CAHIER DE RECHERCHE #1901E
Département de science économique
Faculté des sciences sociales
Université d'Ottawa

WORKING PAPER #1901E
Department of Economics
Faculty of Social Sciences
University of Ottawa

Assessment of Electric Vehicle Incentive Policies in Canadian Provinces[*]

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April 2019

[*] I would like to express my most sincere gratitude and appreciation to my supervisor, Professor Nicholas Rivers from the Graduate School of Public and International Affairs at University of Ottawa, for his excellent guidance and insightful comments in all steps of this paper preparation. I also thank Professor Louis Hotte, Professor David Gray, Professor Maya Papineau, Professor Anthony Heyes, and Professor Philippe Barla who have provided me with invaluable advice and constructive comments. Finally, I thank Matthew Klippenstein from Green Car Canada for providing me with the data required to perform the statistical analysis in this paper.
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Abstract

This study aims to find the effects of financial point of sales incentives on the sales of electric vehicles across the Canadian provinces from September 2012 to December 2016. My findings indicate that purchase incentives cause the sales of new electric vehicles to increase by 8 percent on average due to a $1000 increase in incentives. I find that 47% of electric vehicle sales across the rebating provinces (Ontario, Quebec, and British Columbia) are attributed to the purchase incentives. Results of the counter-factual simulations imply that the cost of eliminating one tonne of carbon emissions across the provinces that offer incentives over the years of my study is, on average, $216/tonne CO_2*.*

2 Introduction

In line with the Canadian federal government's plan to mitigate climate change[1], the federal and provincial governments began to implement a series of policies to reduce greenhouse gas (GHG) emissions. The transportation sector, as the second largest contributor to GHG emissions[2], has been a major target for various policy initiatives across the Canadian provinces. Among various policies, the transition to electric mobility is likely to be a key component in achieving provincial and national emission targets.[3] Therefore, provincial governments began to put in place a range of policy initiatives including electric vehicle (EV) purchase and private charger incentives, unrestricted access to high occupancy vehicle (HOV) lanes, public charging deployment, and carbon taxation and cap-and-trade policies.

This study intends to estimate the impacts of financial purchase incentives on electric vehicle sales using data on sales and incentive amounts by model, province and month from September 2012 to December 2016. I attempt to answer three questions: (1) Do financial incentives encourage consumers to switch away from conventional gasoline vehicles to electric cars? (2) Do changes in gasoline price affect consumers' propensity to purchase electric vehicles? (3) Have the purchase incentive programs been cost-effective in reducing carbon emissions?

Differences in the presence and generosity of the incentive programs across provinces and time serves to identify incentive in this study. The provinces of Ontario, Quebec, and British Columbia offered incentives of differing values on the purchase/lease of new electric vehicles. Ontario and Quebec changed incentive generosity over time and at different points in time, and British Columbia stopped the incentive program in February 2014 and restarted as of April 2015. Also, the incentive amounts vary across electric vehicle models depending on the model attributes and price within each of the rebating provinces.

Other advantages of this study are explained as follows. First, unlike the rebate programs in the form of income (or sales) tax deductions/waivers, the calculation of Canada's incentive programs offered at the time of purchase doesn't require additional data (on income distribution or provincial sales tax, for example). I have access to model-specific incentive data allowing us to incorporate incentives into the models without having to make unnecessary assumptions on the calculation of incentives. Second, I are able to control for the potential correlations that exist between incentives and time-invariant unobserved preferences for

[1]According to the 2015 Paris Accord, Canada set a target to reduce greenhouse gas (GHG) emissions 30% below 2005 levels by 2030.

[2]In Canada, the transportation sector was responsible for over 25% of emissions in 2016 (Environment and Climate Change Canada (2017)).

[3]Axsen et al. (2016) reports that "electric vehicles can reduce emissions by 45% to 98% compared to a gasoline vehicle with Canada's current electricity grid".

each electric vehicle model using model-specific fixed effects. Finally, observing EV sales by month has made it possible to incorporate the changes in incentive programs in the exact months they occur, as well as to control for unobserved factors that vary by month within a particular year.

According to the results of my preferred regression, I find that a $1000 increase in rebates increases the sales of electric vehicles by 8 percent.[4] I also find changes in gasoline prices as another important factor in electric vehicle sales. My results suggest that on average, a 10 cents per liter increase in gasoline prices would result in a 2.8 to 6.1 percent increase in electric vehicle sales.

I calculate the number of electric vehicle sales caused by the incentive programs in each province and year. I find that incentives have been responsible for about 47% of electric vehicle sales in the rebating provinces from 2013 to 2016. This implies that almost half of the new electric vehicle buyers would still have purchased electric vehicles even if they had not been offered incentives. Therefore, a part of the government expenditures on incentives were allocated to consumers who would have bought electric vehicles regardless of the rebates.

I then evaluate fuel savings associated with the incentive programs by calculating the aggregate sales-weighted fuel consumption (using counter-factual sales and other data on vehicle fuel efficiency and average kilometers traveled) in the presence of incentives, and comparing that with fuel consumption of other conventional cars which would have replaced electric vehicles if incentives had not been offered. The fuel savings are then converted into equivalent carbon emission savings using the emissions produced from electricity and gasoline in each province and year. Overall, the lifetime (i.e., 10 years in this study) carbon emission reductions of the EVs sold as a result of the incentive programs are estimated to be 60,000 tonnes on average across the rebating provinces between 2013 and 2016.

Finally, carbon emission savings are divided by the government expenditures on incentives to construct the cost of emissions displaced due to the incentive programs. The cost of carbon emissions reduced is estimated to be on average $216 per tonne across the rebating provinces over this period. This calculation accounts for the emissions produced by electricity generation.

Throughout the paper, I first review the growing literature on different federal and state-level incentive programs to promote the sales of more fuel efficient vehicles (including hybrid and electric cars). Next, I present a summary of the incentive programs by Canadian provincial governments from 2012 to 2016. I then move to the data and empirical methodology section to discuss the identification strategy and estimations models. I conclude by discussing

[4]Note that the econometric specifications in this study estimate changes in the market share of electric vehicles, instead of quantities sold, in response to changes in incentives. Since incentives do not affect aggregate new vehicle sales, the percent changes will be the same for both quantities sold and market shares.

the policy implications.

3 Literature Review

Several researchers and scholars have directed their attention to the factors that impact the adoption of hybrid and electric vehicles in the last decade. They address many socioeconomic and policy variables such as financial and non-financial supports by governments, gasoline prices and fuel costs, consumers' willingness to adopt fuel-efficient technologies, and hybrid and electric vehicles' characteristics and prices as the key determinants of hybrid and electric vehicle adoption. In this section, I will briefly explain the methodology and findings of some of the studies that focus on the impacts of financial incentives and gasoline price on hybrid and electric vehicle sales and summarize their findings in Table 1.

Beresteanu and Li (2011), Diamond (2009), and Gallagher and Muehlegger (2011) investigate the effects of rising gasoline prices and tax rebates, in the form of income tax deductions/credits or sales tax waivers, on hybrid vehicle sales using different empirical analyses over the same period (2000 to 2006) in US.

Beresteanu and Li (2011) conduct simulations to address the effects of rising gasoline prices and federal income tax deductions/credits on hybrid vehicle sales in 22 US Metropolitan Statistical Areas (MSAs). Following Berry et al. (2004), they use a structural method to estimate the demand and supply determinants of hybrid vehicle sales in the US automobile market by taking advantage of both household-level and aggregate market-level sales data. Then, using estimates of the structural model, they perform simulations to compare the cost-effectiveness of different support schemes.[5]

Diamond (2009) evaluates the effectiveness of government incentives (including federal tax credits, state-specific incentives, and other non-financial supports) and other socioeconomic factors (such as gasoline prices and annual miles traveled) on market shares of three hybrid vehicle models.[6] He estimates several models: cross sectional regressions on annual state-level market shares, and panel regressions using fixed, between, and random effects for each hybrid model separately. In addition, he evaluates state-specific responses to financial incentives using monthly sales data in nine individual states where a significant incentive policy was implemented.

Gallagher and Muehlegger (2011) address the affects of various forms of state incentives on the adoption of hybrid vehicles using quarterly sales data in US. They examine the effect

[5]They perform simulations on the sales of five hybrid models: Ford Escape Hybrid, Honda Civic Hybrid, Honda Accord Hybrid, Toyota Highlander Hybrid, Toyota Prius, separately, as well as on the total sales of all hybrid vehicles in each year from 2000 to 2006.

[6]Honda Civic Hybrid, Toyota Prius, and Ford Escape.

of both magnitude and form of different state incentives on hybrid adoption by utilizing within-state∗model variation in incentives and gasoline prices.

All the above studies conclude that rising gasoline prices have greater effects on hybrid vehicle sales than federal tax incentive schemes from 2000 to 2006 in US. As shown in Table 1, the magnitude of the incentive and gasoline price effects, however, differ across these studies. As argued by Beresteanu and Li (2011), one of the important reasons for the larger effects of gasoline price is associated with the substantial increases in gasoline price (from $1.75 in 1999 to $2.60 in 2006), which explain 37% of the increase in hybrid vehicle sales over this period. This is while tax incentives were found more effective in the final year of their study (i.e., in 2006) when more generous tax incentives were in effect; subsidies across the five hybrid models, on average, increased from $460 in 2005 to $1860 in 2006. These studies also attribute the greater impacts of gasoline price to (1) consumers' perception of gasoline price as the most visible signal in fuel savings, and (2) willingness to purchase hybrid vehicles over conventional cars to avoid the uncertainty and volatility of future gas prices in the calculation of future fuel costs. Finally, they show that financial incentives given at the time of purchase have shown greater impacts on hybrid sales than future income tax credits (up to ten times larger effects by sales tax waivers according to Gallagher and Muehlegger (2011)).

In Canada, Chandra et al. (2010) estimate hybrid vehicle sales in response to variations in rebates (sales tax reductions or waivers) over years, across provinces, and across hybrid vehicle models within each province from 1989 to 2006. They find, in their most comprehensive specification, that provincial rebates increase market share for hybrid vehicles by 31-38% whereas the gasoline price has no significant impacts on vehicle shares over this period. They attribute the insignificant effects of the gasoline price to the correlations between fuel costs and various year and model-specific fixed effects in their regressions.[7]

In addition to the studies on hybrid vehicle sales, many of the recent studies examine policies to promote the purchase of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) across the US states. Narassimhan and Johnson (2014) and Clinton et al. (2015) perform similar analyses to estimate the effects of state-level monetary incentives and other demand stimulating factors on EV model registrations (per capita) prior to 2014. Using random effects models on both BEV and PHEV registrations (per capita) from 2008 to 2014, Narassimhan and Johnson (2014) find purchase rebates and income tax credits to have significant positive effects on BEV purchases only, not PHEVs. Clinton et al. (2015)'s analysis find similar impacts of tax credits on BEV purchases (after excluding Tesla BEV from the analysis) using fixed effects regressions on BEV registrations (per capita) from 2011

[7] They use hybrid model-specific fuel costs as a measure to exploit gasoline price variations over time and across provinces and vehicles and therefore find perfect correlation between fuel costs and various year and model-specific fixed effects.

to 2014. Unlike Clinton et al. (2015)'s findings, gasoline prices appear to have increased both BEV and PHEV purchases over the period of Narassimhan and Johnson (2014)'s study.

Regarding the effect of other EV support programs, Narassimhan and Johnson (2014) find heterogeneous effects of high occupancy vehicle (HOV) exemption on BEV and PHEV purchases. Their findings indicate that HOV exemptions have no statistically significant impacts on BEV sales whereas they lead to a 0.31% higher PHEV sales. Clinton et al. (2015)'s study finds no statistically significant effects of HOV exemptions and charging infrastructure on BEV sales due to lack of variation in these support programs over this period.

In the previously mentioned studies in the US where incentives are mostly in the form of income or sales tax deductions/waivers, the calculation of rebates is dependent on the vehicle price or the distribution of income. This adds more complications to the analysis and may require additional assumptions on the calculation of incentives. In the current study, however, the incentives offered to electric vehicles are in the form of point-of-sale subsidies (up-front purchase price reductions off the pre-tax vehicle list price for eligible EV models purchased/leased) rather than tax deductions/waivers. Another advantage of this study is associated with time-series and cross sectional analysis which, unlike some cross sectional analyses in the literature, allows for variations in the timing and generosity of the incentive programs across the rebating provinces. This leads to the isolation of the effect of incentive programs after eliminating the effects of many unobserved regional and temporal factors that may affect EV purchase decisions. While there may still be some unobserved factors influencing EV sales, the identification in my analysis relies on weaker assumptions as compared to the identification in the cross sectional analyses in other studies.

This study, to the best of my knowledge, is the first to address the effects of Canadian provincial point-of-sale incentives on electric vehicle sales. It is most closely related to Chandra et al. (2010). However, my approach contributes in several ways. First, using monthly sales data allows us to more precisely incorporate the timing of the incentive policies in each of the provinces that implemented the incentive programs. For example, British Columbia ceased the incentive program between February 2014 and April 2015, changes in sales in response to this policy change can be precisely evaluated using monthly sales. Second, I observe the list of electric vehicle models eligible for incentives as well as the corresponding incentive amounts associated with each electric vehicle model in each of the treated provinces.[8] This is advantageous as it allows us to use the exact incentive amount offered to each electric vehicle model without having to make unnecessary assumptions on the calculation of incentives. Finally, I use various combinations of fixed effects to control for the unobserved provincial and

[8]My data is obtained directly from the ministries of each of the rebating provinces and covers the electric vehicle models eligible for incentives and the corresponding incentive amount associated with each model.

temporal factors, including other EV support programs, that may influence electric vehicle sales.

4 Electric Vehicles and An Overview of Provincial Incentives Programs

Plug-in electric vehicles (PEVs), which are usually referred to simply as electric vehicles (EVs), consist of two subgroups: battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). BEVs only operate on electricity and do not require gasoline as a fuel source at all. The batteries are rechargeable when plugged into an electric vehicle charger and, depending on the model and battery size, they can travel anywhere between 100 to 500 kilometers on one charge. PHEVs, on the other hand, operate on both electricity and gasoline.[9] Again, depending on the make and mode of the PHEV, they run the first 20 to 60 kilometers on electricity on a single charge and then switch to using gasoline if they run out of charge. For the rest of the paper, EV will be used to point to any type of electric vehicle regardless of its fuel type (i.e., whether it is a BEV or PHEV).

Following the introduction of new policy initiatives towards reducing carbon emissions in Canada after 2010,[10] provincial governments put into effect new policies to promote EV adoption. A short list of the programs that have been offered to induce demand for EVs and facilitate their use includes point-of-sale rebates on the purchase/lease of a new EV as well as financial incentives on private charging stations, non-financial incentives (such as unrestricted access to lanes for high occupancy vehicles and free parking), public charging stations, carbon pricing policies (i.e., carbon tax and cap-and-trade policies) to increase the price of gasoline, regulating policies to reduce the price of low-carbon electricity, and finally developing educational campaigns to raise public awareness about EVs.[11] Table 2 presents the demand-based policies that were in place across Canadian provinces from 2012 to 2016. Over the period of this study, public charging deployment was the only demand-focused

[9]PHEVs, similar to traditional hybrid electric vehicles (HEVs), use two propulsion methods, a combustion engine and an electric motor. HEVs usually draw their power from the electric motor at low speeds and switch to the internal combustion engine to generate power at high speeds. PHEVs, however, use their electric motor to power all aspects of propulsion and will continue to operate until battery runs out of charge. PHEVs are essentially electric vehicles that require gasoline to extend driving range. With PHEVs, energy savings are much more substantial than HEVs (Electric Vehicle News (2012)).

[10]According to Axsen et al. (2016), the goal of 40% new electric vehicle market share is defined as an excellent EV policy progress to meet Canada's long-term plan to reduce greenhouse gas emissions.

[11]There also exist many supply-based incentives that support the research and development of EVs and provide incentives for manufactures and suppliers to increase production and sales. Zero emission vehicle mandates, vehicle emission standards, and low-carbon fuel standards are also examples of supply-based policies. The analysis of the supply-side factors is out of the scope of this study.

policy effective in all ten provinces.[12] Although all provinces began to provide infrastructure to facilitate EV adoption, the three provinces of Ontario, British Columbia, and Quebec engaged in more comprehensive policies to accelerate demand for EVs, each at different points in time, after 2010.[13]

As the first Canadian province that regulated an Electric Vehicle Incentive Program (EVIP), Ontario started offering financial point-of-sale incentives for the lease or purchase of new EVs in December 2010. According to the EVIP program, a rebate of $3000 to $8500 was applied to the lease or purchase price of each eligible EV after all applicable taxes and costs have been applied. The rebate amount varies across new EVs depending on the make, model, fuel type (whether they are BEVs or PHEVs), and the electric battery capacity, model year and year of acquisition. Ontario also offered up to $1000 rebate for private charging stations at the time. Among non-financial incentives, in July 2010, Ontario Ministry of Transportation (MTO) launched Green License Plate Program which granted access to high occupancy vehicle (HOV) lanes on 400 series of highways. Under this program, vehicle charging stations are also eligible for rebates of up to $1000 or 50% of the total purchase and installation cost, whichever is lower. In November 2015, greater Green Investment Funds were granted to support more charging stations across Ontario. In February 2016, EVIP increased the rebate amount granted to EVs to cover between $3000 to $13000 of the lease or purchase price. The rebate amount increases as the battery size and passenger capacity of an electric vehicle rises.[14]

British Columbia announced the Clean Energy Vehicle (CEV) program in November 2011 to encourage the adoption of clean energy vehicles. The CEV program was designed to increase sales of battery and plug-in electric, compressed natural gas, and hydrogen fuel cell vehicles.[15] This program consisted of two phases. Phase 1 of the program that ran between December 2011 to February 2014 provided a rebate of $2500 to $5,000 (depending on the make, model, battery size and net weight of each vehicle) on the pretax Manufacturer's Suggested Retail Price (MSRP) of a new purchased or leased eligible EV. Since 2011, the province also introduced other EV support programs such as unrestricted access to HOV lanes and incentives for replacing older vehicles with EVs. Moreover, British Columbia's carbon tax policy sets the highest price on carbon emissions in Canada, which stayed at $30/tonne during this period. The provincial government stopped the rebate program for over a year

[12] In 2015, there were 20, 168, 49, 71, 28, 51, 49, 260, 146, 29 public charging stations in AB, BC, MB, NL, NB, NS, ON, PEI, QUE, and SK.

[13] According to the Axsen et al. (2016), the number of direct and indirect EV supportive policies varies across Canadian provinces with Quebec (32 policies), Ontario (26 policies), and British Columbia (19 policies) taking the lead in having implemented the largest number of policies, respectively.

[14] A part of these information are obtained from Power (2016).

[15] Hydrogen fuel cell vehicles were not available to the public throughout the CEV program.

between February 2014 to April 2015 as the full budget allocated for 2013/2014 fiscal year had been depleted. The second phase of the program began in April 2015 with the same incentive amount but on a broader range of EV models. CEV Infrastructure Deployment Program also provides funding for EV charging stations and upgrading existing hydrogen fueling stations, general infrastructure design, academic research, curriculum development, and outreach on clean energy vehicles and infrastructure.

In January 2012, the province of Quebec implemented a purchase or rental rebate from $500 to $8000 to individuals, businesses and municipalities willing to purchase a new EV. In November 2013, the purchase or lease rebate amount ranged from 4500$ to 8000$ for new EVs and a $1,000 rebate was also available for low-speed EVs. Like the other two rebating provinces, Quebec also provide EVs with privileged access to reserved lanes where carpool is authorized. In addition, Quebec launched the largest charging network system in Canada, called Electric Circuit, to improve access to public and private charging infrastructure and provided a rebate of up to $600 for purchasing and installing private charging stations. Besides the Drive Electric Program, a cap and trade policy was adopted to impose tax on carbon in 2013. Once again, the rebate amount varies across vehicle models depending on the vehicle's selling price, electric battery capacity, model year, year of purchase, and so on. Later in 2015, Quebec launched a Transportation Electrification Action Plan offering a series of policies to increase the availability of electric public transportation. Several major initiatives were undertaken by this action plan including electric public transportation and school buses plan, supporting pilot projects for the electrification of taxi fleets, installation of several more public and private charging stations along main roads, multi-unit residential buildings, new office buildings, and for on-street parking, research and innovation activities to support projects related to transportation electrification, and education and awareness programs to promote the use of EVs.

Table 3 shows the average rebates (in dollar values) offered to an EV in each of the provinces that offered purchase incentives in this period.

In this study, I will focus on the demand-side factors that influence new EV purchases with a particular attention to financial purchase incentives. I am unable to assess the effect of other demand-inducing factors such as HOV-lane access, charging stations, and private charging incentives: I do not have data on the number of charging stations,[16] and there are no variations in incentives on private charging stations and HOV-lane access over time in the rebating provinces.[17] Failure to account for the effect of these policies may result in omitted

[16] The number of charging stations across the rebating provinces are only publicly available for 2016.

[17] In British Columbia, the monetary incentives on private charging stations were renewed in April 2015 in conjunction with the EV purchase incentives (after the cease of the incentive program for over a year as of February 2014).

variable bias. In section 6, I will discuss how I take advantage of different identification techniques and various combinations of fixed effects to account for the effect of these additional incentive programs.

5 Data

In order to address the effects of financial incentives on new EV purchases, data from various sources are combined together. The EV sales data is obtained from IHS Automotive Canada and is made accessible by Green Car Canada. This data-set includes monthly sales of new EVs by make and model from September 2012 to December 2016. Therefore, markets are defined as province-year-month in my analysis. The IHS Auto data does not include non-EV sales and also does not dis-aggregate sales within the model by fuel type or battery capacity or other vehicle characteristics. As such, I use monthly sales reports from Green Car Canada to dis-aggregate sales by fuel type, which defines whether the vehicle is a BEV or PHEV. Green Car Canada also reports dis-aggregated estimates for monthly sales of EV models: Toyota Prius, Ford C-Max and Ford Fusion, where both hybrid and plug-in hybrid variants exist.[18]

In addition to EV sales data, I obtain the total automobile unit sales (including the sales of passenger cars and trucks separately) in each province and month from Statistics Canada.[19] Aggregate monthly sales data allows me to find the market share of each EV model from the total vehicles sold in each market.

The list of all eligible EV models as well as the corresponding incentive amounts (in dollar value terms) offered to each model are directly collected from the Ministry of Transportation in Ontario and British Columbia and from the Ministry of Energy and Natural Resources in Quebec.[20] Using the exact incentive amounts allocated to each particular EV model allows us to capture incentive effects without having to make unnecessary assumptions to calculate incentive values. As an alternative way to incorporate incentives into the analysis, I use the ratio of incentives to vehicles' list prices by utilizing the Manufacturer Suggested Retail

[18]Green Car Canada estimates the number of electric Ford Fusion and C-Max sales there have been in Canada by taking the sales numbers from Quebec (which are reported in provincial registration numbers periodically) and applying a best-guess of what the nationwide monthly numbers are. For example, for Toyota C-Max PHEV, Green Car Canada estimates monthly Canadian sales assuming Quebec represents 2/3 of electric market in Canada and 2/3 of Quebec C-Max's are plug-in electric.

[19]Statistics Canada, CANSIM, Table 079-0003, New motor vehicle sales, Canada, provinces and territories, annual. 2015.

[20]In each of the rebating provinces, EV manufacturers must apply for the eligibility of every model they desire to qualify for incentives to the Ministry of Transportation and re-apply for each vehicle model and trim already in the program every year.

Prices (MSRPs) data available online at MSN AUTO for each model-year generation.[21] This alternative measure is used to provide insights about the relative incentive effects across different EV models with differing prices. The challenge associated with using vehicle list prices, rather than transaction prices, is that list prices do not account for the dealers' and manufacturers' incentives and the negotiations between the dealer and buyer at the time of purchase. I will discuss this challenge and explain how this might bias the incentive estimates in the econometric specification section (section 6).

To account for the effect of gasoline prices, I calculate dollar value savings from driving one km in an EV compared to driving one km in an average gasoline vehicle using: $F_{jpt} = (FE_{pt}^{Gasoline} * GasolinePrice_{pt}) - (FE_{jpt}^{EV} * ElectricityPrice_{pt})$. The dollar value savings (F_{jpt}, measured in ¢/km) is the cost incurred by driving one km of an average gasoline vehicle (i.e., the first term) minus the cost incurred by driving one km in EV j (i.e., the second term) in province p and year t. The fuel costs of driving one km in a vehicle is the product of its fuel efficiency rating (denoted by FE) and the price of fuel consumed by the given vehicle (i.e., electricity price (in ¢/kWh) for EVs and gasoline price (¢/L) for gasoline cars in my calculation). Natural Resources Canada (NRCan) provides data on fuel efficiency ratings of all EV models (in kWh/100 km) and the fuel economy of an average non-EV model (estimated to be 10.7 (L/100 km)).[22]

I obtain the average tax-inclusive retail gasoline price from Kent Group Ltd.'s survey for retail gasoline, diesel and automotive propane pump collected daily from gas stations in 70 urban cities in Canada. Since Kent Group only reports gasoline price data for major urban cities, I take the average gasoline price of the cities that belong to each province to account for monthly provincial averages in my analysis.[23] Monthly electricity price data are available at Statistics Canada's consumer price index series (Statistics Canada, CANSIM, Table 326-0020).[24]

Finally, I control for provincial demographic trends over months and years using Statistics Canada's surveys. To capture monthly variations in income, I use real labor income calculated from seasonally adjusted wages, salaries and employers' contributions (in 1000 dollars) from the survey of "Estimates of Labor Income". I also control for monthly variations in unemployment rate, as well as annual variations in the fraction of female population, the

[21] I account for year-to-year changes in their list price in my data except for a number of EV models whose list prices did not change over time.

[22] As documented by Rivers and Schaufele (2017), I assume that the fuel consumption rating of an average gasoline vehicle stays relatively unchanged over time.

[23] I follow this procedure for all provinces except for Ontario and Quebec, for which, Kent Group Ltd. provides monthly average prices in their survey.

[24] I also perform my estimations using alternative electricity price data from "Comparative Index of Electricity Prices", residential consumers (in cents per kWh), using HydroQuebec reports: "Comparison of Electricity Prices in Major North American Cities" (2017).

percent of adults (between 20 and 65 years of age) with a college diploma, and median age in each province using Statistics Canada's CANSIM database.[25] All nominal dollar values are normalized to real terms based on the 2002 prices to account for inflation.

Table 4 presents the summary statistics for the EV sales data, provincial incentives, gasoline prices, and socioeconomic measures. Accounting for EV model-level data in addition to province-month data, there are a total of 5644 observations, corresponding to 10 provinces, 52 months, and an average of 10 EV models in each province and month. As shown in the table, there are on average 91 EV sales, with a low of 0 and a high of 649 sales, in each market with BEVs comprising about 42% of total EV sales. The average sales-weighted incentive value across the three rebating provinces over the years of study is $2786, with a minimum of zero dollars offered in BC between February 2014 to April 2015 and a maximum of 7973$ in Ontario in 2014. Excluding the period in BC where incentive programs were inactive, the average sales-weighted incentive value across the rebating provinces becomes larger ($6296), with a minimum of $2465 in BC in 2015. Also, the incentives offered to BEVs are, on average, two times greater than those offered to PHEVs.

6 Identification Strategy and Econometric Specifications

In this section, I will discuss the identification and empirical strategy used to estimate changes in EV market shares in response to the presence and variations in purchase incentives and gasoline prices across provinces and over time. I will also explain how the effects of other observed and unobserved temporal and provincial factors, including other support programs (such as public charging infrastructure, access to HOV-lanes, and monetary incentives on private charging stations, and etc.) are accounted for in my analysis.

Figure 1 shows the trends for EV sales and gasoline prices in Canada from September 2012 to December 2016. The number of new EVs sold, and the real average tax-inclusive retail gasoline price ($/L), across provinces and months are presented.[26] According to this graph, monthly EV sales are, on average, growing substantially over time starting from below 500 sales per month in 2012 to above 1500 in 2016. On the other hand, gasoline price levels are high but they are on average decreasing during this period, changing from high rates of around $1.1/L in the beginning of this period to lower rates of about $0.8/L towards the

[25] These data are collected, respectively, from the seasonally adjusted labor force of working age (15 years and over) that are unemployed (Table 282-0087), the Standard Geographical Classification (SGC) reports (2016), Table 477-0019, and Table 051-0001 of CANSIM database.

[26] As mentioned in the data section, retail tax-inclusive gasoline prices are deflated based on the 2002 price index.

end. It is hard to explain the relationship between monthly gasoline prices and EV sales only based on visual observations of movements during this period.

I also provide Figure 2 to show the aggregate trends in EV market share from total vehicle sales across provinces during the period of study. The Y axis shows the market share of all EVs from total sales of all vehicles sold in the rebating provinces against the rest of Canada in each month. I include all the provinces that don't offer incentives in one group:"Rest of Canada", to avoid overcrowding the graph. As is visually clear in the graph, the trends in the three provinces where EV incentive policies are in effect show substantially higher market shares versus the rest of Canada. The divergence in trends in the treated provinces from the trends in other provinces during 2012, which is the time when rebates were effective in all three treated provinces, is apparent. In the three leading provinces, EV market share trends start at rates lower than 0.01 in 2012 but increase in the following months with Quebec and British Columbia continuing to increase at higher rates than Ontario. The trends in Quebec and British Columbia move at approximately the same pace during 2013 and 2014, but in the last two years, British Columbia outpaces Quebec. This can be attributed to the fact that British Columbia restarted its Clean Energy Incentive policy in April 2015 after it was stopped for more than a year from February 2014.

I intend to capture variations in EV market share trends across provinces and over time, as portrayed in Figure 2, as part of my empirical analysis. However, there may be other time and province specific factors that may influence new EV purchases and are not visible in the graph. Later in this section, I will explain the fixed effect strategies used in my empirical analyses to control for the unobserved temporal and provincial factors that may be correlated with the purchase incentives.

Overall, there are four sources of variation across provinces, over time, and across EV models which allow us to identify incentive effects. The first source is associated with the number of provinces that implemented incentive programs; only three provinces offered purchase incentives to EVs. The second source is related to the generosity of the incentive programs across the rebating provinces in any given year as these provinces differ in the incentive amounts they offer. Also, the incentive amounts vary across different EV models within a given province-year. And finally, there are variations in the incentive amounts offered to a particular EV model within a given province over time (except in Quebec).[27]

[27]Quebec is the only province whose rebate treatment didn't change from 2012 to 2016 and therefore the incentive amounts offered to most eligible EV models stayed unchanged for the duration of my data. There were only a number of EV models whose incentive treatments underwent slight changes over this period. For example, the rebates offered to a Mitsubishi i-MiEV were \$7731 in 2012, \$7731 in 2013, \$8000 in 2014, no incentives in 2015, \$8000 in 2016. Another example is Toyota Prius (PHEV) which was offered \$4607.60 in 2012, \$500 in 2013, \$4000 in 2014, \$500 in 2015, and no incentives in 2016. Due to these small changes in the incentive treatments designed for particular EV models, the mean value of incentives will also vary

My empirical strategy follows the conventional discrete choice model of demand for differentiated products. Assume that there are K vehicle models in each market (province-time) and the price of model k is p_{kpt} $(k \in 1, 2, \ldots, K)$. The utility that individual i will obtain from purchasing a new vehicle in each market can be characterized as:

$$U_{ikpt} = \alpha_i (Y_{ipt} - p_{kpt}) + \beta_i X_k + \epsilon_{kpt} + \lambda_i F_{kpt} + \varepsilon_{ikpt}, \tag{1}$$

where Y_{ipt} represents individual i's income and therefore α_i captures the marginal utility of income. β_i captures vehicle k's observed (by consumers) attributes (X_k), ϵ_{kpt} accounts for the unobserved (by an econometrician) attributes, F_{kpt} is an index for fuel savings for vehicle k[28], and finally ε represents the mean zero stochastic term that captures individual i's unobserved preferences for a particular vehicle. Indexes p and t represent province and time, respectively, and time is defined as month-year in this model.

I incorporate incentives into the analysis by decomposing a vehicle's price into two components: a model-year specific mean (p_{kt}) and a province-time-specific incentive associated with a particular model (Incentive_{kpt}). More precisely, I assume that the price of a particular model consists of a list price that is constant across provinces and an incentive associated with province-specific rebate policies towards purchasing electric vehicles. The price of a particular vehicle can therefore be defined as:

$$p_{kpt} = p_{kt} - \text{Incentive}_{kpt}, \tag{2}$$

where $\text{Incentive}_{kpt} = 0$ for a non-electric vehicle.

I now rewrite the utility function after inserting the vehicle price components:

$$U_{ikpt} = \alpha_i Y_{ipt} - \alpha_i (p_{kt} - \text{Incentive}_{kpt}) + \beta_i X_k + \epsilon_{kpt} + \lambda_i F_{kpt} + \varepsilon_{ikpt} \tag{3}$$

Instead of purchasing a new vehicle, individual i may choose to purchase an outside good and spend their income on other goods than vehicles. I define $U_{i0pt} = \alpha_i Y_{ipt}$ as the utility obtained from purchasing the outside good as I assume that consumers will choose one unit

slightly over time (see Table 3), allowing us to capture average incentive effects in Quebec as well. I was unable to obtain data on provincial EV sales prior to the implementation of incentive programs and therefore can not perform a comparison analysis on the pre versus post effects of incentives on EV sales. I attempt to estimate all models once by including Quebec and another time by eliminating it from the analysis; the results are statistically significant across all models and the magnitude of the effects do not change significantly across models. Additionally, I estimate a model using Quebec as the only treated province (versus non-treated provinces) and find that incentives still have positive significant effects on EV shares but with smaller magnitude compared to the specifications that include all three treated provinces.

[28]Similar to the calculation of fuel savings for an EV model explained in Section 5, fuel savings for any other vehicle model can be calculated from the difference between the given vehicle's fuel costs and that of an average gasoline vehicle.

of the good (a new vehicle or an outside good) that provides the highest utility. Suppose that j denotes a particular EV model ($j \in 1, 2, \ldots, K$). Then, the probability that consumer i will purchase EV j among all $k \in 1, 2, \ldots, K$ and the outside good is:

$$P_{ijpt} = Pr(U_{ijpt} > U_{ikpt}) \quad \text{for} \quad k \in 0, 1, 2, \ldots, K, j \in 1, 2, \ldots, K, \text{and} \quad j \neq k \tag{4}$$

By decomposing preferences into deterministic and random components ($U_{ikpt} = V_{ikpt} + \varepsilon_{ikpt}$),[29] I allow the probability of choosing a particular EV model to be derived from the differences between utilities from the available alternatives (rather than the absolute values of individuals' utility, i.e., $P_{ijpt} = Pr(V_{ijpt} - V_{ikpt} > \varepsilon_{ikpt} - \varepsilon_{ijpt}) \quad \text{for} \quad j \neq k$.

The aggregate market shares for EV j (s_{jpt}) can then be found by integrating over preferences of all individuals in each market:

$$s_{jpt} = \int_{\varepsilon} I(V_{ijpt} - V_{ikpt} > \varepsilon_{ikpt} - \varepsilon_{ijpt} \quad \text{for} \quad j \neq k) f(\varepsilon) d\varepsilon, \tag{5}$$

where I is an index that takes a value of one if the condition in Equation 5 is satisfied and zero if otherwise.

I assume that for all individuals in my analysis, $\alpha_i = \alpha$, $\beta_i = \beta$, and $\lambda_i = \lambda$, meaning that there is no systematic heterogeneity across individuals' preferences and the only source of heterogeneity is in the mean zero stochastic term. Assuming that the error term ε_{ikpt} for all individuals is distributed independently and identically multivariate type-I extreme value, there is a closed form solution for the integral in Equation (5) that yields the standard logit model: $s_{jpt} = \frac{e^{V_{jpt}}}{\sum_K e^{V_{kpt}}}$, where s_{jpt} is the market share of EV j from total vehicle sales in each market.

Finally, I divide the share of EV j by the share of the outside good (s_{0pt}) and estimate the log odds ratio of purchasing a new EV relative to the outside good as a function of product characteristics using the following standard logit specification:[30]

$$\log(\frac{s_{jpt}}{s_{0pt}}) = \alpha p_{jt} - \alpha \text{Incentive}_{jpt} + \beta X_j + \lambda F_{jpt} + \epsilon_{jpt}, \tag{6}$$

where p_{jt} is the list price of EV model j (i.e., the manufacturer's suggested retail price (MSRP)), Incentive$_{jpt}$ in the province-time specific incentive amount offered to each EV model, X_j and ϵ_{jpt} are EV j's observed and unobserved attributes, respectively, and finally

[29] The deterministic component V_{ikpt} captures consumers' observable attributes as well as vehicles' observable and unobservable attributes, and the random term ε_{ikpt}, captures consumers' unobservable preferences over their vehicle choice.

[30] Note that dividing the equation by s_{0pt} and taking logs will cancel out Y_{ipt} and ε_{jpt} from the equation.

F_{jpt} is defined as the dollar value savings (in ¢/km) from driving one kilometer in an EV compared to driving one kilometer in an average vehicle.

The coefficient of interest, α, captures the effect of incentives (in dollar values) on the log odds ratio of purchasing a new EV relative to an outside good in a given market. More specifically, it indicates a shift in preferences from the outside good (i.e., not purchasing a new vehicle at all) to purchasing a new EV due to incentives. This implies that the consumers who would not have purchased any new vehicle in the absence of incentives would choose to buy a new EV when offered incentives. If this has happened, the total number of new vehicles sold in a given market must have increased in response to incentives. To test whether this has happened, I estimate the extensive margin effects of incentives on total vehicle sales in each market after eliminating the provincial and temporal unobserved factors and find that incentives have no significant impacts on aggregate sales.[31] As a result, for the rest of the models in my study, I will use model-specific market shares (as opposed to the odds ratios) as the dependent variable. I will further explain the details of incentive effects on total vehicle sales in the Extensive Margin Effects section (section 8).

The challenge with estimating Equation (6) is that the unobserved EV attributes are likely correlated with EV prices and potentially with other EV observed attributes and therefore may create biased estimates. As such, all estimating equations include EV-model fixed effects to control for all the observed (X_j) and unobserved[32] model attributes that only change across EV models but are constant over time and across provinces.[33]

As mentioned previously, I do not have EV transaction price data and therefore can only control for vehicle list prices in my models. Although the model-specific fixed effects will capture the observed and unobserved vehicle attributes (including vehicle prices), they may not fully control for vehicle transaction prices and the negotiation between the dealer and buyer at the time of purchase. In this study, I estimate a reduced-form impact of incentives on EV shares, therefore, α captures the average equilibrium impact of incentives on EV shares that includes both consumer and manufacturer response to the incentives.

Moreover, several time-varying and provincial factors, in addition to purchase incentives, can influence EV purchases. I employ various combinations of fixed effects to account for these unobserved factors that are correlated with the incentives and might affect EV sales. The fixed effects used in my estimations define the source of identification. In specifications

[31] Many studies in the literature also find it unlikely that financial incentives would affect total vehicle sales in a given market. For example, Chandra et al. (2010) find no evidence that tax rebates would influence consumers to shift preferences from not buying a vehicle at all into buying a new hybrid vehicle.

[32] This refers to the first component included in ϵ_{jpt} that doesn't vary by time and province: $\epsilon_{jpt} = \epsilon^1_j + \epsilon^2_{jpt}$.

[33] Attributes such as make, model, engine type, fuel economy, battery size, number of cylinders, interior and exterior design, performance, and the time and province invariant component of the vehicle retail price (excluding rebates).

without vehicle-province fixed effects, the identification is cross sectional. The challenge with the cross sectional model is that I am unable to differentiate between unobserved preferences by province and vehicle since changes in preferences over time can either be attributed to vehicle characteristics or provincial attributes. As such, I raise the precision of fixed effects by including EV-model-province and EV-model-time fixed effects to account for all the province and time specific factors that might affect the sales of an EV model. Finally, in the most comprehensive model, I apply the highest resolution of fixed effects: EV-model-province, EV-model-time, and province-time fixed effects, to identify the incentive effects based on variations in individual EV model shares within a given province over time in response to the presence and variations in incentives.

EV-model-time (denoted by ϕ_{jt}) and EV-model-province (denoted by ω_{jp}) fixed effects capture the unobserved time-varying and provincial preferences for individual EV models, respectively. EV-model-time fixed effects control for national time-varying unobserved factors that might influence EV sales; year-specific demand shocks, federal regulations and taxation on the vehicle market, and other federal environmental regulations on fuels are examples of such factors. EV-model-province fixed effects are designed to capture the unobserved provincial characteristics that are more consistent with the use of particular EVs. Some examples of these time-invariant provincial factors are climate, geography, density, road structures, culture, and make up of the population, popularity of a given EV in a particular region, perception of the population about environmentalism, and etc. In addition to these unobserved factors, the province fixed effects (interacted with each EV model) also control for the effect of other time-invariant provincial incentive programs, including HOV-lane access and monetary incentives on private charging stations, that are correlated with the purchase incentives.[34] Finally, province-time fixed effects (denoted by κ_{pt}) capture the unobserved preferences across EV models within a given province and year. These unobserved factors also include time-varying provincial regulations in the vehicle market that occur in conjunction with the purchase incentives and therefore might affect EV sales. Regulations such as public charging infrastructure[35] and the extensive policies and funding to support more public charging stations over time, the cap and trade policy to impose tax on carbon in Quebec in

[34]It is worthwhile to add that some empirical evidence in the literature find smaller impacts of support programs such as HOV-lane access and public charging stations on EV sales relative to monetary incentives. Axsen et al. (2016) estimate that HOV-lane access and public charging deployment have an overall impact of 0.57% and 7.8%, respectively, on market shares in the Canadian EV market by 2040. This is while financial purchase incentives are estimated to have a market share impact of 10% by 2040. Some other empirical evidence are explained in the Literature Review.

[35]The programs to deploy public charging infrastructure in the rebating provinces are: the Green Investment Funds Program in Ontario (launched in November, 2015), CEV Infrastructure Deployment Program in British Columbia (launched in November 2011, updated in April 2015), and the Electric Circuit Program in Quebec (launched in November 2013).

2013, the Transportation Electrification Action Plan to provide electric public transportation in Quebec in 2015, and so forth.

Including the preferred fixed effect combination into the model leaves the error term with a mean zero component that varies by time and province (μ_{jpt}) in the following estimation:

$$\log s_{jpt} = \alpha \text{Incentive}_{jpt} + \lambda F_{jpt} + \omega_{jp} + \phi_{jt} + \kappa_{pt} + \mu_{jpt} \tag{7}$$

α is expected to be positive and can be treated as the percent change in the market share of a particular EV model due to a $1000 increase in incentives. For example, assuming that α is 0.09, the market share of a Chevrolet Volt, with an average share of about 0.00059 in Ontario over the period of study, increases to 0.00063 due to a $1000 increase in incentives. As mentioned previously, I also use incentive to the EV's base price ratio as an alternative measure for incentives in my models. λ captures the effect of fuel cost savings associated with driving an EV (compared to a gasoline vehicle) (used as logs and measured in ¢/km) on EV shares, and measures the percent change in EV market shares due to a one percent increase in fuel cost savings. Linear regression with fixed effects is applied to estimate Equation (7) and the standard errors across all the specifications are clustered by province∗class to allow the unobserved characteristics of particular EV classes within a province to have serial correlations with one another over time.[36] It is important to address an issue that arises upon the transformation of the dependent variable to logarithm in the above equation. As there are many zero sales observations in the data (3223 out of 5620 observations), the log transformation of EV shares creates several missing observations. I take advantage of a number of methods suggested in the literature to overcome this problem and explain them in greater details in the next section.

6.1 Alternative Specifications and Zero Sales Observations

In this section, I explain a few approaches that I use to fix the problem associated with the substantial zero sales observations in my data following the methods suggested in the literature. Figure 3 provides the histogram of individual EV shares from total vehicle sales in each market in level and logarithm to show the relevant influence of the mass observations at zero compared to the rest of the sample. The left panel shows a right-skewed distribution for EV market shares with a mean and standard deviation of 0.0001 and 0.0004, respectively. The extensive tail of this distribution reaches to 0.007, which corresponds to the maximum market share level in the sample. The density distribution of the transformed shares (to logarithm)

[36] For example, compact EVs that are within a given province are more likely to undergo similar province-specific changes over time (due to the geography of the region, the make up of the population in that region and etc.) than compact EVs across provinces.

shown on the right panel, however, is closer to normal distribution and clearly has a higher minimum and average (0.0003 and 0.006, respectively) as it corresponds to a smaller sample including only positive shares. Although this sample represents an approximately normal distribution, it is clearly observed that lots of zero share observations are omitted from the sample. In the following subsections, I will explain the methods used to overcome the challenge with the zero market share observations.

6.1.1 Linear versus Generalized Linear Regressions

In my first attempt to deal with zero market shares, I estimate a standard linear regression using market shares (in levels) as the dependent variable. While a standard linear regression is a practical and reasonable approach and the transformation of market shares is not necessary due to the nature of the variable (as ratios), using shares imposes a few problems on the estimation: it would ignore the zero lower bound and therefore would not take account of the decisions of not buying an EV, it predicts non-positive values for market shares, and more importantly the relationship between the dependent and independent variables is not linear due to the large number of observations at zero. As a result, for these specifications, as suggested by Papke and Wooldridge (1996), I take another approach and use Generalized Linear Models (GLM) with a binomial distribution and a logit link function.[37] I only present the GLM results (instead of the results of the standard linear regressions, which I present in the appendix) and apply the different combination of fixed effects (on all market shares including zeros) explained previously to allow for comparison across models with different identification and unobserved controls. These models are also used as a benchmark for comparison with the rest of the methods discussed in this section in dealing with zero share observations.

Another common practice that is widely used in the literature is to add an arbitrary constant that is smaller than the smallest observed positive share (0.000001, in my analysis) to all market share observations to avoid missing data after log transformation. For this specification, I use the same independent variables as in Equation (7) and only apply the most preferred fixed effects (i.e., EV model-time and EV model-province fixed effects). However, as argued by Gaudry et al. (2009) and many other scholars in this literature, this method may imply drastic changes to the data since the results depend on the choice of the arbitrary constant and there is no reason to prefer one value over the others;[38] this can create large negative outliers especially when I am dealing with too many zeros in the data. Having

[37]I also try other potential family and link functions including inverse Guassian and log-gamma but only include the results of the binomial-logit model as it shows to be the best fit among all regressions.

[38]For example, the natural logarithm of 0.01 equals to -4.6 whereas for 0.0001, it equals to -9.21.

mentioned this, I choose a constant that doesn't significantly change the magnitude of the log shares before and after this modification and also test this model using arbitrary constants of differing values to check the robustness of the results; I find that the magnitude and significance of the results are largely unaffected. I only include this model to show the consistency of the main coefficient based on this approach, but will present the results in the Appendix (due to the disadvantages of this model).

6.1.2 Aggregate Regressions

In the next three estimations, I attempt to reduce the number of zero observations by aggregating sales according to the following approaches. First, I aggregate sales by EV model, province, and year and apply a GLM regression using the same model as in Equation (7) except that the dependent variable is the share of each EV model from aggregate auto sales in a given province (p) and year (t) (i.e., time refers to a given year, rather than a year-month). Similar to the previous models, the effect of gasoline price is captured by using fuel cost savings (in ¢/km) for each EV model; the difference between the cost of driving a given EV and the cost of driving a conventional gasoline car in each province and year. I control for EV-model-province and EV-model-year fixed effects and cluster standard errors by province∗class. From the total of 507 observations (corresponding to 10 provinces, 5 years and an average of 10 EV models), there are only 82 observations with zero market shares.

Next, I aggregate EV sales by province and month and estimate the effects of province-wide mean incentives using:

$$s_{pt} = \alpha \text{Mean Incentive}_{pt} + \gamma Z_{pt} + \delta_p + \sigma_t + \xi_{pt} \tag{8}$$

where s_{pt} is EV monthly shares (from aggregate provincial vehicle sales),[39] Z_{pt} are time varying provincial characteristics, including log sales-weighted fuel cost savings from driving EVs rather than non-EVs (in ¢/km) in a given province and month,[40] log real per capita labor income and log unemployment rate, and δ_p and σ_t are province and time (i.e., year-month) fixed effects, respectively. Standard errors are clustered by province. The total number of observations in this particular model is 520 (10 provinces and 52 months) with only 50 observations corresponding to zero shares.

[39] I once divide EV monthly sales by total passenger cars in a given market and another time by total vehicle sales (including passenger cars and trucks) and find that results are not affected by the choice of this variable.

[40] The sales-weighted fuel cost savings of driving EV j in province p and time t is calculated using: $\frac{\sum_j^J (Sales_{jpt} * FuelSaving_{jpt})}{\sum_j^J Sales_{jpt}}$, which is the product of model-specific sales and fuel cost savings, aggregated over all EVs in a given market and divided by aggregate EV sales in that market.

In the last aggregate model, I divide provinces into four groups: Ontario, Quebec, British Columbia, and "Rest of Canada" and estimate the changes in each of the rebating provinces against the "Rest of Canada". The dependent and independent variables and fixed effects are the same as in Equation (8) except that for "Rest of Canada", I use aggregate EV shares over the provinces included in this group and the averages of each of the independent variables across the given provinces. Since a large number of EV models with zero sales in the data correspond to the provinces with no incentive programs, this level of aggregation leads to no zero share observation. Therefore, there are 280 observations for 4 groups of provinces and 52 months in this regression.

For both of the aggregate models by month, I perform additional estimations using log average tax-inclusive gasoline prices (measured in ¢/L) and log average electricity prices (measured in ¢/kWh), instead of sales-weighted fuel cost savings, to capture the effects of changes in gasoline and electricity prices on EV purchases. I find that including these variables do not affect the magnitude and significance of the incentive estimates. As such, I only include the results of these models in the Appendix.

Moreover, the advantage of aggregation by province and month is that, in addition to reducing the number of missing observations by large, these models evaluate the shifts in preferences from non-EVs to EVs in response to incentives and other determining factors in each market. With respect to other factors that likely induce EV purchases (versus non-EVs), a number of demographic variables (in addition to EV support programs and charging infrastructure) are found to be effective in some of the studies in the literature. For example, Narassimhan and Johnson (2014) find median age and percent of college graduates to have positive impacts on PHEV sales, and average residential energy consumption on BEV sales. My data allow us to account for the following annual demographic variables: median age, the fraction of females from total population, and percent of adults (i.e., 24 years above) with a college diploma. I include these variables in the monthly regressions reported in the appendix in addition to gasoline and electricity prices. These additional variables do not have statistically significant impacts on EV sales (versus non-EVs), which is likely due to the small variations in these variable over the years of my data.

Across all aggregate regressions, I apply GLM regressions (rather than log-linear or log-log regressions) as GLM shows to be a better model fit and produce economically meaningful estimates (both in terms of the coefficients' magnitude and statistical significance) in the aggregate models.[41]

[41] The results of the log-linear or log-log regressions of the same model are similar to the GLM results due to the lower number of zero shares in the aggregate models.

6.1.3 Olsen and Schafer Two-part Model

Finally, I employ the Olsen and Schafer (2001)'s model for repeated measurement of semi-continuous data, which is an extension of the two-part model of Duan et al. (1983) to longitudinal data, to take account of the disproportionately large frequencies of zeros. I choose this model over the other methods proposed in the literature to deal with zero observations (such as the Tobit model, the sample selection model of Heckman, and the compound Poisson exponential dispersion model) because of its appealing properties. Unlike the Tobit and Heckman models, this model doesn't assume an underlying normal distribution on idiosyncratic terms especially when zero observations represent actual response outcomes (instead of censored or missing values), has a well-behaved likelihood function, and finally allows for more appropriate interpretations when zeros are true values. The model consists of two parts: the first part is a logistic regression (logit estimation in my analysis) for a dichotomous variable R that takes a value of zero if market shares are zero, and one, if shares are greater than zero,[42] and the second part involves a log-normal regression of some parameters, defined as β_2 in the second stage, that affect the expected value $E[sharejpt|share_{jpt} > 0]$ conditional on market shares being positive (i.e., R=1).[43] The expected value of the dependent variable, EV model share, then consists of two parts: $E[share_{jpt}] = P(share_{jpt} > 0) \times E[share_{jpt}|share_{jpt} > 0]$. I use log fuel cost savings and incentives (in \$1000) as explanatory variables in each stage of the model. I also include EV-model-province, EV-model-time, and province-time fixed effects to control for the unobserved factors that vary by province, year, and by the interaction of the two and are correlated with the incentives.[44] Finally, as it is assumed that $E[\epsilon_2|share_{jpt} > 0, X_2] = 0$, the unconditional expectation can be given by $E[share_{jpt}] = \phi(\beta_1 X_1) \times \beta_2 X_2$.

[42] R = 1, if $share_{jpt} = \beta_1 X_{1jpt} + \epsilon_1 > 0$, and R = 0, if $share_{jpt} \leq 0$, with X_1 serving as a vector of explanatory variables as included in Equation (7).

[43] $E[share_{jpt}|R = 1, X_2] = E[share_{jpt}|share_{jpt} > 0, X_2] = \beta_2 X_{2jpt} + E[\epsilon_2|share_{jpt} > 0, X_2]$, with X_2 again serving as the determinants of EV shares as included in Equation (7).

[44] As the model allows using different explanatory variables in each stage of the model, I try different combinations of independent variables for each part. For example, in the first stage, I include log labor income per capita, log median age, log percent females, and log percent college graduates in the population, as additional explanatory variables to control for the factors that vary by province and time and can influence EV purchase decisions. For this specification, I only include EV-model-province and EV-model-time fixed effects. I find that none of these additional variables add much explanatory power to the estimation and the inclusion of these variables do not substantially affect the estimates for the key variables. As such, I include province-time fixed effects instead of these additional variables (in addition to EV-model-province and EV-model-time fixed effects) to account for the unobserved provincial and temporal factors in the main regressions.

6.2 Nested logit analysis

As explained previously, in logit models, the error term is assumed to be distributed identically and independently (iid) Type I extreme value. The Independence of Irrelevant Alternatives (IIA) property implicit in the logit model is the product of iid structure of the random shock. The IIA property imposes restrictions on the ratios of probabilities and/or on the cross-elasticities of probabilities and therefore can create unrealistic own and cross attribute (including price) elasticities. For example, in my analysis, the IIA implies that the ratio of choice probabilities between two EV models j and h only depends on the systematic utility of the two EV models (i.e., $\frac{P_{ij}}{P_{ih}} = \frac{e^{Vij}}{e^{Vih}}$) and is independent of the characteristics of other alternatives. As such, the probability of choosing a particular EV model over other EV alternatives is invariant to the number of alternatives as well as to the introduction or elimination of alternatives. It also means that substitutions across EV models depend only on their market shares and not on vehicle attributes. This is particularly important from a policy perspective as it may result in the misprediction of incentive effects. I make the following example (in the context of incentives offered to an EV) to explain the kind of misprediction that likely arises in logit models when a change in the attribute of an alternative can cause unrealistic substitutions across the available alternatives. Suppose that there are only three vehicle models in a vehicle market: a Toyota Corolla (a non-EV), a Nissan Leaf (an EV), and a Ford Focus Electric (also an EV which compares to Nissan Leaf in many regards). The probabilities that a consumer will choose each of these models (which are, in fact, equal to their aggregate market shares) are assumed to be 0.66, 0.33 and 0.01, respectively. Now suppose that the government decides to offer financial incentives to Ford Focus Electric buyers only and the incentive amount is sufficient to increase the probability of buying a Ford Focus by 0.09 (i.e., from 0.01 to 0.10). This incentive program results in a change in the final price of Ford Focus relative to the other two alternatives. The logit model would predict the probability of each of the other two alternative models to drop by the same percentage. The probability for Toyota Corolla would drop by 10% (from 0.66 to 0.60) and for Nissan Leaf would drop by the same 10% (from 0.33 to 0.30). This means that the increased probability of Ford focus is predicted by the logit model to come twice as much from Toyota Corolla (0.06) as from Nissan Leaf (0.03). This substitution pattern is unrealistic since Nissan Leaf is a closer substitute to Ford Focus (as they are both EVs and have many common attributes) and a change in the price of Ford Focus is expected to have a significant impact on the choice probability for the Nissan, but next to no effect on the choice probability for the Toyota. Therefore, the IIA property implies that a change in the attributes of an alternative changes the probabilities for all the other alternatives in proportion to their market shares (regardless of their attributes).

To overcome IIA, a few alternative models have been suggested in the literature. For example, Nevo (2001) suggests using nested logit and random parameter logit models. I use a nested logit specification to partially relax the IIA assumption. According to Nevo (2001), by grouping differentiated products into exhaustive and mutually exclusive nests in a way that products with similar attributes fall into one nest, I am allowing the within-nest products to have closer cross attribute elasticities with one another than with products from other nests.[45] For the nested logit specification in my analysis, I group all the EVs sold in each province and month in one nest to allow for more reasonable substitution patterns between EVs as compared to the simple logit model. This means that, in each market, in the first stage of purchasing a new vehicle, consumers decide whether they will buy a new EV or non-EV (rather than choosing between buying or not-buying a new vehicle).[46] Then, in the second stage, they choose which of the EV models, among all EV alternatives, they are willing to purchase. I choose this grouping as it allows all EVs to have closer substitutions with one another than with non-EVs, which is reasonable since EVs have similar attributes.[47] The nested logit equation can be characterized as follows:

$$\log(\frac{s_{jpt}}{s_{kpt}}) = \alpha \text{Incentive}_{jpt} + \pi \log(S_{j/J})_{pt} + \lambda F_{jpt} + \phi_{jt} + \omega_{jp} + \kappa_{pt} + \mu_{jpt} \quad (9)$$

The dependent variable is the logs odds ratio of purchasing an EV relative to a non-EV.[48] All the independent variables and indexes, as well as the combination of fixed effects, are the same as Equation (7). There is only one additional independent variable that is added to the equation: log of within-nest shares, $\log(S_{j/J})_{pt}$. This variable represents the share of an EV model from all EVs sold in a given market. Therefore, π captures the substitutability of EV models with one another and ranges between zero and one with one showing the highest substitutions between EVs within a given market. The within-nest share variable, however, is endogenous since any increase in the share of an EV model compared to a non-EV model in a given market will necessarily increase its share compared to other EV alternatives in that market. Therefore, I use instrumental variables (IVs) to account for the endogeneity of

[45] However, the nested logit model only partially relaxes the IIA assumption because the IIA assumption still applies to the unobserved attributes between products within each nest.

[46] As explained previously, incentives have not caused shifts in preferences along the extensive margin channel. As such, in my nested logit analysis, I will only account for purchase decisions along the intensive margin channel and use model-specific shares in a given market as the dependent variable (rather than the odds ratio of purchasing a vehicle).

[47] I also try grouping EVs by price, make, class, and engine type (BEV or PHEV) and check the robustness of the results based on these additional classifications as well. I find that the incentive effects do not substantially vary across models with different classifications.

[48] The denominator of this term, which I call the share-out variable, shows the fraction of the non-EV sales in each market and equals to (Total Vehicle Sales - Total EV Sales) / Total Vehicle Sales) , and the numerator defines the share of each EV model from total vehicle sales multiplied by (1 - share-out) in each market.

within-nest shares. Moreover, similar to the previous models, since there are several zero value observations for EV model shares as well as within-make shares in the nested logit model, using log shares will result in the loss of many observations. I then use a GMM regression on EV shares and within-make shares (both in levels rather than logs) after accounting for the endogeneity of the within-make share variable using IVs. Following Berry et al. (1995), I use the sum of characteristics of other EVs in the same market as EV j as instruments because these characteristics are correlated with within-nest shares but unlikely to be correlated with the EV to non-EV relative shares and the consumers' valuation of EV j. The consumers' valuation of EV j (relative to non-EVs) is only a function of EV j's own characteristics. Three characteristics of other EVs in the same market as EV j — motor horse power, the recharge time (hours needed to recharge an EV), and the fuel efficiency (both in liter equivalent and kWh per 100 km) are considered as potential IVs for EV model j.

7 Results

I present the results of the models described in section 6. I find that incentives have statistically significant positive impacts on EV market shares; relative change in EV market shares is between 6 to 17 percent due to a $1000 increase in incentives (depending on the fixed effects used in the estimations). In section 7.1, I discuss the findings of the regressions on market shares when various combination of unobserved factors are controlled for. Then I move to the rest of the models discussed previously to deal with zero sales observations. Finally, section 7.2 reports the results of the nested logit specification.

7.1 Main Results

Table 5 presents the results of GLM regressions on market shares using different arrangements of fixed effects. The application of GLM, as explained previously, will take into account zero EV sales and the non-linear relationship between the dependent and independent variables (unlike linear regressions). In all models, the dependent variable is the market share of a new particular EV model (from total auto sales)[49] in a given market. Columns 1 to 6 find the effect of incentives (in $1000) and log fuel cost savings (i.e., the cost of fuel saved due to driving 1 km in a given EV rather than a conventional gasoline car (in ¢/km)) on individual EV market shares using various combinations of fixed effects. Columns 5, 6, and 7 present the results of the preferred specifications. Column 5 presents incentive effects (in $1000), column 6 captures the differential effects of incentives on BEVs and PHEVs separately, and

[49]Using the total passenger car sales instead of total auto sales (which includes all passenger cars and trucks) doesn't significantly change the results.

column 7 reports the incentive effects relative to a given EV's MSRP. As mentioned earlier, I exploit two sources of identification by changing the fixed effect strategy. Columns 1 and 2 report the results of the cross sectional specifications. The combination of fixed effects in the preferred specifications in columns 5, 6, and 7 allows the identification to rely on within-province variations in EV market shares.

Column 1 displays the most parsimonious specification that only includes EV-model fixed effects. In column 2, I add time (year-month) fixed effects to capture national time-varying preferences that are correlated with the incentives. In column 3, I raise the resolution of fixed effects and add province fixed effects to column 2 to capture the unobserved preferences that vary by province. Province fixed effects control for time-invariant unobserved factors that are specific to each province; factors such as climate, geography, density, culture and make up of the population, and other EV support programs such as HOV-lane access and incentives on private charging stations. Column 4 includes province-time controls in addition to EV-model fixed effects. Province-time fixed effects capture the unobserved preferences that change by time, province, and by both. Examples of such factors are the number of charging stations and new provincial regulations and taxation on the vehicle market. Finally, columns 5, 6, and 7 report the most comprehensive specifications that include EV-model-province, EV-model-time, and province-time fixed effects. Identification in the preferred models comes from within-province variations in individual EV shares over time in response to the presence and variations in incentives and fuel cost savings.

It is evident that the effects of incentives on the market share of a particular EV model across these specifications are consistent in sign and statistical significance. The magnitude of the incentive effects does not substantially change as I raise the resolution of fixed effects across models. This is in particular true across the specifications that include province fixed effects. This indicates that the effect of other unobserved provincial and temporal factors, including other EV support programs (as stated above), have small impacts on the magnitude of the incentive estimates. This leads us to conclude that the omitted variable bias has minimal threats to the identification. The result of the most comprehensive model (in column 5) indicates that on average, a $1000 increase in the incentive offered to a particular EV in a given market is associated with a 8 percent increase in the market share of the given EV once EV-model-province, EV-model-time, and province-time unobserved factors are eliminated.[50] Results in column 6 suggest that the incentives have similar impacts on sales of BEVs and PHEVs, causing about 5 percent increase in sales of both EV types due to a $1000 increase

[50]It is important to mention that the results of the standard linear regression of these models (reported in Table 10 in the Appendix) indicate smaller effects (and inconsistent statistical significance) compared with the GLM results because of misrepresenting a linear relationship between incentives and EV shares and not taking into account the effect of zero share observations.

in incentives. By performing a Wald test for the hypothesis that the coefficients for BEVs and PHEVs are equal, I find that I can not reject the equality hypothesis. Therefore, the incentive effects appear to be similar on BEV and PHEV sales. Column (7) suggests that an increase in incentives by one percent of an EV's base price leads to a 3.8 percent increase in its market share.

Regarding the effects of fuel cost savings, the sign and statistical significance are not consistent across the columns. In column 2, since time and EV-model fixed effects are included, only variations in gasoline and electricity prices across provinces are identified by the fuel cost savings variable. As such, the differential effects of cross sectional variations in fuel savings on various EV models (depending on their fuel efficiency (in kWh/km) are captured. The coefficient estimate implies that a one percent increase in the fuel cost savings from driving a particular EV model (compared to a non-EV model) leads to a 0.24 percent increase in the share of the given model, all else equal. However, the model is cross sectional and therefore does not account for province-specific factors that might be correlated with the fuel savings. In column (3), province fixed effects are added and therefore the differential effects of fuel savings over various EV models within a given market is captured. As opposed to the previous model, the coefficient estimate is not statistically significant. In the last four columns, variations in gasoline and electricity prices (as components of fuel cost savings) are highly correlated with province-time fixed effects, and the fuel cost savings do not have statistically significant impacts on EV shares. Overall, none of the preferred models show statistically significant effects of fuel cost savings on EV shares.[51] In Table 6, I will show that fuel cost savings have significant positive impacts on EV market shares in the aggregate regressions.

In Table 6, I summarize the results of the remaining models discussed previously to overcome the problem associated with zero share observations. Column 1 reports the incentive and fuel cost savings effects on EV shares aggregated by model, province, and year. Results indicate that a \$1000 increase in model-specific incentives is associated with a 5 percent increase in the given model's market share. The costs of fuels saved due to driving one km in an EV (compared to a non-EV) have statistically significant impacts on EV market shares, indicating that a one percent increase in the fuel savings of an EV (compared to a gasoline car) is associated with a 0.26 percent increase in its market share. This implies that a 10 cents per liter increase in gasoline price on average would result in a 2.9 percent increase in

[51]Lack of statistical significance across the estimations on individual model shares can partly be due to the high correlations between energy prices (i.e., gasoline and electricity prices) and different fixed effects in my models. The fuel economy of an EV is highly correlated with EV-model fixed effects and gasoline price is correlated with province and time fixed effects. Chandra et al. (2010) also find that gasoline prices do not have statistically significant impacts on hybrid vehicle sales across the Canadian provinces due to similar reasons (i.e., correlations between gasoline costs and various province and time fixed effects).

EV sales.[52]

Columns 2 and 3 present the results of the aggregate EV sales by province and month across all provinces and across each of the rebating provinces versus the "Rest of Canada", respectively. For these two specifications, variations in the monthly share of EVs from total vehicle sales across provinces in response to changes in average province-wide incentives (in both measures) and log of aggregate sales-weighted fuel cost savings and other controls (i.e., log real labor income and log unemployment rate) are considered.[53] Consistent across both columns, a $1000 increase in average province-wide incentives causes a 7 percent increase in EV shares relative to non-EV shares (in the rebating versus non-rebating provinces).[54] Fuel cost savings (in ¢/km) has significant positive impacts on EV shares in both specifications. The coefficient estimates imply that a one percent increase in the fuel savings associated with driving 1 km in EVs (compared to non-EVs) in a given market leads to a 0.41 to 0.55 percent increase in EV market shares. In other words, a 10 cents per liter increase in gasoline price on average would lead to a 4.5 to 6.1 percent increase in EV sales.

Finally, columns 4 and 5 report the results of the Olsen and Schafer (2001)'s two-part model for longitudinal data. Both models find the effects of the incentives (in $1000) and log fuel cost savings on individual EV model shares once EV-model-province, EV-model-time, and province-time fixed effects are accounted for. These fixed effects control for all the unobserved factors that vary by province, year, and by both and can affect EV purchase decisions. Column 4 presents the results of the first part of the model using a logit regression to estimate the probability of purchasing an EV (relative to a non-EV) due to the incentives and log fuel cost savings. The first part of the model defines the probability of observing a zero versus positive market share. As observed in the results, incentives do not have statistically significant effects on the probability of purchasing an EV. Column 5 presents the second part of the model using OLS regression on the log of individual EV shares conditional on a positive market share. The effect of incentives is consistent with the estimates in the other specifications in the table, implying an 8 percent increase in the market share of a given EV model due to a $1000 increase in incentives conditional on buying an EV (significant at the 1% level). Fuel cost savings, similar to other estimations on individual model shares, do not have statistically significant impacts on EV purchases in neither of the stages of the two part model, although are positive in sign and close to the other fuel savings estimates in

[52]A 10 cents per liter increase in gasoline price is equal to 11% increase when compared with the mean value of gasoline price over this period (i.e., 90 cents per liter), and therefore would lead to a 2.9 ($0.26\times0.11=2.9$) increase in EV sales.

[53]In column 3, the monthly averages of fuel cost savings, real labor income, and unemployment rate in each of the rebating provinces and the "Rest of Canada" as a whole are considered.

[54]Using EV shares from total passenger car sales (rather than total auto sales) doesn't change the magnitude or statistical significance of the main coefficient.

magnitude.

Overall, across all the specifications in both tables, incentives show positive significant effects on EV market shares ranging from 6 to 17 percent (due to a $1000 increase in incentives) depending on the level of aggregation and arrangements of fixed effects. Results of the most flexible specification indicate an 8 percent increase in EV sales due to a $1000 increase in incentives. The results of my analysis are consistent with the results of some of the studies in the literature. For example, Gallagher and Muehlegger (2011) find that a tax incentive of $1000 value increases hybrid sales by 5% while a tax incentive of mean value (using a tax incentive dummy as alternatives to the value of the tax incentive across the US states offering incentives) results in 22% increase in sales. Narassimhan and Johnson (2014) shows that monetary incentives (in the form of purchase rebate, tax credit, or sales tax waiver) only have significant impacts on BEV purchases rather than PHEV purchases. They find that a $1000 purchase rebate leads to a 9% increase in BEV purchases. Chandra et al. (2010) also show in their most comprehensive model (with model-specific rebates) that a $1000 increase in the tax rebates increases the share of sales of new hybrid vehicles by 34%. My results show smaller effects for incentives on EV shares relative to the incentive effects found by Chandra et al. (2010). This may be due to the following reasons: (1) the relative influence of British Columbia's incentive program over the course of my study, compared to the other two rebating provinces, as well as the cease of the incentives for more than a year in this province, (2) lack of comparable variations in incentives over time in Quebec against the other two rebating provinces despite the high incentive rates offered in this province, and (3) as the price difference between EVs and gasoline vehicles are much larger than that of between hybrid and gasoline vehicles, a $1000 incentive would have much larger impacts on hybrid vehicle sales (than EV sales).

Lastly, my findings imply that the fuel cost savings associated with driving EVs compared to non-EVs also have significant impacts on EV demand. I find that a one percent increase in fuel cost savings leads to a 0.26 to 0.55 percent increase in EV shares in a given market. This is equivalent to a 2.9-6.1 percent increase in EV sales due to a 10 cents per liter increase in the real average price of gasoline over the period of study (i.e., 90 ¢/L as shown in Table 4). These effects are consistent with the estimates reported in other studies: Gallagher and Muehlegger (2011) find positive correlations between gasoline price and hybrid vehicle sales using US hybrid vehicle sales data from 2000 to 2006; Narassimhan and Johnson (2014) find variations in gasoline price as an effective factor in increasing Gallagher and Muehlegger (2011) estimate that the cross price elasticity of demand for hybrid vehicles with respect to gasoline price is 0.86. Narassimhan and Johnson (2014)'s findings indicate that a 1% increase in gasoline price leads to a 1.3% and 2.8% increase in PHEV and BEV purchases, respectively.

7.2 Nested Logit Results

As explained in the nested logit analysis, I employ an alternative specification to partially relax the IIA assumption implicit in the standard logit model defined in Equation (7). According to this model, I classify all EVs sold in each market into one nest because of the similar attributes that exist between EVs in a given market, and account for substitutions between EVs in that market by including the share of each EV model from total EV sales as an additional variable in the regression. The effects of incentives (in \$1000 and relative to the EV's base price) and fuel cost savings (¢/km) of driving an EV compared to a gasoline vehicle are then measured on the market share of a given EV model (from total vehicle sales in each market) after accounting for the share of that EV model from total EV sales in the given market. Results are presented in Table 7. The consistency of these results with the results of the specifications in the previous section is evident. The coefficient of interest implies that a one percent increase in incentive to the base price ratio is associated with a 2.9 percent increase in the share of sales of a particular EV model in each province and month after accounting for substitutions between all EVs in that market. This effect is equivalent to a 6 percent increase in EV shares due to a \$1000 increase in the amount of incentives. The coefficient π defines the substitutability between EVs within each nest and indicate that the EVs within each market are allowed to have higher substitutions with one another than non-EVs in that market. This coefficient is also significant positive and indicates that the substitutability between EVs with the same make is 37%. Finally, in line with the results of the previous models on individual market shares, fuel cost savings does not have statistically significant impacts on EV market shares.

8 Extensive Margin Effects

As discussed in section 6, a conventional differentiated products demand model suggests a closed-form solution for the aggregate demand of a particular vehicle model. According to Equation (6), the market share of a given EV is considered relative to the market share of the outside good (i.e., any product other than vehicles). As such, a positive coefficient for incentives would imply that any increase in incentives causes an increase in the probability of purchasing a new EV (relative to not purchasing any vehicle at all). As has been argued in the literature (for example by Chandra et al. (2010)), it is unlikely that rebates would cause shifts in preferences from not buying any vehicle at all into buying a new EV. In this section, I will investigate the extensive margin effect of incentives on new EV purchases and find whether total new vehicles sold in a given market have changed due to the incentives. I estimate:

$$\log \text{Sales}_{pt} = \alpha \text{Mean Incentive}_{pt} + \gamma Z_{pt} + \delta_p + \sigma_t + \xi_{pt} \tag{10}$$

where $Sales_{pt}$ is the total number of new vehicles sold in province p and time (year-month) t, incentives are province-wide averages (in \$1000), and Z_{pt} includes other time-varying provincial controls. Some of these controls change by province and month: log real gasoline price (inclusive of all taxes), log real labor income, and log unemployment rate, and some change by province and year: log median age, log fraction of females from total population, and log percent of adults (i.e., 24 years above) with a college diploma. δ_p and σ_t are province and time fixed effects, respectively.[55] I once estimate this regression using aggregate auto sales and another time using passenger car sales. Across all models, linear regression with fixed effects is applied and standard errors are clustered by province.

Results are presented in Table 8. Columns 1 and 2 are based on aggregate auto sales while columns 3 and 4 are based on aggregate passenger car sales. Columns 1 and 3 only include mean incentives as the explanatory variable and no other provincial controls are included. Columns 2 and 4, however, capture the effects of other provincial controls in addition to the incentive effects. I apply linear regressions with province and time (year-month) fixed effects, and cluster standard errors by province, across all specifications. Consistent across all models, incentives do not show any statistically significant effects on aggregate vehicle sales. This means that the incentive programs have no implications on the extensive margin and only cause shifts in preferences along the intensive margin channel (i.e, from non-EVs to EVs). I believe that the following reasons explain why incentives didn't affect total vehicle sales: (1) although EV sales are growing, they still constitute a very small share in the Canadian vehicle market with an average of about 0.34 of all vehicles sold across provinces in Canada, (2) EVs are normally more expensive than their non-EV counterparts, which also offer similar characteristics, and (3) the average incentives across provinces over this period only cover a very small portion of the price of a new EV. It is now reasonable to conclude that the incentive coefficient in the logit model implies that a fraction of the people who were willing to purchase a new vehicle regardless of the incentives decided to shift their preferences away from non-EVs to EVs due the incentives in the treated provinces versus non-treated.

According to the estimates of other provincial controls, real labor income and percent females from total population appear to have homogeneous effects on passenger and total vehicle sales. I find that a 1% increase in real labor income causes a 1.6% and 1.7% increase

[55] Time fixed effects consist of year and month dummies, respectively, as follows: $\sigma_t = \sigma_y + \sigma_m$.

in all vehicle and passenger car sales, respectively, and are statistically significant at the 5% level in both models.[56] Also, a 1% increase in the fraction of females from total population is associated with a 20% and 68% increase in total auto and passenger car sales, respectively. The remaining variables show heterogeneous effects on total and passenger car sales. Median age only has significant negative impacts on passenger car sales whereas real gasoline price and unemployment rate only have significant negative impacts on total vehicle sales (all at a 10% significant level). A 1% increase in real gasoline price and unemployment rate leads to 0.52% and 0.21% decrease in total vehicle sales, respectively.

9 Counterfactuals Simulations

In this section I use the results of the most preferred nested logit estimation presented in Table 7 to calculate counter-factual market shares and the number of EV sales that were induced by incentive programs in each province and month. I will then evaluate the cost-effectiveness of the incentive programs by calculating the total amount of CO_2 emissions (in tonnes) displaced due to the incentives.

First, I calculate the fitted market shares using the estimated α from Equation 8 to find the predicted shares in the presence of incentives (s^*_{jpt}). Analogously, I calculate the fitted shares after setting incentives to zero to find the predicted shares in the absence of incentives($\hat{s_{jpt}}$).[57] The predicted number of EV sales induced by the incentives (i.e., Sales^*_{jpt}) can then be measured using: $(s^*_{jpt} - \hat{s_{jpt}}) \times \text{Sales}_{pt}$, where Sales_{pt} is the total number of vehicles sold in each market.

I obtain the lifetime fuel consumption of each EV model using the predicted sales of the given model (i.e., Sales^*_{jpt}) multiplied by its fuel efficiency, average kilometers traveled, and the vehicle lifespan.[58] Natural Resources Canada (NRCan) provides data on fuel efficiency ratings of all BEV and PHEV models.[59] I use data on the annual vehicle miles traveled (VMT) collected from thousands of North American Ford BEV and PHEV owners from a survey reported in the EVS29 Symposium in Canada in 2016.[60] For all the PHEVs in my data,

[56] I find similar results when I use real labor income per capita, but use real labor income instead since this variable seems to be a better fit for both models in terms of the level of significance.

[57] Note that I take the exponential of the predicted share values since the dependent variable is in logarithmic form. Moreover, the estimation is on the share of sales of an electric vehicle from total auto sales in each province and month, therefore, the sum of predicted shares do not have to add to one.

[58] I assume for simplicity that an EV, like a conventional gasoline car, will stay on the road for 10 years.

[59] The fuel economy data for PHEVs reflect fuel consumption when operating on electricity (in kWh/100 km) and gasoline (in L/100 km) and also take into account the potential amount of gasoline usage while operating on electricity.

[60] CACKETTE (2017) measure average trip length and distance traveled by day, month, and year by the owners of Ford Focus Electric, Ford C-MAX Energi PHEV, and Ford Fusion Energi PHEV from Canada,

I take the average VMT and electric VMT (eVMT) for C-MAX and Fusion from this study and calculate their lifetime fuel consumption following: $[(\text{eVMT}_j \times \text{fuel-economy}_j^{electricity}) + (\text{VMT}_j \times \text{fuel-economy}_j^{gasoline})] * 10$. And for all BEVs, I use the annual eVMT for Ford Focus Electric and only account for electricity consumption.[61]

Next, I measure the total emissions produced in the presence and absence of incentives and calculate the amount of CO_2 emissions displaced as a result of the incentive programs. The carbon emission savings (in tonnes) is obtained from the difference between the aggregate emissions over all the predicted BEV and PHEV sales in my data (i.e., Sales_{jpt}^*) and the emissions generated by the conventional gasoline cars which would have replaced EVs if no incentives had been offered. For BEVs, only the emissions generated from electricity is considered after the carbon intensity of electricity generation in each province is accounted for.[62] And for PHEVs, I use the emissions generated from a mix of electricity and gasoline-only operation following: $[\text{fuel consumption}_j^{electricity} * \text{carbon intensity}_{pt}] + [\text{fuel consumption}_j^{gasoline} * 2.3]$, where 2.3 is the amount of CO_2 emissions produced by a liter of gasoline (NRCan (2017)).

In order to compare the lifetime emissions from EVs with emissions from the conventional gasoline vehicles which would have replaced EVs in the absence of incentives, I use the same annual distance traveled for EVs and their gasoline counterparts in my calculations. This means that, the lifetime emissions from the PHEVs sold during this period are compared with the emissions from their gasoline counterparts with the same annual distance traveled as an average PHEV (i.e., 17,300 km as suggested in CACKETTE (2017)). Similarly, I compare the lifetime emissions from the BEVs sold and the emissions from their gasoline counterparts with the same annual distance traveled as an average BEV (i.e., 13,700 km).[63]

It is important to note that my counter-factual calculations are based on the following two assumptions: the total vehicle sales in each market are assumed to stay unchanged in response

California, the Northeast Zero Emission Vehicle (ZEV) mandate member states, and the remaining of the states in US from 2013 to 2016. I choose the results of this study because: (1) they take into account the weather and geographical conditions in Canada versus the other regions in their study and (2) the period of their study matches perfectly with the period of my analysis.

[61]The results of this study indicate that PHEV owners drive more kilometers than conventional vehicle owners (11,284 and 10,295 miles for Fusion and C-Max, respectively, with 34% eVMT), whereas BEV owners tend to drive less than their conventional and PHEV counterparts (i.e., 8,491 miles or 13,700 km).

[62]CO_2 Intensity is calculated as follows: CO_2 Intensity (kg/kWh)= CO_2 emissions (kg)/Electricity Generation (kWh), and varies by province as each province uses different sources of fuels (such as coal, natural gas, nuclear, hydro, steam from waste heat, and etc).

[63]I also perform an alternative approach; I compare the emissions from EVs and emissions from their gasoline counterparts using the annual distance traveled of an average gasoline vehicle (i.e., 15,300 km according to Statistics Canada (2017)) for each EV sold over this period. However, for PHEVs, I take into account the 34% annual eVMT in my emission calculations (i.e., 5200 km driving on electricity and 10,100 km driving on gasoline). I find that the results are relatively unchanged between the two methods, so I only present the results of the first approach.

to incentives, and there is no rebound effects on driving.[64] The emission savings (in tonnes) can then be converted into dollar value savings when divided by the government expenditures on incentives in a given market. I find the government expenditure by aggregating the incentive amounts over all the EV models sold in each province and year.

The results of the counter-factual calculations are presented in Table 9. Column 1 and 2, respectively, report the actual number of EVs and BEVs sold in each province and year, column 3 is the percentage of EV sales induced by the incentives based on the counter-factual results, column 4 is the CO_2 emission reductions (in tonnes) over the lifetime (i.e., 10 years in my study) of the EVs sold in each year,[65], and finally column 5 displays the government expenditure to eliminate emissions over the lifetime of the EVs sold due to the incentive programs (in dollars per tonne). I only present the annual calculations (rather than monthly) to avoid overcrowding the table.

According to the results of Table 9, the actual number of EV sales across the three rebating provinces are increasing over the years with Quebec experiencing larger sales than the other two provinces.[66] In Ontario, incentives seem to have induced EV sales more than in the other two provinces likely due to the higher population in that province (see Table 3). Overall, incentives explain 60%, 30%, and 52% of EV sales in Ontario, British Columbia, and Quebec, respectively, over these four years. While this implies that the incentive programs have been successful in increasing EV sales, they have been offered to many consumers who would have purchased EVs (or other fuel efficient vehicles) regardless of the incentives.

In addition to larger EV sales in Ontario and Quebec compared to British Columbia, these two provinces have larger reductions in carbon emissions over the lifetime (10 years in my study) of the EVs sold during this period. The larger carbon emission reductions can be due in part to the larger proportion of BEVs from all EV sales and the fact that BEVs on average produce lower carbon emissions than PHEVs. I believe that the incentives in British Columbia have been less effective due to the following reasons: (1) lower incentive rates offered over this period, (2) the cease of the incentive program for more than a year from February 2014 to April 2015 (which, as shown in Table 9, has caused the incentive-induced EV sales and fuel savings to decrease in 2014), (3) insufficient financial and infrastructural support on charging stations until the start of the CEV program in April 2015, and finally

[64] This means that EV owners are assumed to not increase driving due to lower fuel costs of driving per kilometer. If a rebound effect exists, the marginal cost of driving an EV per kilometer, and consequently the emissions produced, will be higher which will result in lower fuel savings associated with the incentive programs as compared with the counter-factual results of my analysis.

[65] An approximation of the emission reductions for each year (rather than the emission reductions over ten years of using EVs) can be obtained by dividing the numbers in column 4 by 10.

[66] Note that the year 2012 is not included in the table as I only have data for four months in 2012 (from September 2012).

the fact that residents of British Columbia have already been using fuel efficient vehicles over the past decade and therefore didn't shift preferences into buying EVs in comparison with the residents of Ontario and Quebec.

The cost of emissions saved (per tonne of carbon dioxide) due to the incentive programs varies across the rebating provinces with an average of $260 in Ontario, $80 in British Columbia, and $251 in Quebec over this period.[67] This is while the cost of purchasing a liter of gasoline ranges from the highest rate of $1.18/L in 2013 in British Columbia to the lowest rate of $0.68/L in Ontario in 2016 (based on the 2002 adjusted tax-inclusive gasoline prices). Across these three provinces over this period, on average, $216 was spent to displace a tonne of CO_2, which is equivalent to 434 liters of gasoline given that a liter of gasoline produces 2.3 kg CO_2). Overall, I find that EV purchase incentives have not been cost-effective in reducing carbon emissions when compared with the price of carbon set at $30/tonne (as used by the US and Canadian governments for policy making purposes).

10 Conclusion

Three provinces of Ontario, Quebec, and British Columbia offered financial incentives of differing values on the purchase/lease of EVs at different times after 2010. The characteristics of the incentive policies provide a great opportunity to evaluate the effects of provincial rebates on EV adoption due to the variations in the number, timing, and generosity of the incentive program across the Canadian provinces between 2012 and 2016. This paper investigates whether consumers shift preferences from purchasing a non-EV to an EV in response to incentives. It also evaluates whether the incentive policies have been cost-effective in reducing carbon emissions over this period.

Using monthly sales data on all new EVs sold across the Canadian provinces along with the incentive amounts offered to each EV model in each of the rebating provinces over time, incentive programs appear to have increased EV purchases by an average of 8 percent due to an incentive increase of $1000. This corresponds to about 4 percent increase in EV sales due to an increase in incentives by one percent of a given EV's base price, in the rebating versus non-rebating provinces.

The results of the counter-factual estimations on fuel savings and carbon emission reductions associated with the incentive programs indicate that incentives contributed to reducing carbon emissions by an average of 60,000 tonnes over the life-time (10 years in my study) of

[67]Note that the small value of fuel savings in British Columbia in 2014 is due to the fact that the incentive programs were only available in the beginning of 2014; the provincial government stopped the incentive program from February 2014 to April 2015.

the EVs sold in the rebating provinces. However, the results on the costs of fuel savings indicate that incentives have not been cost-effective in reducing carbon emissions. The average cost of emission reductions across the provinces that offer incentives is $216 per tonne (over ten years of using EVs sold during the period of study). This indicates that the purchase incentives have not been cost-effective when compared with the cost of carbon pricing of $30/tonne set out by the Canadian federal government for policy implications.

11 Acknowledgment

I thank Matthew Klippenstein of Green Car Reports, the IHS Automotive Inc., the Ministry of Transportation in Ontario and British Columbia, and the Ministry of Energy and Natural Resources in Quebec, for generously providing the primary data used in this study. I are also grateful for the useful comments and suggestions from Louis Hotte and Henry Thille. The current version of this paper has been presented at the Canadian Economics Association annual conference.

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12 Figures

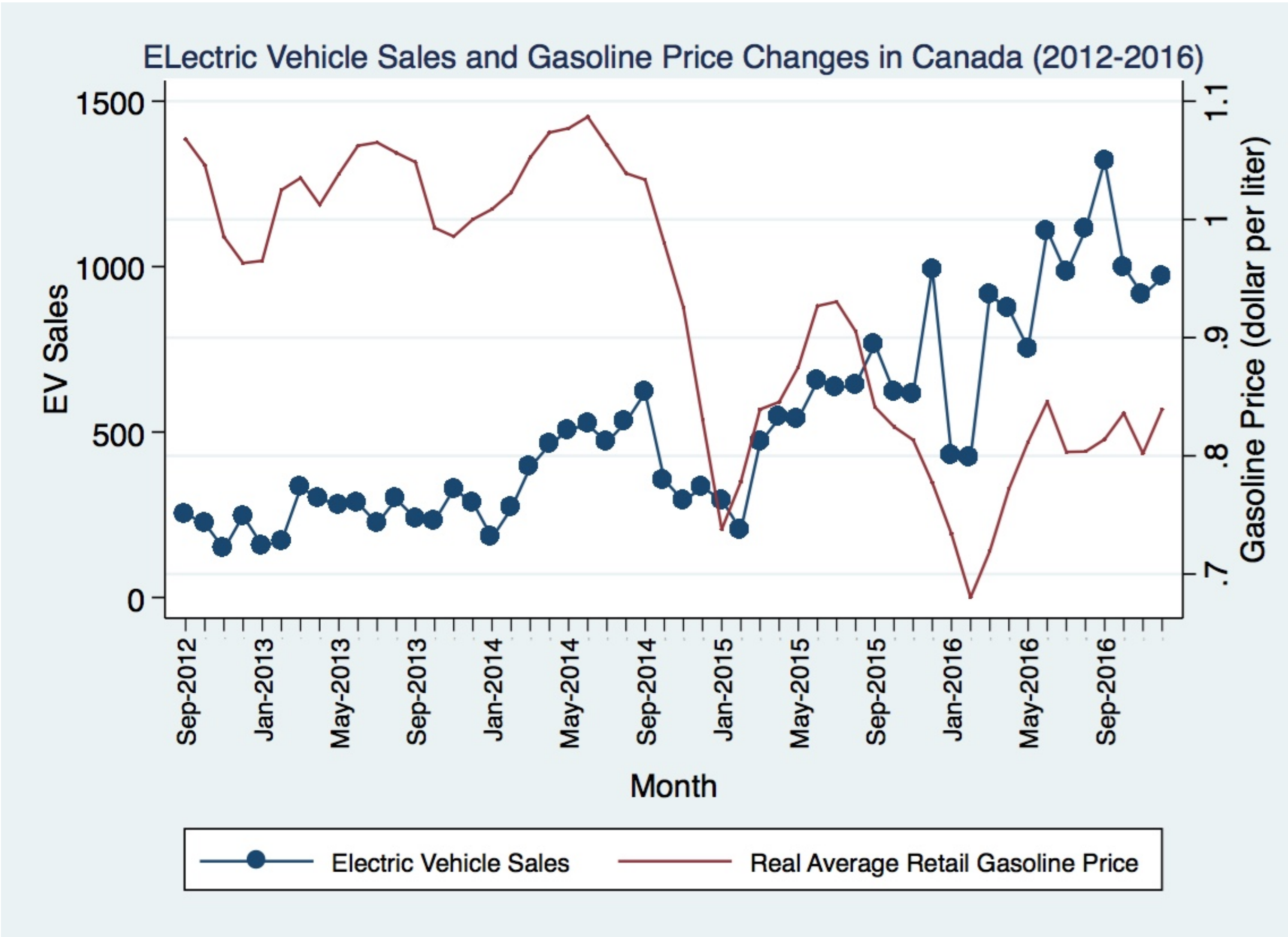

Figure 1. National monthly EV sales and gasoline prices. Note: EV monthly sales are presented on the primary axis and the 2002 adjusted gasoline prices inclusive of all taxes (in $/L) are shown on the secondary axis.

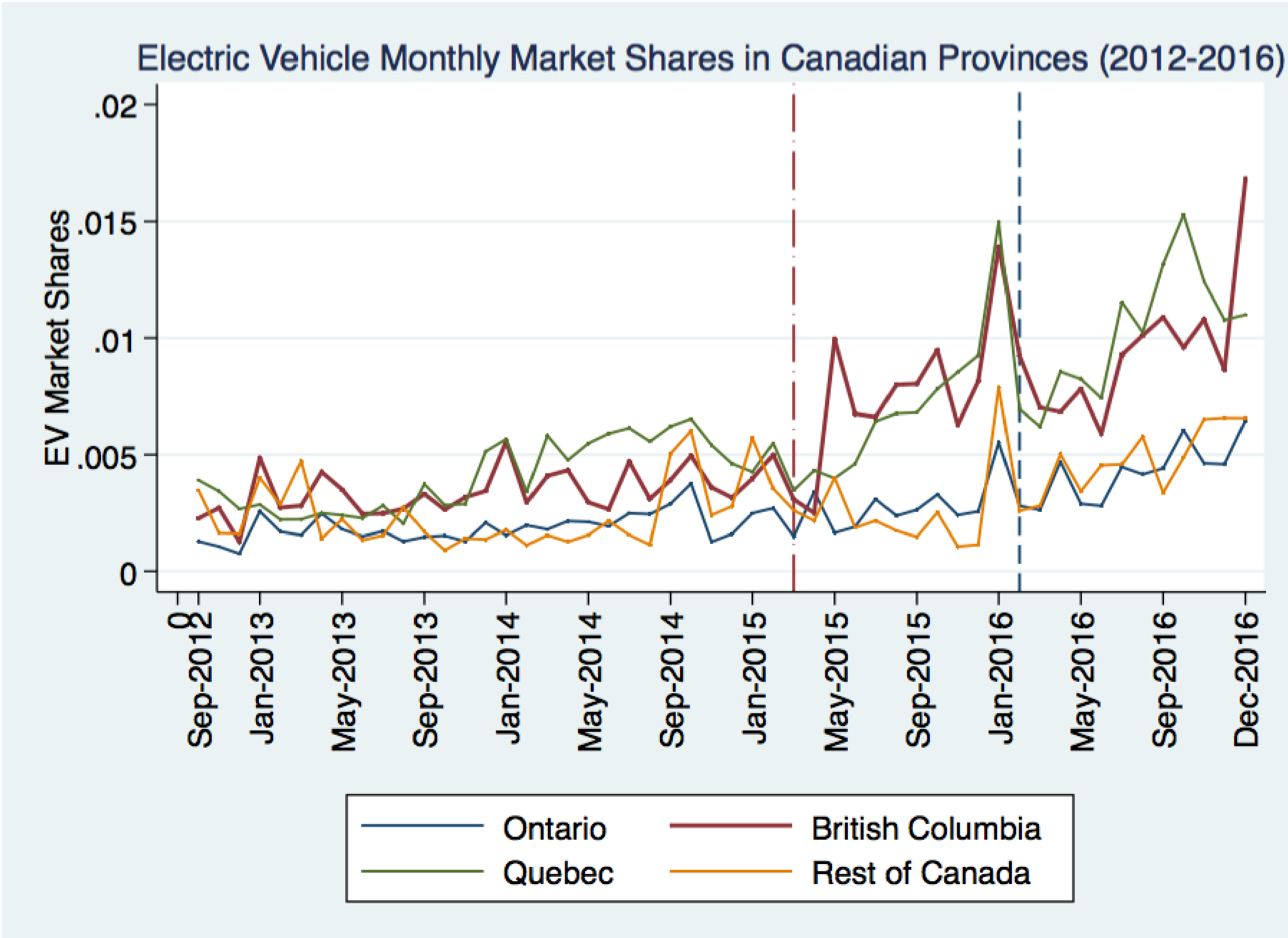

Figure 2. Monthly provincial trends of EV market shares. Y axis shows the aggregate market share of EVs from total auto sales by month in each of the rebating province versus the rest of Canada. The vertical lines represent the timing of the change in the incentive programs; British Columbia in March 2015 and Ontario in February 2016.

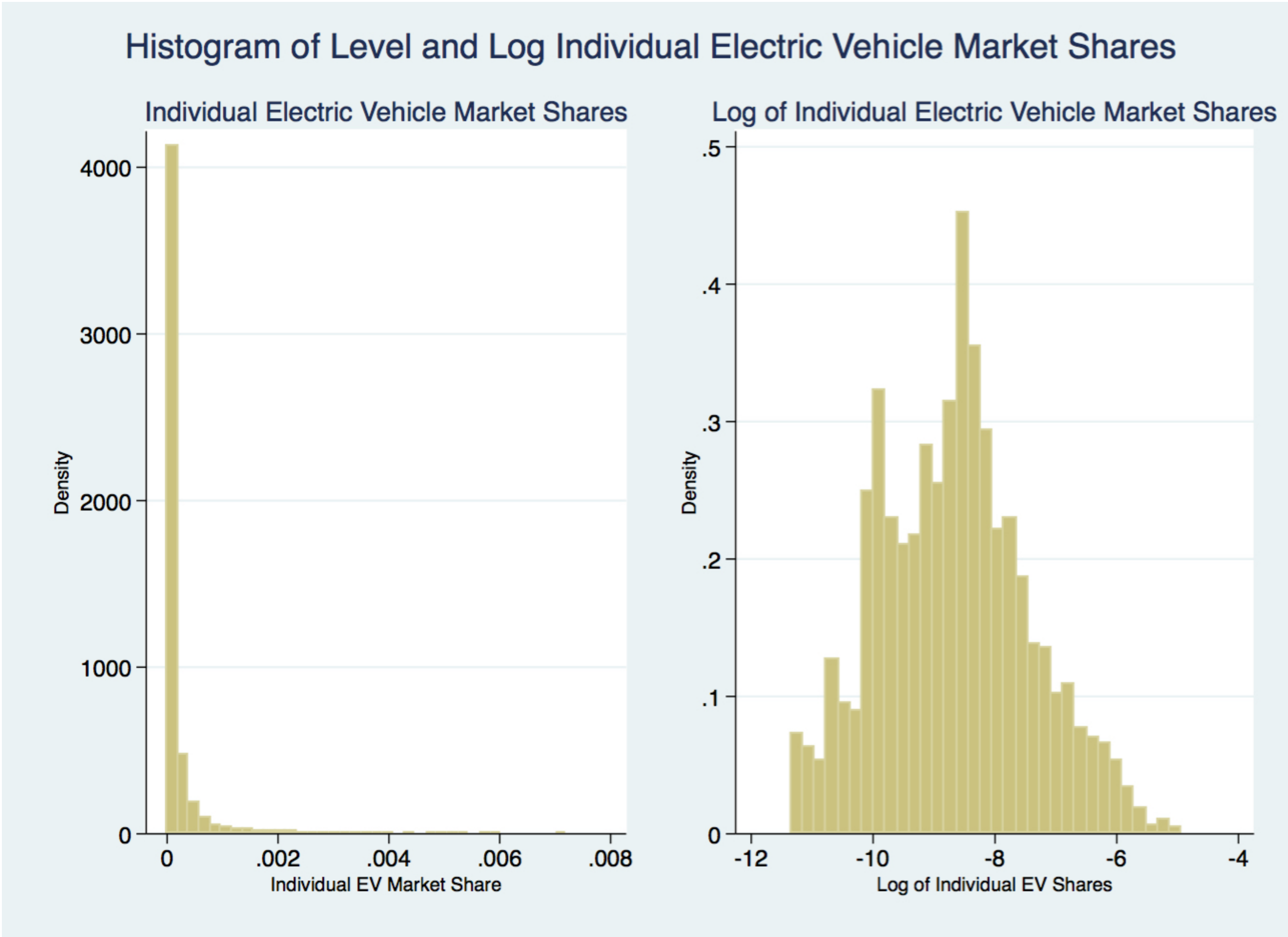

Figure 3. The left panel shows the density distribution of individual EV market shares from total vehicle sales in each province and month and the right panel shows the density distribution of the logarithm of these market shares.

13 Tables

Table 1: Literature Review Summary

Study	**Country & Time Period**	**Gasoline Price Effects**	**Incentive Effects**
Beresteanu and Li (2009)	1999-2006, US	14% to 17% of overall hybrid sales	27% to 31% of overall hybrid sales
Diamond (2009)	2000-2006, US	11% to 50% increase in hybrid sales due to a 10% increase in gasoline price	No significant effects over the entire period
Gallagher and Muehlegger (2011)	2000-2006, US	27% of hybrid sales	6% of overall hybrid sales and 22% per mean value incentives
Chandra et al. (2010)	1989-2006, Canada	No significant impact	26% of all hybrid vehicle sales and 34% impact per 1000$ incentives
Narassimham and Johnson (2014)	2008-2014, US	13% and 28% increase in PHEV and BEV sales, respectively, due to a 10% increase in gasoline price	4% impact on BEV sales per 1000$ incentives
Clinton et al. (2015)	2011-2014, US	No significant impact	2% to 10% per 1000$ of incentives

Source: Author

Table 2: Demand-based policies for electric vehicles across Canadian provinces, 2012-2016.

Financial purchase incentives	Charging infrastructure subsidies	Carbon pricing	Public charging deployment	HOV-lane access
		AB	AB	AB
BC	BC	BC	BC	BC
			MB	
			NL	
			NB	
			NS	
ON	ON	ON	ON	ON
			PEI	
QUE	QUE	QUE	QUE	QUE
			SK	

Source: Author.

Table 3: Rebate Amount for an Average Battery Electric (BEV) and Plug-in Hybrid (PHEV) Over Years and Across Provinces, 2012-2016.

Province	Vehicle Type	2012	2013	2014	2015	2016
Ontario	BEV	8432.75	8432.75	8461.57	9237.00	9211.33
	PHEV	7243.66	6211.75	6927.14	5926.55	5957.75
British Columbia	BEV	5000	5000	0	5000	5000
	PHEV	2500	2500	0	2500	2500
Quebec	BEV	6346	6621	7000	6222	8000
	PHEV	6779	3566	3586	2722	3428

The rebate amounts in the table shows the average rebate that was paid to a BEV or PHEV over the period of analysis. In Ontario, PHEVs with a MSRP between $75000 and $150000 are eligible for a maximum rebate of $3000. PHEVs and BEVs with a MSRP equal to, or greater than $150000 are not eligible for an incentive. In British Columbia, the new EVs with a MSRP above $77000 are not eligible for an incentive. Chevrolet Volt, which is an extended range PHEV, is the only vehicle that was offered a rebate of $5000. In Quebec, a rebate of $3000 on the purchase or lease of new eligible BEVs with a MSRP between $75000 and $125000, and $8000 on new eligible BEVs with a MSRP less than $75000. For new eligible PHEVs with a MSRP less than 75000, the rebate amount varies between $500, $4000, and $8000 depending on the electric battery capacity.

Table 4: Summary statistics for sales, incentives, and socioeconomic data

Variable	N	Mean	Std. Dev.	Min.	Max.
Electric Vehicle-Province-Month Data					
Fuel efficiency rating (kWh/km)-BEV	2332	0.20	0.02	0.17	0. 27
Fuel efficiency rating (kWh/km)-PHEV	3312	0.26	0.07	0.13	0.43
Fuel cost savings (¢/km)	5644	8.7	2.2	1.1	13.8
Province-Month Sales and Incentive Data					
New EV sales	520	91.3	124	0	649
New EV sales per thousand people	520	0.01	0 .01	0	0.07
New BEV sales	520	55	66.2	0	311
New PHEV sales	520	36.3	64.8	0	338
EV purchase incentives	520	2086.4	3255.8	0	13000
BEV purchase incentives	520	3055.7	3868.5	0	13000
PHEV purchase incentives	520	1379.3	2496.8	0	10224
Province-Month Price and Demographic Data					
2002 adjusted gasoline price tax-inclusive (¢/L)	520	90.3	14.2	52.7	118.3
2002 adjusted electricity price (¢/kWh)	520	9.1	2.3	5.4	13.9
Labor income per capita (dollars×1,000)	520	1.9	0.4	1.4	3.1
Unemployment rate	520	7.9	2.5	3.3	15.2
Province-Year Demographic Data					
Labor income per capita (dollars×1,000)	50	28.2	0.5	27.3	28.8
Unemployment rate	50	7.3	0.12	7.1	7.4
Median household income (dollars×1,000)	50	78.9	8.8	65.9	10.07
Percent female	50	0.5	0.005	0.49	0.51
Percent of adults graduating college	50	0.008	0.002	0.005	0.015
Mean age	50	41.1	3.05	36	45.3

For all sales data, N is the number of all observations including the zero observations. There are 10 provinces, 52 months and average of about 10 EV models in each market. For vehicle-province-month data, N reports the total number of observations in my data-set (i.e., 5644). For provincial demographics, N reports the number of province-month and province-year observations, respectively. Fuel cost savings (¢/km) is the difference between the cost of driving 1 km in an EV and the cost of driving 1 km in an average gasoline vehicle. Labor income per capita represents “seasonally adjusted wages, salaries, and employer’s contributions” per-capita, and is reported at both monthly and annual levels.

Table 5: Panel regression with Fixed Effects for New Electric Vehicle Market Shares

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Incentive (in 1000$)	0.17***	0.16***	0.06*	0.06*	0.08***		
	[0.03]	[0.03]	[0.03]	[0.02]	[0.02]		
Incentive (in 1000$) * BEV						0.05**	
						[0.02]	
Incentive (in 1000$) * PHEV						0.04**	
						[0.02]	
Incentive to MSRP Ratio							3.84***
							[0.93]
Log Fuel Savings	0.24	2.47**	0.05	-0.17	0.19	0.19	0.18
	[0.25]	[0.79]	[0.29]	[0.29]	[0.29]	[0.29]	[0.29]
EV-model FE	Yes	Yes	Yes	Yes			
Time FE		Yes	Yes				
Province FE			Yes				
Province-time FE				Yes	Yes	Yes	Yes
EV-model-province FE					Yes	Yes	Yes
EV-model-time FE					Yes	Yes	Yes
N	5644	5644	5644	5644	5644	5644	5644
R^2	0.70	0.71	0.71	0.71	0.88	0.88	0.88

Standard errors in brackets

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table reports the GLM results of the estimations on the market share of a particular new EV in response to variations in model-specific incentives and log fuel cost savings (from driving the given EV compared to driving an average gasoline car, in ¢/km) using various combination of fixed effects. I use the same dependent and independent variables across the models and only change the arrangement of fixed effects to control for unobserved factors that may influence the market share of a given EV. I start with EV-model generation fixed effects in column 1. Then, in column 2, I add time (i.e., year-month) fixed effects. Moving to column 3, province fixed effects are also added. Column 4 includes EV-model and province-time fixed effects. Columns 5, 6, and 7 present the results of the most comprehensive models and thus all control for EV-model-province, EV-model-time, and province-time fixed effects. Column 5 includes the dollar value of incentives (in 1000$) on the average EV while column 6 shows the differential effects of incentives (in 1000$) on BEVs and PHEVs separately. Finally, column 7 reports the incentive effects relative to MSRPs. Standard errors are clustered by province-class across all models.

Table 6: Alternative Specifications and Aggregate Regressions

	1	2	3	4	5
Incentive (in 1000$)	0.05***	0.07***	0.07*	0.007	0.08***
	[0.01]	[0.02]	[0.03]	[0.03]	[0.01]
Log Fuel Savings	0.26***	0.41***	0.55*	0.78	0.45
	[0.04]	[0.1]	[0.22]	[17.9]	[0.35]
EV-model-province FE	Yes			Yes	Yes
EV-model-year FE	Yes				
EV-model-year-month FE				Yes	Yes
Province FE		Yes	Yes		
Year-month FE		Yes	Yes		
Province-time FE				Yes	Yes
Other Controls		Yes	Yes		
N	507	520	208	2776	2421
R^2	0.80	0.80	0.80	0.80	0.89

Standard errors in brackets

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table presents the results of the alternative specifications to deal with the problem associated with zero share observations. All the specifications estimate the average effects of incentives (in $1000) and log of fuel cost savings using different levels of aggregation and combination of fixed effects. Column 1 uses a GLM regression to estimate within province variations in EV-model specific incentives (in $1000) and fuel cost savings on aggregate market shares by EV-model, province, and year, using EV-model-province and EV-model-year fixed effects. Standard errors are clustered by province-class in this model. Columns 2 and 3 present the GLM results of aggregate EV shares by month across all provinces, and in each of the rebating provinces versus the "Rest of Canada", respectively, after controlling for province and month fixed effects. Both models also control for log fuel cost savings (i.e., log of sales-weighted fuel cost savings (in ¢/km) from driving EVs compared to driving non-EVs in a province and month) and additional controls, including log median labor income, log median age, log percent female and log percent college graduates from the population, and log unemployment rate. Standard errors are clustered by province for these specifications. Finally, the results of the two-part model are presented in columns 4 and 5. The first part (presented in column 4) defines the probability of purchasing an EV from all other vehicle alternatives in each market as a function of model-specific incentives (in $1000) and log fuel cost savings (using a logistic regression) and the second part (presented in column 5) defines the magnitude of the effects conditional on positive EV shares (using OLS regressions). Standard errors are clustered by province-class in the two part model.

Table 7: Nested Logit Results on Individual EV Market Shares

	(1)	(2)
Incentive ($1000)	0.06**	
	[0.01]	
Incentive to MSRP Ratio		2.96***
		[0.45]
Within-nest Shares	0.37***	0.37***
	[0.15]	[0.15]
Log Fuel Savings	0.19	0.19
	[0.29]	[0.29]
EV-model-province FE	Yes	Yes
EV-model-time FE	Yes	Yes
Province-time FE	Yes	Yes
N	5644	5644
R^2	0.91	0.91

Standard errors in brackets

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table reports the IV regression results of the nested logit model on individual EV model shares. The dependent variable is the market share of sales of individual EV models from total vehicle sales in each market (province, year, and month) and the independent variables are incentives (in $1000 and relative to individual EV's base prices), within-nest EV shares, and log fuel cost savings associated with driving an EV compared to an average gasoline car. The within-nest share variable is the market share of each EV model from total EVs sold in each market. Three EV characteristics: horse power, the recharge time, and the fuel efficiency (both in liter equivalent and kWh per 100 km) are used as IVs for within-nest shares. EV-model-province, EV-model-time, and province-time fixed effects are added and standard errors are clustered by province-class, in both models.

Table 8: Effect of Incentives on Total Vehicle Sales

	(1)	(2)	(3)	(4)
Mean Incentives (in $1000)	-0.005	-0.005	-0.012	-0.005
	[0.008]	[0.008]	[0.008]	[0.006]
Log real gasoline price		-0.52*		-0.43
		[0.17]		[0.28]
Log real labor income		1.66**		1.74**
		[0.45]		[0.49]
Log percent female population		20.48*		68.42***
		[8.19]		[12.86]
Log percent adults with college diploma		0.035		0.042
		[0.16]		[0.30]
Log median age		0.60		-6.77*
		[1.80]		[2.57]
Log unemployment rate		-0.21*		-0.11
		[0.08]		[0.09]
Province fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
N	520	520	520	520
R^2	0.99	0.99	0.99	0.99

Standard errors in brackets

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table reports the extensive margin effects of incentive (in $1000) on the log of aggregate auto sales (columns 1 and 2) and the log of passenger car sales (columns 3 and 4) by province. In columns 1 and 3, only province and time (i.e., year-month) fixed effects are included (without any other provincial control) while in columns 2 and 4, other provincial controls are included in addition to province and time fixed effects. Controls contain log real gasoline price (in dollar per liter), log real labor income, log unemployment rate, log percent females from total population, log percent adults (24 years above) with college diploma, and log median age. Linear regressions with fixed effects are performed, and standard errors are clustered by province, across all models.

Table 9: Counterfactual results: electric vehicles versus other vehicles

Province	Year	1	2	3	4	5
Ontario	2013	1090	618	0.44	31,266	270
	2014	1666	1088	0.52	48,885	271
	2015	2125	1492	0.63	63,457	253
	2016	3463	1590	0.81	92,427	249
British Columbia	2013	596	408	0.38	18,634	145
	2014	734	559	0.01	22,410	6
	2015	1563	1303	0.20	48,588	79
	2016	2063	1279	0.31	60,702	93
Quebec	2013	1243	526	0.56	37,052	241
	2014	2339	1052	0.58	67,259	262
	2015	3017	1753	0.48	94,248	234
	2016	4772	2084	0.48	134,827	269

This table summarizes the results of the counter-factual calculations for each of the rebating provinces in each year. Columns 1 and 2, respectively, show the actual number of EVs and BEVs sold in each province and year, column 3 is the percentage of EV sales induced by the incentive programs based on the counter-factual results, column 4 is the CO_2 emission reductions over ten years of using EVs (in tonnes), and finally column 5 is the cost of carbon emissions saved over the ten years of using EVs (in dollars per tonne of CO_2) are calculated.

14 Appendix

Table 10: Results of Linear Regressions with Fixed Effects on New Electric Vehicle Market Shares

	(1)	(2)	(3)	(4)	(5)	(6)
Incentive ($1000)	0.00004**	0.00003**	0.00003*	0.00003*	0.0000002	
	[0.00001]	[0.00001]	[0.00001]	[0.00001]	[0.000009]	
Incentive to MSRP ratio						0.00004
						[0.0002]
Log fuel cost savings	0.00005	0.0003*	-0.00009	-0.0004+	0.0002	0.0002
	[0.00003]	[0.0001]	[0.0001]	[0.0002]	[0.0001]	[0.0001]
EV-model FE	Yes	Yes	Yes	Yes		
Time FE		Yes	Yes			
Province FE			Yes			
Province-time FE				Yes	Yes	Yes
EV-model-province FE					Yes	Yes
EV-model-time FE					Yes	Yes
N	5644	5644	5644	5644	5644	5644
R^2	0.21	0.23	0.29	0.33	0.76	0.76

Standard errors in brackets

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table reports the results of linear regressions on market share of a particular new EV in response to variations in model-specific incentives and log fuel cost savings (from driving the given EV compared to driving an average gasoline car, in ¢/km) using various combination of fixed effects. These models replicate the models in Table 5 but apply linear regressions on individual market shares rather than GLM estimations. I use the same dependent and independent variables across the models and only change the arrangement of fixed effects to control for unobserved factors that may influence the market share of a given EV. I start with EV-model generation fixed effects in column 1. Then, in column 2, I add time (i.e., year-month) fixed effects. Moving to column 3, province fixed effects are also added. Column 4 includes EV-model and province-time fixed effects. Columns 5 and 6 present the results of the most comprehensive models and thus control for EV-model-province, EV-model-time, and province-time fixed effects. Column 5 includes the dollar value of incentives (in 1000$) on the average EV while column 6 reports the incentive effects relative to MSRPs. Standard errors are clustered by province-class across all models.

Table 11: Log-linear Results on Individual EV Market Shares Added by a Constant Value

	1	2
Incentive (in $1000)	0.08*	
	[0.03]	
Incentive to MSRP Ratio		2.72*
		[1.21]
Log Fuel Savings	0.18	0.18
	[0.29]	[0.29]
EV-Model-Province FE	Yes	Yes
EV-Model-Year-month FE	Yes	Yes
Province-time FE	Yes	Yes
N	5644	5644
R^2	0.71	0.71

Standard errors in brackets

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table reports the regression results of the one of the alternative practices to overcome the challenge with zero share observations where a constant is added to EV individual market shares. As such, the dependent variable is the market share of each EV model from total auto sales in a given market plus a constant that is smaller than the smallest share(i.e., 0.000001 in this regression). I estimate EV shares on both measures of incentive: dollar values (in $1000, shown in cloumn 1) and relative to an EV's MSRP (shown in column 2), as well as on log fuel cost savings (i.e., the cost of fuel saved due to driving 1 km in an EV comapred to driving a gasoline car). Linear regression with EV-model-province, EV-model-time, and province-time fixed effects are applied, and standard errors are clustered by province∗class, in both specifications.

Table 12: Monthly Aggregated Specifications on EV Shares with Provincial Controls

	1	2
Mean Incentive (in $1000)	0.08**	0.09**
	[0.03]	[0.03]
Log real gasoline price	0.49	0.42
	[0.31]	[0.27]
Log real electricity price	-0.06	-0.06
	[0.41]	[0.4]
Log real labor income	-3.21	-3.81*
	[1.86]	[1.86]
Log percent female population	42.23	49.57
	[55.29]	[54.61]
Log percent adults with college diploma	-1.13	-1.19
	[1.71]	[1.7]
Log median age	-7.87	-6.56
	[14.35]	[14.24]
Log unemployment rate	-0.23	-0.17
	[0.45]	[0.45]
Province FE	Yes	Yes
Year-Month FE	Yes	Yes
N	520	208
R^2	0.80	0.80

Standard errors in brackets

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

This table presents the results of aggregate EV shares by province and month after accounting for other provincial controls. Columns 1 and 2, respectively, present the GLM results of aggregate EV shares across all provinces, and in each of the rebating provinces versus the "Rest of Canada", after controlling for province and month fixed effects. Other controls include log real gasoline price, log real electricity price, log real labor income, log percent female population, log percent adults with a college diploma, log median age, and log unemployment rate. and cluster standard errors by province. Standard errors are clustered by province in both models.