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Green drivers or free riders? An analysis of tax rebates for hybrid vehicles

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ABSTRACT

We estimate the effect of tax rebates offered by Canadian Provinces on the sales of hybrid electric vehicles. We find that these rebates led to a large increase in the market share of hybrid vehicles. In particular, we estimate that 26% of the hybrid vehicles sold during the rebate programs can be attributed to the rebate, and that intermediate cars, intermediate SUVs and some high performance compact cars were crowded out as a result. However, this implies that the rebate programs also subsidized many consumers who would have bought either hybrid vehicles or other fuel-efficient vehicles in any case. Consequently, the average cost of reducing carbon emissions from these programs is estimated to be $195 per tonne.

1. Introduction

Concerns over global warming and energy security have led governments in Canada and the United States of America to introduce incentives encouraging the sale of hybrid electric vehicles (HEV's). In the year 2000, the province of British Columbia was the first in Canada to offer a provincial sales tax rebate on HEV's. By 2006, five other provinces (of a total of 10) had implemented similar sales tax or cash rebates. In 2007, the Canadian federal government announced a two year eco-auto program encouraging the sales of fuel efficient and alternative fuel cars through cash rebates.

The US federal government introduced personal income tax credits for HEV's in the year 2005 and by the year 2007, 13 state governments had implemented tax incentives for their purchase. Additionally in the USA, several state and local governments offer benefits such as unrestricted access to high occupancy lanes, free parking, reduced registration fees and exemptions from emission testing. This widespread support indicates that North American governments believe hybrid technology to be an important component in their efforts to reduce fuel use in transportation.

In this paper we evaluate the cost-effectiveness of Canada's provincial rebates for purchasing HEV's. We estimate the impact of the rebate on the sales of HEV's and competing vehicles in the new car market. We then combine these estimates with information on the fuel economy of various car models, and average kilometers driven to calculate a cost per tonne of carbon dioxide saved through these programs.

Provincial rebates for HEV purchases in Canada provide an excellent opportunity for such an analysis. Provincial governments began offering rebates of different values at different times, and often varied the value of the rebate offered

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during the period we analyze. In addition, as most rebates are a reduction or a waiver of the provincial sales tax, they also vary across HEV models within a given year.

By using Canadian data we are able to isolate the impact of such rebates more easily than if we used data from the US. This is due to two main reasons. First, US federal rebates and some state rebates depend on income; thus, estimating the effect and cost of these rebates requires detailed data on the income distribution. Second, concurrent with federal and state monetary rebates, various non-monetary incentives for hybrid cars are in effect at different jurisdictions in the US. This makes isolating the impact of monetary rebates a much harder task. By contrast, during the period of our analysis there were no other forms of support to HEV's at federal, provincial, or local levels in Canada.

The primary data for our analysis are vehicle purchase and lease data by model, year and province in Canada from 1989 to 2006. We also use data on the characteristics of models and of provinces. Due to the richness of the data, and the wide variation in rebate programs both temporally and cross-sectionally, we are able to use straightforward estimation techniques without imposing strong assumptions or unnecessary structure on the data generating process. Identification is achieved by comparing a model's share of sales over time within the same province, as well as across provinces, while varying the presence and amount of rebates. We control for model characteristics that are time-invariant, province level preferences for vehicle segments, as well as time-varying preferences for vehicle segments.

We find that a $1000 increase in the provincial sales tax rebate increases the market share of hybrid cars by 31–38%.[1] The share of hybrid vehicles in total light vehicle sales in Canada for 2005 was 0.35%. We also find that the increased sales of hybrid cars crowded out intermediate passenger cars, intermediate SUV's, and high performance compact cars (using classifications defined by the Automotive Industry of Canada).[2] Other vehicle segments did not see a statistically significant decline in their sales due to these rebates. A significant decline in intermediate passenger cars can be explained by the fact that the largest selling hybrid passenger cars (the Toyota Prius and the Toyota Camry Hybrid) belong to the intermediate category and are priced in the range of intermediate passenger cars. Thus, consumers who buy the hybrid vehicle are likely to substitute it for a vehicle that costs approximately the same and offers them comparable vehicle characteristics. A similar argument can be made for the other two vehicle segments affected. High performance compact cars (such as the Honda Si series, or Volkswagen GTI) cost roughly the same as the smaller hybrid models (such as the Honda Civic Hybrid, or Insight). Similarly, a majority of the hybrid SUV's either belong to the intermediate SUV segment or are priced approximately in the range of an intermediate SUV.

Using these estimates we construct counterfactual sales for all models in each province and year assuming that there were no rebates offered. We find that after rebates were offered, approximately 26% of all HEV's sold (in provinces offering rebates) could be attributed to the rebates. Given that most of the hybrids sold were not due to the rebate program, and that the vehicles crowded out were relatively fuel efficient, we conclude that the rebate programs largely subsidized consumers who would have bought hybrids or other fuel efficient cars in any case.

We then use these counterfactual numbers along with other information—on the fuel economy of various models, the average lifespan of current vehicles in Canada, and average kilometers driven by province—to estimate the total gasoline saved through these rebate programs. We then convert the gasoline saved into carbon dioxide savings and construct a cost per tonne of carbon dioxide saved due to the rebates. The cost (in terms of revenue forgone) of carbon dioxide saved ranges from $129 per tonne in Ontario in 2002 to as much as $270 per tonne saved in British Columbia (BC) in 2006. The overall average over the five provinces offering rebates is $195 per tonne.[3]

The variation across provinces and time is partly due to differences in consumer purchasing patterns. For example, consumers in BC tend to buy more fuel efficient vehicles than consumers in other provinces. This implies that the average car crowded out in BC is more fuel efficient. This lowers the fuel saved and raises the cost of reducing CO_2. This effect is also observed over time. As fuel prices peaked in our data (in 2006), vehicle buying trends moved towards the purchase of fuel efficient vehicles and the average cost per tonne of carbon dioxide saved rose over time in all provinces.

There are several possible comparisons to our estimates. The most obvious is the price of carbon dioxide credits on a climate exchange. The price for a tonne of carbon dioxide at the Chicago Climate Exchange was 2.15 US dollars or approximately 2.6 Canadian dollars on January 30th 2009. The average price of a futures contract for a tonne of carbon dioxide settled in the European Climate Exchange in 2008 was 25.50 Euros, or approximately 40 Canadian Dollars given the average exchange rate for 2008. One can also compare our results with the estimated carbon dioxide abatement costs in transportation. Lutsey and Sperling [11] estimate the abatement cost of reducing a tonne of carbon dioxide by converting 50% of the current vehicle fleet to hybrid electric vehicles by 2025 to be 42 current US dollars (46 Canadian Dollars).[4]

[1] All figures are in nominal Canadian Dollars unless otherwise stated. As of June 2009, one Canadian dollar was worth 0.91 US dollars. However, this value has fluctuated considerably during the period of the analysis.

[2] High performance compact cars are listed in a vehicle segment titled "Sports Cars." This segment mainly includes high performance compact cars such as the Honda Civic Si series, the Corolla Sports versions, and Volkswagen GTI. High performance sports cars which are usually recognized as such (for example, the Corvette, various Porsche models, the Acura NSX, and the Nissan Z series, etc.) are included in a vehicle segment titled "Luxury Sports".

[3] There may be reasons other than reducing carbon emissions that motivate the policymaker to encourage the sales of hybrid vehicles. These include promoting economies of scale in the manufacture of HEV's, improving local air quality, etc. We discuss the relevance of these arguments for this analysis later in the paper.

[4] Welfare costs of reducing fuel use through either gasoline taxes or fuel economy standards in the US are also available. However, it is unclear how one can compare welfare costs with our cost of revenue forgone. Our measure of cost in terms of revenue forgone does not account for the welfare costs associated with policy. Our analysis takes as given the fact that governments will spend some of their money on carbon abatement through programs such as HEV rebates. The value added of this paper is to provide an estimate of the opportunity cost in terms of carbon saved of this particular instrument.

Thus, it appears that hybrid rebates are strikingly more expensive than other means of reducing carbon emissions.[5]

Through this paper we present a comprehensive analysis of provincial rebates for purchasing HEV's in Canada. Compared to other papers studying the impact of rebates to HEV's (as discussed in Section 2 below), we have two main advantages. First, our data span the entire new vehicle market and not just sales of HEV's. Second, our policy variable varies across province, time and make and model of HEV. This allows us to estimate the types of cars that are crowded out by the rebate (which is crucial for estimating the cost-effectiveness of such rebates), and more importantly also allows us to gain valuable insights into other factors such as consumer preferences and gasoline prices that might determine the cost-effectiveness of such rebates. These insights have clear policy relevance in both Canada and the United States.[6]

2. Related research

There have been a number of recent studies analyzing the impact of government incentives on HEV sales. Diamond [4] uses monthly US state registration data for HEV's to evaluate the relative impact of state incentives and gasoline prices on HEV adoption. He finds that while gasoline prices have a very strong relationship with hybrid vehicle adoption, government incentives have a weaker link. Gallagher and Muehlegger [6] also use quarterly sales data on HEV models for US states to study the relative effect of tax incentives, gasoline prices, social preferences and other non-monetary incentives (for example, preferential access to high occupancy lanes and parking, etc.). The authors attribute 6% of existing hybrid sales to tax incentive schemes, approximately 33% to personal (social) preferences, and 27% to rising gas prices. They report that sales tax incentives have a much greater effect on the demand for hybrid vehicles than income tax incentives and find that single-occupancy HOV access is correlated with substantial hybrid adoption in the state of Virginia, but not in other states. Sallee [15] studies the incidence of state and federal tax incentives offered to Toyota Prius owners. He finds that a majority of state and federal tax incentives are captured by consumers, rather than producers. This is despite the fact that the Prius market was characterized by excess demand. Similar to the papers above, one of our aims is to evaluate the impact of tax rebates on HEV purchases. However, there is also a very important difference; in our paper we include data on the sales of cars other than hybrids. Thus, in addition to estimating the increase in hybrid vehicle sales from tax rebates, we can also estimate which cars were crowded out due to these rebates. Unlike the papers listed above, this allows us to estimate the cost-effectiveness of tax rebates.

Beresteanu and Li [1] evaluate the effect of gas prices and government incentives on the purchase of HEV's in 22 US Metropolitan Statistical Areas (MSA) in the USA. They find that rising gas prices from 1999 to 2006 and government subsidies explain 14–17%, and 27–32% of the diffusion of hybrid vehicles in these areas. Similar to our paper, they also estimate the cost of reducing carbon dioxide emissions (between US$ 100 and 119 per tonne) by accounting for which vehicles are crowded out in the new car market. There are several important differences between their paper and ours. First, Beresteanu and Li evaluate the US federal HEV tax rebate. This implies that their policy variable only varies over time which prevents them from exploiting cross-sectional variation to identify the effect of the rebate program. In our study, we can use both cross-sectional and temporal variation to identify the impacts of provincial tax rebates. This also gives us insight on the factors that make the rebate more or less cost-effective across space and time. Second, in the US federal program the amount of the rebate depends on an individual's income (as the rebate is either an income tax deduction or an income tax credit). Thus, Beresteanu and Li have to use data on the distribution of income in each MSA to estimate the impact and cost of the rebate programs. By contrast, all the programs in Canada provided rebates that were independent of income. As a result, we can directly calculate the cost of rebates without needing to estimate the relationship between hybrid vehicle sales and the income distribution of consumers.[7] Other papers studying HEV's include [2,9].

(*footnote continued*)

Assuming that the government is going to use some of its revenue towards carbon abatement our aim is to help the government maximize carbon saved through such spending. Notwithstanding the difficult comparison here are some estimates from the literature. Kleit [10] estimates the welfare cost of reducing the consumption of a gallon of gasoline through corporate average fuel economy (CAFE) standards to be 78 US$, which corresponds to a cost of approximately 97 CA$ per tonne of carbon saved. Jacobsen [8] estimates a welfare cost of both the gasoline tax and the CAFE standard by allowing for interactions with the second hand car market and technological innovation in the automotive industry. His estimated welfare cost per gallon of gasoline saved through the gasoline tax is 0.82 US$ which corresponds to approximately 102 CA$ per tonne of carbon and the estimate cost of using the CAFE standard to save a gallon of gasoline is 1.97 US$ which corresponds to approximately 246 CA$. All these conversions are made using the US$-CA$ exchange rate on the 16th of June 2009.

[5] One exception is the cost of reducing a tonne of CO_2 through tax credits for ethanol, which is estimated at approximately 1700 US Dollars [12].

[6] As the Canadian and US automobile markets are fairly well-integrated the results from this study are relevant for policymakers in both the US and Canada. The integration of both markets is due to similar consumer preferences and available products, and the Canada–United States Auto Pact of 1965 (see http://www.canadianeconomy.gc.ca/English/economy/1965canada_us_auto_pact.html, accessed on January 23rd, 2009, for more information).

[7] Additionally, they use data from 22 MSAs in the USA for their analysis, while we use data on all vehicle sales across Canada.

3. Hybrid electric vehicles and provincial tax rebates

3.1. Hybrid electric vehicles

HEV's are a proven means to reduce fuel consumption when compared to an equivalent conventional Internal Combustion Engine (ICE) vehicle [7]. Consequently, HEV's provide environmental improvements in the use-phase [16], and the current fleet (2007 vehicles) reduces carbon emissions by an average of 6 t per vehicle over its lifetime [14]. Such benefits come from the use of a smaller, more efficient ICE; an electric motor that either enhances or substitutes the torque of the ICE during the drive cycle; and regenerative braking which captures dissipative energy and uses it to recharge the Nickel metal hydride battery used to power the electric motor.

Since HEV's were first introduced to the Canadian market, automotive manufacturers have offered an increasing variety of model types. While in 2000 only two models (Honda Insight and Toyota Prius) were available, in 2007 13 were available. Until 2004, hybrid-electric engine technology remained the exclusive domain of the smaller car segments, with most sales being captured by the Toyota Prius. Since then this technology has been extended to other segments and HEV's now extend from compact cars (Honda Civic Hybrid), to intermediate cars (the Toyota Prius and Camry) and luxury Sports Utility Vehicles (SUV's) such as the Lexus RX 400h. Hybrid SUV's are a sharply increasing segment, and in the Canadian market hybrid SUV's made up approximately 28% of total hybrid sales in 2006 (see Table 1). In addition to the growing diversity of model offerings, HEV annual sales continue to grow both in numbers and as a proportion of the total light-duty vehicle sales. In 2000, HEV sales represented only 0.03% of total light vehicle sales in Canada; by 2007 this proportion had risen dramatically to 0.88% (from 426 cars sold in 2000 to 14,828 cars sold in 2007). Toyota dominates the hybrid market with the Prius, Camry and Lexus models capturing approximately 72% of the market share in 2007. The Toyota Camry Hybrid was the highest selling hybrid model in Canada in 2007 with approximately 39% of the market share of all hybrid vehicles sold.

3.2. Tax rebates for hybrid electric vehicles in Canada

Before the Canadian federal eco-auto program (awarding cash rebates to fuel efficient vehicles) was announced in 2007, five Canadian provinces, British Columbia (BC), Manitoba, Ontario, Prince Edward Island (PEI), and Quebec were already providing tax or cash rebates of varying amounts for hybrid vehicles (see Table 2 for more details). In August 2000, the provincial government of BC announced a 30% refund of the provincial sales tax (PST) (up to a limit of $500) for all HEV's purchased or leased. This maximum was raised to $1000 in 2001. In 2005, the government changed the rebate to a point of sale exemption of all of the PST applicable up to a maximum of $2000. Then, Ontario instituted a rebate of up to $1000 of the retail sales tax (RST) on all hybrid electric vehicles purchased or leased after May 10th 2001. For vehicles purchased after 23rd of March, 2006, this limit was doubled to $2000. In 2004, PEI allowed all HEV's purchased or leased after March 30, 2004 a rebate of up to $3,000 of the paid PST. The province of Quebec allowed all HEV's purchased or leased after March 23, 2006, a rebate of the PST paid up to $1000. This maximum limit was increased to $2000 on February 20, 2007. In Manitoba, residents who purchase or lease an eligible hybrid vehicle after November 15th 2006 receive a check of $2000 in the mail. The remaining five Canadian provinces do not offer tax rebates or subsidies for the purchase or lease of HEV's.

Besides the program in the province of Manitoba, other provincial rebates are refunds on provincial taxes paid and in order to calculate an accurate dollar value of the rebate we require the transaction price of each HEV sold when the rebate

Table 1
Shares of the HEV market in Canada.
Source: R.L. Polk Canada Inc.

Model	2000	2001	2002	2003	2004	2005	2006	2007
Chevrolet Malibu	–	–	–	–	–	–	–	0.03%
Ford Escape	–	–	–	–	7%	17%	7%	7%
Honda Accord	–	–	–	–	1%	11%	6%	2%
Honda Civic	–	–	51%	61%	8%	7%	16%	14%
Honda Insight	39%	21%	14%	2%	0.30%	0.10%	0.20%	0.03%
Lexus GS450H	–	–	–	–	–	–	2%	1%
Lexus LS 600H	–	–	–	–	–	–	–	1%
Lexus RX400H	–	–	–	–	–	15%	9%	8%
Nissan Altima	–	–	–	–	–	–	–	2%
Saturn Aura	–	–	–	–	–	–	–	0.50%
Saturn Vue	–	–	–	–	–	–	2%	4%
Toyota Camry	–	–	–	–	–	–	24%	39%
Toyota Highlander	–	–	–	–	–	12%	10%	4%
Toyota Prius	61%	79%	35%	37%	83%	37%	24%	19%
Total Hybrid Sales	426	495	513	671	2303	5124	8924	14,828

Table 2
Tax rebates for hybrid vehicles in Canadian provinces.

Province	Vehicle eligibility	Rebate amount and timing
British Columbia Policy announced: August 2000 PST rate: 7%, with graduated increases for vehicles over $55K	All hybrid vehicles with regenerative braking (cars and SUV's eligible)	30% of tax paid up to $500 for vehicles bought before July 31st 2001 30% of PST paid up to maximum of $1000 after July 31st 2001 A point of sale reduction of all PST till a maximum of $2000 after February 16th 2005 Additional rebates in PST (reductions in graduated increase of PST over 7%) for hybrid vehicles over 55K (see Note 1)
Prince Edward Island Policy announced: March 2004 PST rate: 10%	All hybrid vehicles are eligible	All the PST paid until $3000, for vehicles bought after March 30th 2004
Ontario Policy announced: May 2001 PST rate: 8%	All hybrid passenger cars (with regenerative braking) eligible 2001, SUV's eligible 2002	PST rebate up to a maximum of $1000 for cars bought after May 10th 2001 Hybrid SUV's and trucks included June 18th, 2002. A point of sale reduction of all PST till a max of $2000 after March 23rd 2006
Quebec Policy announced: March 2000 PST: 7.875%	See Notes (2) below	All PST paid to a maximum of $1000 for vehicles bought after March 23rd 2006 and before February 21st 2007 All PST paid to a maximum of $2000 for vehicles bought after February 22nd 2007 and before January 1st 2009
Manitoba Policy announced, November 15th 2006 PST rate: 7%	See Notes (3) below	Flat $2000 rebate for all vehicles bought after November 15th 2006

Notes:
1. People buying light vehicles which are priced $>$ $55,000 have to pay a higher PST rate. This rate increases by 1% for the first $1000 over $55,000 and continues to increase by 1% for every additional $1000 to a maximum of 10% (for vehicles costing more than $57,000). For hybrid vehicles the graduated increases come with an additional exemption of $7000 on the threshold. This implies that the PST does not increase for hybrid vehicles till their price reaches $62,000.
2. Cars eligible for a rebate in Quebec are: 2005 and 2006 Honda Insight; 2005–2007 Toyota Prius; 2007 Toyota Camry Hybrid; 2008 Ford Escape Hybrid (two-wheel drive); 2005–2007 Honda Civic Hybrid; 2005 Honda Accord Hybrid; 2007 Nissan Altima Hybrid.
3. Cars eligible for a rebate in Manitoba are: Honda Insight; Lexus GS 450H; Lexus RX 400H; Toyota Camry Hybrid; Toyota Highlander Hybrid; Toyota Prius; Chevrolet–Silverado 1500 LS Hybrid; Ford Escape Hybrid; GMC Sierra 1500 SLE Hybrid; Honda Accord Hybrid; Honda Civic Hybrid; Saturn VUE Green Line.

was offered. Unfortunately, we do not have access to data on transactions prices. Instead we use the base price for the HEV model in each year to approximate the value of the rebate.

This approximation will be a lower bound for the true dollar value of the rebate if the transacted price of the vehicle is at least as high as its base price. This seems a plausible assumption since transacted prices add delivery and destination charges and the price of options to the base price (before deducting dealer incentives and individually negotiated price reductions). Due to the high demand for most hybrid vehicles we expect dealer incentives and customer negotiated price reductions to be relatively small, and likely less than delivery, destination and options charges. Proceeding under this assumption, we then calculate the value of the rebate on a given hybrid car model as follows:[8]

$$R_{mvt} = \min\{\eta_{mvt}(PST_{v*}BP_{mt}), Limit_t\}, \quad (1)$$

where the subscript m denotes model, v denotes province, and t denotes year. The variable η_{vt} is the proportion of *PST* returned to the consumer on purchase of the hybrid vehicle, *BP* denotes the base price of the model, and *Limit* denotes the maximum PST rebate possible in that province and year.[9] In 2006, PEI had the highest maximum rebate per hybrid with BC's rebate second largest. We also calculate the maximum rebate possible for an HEV (relative to its base price) in

[8] For the province of BC we have to account for an exemption to an increase in the PST to a luxury tax given to hybrid vehicles. For vehicles that are priced between $55,000 and $58,000 sold in BC the formula is amended to: $rebate_{mBCt} = \min\{(PST_{BC*}BP_m), Limit_{BCt} + (Lux_{BC} - PST_{BC})BP_m\}$. The additional term added captures the loss in revenue from the exemption granted to hybrid vehicles. In our data this additional term is relevant for only one hybrid model, the Lexus RX400h sold in 2005 and 2006.

[9] In the online appendix to this paper we list the maximum rebates across provinces and years.

province v at time t (R_{vt}),

$$R_{vt} = \max_{m}\{R_{mvt}\}. \quad (2)$$

The tax rebates we analyze are introduced or modified in different months of the year. As our data are annual, in order to relate annual vehicle sales to rebates we need to adjust the rebate variable for the month of introduction or modification. Thus, we assign sales-based weights to the rebates (both R_{mvt} and R_{vt}) using data on the monthly distribution of light vehicle sales in Canada.[10] This monthly distribution is strikingly similar across different years with January being the lean sales month with usually only 5–6% of the year's light automotive sales and either May, or June being the peak sales month,with approximately 10–11% of yearly sales. We base our sales weights on the average monthly distribution of light vehicle sales in 2006–2007.[11]

4. Data and empirical strategy

4.1. Data

The primary sales data used in our analysis are generously provided by DesRosiers Automotive Consultants Inc. The data include vehicle sales figures, by make and model, for each province, and for each year from 1989 to 2006.[12] The sales data are not disaggregated within models by engine type, or drive train. Thus, if a model has a hybrid variant, its sales are not separately identified. For this reason we supplement the DesRosiers data with data on hybrid vehicle sales by make and model, for each province, and for all years provided by R. L. Polk Canada Inc. Among HEV's, the DesRosiers dataset provides sales data for the Toyota Prius and Honda Insight, which are hybrid cars with distinct model names. The dataset from Polk provides us with numbers for all other hybrid models sold in Canada.[13]

The DesRosiers dataset also classifies each vehicle into a vehicle segment defined by the Automobile Industry in Canada. Passenger Cars are classified into subcompact, compact, intermediate, sports, luxury, luxury sports, luxury high end. Light Trucks are classified into compact sport utility, intermediate sport utility, large sport utility, small pickup truck, large pickup truck, small van, large van, luxury sport utility. In Table 3 we present the market share for vehicle segments in Canada for 2003 and 2006. Compact cars constituted almost 25% of all vehicle sales, and intermediate cars roughly 14% in 2006. Pickup trucks (large and small) constituted roughly 15% of all vehicle sales, and compact sports utility vehicles made up of roughly 11% in 2006. During 2003–2006, subcompact cars, luxury cars, compact sports utilities and small pickup trucks saw significant increases in their market shares while small vans, intermediate sports utility vehicles, and intermediate cars saw significant declines. Note that hybrid vehicles experienced an unprecedented increase in market share.

We obtain fuel economy data for each model from the US Environmental Protection Agency's database available online at www.fueleconomy.gov. This database provides fuel economy indicators disaggregated for each model by engine and transmission. We aggregate the data to match our model-based sales data, and obtain the minimum, maximum, mean and median of the distribution of two fuel economy indicators—combined MPG and unrounded combined MPG—for each model. We obtain data on average vehicle kilometers driven for light duty vehicles (vehicles up to 4.5 t) for each province and year, and total light vehicle sales in Canada by month and year from Statistics Canada. We obtain base prices for all HEV models from the website for Sympatico, MSN Autos.[14] We incorporate information on model generations, which are major overhauls of the same model. For example, the first generation of the Honda Accord sold as the Honda Accord model year 1976 to 1981, and the eighth (current) generation started selling as the Honda Accord model year 2008. Our empirical specification treats different generations of the same car as different models, allowing for varying consumer preferences across model generations.[15]

[10] These data were obtained from Statistics Canada. For robustness we try an alternative scheme, where we assume that the rebate is in place for the entire year if it is implemented on or before July, the month where the median light vehicle is sold. Thus if the rebate is implemented on or before July of the year, it is valid for the entire year. However, if implemented later than July we assume that there was no rebate offered that year. This only impacts Manitoba, where the median adjustment implies that we assume there is no rebate offered in 2006. Corresponding results from this specification are presented in the online appendix, available at the JEEM archive of supplementary material, which can be accessed at http://aere.org/journals/

[11] The sales weights we use are 0.4 for BC's extension of the rebate maximum on July 31st 2001 (calculated as 60% of all automotive sales are made by the 31st of July in 2006–2007). The sales weight is 0.91 to BC's extension of the HEV rebate to CAD 2000 on February 16th 2005 (as only 9% of sales are made by the 15th of February). The sales weight is 0.4 for BC's policy introduced in August 2000. Even though that policy applied to previously sold HEVs, the relevant date is the one on which the policy was announced. Other sales weights are 0.66 for Ontario's policy introduced on May 10th 2001, 0.82 for the point of sale policy introduced on March 23rd 2006. The sales weight is 0.80 for the provincial rebate introduced in PEI on March 30th 2004; is 0.82 for Quebec's rebate policy introduced in March 2006, and is 0.11 for Manitoba's policy introduced in November 2006.

[12] We drop three observations with negative sales numbers. As our data are dealer reported sales figures, these could be dealer adjustments of inventory with their manufacturers.

[13] The intersection of the two datasets also allows us to verify consistency in sales numbers across the two datasets.

[14] http://en.autos.sympatico.msn.ca—accessed September 22nd 2008.

[15] Information on model generations (major overhauls of the same model) was initially gathered from Wikipedia (www.wikipedia.org), and then cross-checked by using the EPA's fuel economy data (as major overhauls are associated with substantial differences in fuel economy) and also cross-checked with information from Ward's Automotive Yearbooks (1989–2006) which details other model characteristics such as horsepower, dimensions, weight and price.

Table 3
Market share across vehicle class.
Source: authors' calculations.

Vehicle segment	Share of total vehicle sales	
	2003	2006
Passenger cars		
Subcompact PC	4.10%	6.40%
Compact PC	25.40%	24.80%
Intermediate PC	17.60%	14.10%
Sports PC	2.20%	2.00%
Luxury PC	2.70%	3.90%
Luxury sports PC	0.50%	0.40%
Luxury high end PC	1.80%	1.40%
Hybrid	0.04%	0.41%
Light trucks		
Compact sport utility	7.00%	11.20%
Intermediate sport utility	6.60%	4.40%
Large sport utility	1.30%	1.10%
Luxury sport utility	2.00%	2.80%
Small van	12.50%	9.40%
Large van	1.70%	1.80%
Small pickup truck	1.80%	3.00%
Large pickup truck	12.70%	12.70%
Hybrid	0.00%	0.12%
Passenger cars	865,873	863,292
Light trucks	728,043	752,206
Total vehicle sales	1,593,916	1,615,498

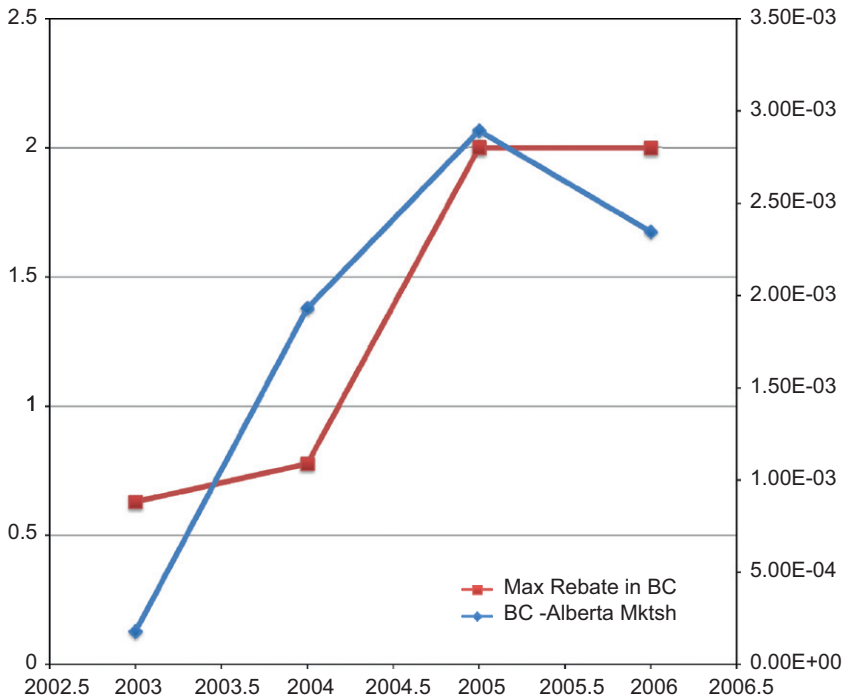

Fig. 1. Relating HEV rebates to market share: second generation Toyota Prius Liftback.

4.2. Background for the estimating equation

In Fig. 1 we graph the difference in the market share of the Prius Liftback (the second generation of the Prius sold in North America) between the two provinces of BC and Alberta. BC offers rebates for the purchase of hybrid vehicles while Alberta does not. We also plot the maximum rebate offered in BC for the same time period. This corresponds to a difference in rebates between BC and Alberta. A correlation between the two series is visually apparent. The first Prius is sold in year

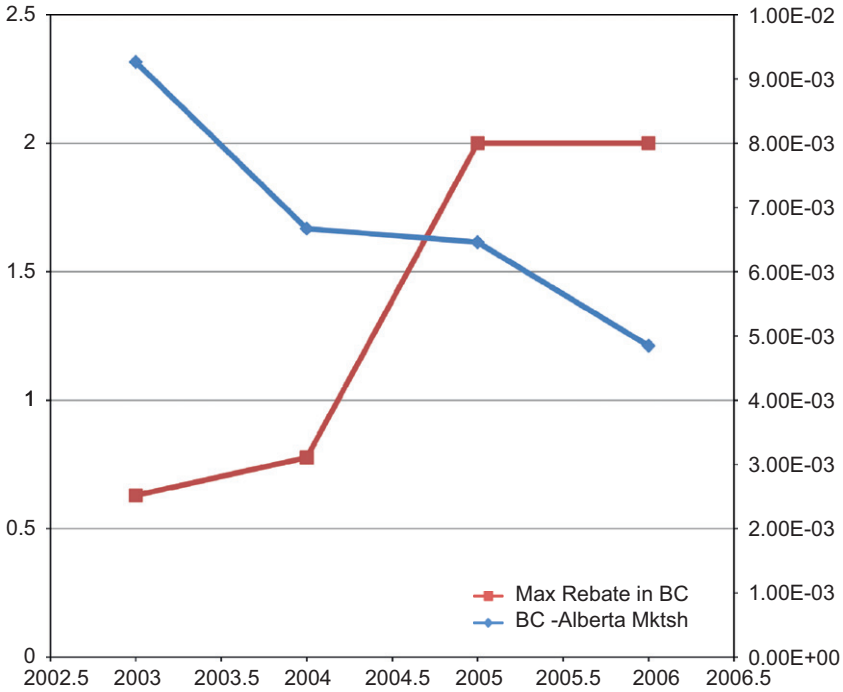

Fig. 2. Relating HEV rebates to market share: seventh generation Honda Accord (non-hybrid).

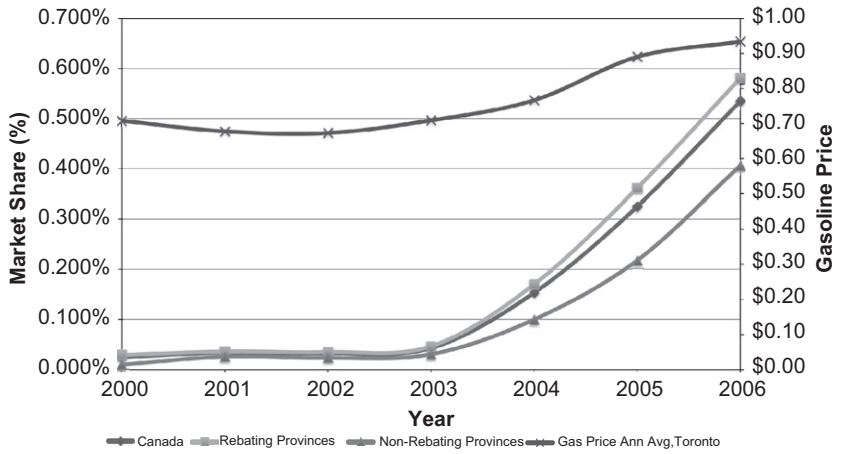

Fig. 3. HEV market shares: rebating vs non-rebating provinces.

2003 (when BC was offering a maximum rebate of up to $630) and the difference in market share between the two provinces rises sharply as the rebate rises after 2004.

An increase in the market share for hybrid vehicles comes at the expense of other, non-hybrid cars. In Fig. 2 we plot the difference in market share of the seventh generation Honda Accord (non-hybrid version) in BC vs Alberta, and the rebate in BC. A negative correlation is again apparent, suggesting that the Accord lost market share in BC, relative to Alberta, as hybrid rebates were introduced and expanded. Our estimation is designed to formally capture these relationships.[16]

Even though the effect of the rebate is identified at the level of the model-generation, aggregate trends in HEV sales also lend valuable insight to our estimation. In Fig. 3 we plot the aggregate market share of all HEV's across provinces that offer rebates for HEV purchases and those that do not. Provinces that offer rebates are BC, Manitoba, Ontario, Quebec, and PEI. The middle line represents the aggregate share of all HEV's in Canada. The market share for HEV's tends to be higher in

[16] We also plotted the difference in the share of all HEV's in Alberta and BC with the maximum rebate offered in BC; a correlation between these two series is also apparent.

provinces that offer rebates, and these shares diverge significantly after 2003. Aggregate market shares for HEV's in selected provinces show similar trends (we do not include a figure to conserve space). Aggregate market shares for HEV's in BC, PEI, and Ontario are higher than the Canadian average market share of hybrid vehicles, while corresponding shares in non-rebating provinces of Alberta and Saskatchewan are lower than the Canada average.

This points to two potential issues relevant to our estimation. First, there seems to be a uniformly higher aggregate market share for HEV's in most provinces offering rebates over those that do not. If there are reasons other than provincial rebates leading to this higher share we need to consider them in our analysis so as to avoid mis-attributing their effect to the provincial rebate.

The most likely reason for a higher share of HEV's in rebating provinces is a purchasing pattern biased towards subcompact, compact and intermediate passenger cars. From 2000 to 2006, HEV models classified as passenger cars in the subcompact, compact or intermediate segments make up on average 88% of all hybrid sales in Canada. Further, prior to 2004 (when the Ford Escape Hybrid—the first SUV hybrid—was introduced), HEV's were only available in these categories. Provincial characteristics such as geography, city density, road network, and the makeup of the population influence the type of vehicle appropriate for a region. If the population in provinces that offer rebates have a historical tendency to purchase passenger cars belonging to the above segments, the corresponding share of HEV's is likely to be higher. The data reveal that this is indeed the case; the market share for cars classified as subcompact, compact or intermediate is uniformly higher in provinces that offer rebates than in those provinces that do not. Thus, in our estimation we control for provincial preferences for vehicle segments as defined by the Automotive Industry of Canada.[17]

The second issue derives from the fact that the market shares for HEV's increase sharply for all provinces after 2003 (see Fig. 3). This is approximately the same time that HEV rebates also rose sharply across the rebating provinces. If there are factors other than provincial rebates contributing to this increase and if we do not account for them, we might mis-attribute their impact to the rebate. One possible reason for this increase is technology diffusion, on both the demand and supply sides [2]. On the demand-side, consumers get the opportunity over time to gather information from third party agencies, such as consumer reports and JD power, on the reliability of HEV technology. On the supply-side, the technology diffuses over time through different manufacturers and across different vehicle platforms. For example, while HEV's were initially only available as small to intermediate passenger cars, they have subsequently become available as SUV's, luxury passenger cars, etc. In our estimation we control for technology diffusion and changing preferences for hybrid cars and for different vehicle segments over time.

A second reason for the increase in HEV sales over time may be rising fuel prices. In our estimation we control for the impact that variation in gasoline prices across years and provinces has on a model's demand using a combination of fixed effects. We explain our approach in greater detail in the next section.

5. Empirical specification and results

5.1. Derivation of the estimating equation

Assume that there are M car models available in a given province v. Assume that these M models are partitioned into C segments such that each model m is a member of exactly one segment c (mnemonic for class). The utility to individual i in province v from purchasing model m is given by

$$u_{imv} = \alpha_i[y_i - p_{mv}] + \beta_i x_m + \xi_{mv} + \varepsilon_{imv}, \tag{3}$$

where x_m contains observed attributes of model m, ξ_{mv} contains unobserved attributes, y is the consumer's income and p is the price of the model. Additionally, ε is a mean zero random variable capturing the consumer's idiosyncratic preference for the model. The empirical specification allows attributes to also vary over time; however, we suppress the time subscripts for now.

We assume that

$$p_{mv} = p_m - R_{mv} \tag{4}$$

implying that the price of a particular model in a given province is equal to a model specific mean less a model-province specific rebate R. In other words, we assume that a given model has a constant list price across all provinces and a discount which depends on province specific rebate policies towards hybrid vehicles.

We model unobserved characteristics in the following way:

$$\xi_{mv} = \xi_m + \Delta\xi_{cv}, \tag{5}$$

where c is the segment corresponding to model m as described above. This implies that the model-specific unobserved term can be decomposed into a model attribute that is constant across provinces, and a province-specific term that is

[17] This is done by including province*segment fixed effects, which capture time-invariant preferences for various segments across provinces. If these preferences are time-varying, and are correlated with the rebates, then our results may be biased. In particular, if provinces offer rebates due to an increasing number of 'green' residents, then we may over-estimate the effect of the rebates on hybrid market shares. However, this will strengthen our results regarding the cost-effectiveness of the rebates. Thus, our results on cost-effectiveness may be taken as being conservative estimates.

constant for all models in the same segment. As these segments are usually associated with size, capacity, performance, etc., the segment variable represents certain functions that the vehicle performs for the individual (or family). We allow provincial preferences for a segment to vary as the geography, city density, road network, and the makeup of the population often influences the vehicle segment appropriate for a region.[18]

We assume that, for all individuals i, $\beta_i = \beta$ and $\alpha_i = \alpha$, that is, the only individual source of heterogeneity in preferences is through the mean-zero additive error term.

At this stage, it is common to proceed by specifying an outside good as well as assuming that the error term is distributed Type-1 extreme value. This allows estimation of the familiar logit model, with the dependent variable being a log odds ratio. We present the results from estimating such a model in the online appendix. The results are reasonable, and are similar to the results of our preferred specification, presented below.

However, as has been often pointed out, the logit model implies unrealistic own and cross-price elasticities [13]. Own price elasticities increase in the price of the product and decrease in the market share of the product. Further, cross-price elasticities with respect to the product attribute (price, or rebate in our case) are higher if the share of the substitute is higher. In our application, it would be appropriate to specify the outside good as not purchasing a new car in a given year. Doing so would lead the outside good to have the largest share, and also the highest cross-rebate elasticity. This implies that the logit model would predict that a large portion of the HEV's purchased due to the rebate were by people who would not otherwise have bought a new car.[19]

For our preferred specification, we do not consider the outside good. Instead we directly model market shares as a function of the rebates and other attributes. We do this because we find no evidence that the rebates had an effect on the aggregate number of new cars sold.[20] We find that sales of new cars remain remarkably constant over provinces and time, at about 4.2% per capita, and are unaffected by the presence and amount of rebates.

Our estimating equations capture model-specific attributes by including a model∗generation fixed effect. This includes attributes such as horsepower, fuel economy, interior comfort, exterior appearance, brand, model perceptions, standard/optional features, and the time and space invarying component of the omitted retail price (for a specific model generation). We omit all prices, be they listed or transacted, from our regressions.[21] A province∗segment fixed effect captures $\Delta\xi_{cv}$ described above. This province∗segment fixed effect is designed to capture why a certain vehicle segment is appropriate for a region based on the region's geography, density and so on. We include the 15 segments identified by the automotive industry of Canada (compact, intermediate, etc.). These do not include hybrid vehicles as a separate segment because hybrids include vehicles that span multiple segments.

We assume that observed attributes of a given segment remain constant over a year. Consumers purchase vehicles in a certain segment based on the attributes and vehicle variety available within that segment. Further, as models vary within segments the relative price for purchasing different attributes also change. We thus include a segment∗year fixed effect. This segment∗year effect captures changing preferences for certain vehicle segment across different years in our data. For instance, this would capture the Canada-wide decline in the market share of intermediate cars during 2003–2006 as seen in Table 3. While creating segment∗year fixed effects we depart from the classification presented by the automotive industry of Canada. Here we include 16 segments and the addition segment is created by classifying all HEVs as a separate segment.[22] By including hybrid∗year effects we capture the diffusion of HEV technology, as discussed in Section 4.2 above, in the most flexible manner possible.[23]

Our estimating equation is as follows:

$$\ln(s_{mvt}) = \beta_0 + \beta_1 R_{mvt} + \theta_m + \gamma_{vct} + \varepsilon_{mvt}, \tag{6}$$

where s_{mvt} is the market share of model m, in province v, in year t, θ refers to a model generation fixed effect and γ refers to a combination of province, segment and year fixed effects, and ε is a mean zero error term. The coefficient β_1 captures the impact of the rebate on the market share of the average hybrid model in our data. Government rebates for purchasing hybrids may not necessarily be passed through completely to consumers of these vehicles. Some of the rebate amount may be absorbed by manufacturers or dealers and may therefore be reflected in higher list prices. Additionally, in response to a rebate, a dealer might provide incentives or allow greater negotiation room for customers buying non-HEV's competing

[18] This province-specific class term addresses reasons why purchasing patterns in certain provinces might be biased towards hybrids as discussed in Section 4.2.

[19] One way to address this problem is by allowing different substitution patterns among car choices. In the online appendix we also present various specifications of a nested logit model which allows such flexible substitution patterns. The coefficient on the rebate variable using those models is positive, significant and stable across all specifications.

[20] We present evidence to this effect in the online appendix. This fact is unsurprising for a few reasons. First, the market share of HEVs was very small during the sample period. Second, the average rebate across provinces and years was around 4% of the price of a new car. Moreover, hybrid cars are generally more expensive than other cars within the same vehicle class. For this reason, the rebates were unlikely to have shifted consumers from not buying a new car at all towards buying a hybrid car.

[21] Note that as our aim is to estimate the equilibrium impact of HEV rebates on HEV sales and non-HEV sales (instead of the structural price elasticity) omitting prices is not an issue for our estimation. We discuss this in greater detail below.

[22] This does not turn out to affect the results much. If we define segment-year fixed-effects according to the original 15 segments our results are very similar, though they imply slightly larger effects of the rebates on the sale of hybrid cars. This is intuitive, because if we do not capture HEV technology diffusion then all of the increase in hybrid cars over time is attributed to the rebates.

[23] Note that our specification does not capture local network externalities from the existence of hybrid cars. For instance the large number of Prius hybrid taxicabs in Vancouver allow residents to see the vehicle first hand and might spur the diffusion of these vehicles in Vancouver.

Table 4
Regression results: model specific rebates.

Depvar: log market share	(1)	(2)	(3)	(4)
Weighted rebate by model	0.38	0.31	0.33	0.34
($1000)	(0.07)**	(0.07)**	(0.07)**	(0.07)**
Model-generation FEs	Yes	Yes	Yes	Yes
Province FEs		Yes		
Year FEs		Yes		
Province-year FEs			Yes	
Province-segment FEs				Yes
Segment-year FEs				Yes
Constant	−6.75	−5.54	−5.49	−6.99
	(0.01)**	(0.03)**	(0.07)**	(0.04)**
Observations	38,110	38,110	38,110	38,110
R-squared	0.72	0.74	0.74	0.78

Standard errors in parentheses. Superscripts * and ** denote significance at 5% and 1%, respectively. Sample extent: all model-generations, all years from 1989 to 2006.
Model-specific rebates are weighted according to the monthly distribution of sales.

with rebated HEV's.[24] Market effects such as these would reduce the impact of the rebate relative to the true price elasticity for the same vehicle model. It is thus important to note that our coefficient β_1 estimates the average equilibrium effect of the tax exemption for rebated hybrid vehicles. This estimate subsumes the impact of market responses that emerge due to the rebate. We also believe that this is the relevant estimate for analyzing rebate programs.

It may be argued that the price of gasoline should be a regressor in the specification above since a variation in gasoline prices induces a variation in the desirability of fuel-efficiency of each vehicle. For example, hybrid cars may become more desirable as fuel costs rise. The most straightforward way to model this would be to include a vehicle-specific measure of fuel costs, while allowing this measure to vary over time and provinces. We estimated regressions that included this measure but found it to be insignificant in all specifications; this is unsurprising since the fuel costs are almost perfectly correlated with our various province, time and model-generation fixed effects.[25]

We briefly discuss the sources of identification in the empirical specification. There are three sources: The first is variation across the 10 Canadian provinces, since only a subset of provinces offered tax exemptions for hybrid vehicles over the last decade. Moreover, those that offered these exemptions started doing so at different points in time, thus creating considerable variation within any given year in the number of provinces with such programs. The second source is variation within provinces across years, due to the fact that rebating provinces have gradually increased their average maximum rebate over time. Thus, within-province variation in the amount of rebates is considerable.

The final source of identification is variation across car models within a given province and year. This is because rebates are generally a reduction in provincial sales tax, which is a percentage of the vehicle's sale price. Thus, even within any given province and year, hybrid vehicles of differing values will have different rebate amounts associated with them. This final source of identification is only employed in the regressions that use model-specific rebates, and is not available in specifications that use province-wide maximum rebates.

5.2. Results

Results from estimating Eq. (6) are presented in Table 4. All regressions presented below utilize 38,110 observations, which correspond to data points for all models sold during years 1989–2006 in all 10 provinces of Canada. The coefficient on the rebate has a positive value for the relevant hybrid model in the year and province that the rebate is offered.[26] We run four specifications, all of which include model generation fixed effects. In addition to model generation fixed effects, the first specification only includes the rebate, the second includes province and year fixed-effects, the third includes province∗year fixed-effects and the final specification includes province∗segment fixed-effects and segment∗year

[24] For example, the 2007 eco-auto program provided greater subsidies for the Toyota Yaris and the Toyota Corolla than competing Honda models; Honda Canada responded by offering a fuel efficiency discount on the Honda Fit and the Honda Civic, matching the difference in subsidy (see http://www.cbc.ca/consumer/story/2007/05/18/honda-incentive.html, accessed April 02, 2010).

[25] We define the cost of driving as P_{vt}/MPG_{mt} where P is the consumer price index of gasoline by province and year, and MPG is the EPA defined fuel economy for each model and each year. Similar measures have been used by Linn and Klier (unpublished paper, 2007) and Gramlich (unpublished paper, 2009). The gasoline CPI is highly correlated with year fixed-effects; the MPG measure is perfectly correlated with model fixed-effects. Thus the ratio of the two is highly correlated, though not perfectly, with our various fixed-effects.

[26] All regressions presented in the main text of this paper use the rebate variable adjusted for the month it was introduced or changed using a weight corresponding to the proportion of vehicles sold after that month (as described in Section 3.2). We present corresponding regressions employing the rebate which is adjusted using the median weighting method in the online Appendix.

Table 5
Maximum rebates: hybrids vs non-hybrids.

Depvar: log market share	(1)	(2)	(3)	(4)
Rebated hybrids*max rebate	0.37	0.32	0.33	0.38
($1000)	(0.07)**	(0.07)**	(0.07)**	(0.07)**
Max rebate	0.01	−0.02	−0.67	−0.04
($1000)	(0.01)	(0.01)	(0.04)**	(0.01)**
Model-generation FEs	Yes	Yes	Yes	Yes
Province FEs		Yes		
Year FEs		Yes		
Province-year FEs			Yes	
Province-segment FEs				Yes
Segment-year FEs				Yes
Constant	−6.75	−5.54	−5.49	−6.97
	(0.01)**	(0.03)**	(0.07)**	(0.04)**
Observations	38,110	38,110	38,110	38110
R-squared	0.72	0.74	0.74	0.78

Standard errors in parentheses. Superscripts * and ** denote significance at 5% and 1% , respectively. Sample extent: all model-generations, all years from 1989 to 2006.
Maximum rebates are weighted according to the monthly distribution of sales.

fixed-effects.[27] We find that the hybrid rebate increases the share of hybrid vehicles in a positive and significant manner in all four specifications. In addition, the coefficient value remains stable, varying between 0.31 and 0.38.[28]

Rebates and model-generation fixed effects explain a large fraction of the variation in vehicle sales across provinces and time, as can be seen from Column 1. However, we include various combination of province, year and class fixed-effects in order to capture features of the auto market as described in Section 5.1. Adding these fixed effects naturally improves the fit of the regression, but also reduces the coefficient on the rebate variable. This implies that the amount of rebates is correlated with various province and class specific factors, as was suggested by Fig. 3. Our preferred specification is in Column 4, which includes province-segment and segment-year effects. This specification also has the best fit.

In Table 5 we present results for the regression where instead of a model specific rebate, we use the maximum provincial rebate offered (R_{mvt} is replaced by the maximum offered in each province and year, R_{vt}). Using the provincial maximum has the distinct advantage of allowing us to easily evaluate the impact of offering a rebate on both hybrid and non-hybrid vehicles. We use the sales weights described in Section 3.2 to adjust the provincial maximum for the date of introduction. We divide all vehicles into two categories: hybrids and non-hybrids. We run four specifications similar to those described above. The estimated coefficient on the maximum rebate interacted with the hybrid indicator, which is the variable of interest, is remarkably similar to the regression where we used the model specific rebates. This coefficient is positive and significant in all specifications, and stays around 0.35. The coefficient on the rebate variable alone is either zero or negative, implying that non-hybrid cars lost market share as the rebate programs were introduced.[29] Consider the preferred specification, with province∗segment and segment∗year effects. We find that the tax rebate had a negative and significant effect on the sales of non-hybrid vehicles. This implies that the effective coefficient of the rebate on hybrid vehicles alone is approximately 0.34 which is the same as in the corresponding specification for the model specific rebate variable (see Table 4).

Next, in Table 6 we present results for the regression with the maximum provincial rebate interacted separately with each of the 15 vehicle classes.[30] The rebates are again weighted in the introductory year according to the month of introduction. We run the same four specifications. Note that the hybrid rebate increases the share of hybrid vehicles in a positive and significant manner in all specifications, as the coefficient on the interaction between the hybrid and the rebate variable is positive and significant. The coefficient value stays around 0.3 which demonstrates its robustness further. Across all four specifications only three classes are robust in losing market share associated with the rebate; intermediate cars, intermediate sports utilities and sports passenger cars (which are primarily high performance compact cars). For example, in the first three specifications we find that the rebate was associated with a decrease in the share of large sports utility vehicles. However, when we include province∗segment fixed-effects and segment∗year fixed-effects this coefficient is not significant anymore.

Based on the estimates from specification 4 of Table 6 we can assert that a one thousand dollar increase in the tax rebate increases the share of hybrid vehicles among all new cars sold by approximately 34%, with a 95% confidence interval

[27] We use data from years before the introduction of the rebate programs to better estimate model fixed effects and province-class fixed effects. Results are similar if we restrict the sample to the years 2000–2006.

[28] The estimates remain significant when we cluster standard errors by province-year. We cannot cluster by province since there are only 10 provinces and for the OLS asymptotics to be valid, the number of clusters needs to be large relative to the number of within cluster observations. When we cluster by province-year the standard errors on the key variables are similar and the significance levels are unchanged.

[29] Note that the coefficient on the max rebate variable increases significantly when province-year fixed effects are included. This is due to the high correlation between the max rebate (which changes by province and year) and the province-year fixed effects. This is another reason for why we prefer the final specification in column 4 among all the regressions presented.

[30] The omitted category is compact passenger cars. Note that hybrid cars that received rebates are included as a separate category.

Table 6
Maximum rebates: all classes.

Depvar: log market share	(1)	(2)	(3)	(4)
Subcompact PC*max rebate	−0.03	−0.05	−0.05	−0.02
	(0.07)	(0.07)	(0.07)	(0.07)
Intermediate PC*max rebate	−0.29	−0.29	−0.29	−0.11
	(0.05)**	(0.05)**	(0.05)**	(0.05)*
Sports PC*max rebate	−0.21	−0.17	−0.16	−0.13
	(0.06)**	(0.06)*	(0.06)*	(0.07)*
Luxury PC*max rebate	0.17	0.13	0.14	−0.1
	(0.06)**	(0.06)*	(0.06)*	(0.06)
Luxury sports PC* max rebate	0.15	0.16	0.18	−0.15
	(0.07)*	(0.06)**	(0.07)**	(0.08)
Luxury high end PC*max rebate	0.25	0.28	0.29	−0.11
	(0.06)**	(0.06)**	(0.06)**	(0.07)
Compact SUV*max rebate	−0.07	−0.08	−0.08	−0.09
	(0.06)	(0.05)	(0.05)	(0.06)
Intermediate SUV*max rebate	−0.21	−0.25	−0.24	−0.19
	(0.06)**	(0.05)**	(0.05)**	(0.06)**
Large sports utility*max rebate	−0.18	−0.22	−0.22	−0.05
	(0.07)*	(0.07)**	(0.07)**	(0.08)
Luxury SUV*max rebate	0.25	0.21	0.23	−0.14
	(0.06)**	(0.06)**	(0.06)**	(0.07)
Small van*max rebate	−0.11	−0.14	−0.14	−0.09
	(0.06)	(0.06)*	(0.06)*	(0.06)
Large van*max rebate	−0.13	0.03	0.03	−0.04
	(0.09)	(0.08)	(0.08)	(0.1)
Small pickup truck*max rebate	−0.08	0.02	0.02	−0.04
	(0.07)	(0.06)	(0.06)	(0.07)
Large pickup truck*max rebate	−0.13	−0.16	−0.16	−0.02
	(0.07)	(0.07)*	(0.07)*	(0.08)
Rebated hybrids*max rebate	0.32	0.27	0.28	0.28
	(0.08)**	(0.08)**	(0.08)**	(0.08)**
Max rebate	0.06	0.04	−0.6	0.05
	(0.04)	(0.04)	(0.05)**	(0.04)
Model FEs	Yes	Yes	Yes	Yes
Province FEs		Yes		
Year FEs		Yes		
Province-year FEs			Yes	
Province-segment FEs				Yes
Segment-year FEs				Yes
Constant	−6.75	−5.54	−5.48	−6.79
	(0.01)**	(0.03)**	(0.07)**	(0.04)**
Observations	38,110	38,110	38,110	38,110
R-squared	0.72	0.75	0.76	0.78

Standard errors in parentheses. Superscripts * and ** denote significance at 5% and 1%, respectively. Sample extent: all model-generations, all years from 1989 to 2006.
Maximum rebates are weighted according to the monthly distribution of sales.

of 21–47%.[31] We also find that while buying more hybrids consumers bought fewer non-hybrid intermediate passenger cars, intermediate SUV's, and high performance compact cars. We find that non-hybrid vehicles in other classes did not see a statistically significant reduction in their market shares from an introduction of these policies. The best selling hybrid passenger cars (the Toyota Prius and the Toyota Camry Hybrid) in the Canadian market are priced roughly in the range of high end intermediate passenger cars. These vehicles are classified as intermediate vehicles and offer characteristics that are similar to other intermediate passenger cars. Thus consumers who buy the hybrid vehicle are likely to substitute it for a vehicle that costs approximately the same and offers them comparable vehicle characteristics. A similar argument can be made for the other two vehicle segments affected. High performance compact cars (classified as the segment sports passenger cars, which includes the Honda Si series, the Toyota Corolla Sport, the Volkswagen GTI, and the Honda Insight)[32] have prices and characteristics roughly similar to those of the smaller hybrid passenger cars (such as the Honda Civic Hybrid, and the Honda Insight). Finally, the same argument can be used to explain why intermediate SUV's experience a decline in sales from the introduction of rebates for hybrid vehicles. The most popular hybrid SUV's—such as the Ford

[31] The exact percentage value of the mean effect was obtained by the calculation $100[\exp(0.28)-1]$. The confidence interval was obtained using a similar calculation on $0.28 \pm 1.96*0.08$.

[32] More traditional high performance sports cars such as the Chevrolet Corvette, all Porsche models, Acura NSX and the Nissan Z series are included in the category Luxury Sports Passenger Cars, which is unaffected by the rebate.

Table 7
Cost of rebates: hybrids vs other cars.

Year	BC			Ontario			PEI			Quebec			Manitoba			Canada		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
2000	61	17.2	93.1	258	–		2	–		72	–		6	–		399	17.2	93.1
2001	151	21.1	102.1	198	22	97.5	2	–		55	–		12	–		418	21.6	99.5
2002	103	21.1	95.1	247	31.4	100.8	1	–		74	–		9	–		434	26.3	99.6
2003	160	21.1	107.0	262	31.4	106.6	1	–		142	–		23	–		588	26.3	106.7
2004	641	25.3	90.2	953	31.4	101.3	7	59.3	143.1	349	–		33	–		1983	38.7	98.1
2005	1401	52.8	200.2	1936	31.3	145.4	24	67.6	289.5	654	–		120	–		4135	50.6	175.3
2006	2202	52.7	242.4	3475	49.4	170.8	55	67.5	294.7	1188	26.5	171	293	8.1	107.9	7213	40.8	191.7
All	4719	30.2	200.9	7329	32.8	150.5	92	64.8	273.9	2534	26.5	171	496	8.1	107.9	15,170	32.5	169.8

Note: For each province, Col. (1) represents actual sales of hybrid vehicles in the corresponding year. Col. (2) represents the authors' calculations of the percentage of these hybrid sales that were induced by the rebates. Col. (3) contains estimates of the cost per tonne of CO_2 saved.
Estimates are based on the results of Table 5, using only hybrids vs non-hybrids.

Escape Hybrid and the Toyota Highlander Hybrid—are classified by the industry as intermediate SUV's (though they are in a separate category, along with all other hybrids, in our regressions) and have prices that are in the range of high end intermediate SUV's.[33]

6. Counterfactuals

We use the results from Tables 5 and 6 to calculate the fuel savings associated with the various rebate programs. Unlike Table 4 these two tables list the results from regressions using the provincial maximum rebate as a regressor and allow us to easily calculate the impact of the rebate programs on non-hybrid vehicles. We calculate the fuel savings by predicting consumer choices on hybrid and non-hybrid vehicles made in the absence of the rebate programs.

Using the estimated coefficients from each specification, we first calculate fitted market shares, $\hat{s}_{mvt}$, by taking the exponential of the predicted dependent variable. In a similar way, we calculate fitted market shares setting the rebate variable to zero, s^*_{mvt}. Since the coefficient on the rebate variable is negative, and the coefficient on the rebate interacted with the hybrid segment indicator is positive, these fitted values predict lower market shares for hybrid vehicles and correspondingly higher shares for all other vehicles, in the absence of the rebates. We use the ratio of these fitted values, multiplied by true market shares, $(s^*_{mvt}/\hat{s}_{mvt})_* s_{mvt}$, to calculate counterfactual market shares and hence the predicted number of cars sold, for each model and in each province and year, in the absence of the rebates. We impose an adding-up constraint which specifies that the total number of new cars sold in a given province and year is unchanged under the new policy.

We then calculate the fuel savings associated with these programs using data from the EPA on the average fuel efficiency of each model. The fuel savings depend on the relative fuel efficiency of hybrid cars that consumers were induced to buy vs those cars that they would have bought had the rebates not been offered. We used data from Statistics Canada on the average number of miles driven per automobile by province and year to calculate the total gasoline consumption in each case. We sum these savings across all models and account for the fact that the average car is on the road for 15 years.[34] By converting the gasoline savings into a savings of carbon dioxide (using the conversion factor of 2.4 kg of CO_2 emitted per liter of gasoline from Natural Resources Canada) we calculate the total CO_2 emissions saved. We also estimate the total cost of these rebates by summing up individual rebates across models.[35]

In Table 7 we present information from this counterfactual exercise using results from the fourth column (with province∗class and class∗year fixed effects) presented in Table 5 where all vehicles are classified as either a hybrid vehicle or a non-hybrid vehicle. The cost per tonne of CO_2 saved ranges from $93.1 in the province of BC in 2000 to $294.7 per tonne in the province of PEI in 2006.[36]

In Table 8 we present results using the estimates from the fourth column of Table 6 instead. The calculations here use more information than those of Table 7 since we estimate rebate coefficients interacted with each of 15 categories, plus hybrid vehicles in their own category, rather than simply dividing the data into hybrid and non-hybrid cars. We calculate the probability of substitution between hybrid cars and other individual classes, and can therefore predict which classes

[33] In the online appendix we present results using the rebate variable adjusted for month of introduction using the median adjustment, as opposed to the sales weighted adjustment (discussed in Section 3.2). Note that the results are almost identical, with hybrid cars seeing a large and significant increase as a result of the rebates, at the expense of intermediate passenger cars, intermediate SUVs and high performance compact cars.

[34] Our assumptions on vehicle age are based on data given in Desrosiers [3].

[35] These calculations do not account for a *rebound effect*: on acquiring an HEVs the owner is likely to increase their driving due to a lower marginal cost of driving per kilometer. If this is true the gasoline savings associated with these programs will be smaller, and the cost per tonne of carbon emissions saved would be higher than estimated here. In other words, if we believe that a 'rebound' effect exists we should expect these programs to be more expensive than what we estimate.

[36] All dollar amounts in this paper are in nominal terms.

Table 8
Cost of rebates: 16 classes of cars.

Year	BC			Ontario			PEI			Quebec			Manitoba			Canada		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
2000	61	13.1	132.0	258	–		2	–		72	–		6	–		399	13.1	132.0
2001	151	16.2	140.7	198	16.9	128.9	2	–		55	–		12	–		418	16.6	133.9
2002	103	16.2	129.2	247	24.5	129.6	1	–		74	–		9	–		434	20.4	129.5
2003	160	16.2	140.3	262	24.5	134.3	1	–		142	–		23	–		588	20.4	135.9
2004	641	19.6	114.7	953	24.5	126.1	7	48.9	159.0	349	–		33	–		1983	31.0	122.8
2005	1401	43	239.3	1936	24.5	177.2	24	57	256.0	654	–		120	–		4135	41.5	210.8
2006	2202	43	270.2	3475	40	187.5	55	57	262.1	1188	20.5	169.3	293	6.2	137.7	7213	33.3	209.3
All	4719	23.9	236.2	7329	25.8	173.5	92	54.3	249.6	2534	20.5	169.3	496	6.2	137.7	15170	26.1	195.2

Note: For each province, Col. (1) represents actual sales of hybrid vehicles in the corresponding year. Col. (2) represents the authors' calculations of the percentage of these hybrid sales that were induced by the rebates. Col. (3) contains estimates of the cost per tonne of CO_2 saved.
Estimates are based on the results of Table 6, using hybrids vs 15 other classes of cars and the weighted rebate variable.

would have increased their market shares in the absence of rebate programs, and the fuel savings associated with this counterfactual scenario.[37]

The cost per tonne saved now ranges from $128.9 in Ontario in 2001 to $270 in the province of BC in 2006. Across all provinces and years, the average cost per tonne of CO_2 saved is approximately $195. The corresponding cost for a liter of gasoline saved ranges from 31 cents in Ontario, 2001 to 65 cents in BC, 2006 with a Canada average of 47 cents a liter (the 2006 average price for a liter of gasoline in the major urban centers of Canada was $1.01).

BC and PEI are more expensive than the average, while Quebec is below the average. We find that there are two reasons for this. The first is that drivers in BC, for example, have a high preference for fuel efficient cars. Even within the affected vehicle segments (intermediate, intermediate SUV, and high performance compact cars) the average vehicle in BC is more fuel efficient than other provinces. Thus, rebates in this province are less likely to switch consumers from fuel inefficient vehicles to HEVs. The second reason is that the effect of the rebate is not linear. In BC in 2005, for example, when the maximum rebate increased from $1000 to $2000, the amount of gasoline saved rose by a factor of around 3, but the cost jumped by a factor of 7. This is because the subsidy for people who would have bought hybrid cars in any case doubled, while relatively fewer people were induced to switch to buying HEVs. This effect is also observed over time. As fuel prices peaked in our data (in 2006), vehicle buying trends moved towards the purchase of fuel efficient vehicles and the average cost per tonne of carbon dioxide saved rose over time across all provinces. Further, the highest rebates were offered in the provinces of BC, Ontario, and PEI after the year 2004, which also raised the cost over time.[38]

Overall, we find that the rebates are not cost-effective in any province if compared with the price of purchasing a tonne of carbon dioxide credits on the Chicago Climate Exchange (2.15 US dollars or approximately 2.6 Canadian dollars on January 30th 2009). It is also higher than the average price of a futures contract for a tonne of carbon dioxide settled in the European Climate Exchange in 2008 (at 25.50 Euros, or approximately 40 Canadian Dollars given the average exchange rate for 2008).

7. Conclusions

In this paper we analyze the cost-effectiveness of tax rebates for HEV's. We find that these rebates had a positive and significant effect on the market share of hybrid electric vehicles and a negative and significant effect on the market share of intermediate cars, intermediate SUVs and high performance compact cars. Vehicle sales in all other segments are unaffected. We use this information to construct estimates on the cost of fuel and carbon dioxide savings associated with the provincial HEV tax rebate programs. Our results suggest that these programs primarily subsidize people who would have bought hybrids or fuel efficient cars in any case.

There might be reasons for a relatively high cost of saving fuel or reducing carbon emissions to be acceptable. For instance, the rebate program might have been designed to accelerate the diffusion of HEV technology and take advantage of the economies of scale in vehicle production. However, the numbers of HEV's sold in Canadian provinces are probably too small for this purpose. Amongst provinces that provided rebates in the year 2006, the province of Prince Edward Island had the lowest number of HEV sales (only 55) and the province of Ontario had the highest number (with 3475 HEV's sold).

[37] We also calculated results using the rebate variable using the median adjustment rather than the weighted adjustment. The results are very similar to the ones using the weighted rebate and are not presented here.

[38] This explains why, for example, the lowest cost region for reducing carbon consumption was BC, in 2000, and the highest-cost region was also BC, in 2006. Although BC is generally a high-cost region due to the vehicle purchasing patterns of its residents, it was also the only province offering rebates in the early part of the decade, when gasoline prices were low.

Even in the aggregate, vehicle sales numbers in Canada are too low to justify providing rebates for this purpose.[39] Another reason could be benefits other than fuel savings and carbon emissions reductions from HEV's. Research suggests that HEV's are associated with lower local air pollutants [5]. While a complete analysis of these benefits is beyond the scope of this paper, it seems unlikely that these gains could justify the large cost differential between the costs from the programs and buying carbon dioxide permits in an exchange. Finally, hybrid cars might generate local network externalities that provide valuable information for non-adopters in the same area and thus spur the subsequent purchase of these cars. Our analysis is not designed to capture such local network externalities and we are thus unable to determine whether their magnitude is large enough to make the estimated high costs of supporting HEV's worthwhile.

By exploiting the variation in rebates across time and province we are able to gain insight into what determines the cost of such programs. We find that the rebate program is more expensive in BC than other provinces. This is because people in BC buy relatively smaller and more fuel efficient vehicles than those in other provinces. The rebate program is also significantly more expensive in the last two years of our analysis. There are two reasons for this: first, the last two years of our analysis are also the years with the highest gasoline prices. Thus the cars sold in these two years are on average more fuel efficient than those sold earlier. Second, the last two years are also the years when big provinces of BC and Ontario offer large rebates for HEV's. This raises the cost of the program disproportionately compared with the savings associated with the rebate.

In summary, the results in our paper indicate that hybrid tax incentives structured as they are in Canada may not be the most effective way to encourage people to switch away from fuel inefficient vehicles like large SUV's or luxury sport passenger cars, at least in the short or medium run. In order to effectively shift people away from fuel inefficient vehicles, the government might need to explore alternative policy options.

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[39] The overall sales for HEV's in Canada for the year 2006 was only 8924 HEV's which is dwarfed by the USA where 263,271 HEV's were sold in the same year. In other words the government of a larger market (such as the USA) could possibly use such policies to accelerate the diffusion of HEV technology.