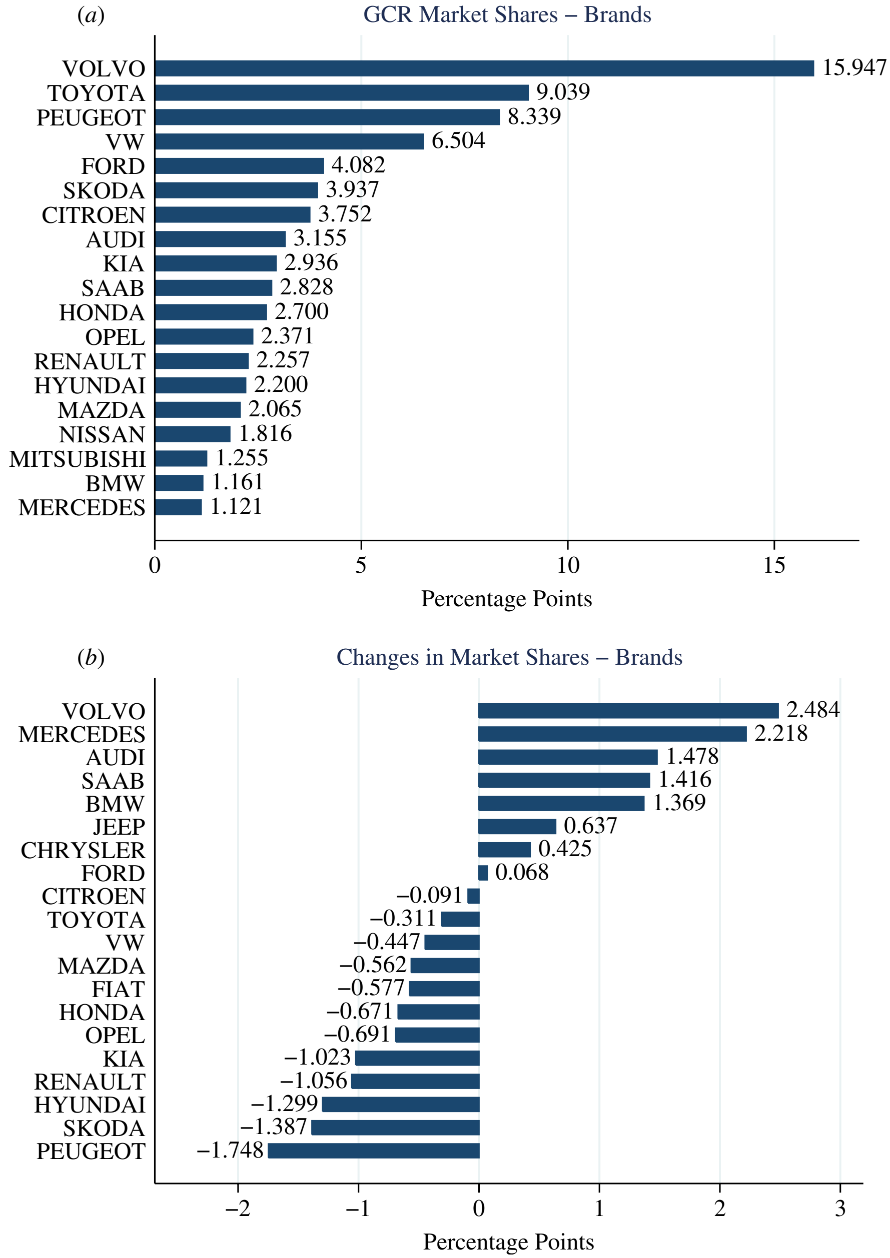
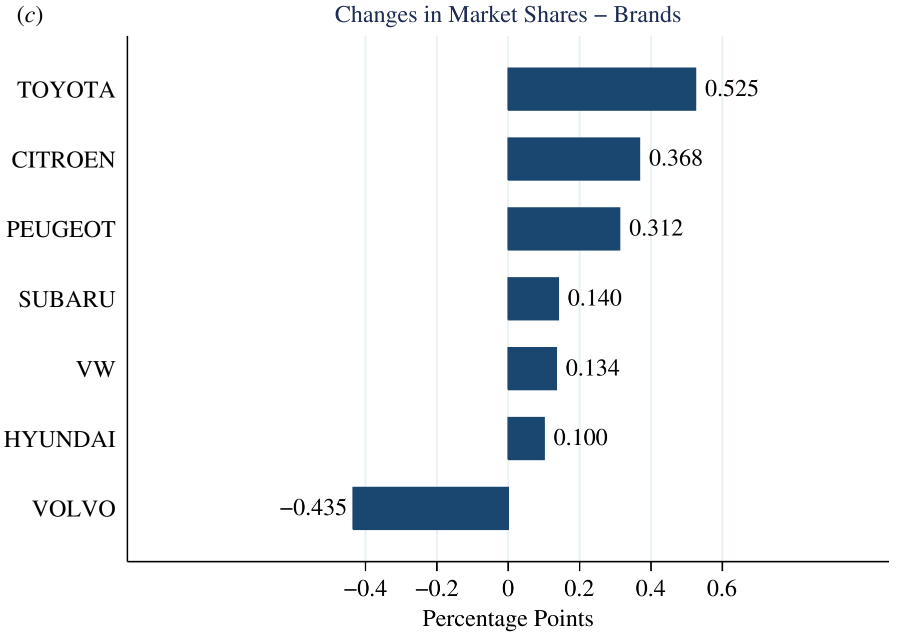


Fig. 3. *Effects of Alternative Policies on Brand Market Shares*

Notes. This Figure displays brand market shares under the GCR and changes in market shares induced by alternative policies. (*a*) Market shares under the GCR (actual policy); (*b*) changes in market shares under the counterfactual of no policy (i.e. no GCR) as compared to the GCR; (*c*) changes in market shares under the counterfactual of a symmetric GCR as compared to the GCR; (*d*) changes in market shares had all carmakers replaced their captive petrol 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.



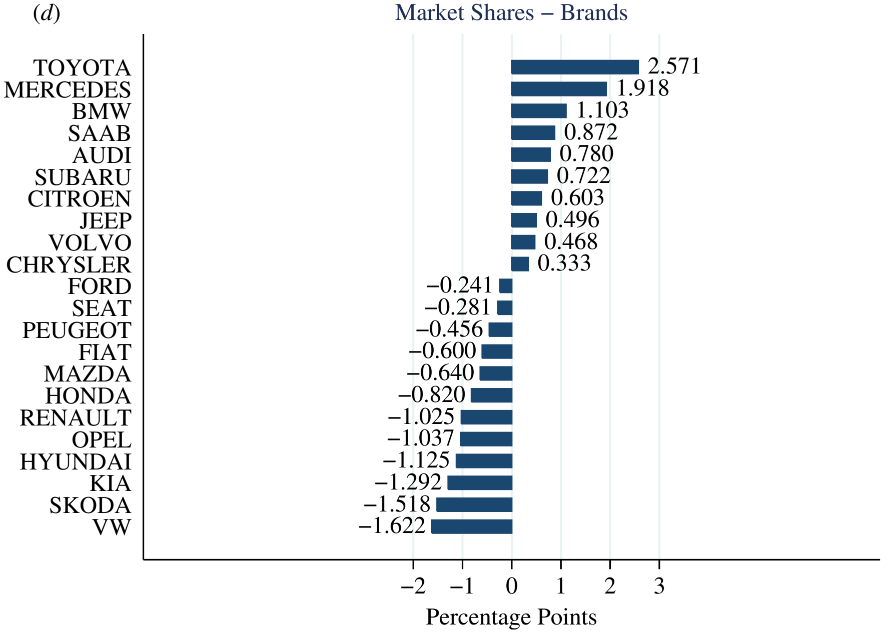


Fig. 3. *(Continued)*

the GCR, whose high-emission petrol vehicles would become FFVs and recover market share. Importantly, Volvo would experience a mild increase of less than 0.5 pp 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 1.1–1.6 pp. 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 petrol models to the FFV technology.

5. Conclusion

This article estimates a structural model of the Swedish car market to examine environmental and market effects of the Swedish GCR. its findings can be summarised as follows. First, the cost of the programme was comparable to those of recent US counterparts, with an estimated cost of CO_2 emission savings to be in the range \$109–132/ton CO_2. 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 programme 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 petrol 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 another way, the FFV technology would not need to be subsidised 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 programme 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 petrol cars to the FFV technology, the cost of the GCR would have increased by a fivefold, but without obvious improvements in terms of CO_2 savings or costs thereof.

In assessing a unique policy skewed towards 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, for example, hybrid, multifuel, are brought to market in the coming years.

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Submitted: 23 January 2013
Accepted: 12 April 2013

Additional Supporting Information may be found in the online version of this article:

Appendix A. Data.
Appendix B. Mileage Regressions.
Appendix C. Counterfactuals.
Appendix D. Alternative Demand Specifications.
Appendix E. Brand Market Shares Within Fuel Segments.

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