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Exploring the Determinants of Electric Vehicle Adoption in Canada: A Multi-City Study

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ABSTRACT

This study provides a multifaceted exploration of factors contributing to the demand for electric vehicles (EVs) in Canada. We employ a comprehensive dataset spanning from 2017 to 2022, incorporating variables such as fuel prices, minimum temperature, rebates, GDP per capita, and the availability of public EV charging infrastructure. A fixed-effects regression model was applied to analyze EV, BEV, and PHEV registrations per capita. The results highlight the importance of city-specific effects, with local factors playing a crucial role in EV adoption. The findings reveal a positive correlation between gasoline prices and EV registrations, indicating that higher fuel prices incentivize the adoption of EVs. Additionally, minimum temperature, rebates, and GDP per capita are positively associated with EV adoption, suggesting the influence of climate, financial incentives, and economic capacity. These findings have significant implications for policymakers, manufacturers, and consumers. Policymakers should focus on implementing effective economic incentives, such as rebates, to encourage EV adoption. Manufacturers can target markets more effectively by considering local factors such as climate. Consumers can make informed decisions based on the identified determinants of EV adoption. However, it is important to acknowledge the limitations of the study, including the assumption of constant factors and the exclusion of public awareness and attitudes toward EVs.

Keywords: Electric vehicles; Renewable energy; Climate change; Fixed-effects model

1. INTRODUCTION

The increasing threat of climate change has emerged as a defining issue for our generation (IPCC, 2014). As the world faces increasingly severe environmental consequences, the focus has shifted to the industries that contribute the most to global greenhouse gas (GHG) emissions. On a global scale, the transportation industry accounts for approximately one-quarter of greenhouse gas emissions mainly CO2, with road transportation accounting for approximately 72% of these emissions (IPCC, 2014). It is evident that, to effectively combat climate change, a shift to more sustainable modes of transportation can be important (Axsen et al., 2020).

Electric vehicles (EVs), which include both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), are identified as critical components of this necessary transformation. Unlike traditional vehicles that use internal combustion engines (ICEs), EVs are powered by electricity. In regions where renewable energy sources and low CO2 emitting forms of electric power generation are widely used, the total operating CO2 emissions of BEVs become less than that of ICEs (Kawamoto et al., 2019). EVs are a possible route for dramatically reducing the environmental effect of personal mobility due to their more energy-efficient systems and the potential for electricity to be supplied from renewable sources (Spangher et al., 2019; Guo et al., 2020). Further reductions in the environmental impact of EVs are expected as technology advances and battery efficiency increases (Philippot et al., 2022). Indeed, the International Energy Agency (IEA) predicts that by 2030, more than 60% of vehicles sold worldwide will be electric, suggesting a significant potential for growth and positive environmental effects (IEA,2022).

The transition to EVs has been slower than anticipated, despite their environmental benefits and the growing awareness of climate change among the public (Wang et al., 2017). Even though the current EV market is expanding, it is still in its early stages while several formidable obstacles to widespread adoption (Wang et al., 2017). Some of these problems include high up-front costs, a short driving range, and a lack of charging stations. Notably, while EVs are becoming more accessible, they are still generally more expensive than vehicles with internal combustion engines (ICEs). Furthermore, despite continual advancements in battery technology, "range anxiety" remains a significant impediment — the concern that a car will not have sufficient range to reach a destination. Long charging durations and the limited availability of charging infrastructure, which can dissuade potential EV adopters, exacerbate these concerns (Wang et al., 2021).

These difficulties underline the significance of proactive government actions in promoting and sustaining the transition to electric mobility. Many developed-country governments now play an important role in formulating and implementing policies that encourage EV adoption. These interventions can take many different forms, such as providing financial incentives to consumers, investing in charging infrastructure or enforcing tighter pollution requirements on ICE vehicles. Understanding the impact, efficacy and influence of these measures on EV uptake is critical for policy design and implementation. It can shed light on the most effective techniques for overcoming hurdles to EV adoption and contribute to the development of a sustainable transportation future.

With its enormous road network and high car ownership rates, Canada provides an intriguing example in this global shift toward electric mobility. The country's distinct geographical and climatic characteristics, paired with its commitment to attaining aggressive climate objectives, highlight the significance of EV adoption. Recognizing this, Canada's government has taken proactive measures to assist and promote EV adoption. The iZEV (zero-emission vehicle) program, which was established in 2019, is one of the major pillars of Canada's approach to promoting EV adoption. The iZEV program is a policy intervention to help remove barriers to EV adoption. Purchase incentives are available for qualifying new battery-electric, hydrogen fuel cell, and longer-range plug-in hybrid automobiles. The incentives range from $2,500 to $5,000 (Government of Canada, 2019), depending on the model of the EV and the size or capacity of its battery. This program effectively lowers the high initial expenses of EVs and makes them more affordable for Canadians. Non-financial hurdles to EV adoption are also addressed by the iZEV program. It includes, for example, steps to establish and expand charging infrastructure across the country, which is a vital step toward easing 'range anxiety' and making EVs a viable option for more people. The program also includes initiatives to promote EV adoption in commercial fleets, increasing its influence beyond personal transportation (Government of Canada, 2019).

Despite these efforts, EVs will only account for a small proportion of the Canadian automobile market by 2022. Figure 1 depicts the share of EVs (BEVs & PHEVs) in total new vehicle registrations in Canada from the first quarter of 2017 to the fourth quarter of 2022. Note that, despite the rising trend, the market share of all EVs was only 9.8% at its peak. The numbers of all EVs, BEVs and PHEVs registered as a proportion of total vehicle sales over the period from Q1 2017 to Q4 2022 in Canada are provided in Figure 2; note that the proportion of PHEV sales has been very low and is showing signs of a downward trend. The complexity of the Canadian context, defined by adverse weather conditions, a geographically dispersed population, and regional variances in energy supply, complicates the dynamics of EV adoption even more. The impact of these and other variables on EV adoption differs across the country, necessitating a thorough understanding of their interplay.

The objective of this study is to address questions of EV adoption by delving into the intricate network of factors that influence EV demand in Canada. We investigate the impact of major economic and environmental variables on EV adoption, such as fuel prices, energy prices, minimum temperature, GDP per capita, incentives for new EV purchases, and the availability of public EV charging infrastructure. The study then looks at how these characteristics interact with one another and how their effects differ throughout Canada. This study thereby throws fresh light on the complex dynamics of the Canadian EV market and provides a foundation for informed policy decisions to further expedite the transition to sustainable transportation in the battle against climate change.

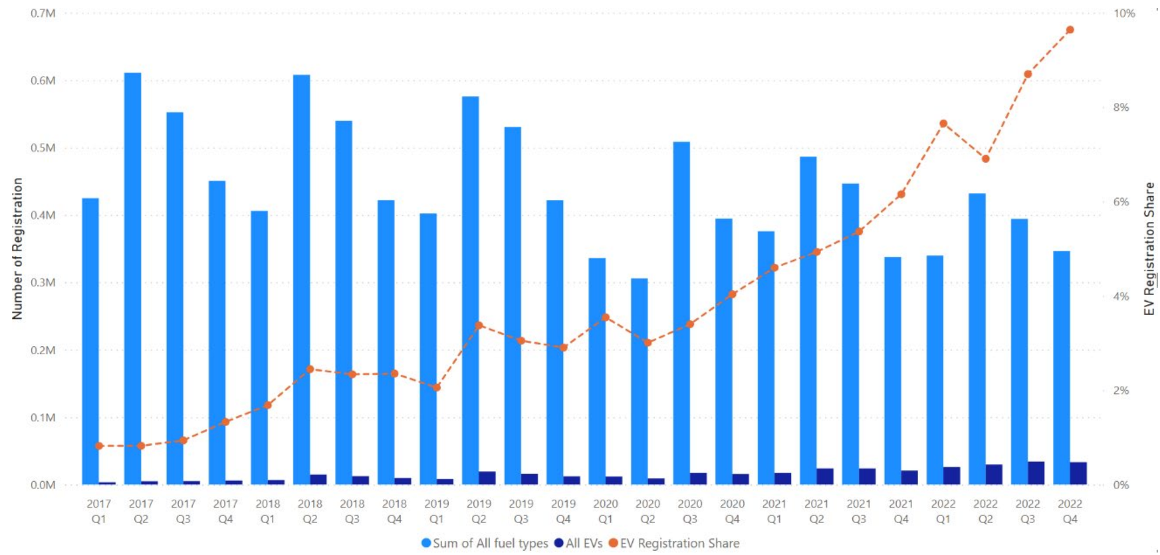

Figure 1: Electric and Total Vehicle Registration in Canada from 2017Q1 to 2022Q4
Data Source: Statistics Canada. Table 20-10-0024-01 New motor vehicle registrations

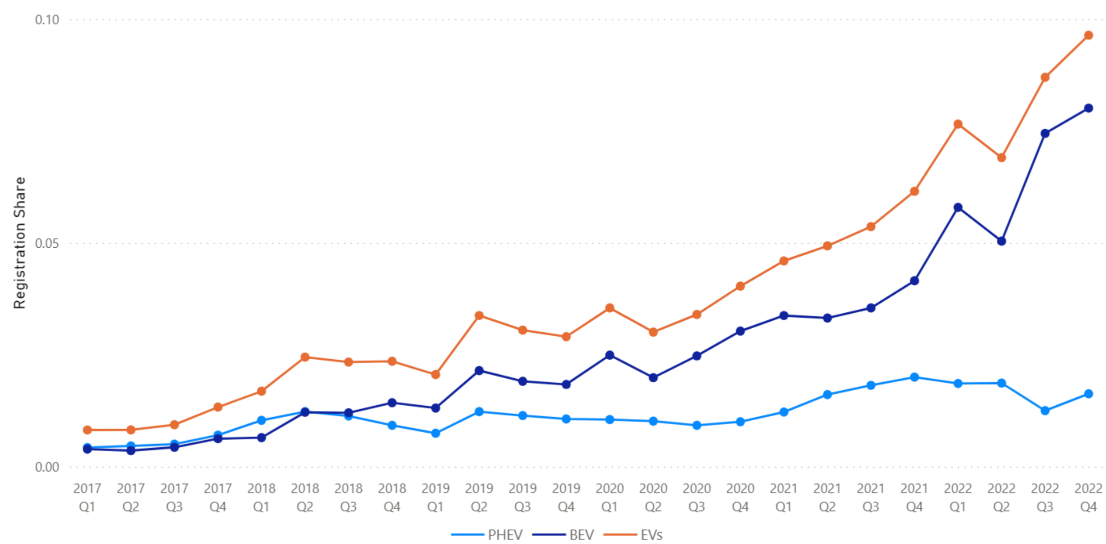

Figure 2: Shares of EVs, BEV and PHEV in Total Vehicle Registration in Canada from 2017Q1 to 2022Q4
Data Source: Statistics Canada. Table 20-10-0024-01 New motor vehicle registrations

We begin in the next sections by looking at Canada's EV market, with a focus on the determinants of EV adoption. Section 2 scrutinizes the literature on EV adoption, highlighting key findings from international studies. Section 3 outlines the research methodology, which involves describing how the data was gathered, what variables were used, and how the data was processed to identify their connections. Section 4 then displays the findings, explaining what my regression models revealed concerning EV adoption in Canada. Section 5 discusses and compares these results to those of other studies, aiding in placing the findings in a broader context. Section 6 concludes this study.

2. LITERATURE REVIEW

In the ongoing global shift towards EVs, a myriad of factors come into play, influencing the rate of adoption in different contexts. This literature review seeks to consolidate findings from various international studies, shedding light on the key determinants of EV adoption and the potential commonalities and differences across countries.

2.1 Factors Influencing the Adoption of EVs Across the World

Gallagher and Muehlegger (2011) conducted an in-depth analysis of the factors influencing the adoption of hybrid vehicle technology in the United States. A regression model incorporating state tax incentives, a dummy variable for single-occupant access to HOV lanes, annual gasoline savings, and state demographics revealed that the value of state tax incentives is positively correlated with hybrid sales. There is a correlation between a $1,000 tax credit and a 5% increase in hybrid sales. A 1% increase in tax incentives on a vehicle's Manufacturer's Suggested Retail Price (MSRP) is associated with a 1.2% increase in sales. (Gallagher and Muehlegger, 2011). The authors offer valuable insights into the function of state incentives in promoting the adoption of hybrid vehicles.

In another study, Vergis and Chen (2015) examined the factors affecting the market shares of PHEVs versus BEVs, incorporating a multiplicity of state-specific factors. The authors investigate the charging infrastructure, EV model options, energy expenditure and savings, fiscal stimuli, access to high-occupancy vehicle (HOV) lanes, awareness levels, environmentalism, annual vehicle miles travelled (VMT), demographic density, economic health indicators, levels of education, regulations and standards, climatic influences, and non-plugin hybrid electric vehicle market shares. They observed that non-residential charging provisions, EV model availability, direct monetary incentives, HOV lane access, awareness campaigns, environmental consciousness, and robust hybrid-model market shares promoted EV adoption. These findings highlight the strategic significance of a strong infrastructure, carefully formulated policies, and extensive education and awareness campaigns.

Wee (2018) examined the impact of EV incentives on new registrations, discovering that there was a positive relationship between fiscal incentives and EV registrations. A $1000 increase in state-level EV incentives could boost EV registrations by 7.5%.

A study by Mersky et al. (2016) on the effectiveness of incentives on EV adoption in Norway found that individuals who commute to major cities are more likely to purchase an EV to take advantage of its infrastructure. On a municipal level, corporate vehicles were much more sensitive than personal vehicles to the number of charging stations, suggesting the importance of a robust charging infrastructure. The study also highlighted the role of policy incentives in promoting EV adoption. However, it acknowledged an inability to analyze certain government incentives due to lack of data, and suggested areas for future work, including a more detailed investigation of demand elasticity and the effects of short and long-term trends in gas pricing.

Mutavdija et al. (2022) they developed a model that captures the factors that influence attitudes toward EV adoption in Croatia. Their research identified a reduction in greenhouse gas emissions due to the use of EVs and the existence of a service network as potent catalysts. However, they also found the high cost of EV battery replacement, the lack of charging infrastructure, and the absence of EV services to be obstacles to greater adoption of EVs.

Several Chinese studies provide valuable insights into EV adoption trends and barriers. Zheng et al. (2020) investigated the sales and market trends of plug-in EVs in the centre of Asia. They discovered that only 17% of consumers foresee EVs as their principal mode of transportation within the next two decades, despite the allure of owning an environmentally friendly EV. This indicates that while there are signs of EV market growth, there are still significant perception and acceptance obstacles to overcome.

Guo et al. (2020) analysed the impact of air pollution and income levels on EV sales. Their findings revealed that deteriorating air quality was a significant driver of EV adoption, particularly in affluent urban areas, suggesting that environmental and quality-of-life advantages are crucial for EV adoption, particularly in affluent urban areas.

Yang et al. (2022) added a new dimension to the Chinese scenario by analysing the online evaluations of the public to determine what drives demand. They discovered that the comfort, manoeuvrability, space, and cost performance of EVs were important drivers of EV sales. In addition, they identified the buffering effect of subsidy policies between public perception of these attributes and sales.

Lastly, Briseño et al. (2021) analyzed the interplay between economic, and environmental factors and EV sales in Mexico. The researchers analysed the complex relationship between hybrid and EV sales and variables including per capita GDP, electricity costs, petroleum prices, and a sustainability indicator variable. Their findings suggested a complementary relationship between economic and environmental factors and EV sales.

2.2 Summary

The review of relevant literature provides a comprehensive analysis of the adoption of EVs in various nations around the world. Studies identified distinct factors that have influenced the expansion or retardation of EV adoption. The review suggests a multifaceted strategy to promote EV adoption, including policy incentives, infrastructure improvements, education, and practical problem-solving for prospective EV owners. However, there is no exhaustive analysis for Canada, indicating a gap in the literature and a need for additional research into the factors that would influence EV adoption in the Canadian market. This essay seeks to fill this knowledge gap, aiming to delve into the unique Canadian landscape and shed light on the interplay of factors affecting EV adoption.

3. DATA AND METHODOLOGY

The study's methods are outlined in this section. The selection of the sample data and a description of the data are provided followed by the statistical model employed in the analysis.

3.1 Regions

The geographical context for this study comprises 22 cities — Vancouver, Victoria, Nanaimo, Kelowna and Kamloops, Winnipeg, Winkler, Thompson, Brandon, Toronto, Ottawa, Hamilton, Kitchener, London, Montreal, Sherbrooke, Trois-Rivières, Quebec City, Saskatoon, Regina, Yorkton, and Moose Jaw — across five Canadian provinces — Ontario, Saskatchewan, British Columbia, Quebec, and Manitoba. The selection of these cities and provinces encapsulates a broad spectrum of population, socio-economic, environmental, and policy conditions, forming a comprehensive landscape for studying EV demand.

According to Statistics Canada in 2022, these provinces accounted for 81% and 78%, respectively, of the nation's total population and total GDP, as shown in Figure 3. The provinces included in the study represent diverse economic profiles. For instance, Ontario, the most populous province in Canada, has the largest economy, contributing 38% to the national GDP (Statistics Canada, 2022). Moreover, several automobile manufacturers are headquartered there, making this a key area for researching EV uptake (Ahmadi et al., 2015).

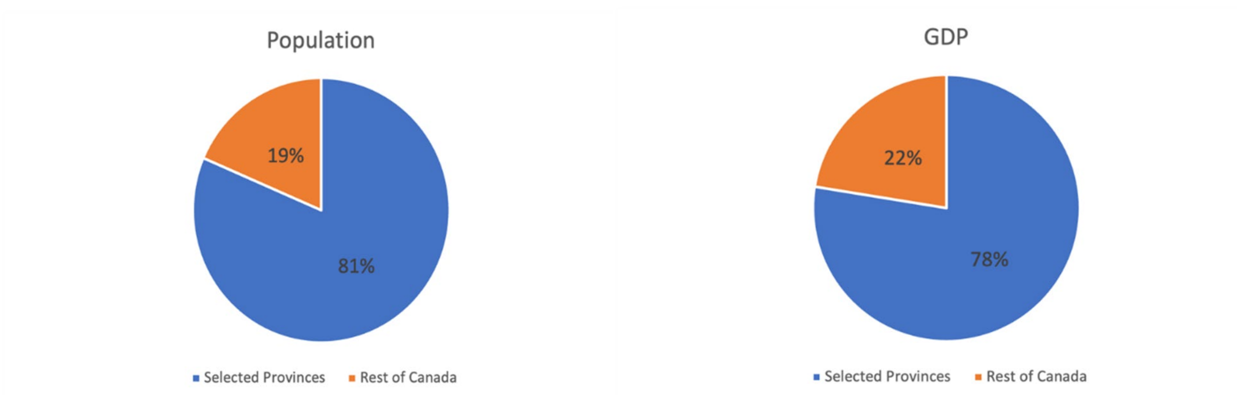

Figure 3: Share of Population and GDP for Selected Provinces in 2022
Data Source: Statistics Canada. Table 17-10-0009-01 & Table 36-10-0402-01

In contrast, Saskatchewan, with its comparatively smaller population and economic size, plays a crucial role in the country's energy sector. The province is a significant producer of oil and gas (Government of Saskatchewan, 2023), creating a unique juxtaposition of traditional energy production and the adoption of green technology like EVs.

British Columbia has been recognized for its proactive efforts in promoting EV adoption. The province's iZEV Program has facilitated a higher adoption rate of EVs, making it an interesting case for understanding the impact of policy incentives (Government of British Columbia, 2019). Further, BC's favourable weather and reliance on hydropower make it an ideal jurisdiction for EV adoption.

Quebec is the second most populous province after Ontario (Statistic Canada, 2023), but was the first province in Canada to adopt a zero-emission vehicle (ZEV) standard that required automakers to sell a certain number of electric, plug-in hybrid, and hydrogen fuel cell vehicles (Canada Energy Regulator, 2018). Along with its large hydropower output, the province's transportation electrification strategy has significantly contributed to the adoption of EVs, making it an essential sample component.

Finally, Manitoba has established itself as a green energy leader by producing 98 percent of its electricity from renewable hydroelectricity (Government of Manitoba, 2015).

These five provinces have also been chosen for their varied climatic conditions. Previous studies have shown that local weather patterns can significantly impact EV range and performance (Yuksel and Michalek, 2015), thus influencing consumer preferences. The variation in climatic conditions across these provinces helps us understand these influences better.

Data availability was another crucial factor guiding the sample selection. Thus, despite being Canada's fourth most populous province (Statistics Canada, 2022) and the major player in the country's energy sector, Alberta was excluded because it does not disclose vehicle sales or registration data. This lack of data poses a limitation on the comprehensiveness of the study, highlighting the challenges faced in data collection for such research. However, despite such limitations, the selected provinces provide a robust sample that captures diverse and significant aspects influencing EV demand.

Each province's unique interplay of socio-economic conditions, climate, and policies forms the crux of this research's geographical sample, offering a comprehensive view of the potential drivers of EV demand. Given that provinces exhibit significant variance in temperatures and other attributes across their landscape, reliance on cities provides additional variation for improved statistical analysis. Thus, to understand these influences at a more granular level, the research delves deeper into city-level data within each province. The chosen cities represent a mix of metropolitan and non-metropolitan areas, providing an additional layer of diversity to the study's sample.

3.2 Variables

As noted above, the data are from the first quarter of 2017 (2017Q1) to the fourth quarter of 2022 (2022Q4). This period captures various stages of EV policy implementation, fuel price fluctuations, and other temporally dependent factors, presenting an ideal scenario for a dynamic investigation of EV demand patterns. Table 1 summarizes the variables studied in my panel data analysis.

Table 1: Definitions of the variables selected to study.

Variables	Definition	Time Range	Sources	Unit
EV	EV (BEV &PHEV) Registration Per Capita	2017-2022	Statistics Canada	
FP	Fuel Prices (Gasoline and Diesel)	2017-2022	Statistics Canada & GasBuddy	Cents per litre
EPSPindex	Electricity Power Selling Price Index	2017-2022	Statistics Canada	Index, 2014=100
MinTemp	Minimum Temperature	2017-2022	Climate Data Canada	ºC
Rebate	Rebates for New EVs	2017-2022	Multiple sources	Canadian Dollars
APCP	Available Public EV Charging Ports	2022	Government of Canada	
GDP	Gross domestic product Per Capita	2017-2022	Statistics Canada	Canadian Dollars

3.2.1 Dependent Variable

Statistics Canada provides registration data for new zero-emission vehicles from the first quarter of 2017 to the fourth quarter of 2022.[1] This also explains the use of our period 2017Q1 to 2022Q4. The dataset contains information on many cities in Canada, except ones in Alberta, Nova Scotia, Nunavut, and Newfoundland & Labrador due to contractual limitations of the existing data-sharing agreement (Statistics Canada, 2023). Instead of using raw EV registration data, a per capita measure is used to account for the size disparity among different cities. This adjustment ensures that the findings are not skewed by population differences across cities. With per capita registration data, we can better compare the rate of EV adoption between smaller and larger cities on a level playing field (Gallagher and Muehlegger, 2011). The resultant figure gives us a more standardized measure of EV uptake, removing population size as a confounding factor and allowing us to focus on the impact of other independent variables.

Figure 4 displays the proportion of electric vehicles among all new vehicle registrations for five selected provinces from 2017Q1 to 2022Q4, indicating changes in overall EV registrations over time. The figure enables us to visualize and understand the growing prominence of EVs in the new vehicle market over time, providing additional context for the impact of the independent variables we are examining.

[1] Statistics Canada. New zero-emission vehicle registrations. Table 20-10-0025-01. New zero-emission vehicle registrations, quarterly. https://doi.org/10.25318/2010002501-eng.

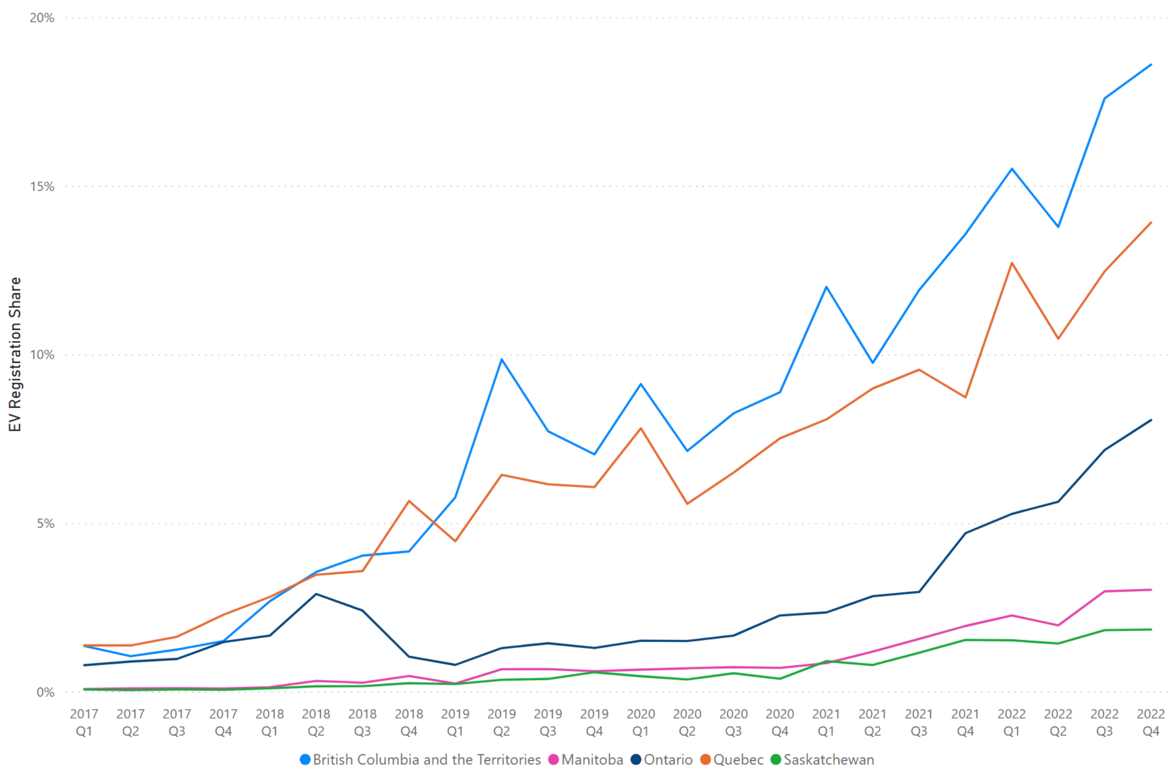

Figure 4: Shares of EVs in total new vehicle registrations for Selected Five Provinces from 2019Q1 to 2022Q4.
Data Source: Statistics Canada. Table 20-10-0024-01 New motor vehicle registrations

3.2.2 Independent Variable

Data from Statistics Canada are integrated with data from the GasBuddy gasoline price inquiry website to generate comprehensive quarterly gasoline price statistics for selected cities.[2] As indicators of the operating cost of conventional vehicles, these variables assess how fluctuations in fuel prices may influence the relative attractiveness of EVs (Briseño et al., 2021). The changes in the price of gasoline and the number of registered EVs in Montreal, Toronto, Saskatoon, and Vancouver are illustrated in Figure 5 throughout the study timeline. As shown in the figure, the

[2] Gasbuddy. GasBuddy Charts: Fuel Price History for All. https://www.gasbuddy.com/charts [Accessed 29, May 2023]. Statistics Canada. Retail Prices for Gasoline and Fuel Oil. Table 18-10-0001-01. Monthly average retail prices for gasoline and fuel oil, by geography. https://doi.org/10.25318/1810000101-eng.

trend suggests a positive relationship: an increase in gasoline prices generally coincides with an uptick in EV registrations, implying that higher operating costs for conventional vehicles could be a motivating factor for consumers to switch to EVs.

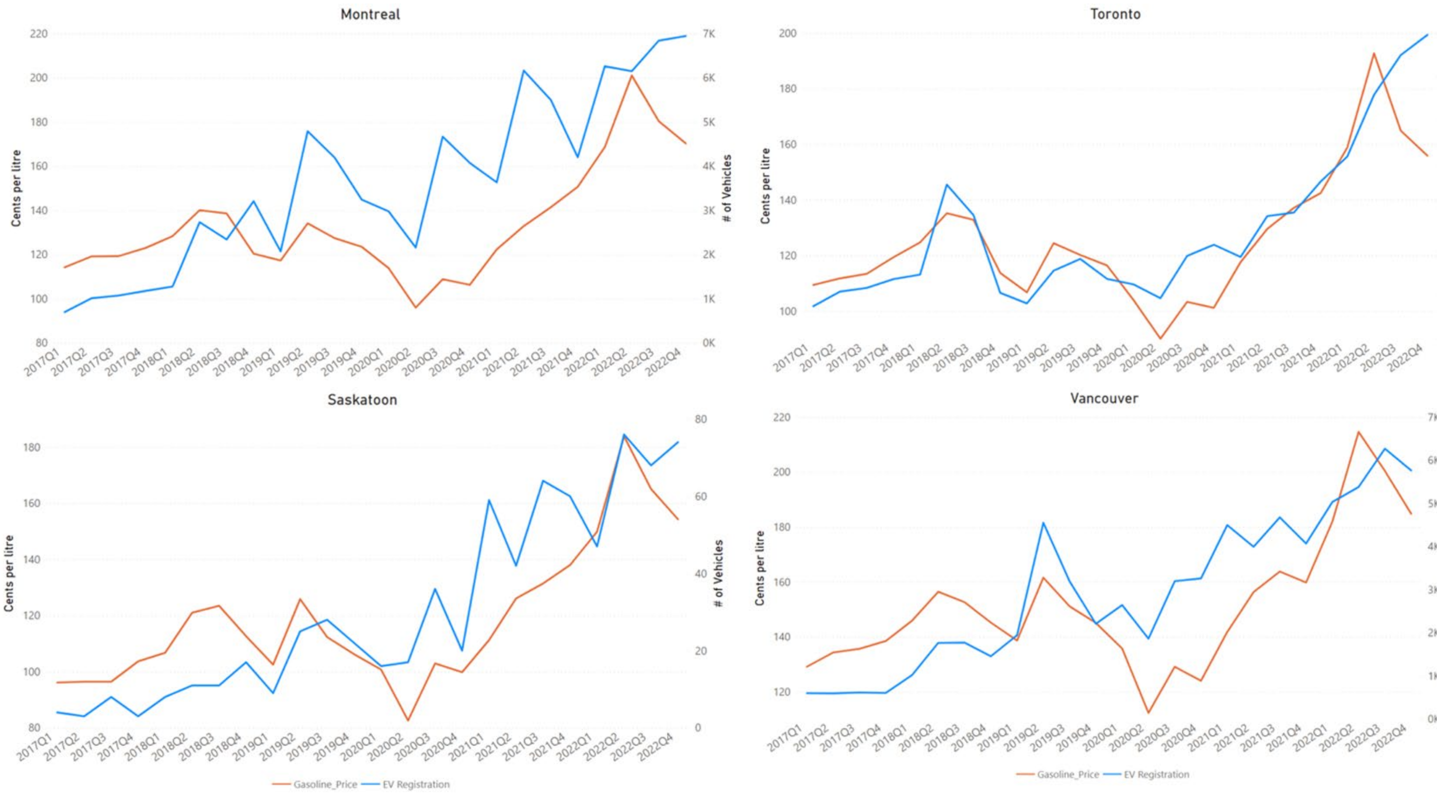

Figure 5: Trends in Gasoline Prices and EV Registrations in Toronto, Vancouver, Saskatoon, and Montreal from 2017Q1 to 2022Q4.
Sources: Statistics Canada. Table 18- 10-0001-01 Monthly average retail prices for gasoline and fuel oil, by geography & Table 20-10-0024-01 New motor vehicle registrations

The Electricity Power Selling Price Index is also available from Statistics Canada. [3] The monthly data were converted into quarterly data. This variable represents the cost of powering an EV, indicating how the economics of EV ownership vary over time and location (Briseño et al., 2021).

[3] Statistics Canada. Table 18-10-0204-01 Electric power selling price index, monthly. https://doi.org/10.25318/1810020401-eng

Information on minimum temperatures comes from a website created by Environment Canada and provides historical data for each Canadian weather station.[4] The daily data were converted to quarterly data by computing the average minimum temperature. The minimum temperature serves as an indicator of local weather patterns; the minimum temperature assesses the impact of weather on EV performance and consumer preference for EVs (Yuksel and Michalek, 2015). As shown in Figure 6, there are correlations between average minimum temperatures and EV registrations in Montreal, Toronto, Saskatoon, and Vancouver from Q1 2017 to Q4 2022. The graphs show how local weather patterns, especially those indicated by minimum temperature, might affect the consumer preference.

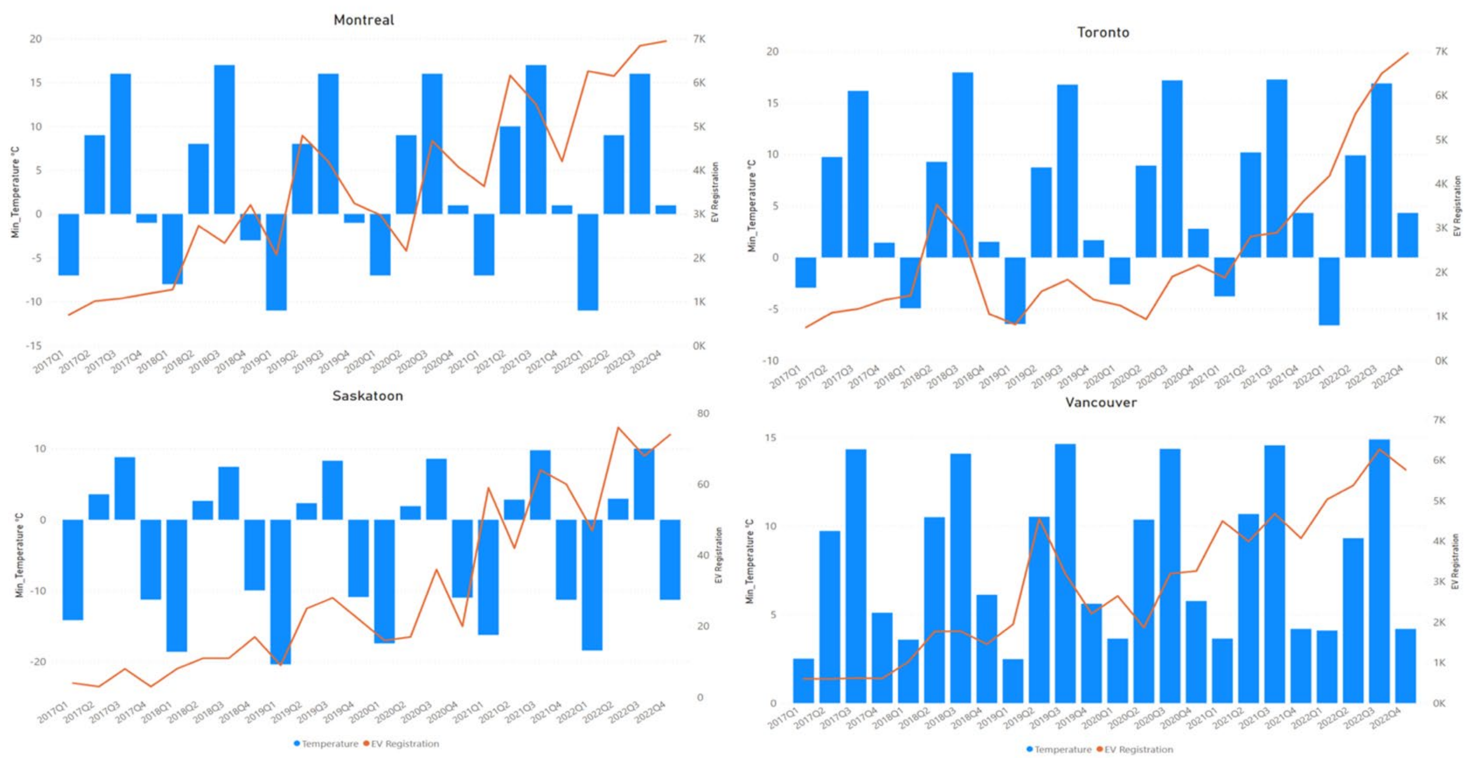

Figure 6: Trends in Minimum Temperature and EV Registrations in Toronto, Vancouver, Saskatoon, and Montreal from 2017Q1 to 2022Q4.
Sources: Environment Canada. Average temperature for Canadian cities & Statistic Canada. Table 20-10-0024-01 New motor vehicle registrations

[4]Environment Canada . Climate Data Canada. (n.d.). Average temperature for Canadian cities. https://climatedata.ca [Accessed 29, May 2023].

For rebate information, the federal and provincial governments' websites of Canada only disclose the most recent subsidy policies. Data on historical rebates provided by the Canadian federal government and the five selected provinces from 2017Q1 to 2022Q4 were obtained by summarizing many news websites and collecting data according to the time node of each quarter.[5] Data on rebates reflect policy incentives for purchasing EVs, a factor that can substantially lower the upfront cost of EVs and promote their adoption (Wee, 2018).

Data on charging facilities, a crucial factor influencing the decision to purchase electric vehicles (Mutavdija et al., 2022), are available from the Government of Canada via the Electric Charging and Alternative Fueling Stations Locator.[6] However, we encountered a limitation in data availability, as historical records for available public EV charging ports across the selected cities were unavailable. The only accessible data were specific to the year 2022. As a result, the available data were treated as an interaction term with a dummy variable for the year 2022. This strategy enables us to capture the availability of EV charging ports and its specific effect on EV demand in 2022, notwithstanding the absence of historical data.

Annual GDP data are provided by Statistics Canada for each province; the same annual

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[5] Government of British of Colombia. BC Passenger EV rebate. https://goelectricbc.gov.bc.ca/personal-rebate-offers/passenger-vehicle-rebates/[Accessed 29, May 2023].
Electrek. (2018, July 11). Ontario shuts down EV rebate, Tesla Model 3, and efforts to reduce gas price. Electrek. https://electrek.co/2018/07/11/ontario-shuts-down-ev-rebate-tesla-model-3-reduce-gas-price/ [Accessed 29, May 2023].
Gouvernement du Québec. Québec Passenger EV rebate. https://goelectricbc.gov.bc.ca/personal-rebate-offers/ [Accessed 29, May 2023].
Gazette. (2022, Mar 23). Quebec budget reduces rebates for electric vehicles. Driving.ca. https://driving.ca/auto-news/local-content/quebec-budget-reduces-rebates-for-electric-vehicles/ [Accessed 29, May 2023].
Transportation of Canada. Incentives for purchasing zero-emission vehicles. https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/light-duty-zero-emission-vehicles/incentives-purchasing-zero-emission-vehicles [Accessed 29, May 2023].

[6] Government of Canada. Electric Charging and Alternative Fuelling Stations Locator. https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/electric-charging-alternative-fuelling-stationslocator-map/20487#/analyze [Accessed 29, May 2023].

data are used for each quarter throughout the year, but then divided by provincial population.[7] Per capita GDP is a commonly used measure of a region's economic activity per person and can serve as a proxy for income level. Population data are available from Statistics Canada as well. By using GDP per capita, economic output is normalized by population size, yielding a more precise measure of the average income level in each city. Thereby, one can better assess the potential financial capacity of residents to purchase EVs and the relative economic incentives or barriers they face. This normalization allows for meaningful comparisons across provinces/cities and aids in interpreting the impact of economic conditions on EV adoption (Briseño et al., 2021). Further, lacking city-level GDP data, the provincial GDP data are employed.

In conclusion, the selection of the sample in this study offers a rich and varied setting to investigate the myriad factors influencing EV demand. The combination of provinces and cities represents diverse socio-economic, policy, and climatic conditions, thus enabling a holistic exploration of the EV landscape in Canada.

Summary statistics are provided in Table 2. These include the mean, standard deviation, minimum, and maximum values for each variable employed in the regression model. The statistical model employed in the study is described in the next section.

[7] Statistics Canada. GDP. Table 36-10-0402-01 Gross domestic product (GDP) at basic prices, by industry, provinces and territories (x 1,000,000). https://doi.org/10.25318/3610040201-eng .

Table 2: Summary Statistics.

	N	Mean	Sd	Min	Max
EV	528	.00037	.0004	0	.0022
FP	528	127.99	27.64	80.8	214.67
EPSPindex	528	114.79	6.15	100	126.3
MinTemp	528	1.15	9.99	-28.5	18
Rebate	528	5946.01	4152.02	0	14000
APCP	528	65.10	316.55	0	2460
GDP	528	50738.67	8079.918	41939	70844

3.3 Statistical Model.

For this study, a panel data regression model with fixed effects is used. This approach is particularly suitable for analyzing panel data that are characterized by having a mix of time series and cross-sectional observations (Bell and Jones, 2015). In the current context, the cross-sections are cities, and the time series constitutes the quarterly data for each city.

3.3.1 Panel Data and Fixed Effects Model

Panel data possess a multi-dimensional nature, integrating both cross-sectional and time-series dimensions. This type of data, also known as longitudinal data, allows for control over individual heterogeneity, offers variation across time and entities, and provides a larger sample size, thereby improving the efficiency of the econometric estimates (Hsiao et al., 1995).

Bollen and Brand (2010) mentioned that for panel data analysis, the fixed effects model serves as a highly effective tool, specifically due to its capability to control for time-invariant characteristics. By focusing on the changes within each city over time, the fixed effects model eliminates the influence of time-invariant characteristics, which differ across cities but remain constant over time, such as geographical and cultural factors. This method thus allows us to isolate the net effects of the predictor variables on the dependent variable.

3.3.2 Fixed Effects Model versus Random Effects Model

Both fixed effects and random effects models were contemplated. The choice of the model fundamentally hinges on the assumptions about the correlation between the unobserved individual heterogeneity and the independent variables. The fixed effects model assumes that the individual-specific effects, in this case, the city-specific unobserved factors, are correlated with the explanatory variables. Given the subject of this investigation, this assumption is entirely plausible. For instance, local policies, cultural tendencies, or geographical characteristics inherent to specific cities may impact both the independent variables, such as minimum temperature or GDP per capita and the dependent variable EV registrations per capita.

The random effects model, on the other hand, operates under the assumption that the unobserved individual-specific effect is not correlated with the independent variables. In the context of my research, this assumption is unlikely to hold. Hence, the fixed effects model is preferred over the random effects model.

The choice of a fixed effects model was further supported by the results of the Hausman test shown in Table 3. It indicates that the fixed effects model offers a statistically superior fit for the data as compared to a random effects model. The statistically significant outcome (Prob > chi2 = 0.0000) rejects the null hypothesis, thereby favoring the fixed effects model.

Table 3: Hausman Test Results

Test Statistics	36.52
Degrees of Freedom	6
p-value	0.000

Given these considerations, the fixed effects model is chosen as the most appropriate method for analyzing my panel data. By incorporating city-specific fixed effects, it is possible to account for unobserved heterogeneities, control for within-city variations over time, address endogeneity issues, and capture city-specific effects. This allows for a rigorous and robust analysis of my research questions and provides valuable insights into the relationships under investigation. The idea of employing a pooled regression was dismissed due to its potential drawbacks. Pooled regression, while useful in certain situations, fails to consider time and entity-fixed effects in panel data, which could lead to biased and inconsistent estimates. In the current context, where a correlation is suspected between the individual-specific effect and the explanatory variables, pooled regression could lead to an omitted variable bias. The fixed effects model remedies this issue by accounting for both time-invariant and entity-specific characteristics (Ziegler, 2012). Consequently, it provides a more accurate and reliable understanding of the relationships that are to be examined.

3.3.3 Model Specification

The regression equation used in this study is like Briseño et al. (2021) and Guo et al. (2020). The model is specified as:

$$EV_{it} = \beta_0 + \beta_1 MinTemp_{it} + \beta_2 FP_{it} + \beta_3 Rebate_{it} + \beta_4 EPSPindex_{it} + \beta_5 GDP_{it} + \beta_6 APCP_{i2022} \times Year\ 2022 + \mu_i + \varepsilon_{it} \sim n.i.d\ (0\ , \sigma^2) \quad (1)$$

where EV_{it} is EV registration per capita for the city i at time t. $MinTemp_{it}$ is minimum temperature in city i at time t; $MinTemp_{it}$, FP_{it}, $Rebate_{it}$, $EPSPindex_{it}$ and GDP_{it} are variables representing minimum temperature, fuel prices, rebates, electric power selling price, and GDP of region i at time t, respectively; and $\beta_6 Charge_{i2022} \times Year\ 2022$ is an interaction term for the effect of charging ports in 2022.

The purpose is to estimate the effect of each independent variable on EV registrations per capita, holding all other variables constant. Notably, $\beta_6$captures the interaction effect between the

EV charging ports in the year 2022 and the year itself, shedding light on how EV charging infrastructure influences EV demand specifically in 2022. The term μ_i allows the model to account for city-specific characteristics that are not explicitly included in the model but are constant over time, thereby mitigating the potential omitted variable bias. On the other hand, $\varepsilon_{\mathrm{it}}$ is an error term accounting for other potentially influential factors that are not incorporated in the model.

In summary, the decision to employ a panel data regression with a fixed effects model was made after careful consideration of the nature of the data and the research question at hand. By doing so, the study aims to provide robust, unbiased, and consistent results that will contribute meaningfully to the understanding of factors influencing EV registration per capita.

4. RESULTS

The results are derived from three fixed-effects regressions based on the forgoing model — a regression based on one for all Electric Vehicles (EVs), one for Battery Electric Vehicles (BEVs), and another for Plug-in Hybrid Electric Vehicles (PHEVs). Each model utilizes the same selection of control variables that include the gasoline price, EPSP index, minimum temperature, rebate, Available APCP dummy variable for 2022, and GDP per capita.

To enhance the robustness and interpretability of our regression results, we undertook a crucial methodological step — standardization of my variables. This process involved adjusting each predictor by subtracting its mean and subsequently dividing by its standard deviation. Given the diverse nature and scale of my control variables, ranging from gasoline prices in cents per liter to GDP in Canadian dollars, standardization ensures that all predictors operate on a consistent scale. This uniformity is pivotal for a coherent interpretation of regression coefficients, not only clarifies the results but also provides a more intuitive understanding of the relative influence of each predictor.

The models estimate factors explaining EV, BEV, and PHEV registrations per capita in given cities, with each model producing unique and insightful findings, as illustrated in Table 4.

Table 4. Model estimation results regarding the EVs of different sales

Regressor	EV	BEV	PHEV
Minimum Temperature	0.0811*** (0.0249)	0.0679*** (0.0268)	0.0927** (0.0254)
Fuel Price	0.2438*** (0.0300)	0.2308*** (0.0323)	0.2213*** (0.0305)
Rebate	0.2016*** (0.0303)	0.1752*** (0.0326)	0.2170*** (0.0308)
EPSP Index	0.0447 (0.0403)	0.0552 (0.0434)	0.0127 (0.0410)
GDP	1.2406*** (0.1912)	1.1902*** (0.2075)	1.0927*** (0.1944)
APCP_Dummy2022	0.00060*** (0.00008)	0.000090*** (0.00009)	-0.00001 (0.00008)
Constant	-0.0327 (0.0226)	-0.0503** (0.000447)	-0.0121 (0.0001961)
R^2 (within)	0.4604	0.4710	0.2911
Prob > F	0.0000	0.0000	0.0000

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The three fixed-effects regression models yielded strong fit statistics with R^2 (within) values of 0.4604, 0.4710, and 0.2911, respectively. The results of each regression are discussed in the following subsections.

4.1 EV Registration Model

In the EV model and apart from the Electric Power Selling Price (EPSP) Index, each of the regressors is statistically significant in predicting the number of EV registrations. Notably, when the price of gasoline increases, so does the number of EV registrations. The same positive trend was seen with the minimum temperature, the availability of rebates, the number of EVSE Ports in 2022, and the GDP per capita.

4.2 BEV Registration Model

This model had the same pattern as the EV model. All variables, except the EPSP Index, play a statistically significant role in predicting BEV registrations. Similarly, BEV registrations can be explained by the following: a higher price of gasoline, higher minimum temperatures, the availability of rebates, the number of EVSE Ports in 2022, and higher GDP per capita.

4.3 PHEV Registration Model

The PHEV model was slightly different. Here, both the EPSP Index and the number of EVSE Ports in 2022 were not significant in predicting PHEV registrations. This is not unexpected as the operation of a PHEV is not reliant on a charged battery. However, like the previous two models, an increase in the price of gasoline, minimum temperature, or GDP per capita results in more PHEV registrations. Interestingly, unlike the previous two models, the number of EVSE Ports had a negative (though insignificant) relationship with PHEV registrations.

4.4 Interpretation of Findings

The regression models yield robust results for understanding the nuances of EVs, BEV, and PHEV registrations. First, city-specific effects play a crucial role in EVs, BEV, and PHEV registrations. This emphasizes the influence of local factors, such as local regulations, infrastructure availability, and socio-economic conditions, in shaping the adoption of EVs. This finding aligns with earlier research that has underscored the importance of local policies and circumstances in EV adoption (Vergis and Chen, 2015; Mersky et al., 2016).

The model shows that gasoline price is a determinant of EVs, BEV, and PHEV registrations. Specifically, an increase in fuel price by one standard deviation ($0.2764) results in an augmentation of 24.38%, 23.08%, and 22.13% standard deviations in the registration per capita of EVs, BEVs, and PHEVs, respectively. More precisely, our analysis for Canada suggests that a 10% decrease in average gasoline prices (reduced to approximately $1.15 from $1.28 per liter) would lead to a decline of about 514 EV registrations in a city with an average population of 1,033,924, holding other variables constant. For instance, in the fourth quarter of 2022, Vancouver witnessed a total of 5,767 new registrations of electric vehicles. However, it is estimated that if there had been a 10% drop in gasoline prices during this time, there may have been a decrease of 1,520 EV registrations, bringing the total number down to only 4,247. This direct relationship underscores the sensitivity of electric vehicle demand to changes in gasoline prices. These findings are consistent across all specifications and are statistically significant at the 1% level, emphasis-zing the importance of fuel costs in driving EV adoption. This trend is illustrated in Figure 5. When a substitute (gasoline-powered vehicles) becomes more expensive, demand for the alternative (electric vehicles) increases. These findings echo prior research indicating that fuel prices are significant determinants of EV adoption (Briseño et al., 2021).

Factors like minimum temperatures, rebates, and GDP per capita also demonstrated positive relationships with EVs, BEV, and PHEV registrations, implying that these factors positively influence consumers' propensity to adopt electric vehicles.

The model reveals that the effect of temperature is consistently positive across all types of EVs. For each standard deviation increase in the minimum temperature (approximately 10 degrees), the standard deviation of EVs registration per capita increase by 8.11%, BEV registrations by 6.79%, and PHEV registrations by 9.27%. Translated to real-world terms, a 10-

degree uptick in average minimum temperature could result in an additional 29.8 EV registrations in cities with an average population nearing 1,033,924, all else being equal. Specifically, in Vancouver's context for the fourth quarter of 2022, such an average minimum temperature shift from 4 degrees to 14 degrees could have increased EV registrations from 5,767 to an estimated 7,025. All these estimates are statistically significant, most notably at the 1% level, indicating a strong relationship between temperature and EV adoption. The finding regarding minimum temperature corroborates both our hypothesis drawn from Figure 6 and previous studies. Milder climates foster higher demand for EVs, a trend that can be attributed to the specific performance characteristics of electric vehicles (Yuksel and Michalek, 2015); for example, batteries cannot be recharged in temperatures approaching minus 40ºC.

Our results suggest that the influence of rebates is substantial on the sales of all types of electric vehicles. Specifically, a standard deviation increase in rebate amounts (\$4152.05) is associated with a 20.16% increase in the standard deviation of EVs registrations per capita, 17.52% for BEV, and 21.70% for PHEV. Once again, these coefficients are statistically significant at the 1% level. From our model, by removing the average rebates, which corresponds to a reduction of roughly \$5946, we could anticipate 120 fewer EVs registered in an average-sized city of 1,033,924 residents in Canada, with all other factors remaining constant. For example, the removal of all rebates for Vancouver in fourth quarter of 2022, would reduce EV registrations by approximately 810 EV registrations, bringing the total from 5,767 down to about 4,957 registrations. The positive impact of rebates aligns with research demonstrating that financial incentives significantly boost EV adoption (Gallagher and Muehlegger, 2011; Mersky et al., 2016). Figure 4 can intuitively ascertain the impact of this factor on the adoption of EVs in Canada. Increases in the percentage of electric vehicles in these provinces can be traced back to the beginning of 2019 when the federal government of Canada launched its iZEV program. British Columbia has the highest and fastest-growing share of EVs, followed by Quebec, Ontario, Manitoba, and Saskatchewan. This tipping point illustrates the critical function of government incentives in the growth of the Canadian EV market. Changes in Ontario's share of electric vehicles are another notable example. Since the Ontario government announced in the second quarter of 2018 that it would no longer provide rebates for the purchase of electric vehicles in the province (Government of Ontario, 2018), the number of EV registrations in Ontario has dropped significantly. Electric vehicle ownership in Ontario started to increase again in the first quarter of 2019 once the iZEV project was launched, however, it took a very long time to reach the prior peak. This is because the maximum rebate for the iEVZ offered by the federal government is $5,000, while the maximum rebate in Ontario was $14,000.

Available public EV charging ports have positive impact on EVs and BEV but not PHEV. PHEVs have both an internal combustion engine and an electric powertrain, which means they can run on either gasoline or electric power. Because of this flexibility, PHEV owners can choose to refuel their vehicles with gasoline if charging stations are not readily available or convenient. This means that the availability of public EV charging infrastructure may not be as significant a factor influencing PHEV adoption as it is for EV and BEV.

While the EPSP Index is not statistically significant at the 10% level for any EV type, it's worth noting its positive relationship with BEV (5.52%) and its almost negligible influence on PHEV (1.27%).

Lastly, economic growth, represented by GDP, has a prominent influence on EV sales. One standard deviation ($8080) increases in GDP per capita leads to a 124.06% increase in the standard deviation of EVs registration per capita, 119.02% for BEV, and 109.27% for PHEV. This is significant at the 1% level across all categories. To further elaborate, it becomes evident that an incremental increase of $8080 in GDP per capita translates directly to a significant boost in EV, BEV, and PHEV registrations across the board. In a Canadian city with an average population of 1,033,924, this translates to an expected growth of approximately 872 for EVs, 851 for BEV, and 813 for PHEV. Applied to Vancouver, the 2022Q4 EV registrations would increase from 5,767 to an estimated 7,155, marking an additional 1,388 registrations, given the same GDP increase. This correlation highlights the significant impact that economic growth can have on the adoption of electric vehicles. This is understandable, as wealthier consumers are more likely to afford the higher upfront costs associated with EVs (Wee, 2018).

4.5 Implications of Findings

The implications of these findings are multi-fold. For policymakers, the study underscores the effectiveness of economic incentives such as rebates in boosting EV adoption. Furthermore, the findings suggest that changes in electricity prices are unlikely to impact EV purchases in Canada. Similarly, for manufacturers and retailers, understanding these factors can help them target markets more effectively. For example, regions with higher minimum temperatures could be potential target markets due to the performance benefits of EVs in such climates.

4.6 Limitations

While the results are insightful, some limitations should be noted. First, the findings of this study assumed that all other factors remain constant, which may not hold in real-world scenarios. Second, the study did not consider other possible factors, such as public awareness and attitudes toward EVs, which can significantly influence EV adoption (Yang et al., 2022; Guo et al., 2020). Additionally, the study did not account for potential lag effects, where a change in one of the variables might not immediately impact EV registrations.

One unexpected result in the analysis was the statistically insignificant role of the EPSP Index in all three models. This finding contradicts existing literature suggesting that electricity prices have a negative impact on EV adoption (Wee, 2018). While the EPSP Index's insignificance in our models may seem counterintuitive, it likely reflects the unique energy landscape of Canada.

A significant proportion of the Canadian population lives in provinces where electricity costs are relatively low, particularly in areas that benefit from hydroelectric power generation, such as Quebec and British Columbia (see Figure 7), and Manitoba (Government of Canada, 2022). Such low costs may alter the perceived expense of operating EVs, thus diminishing the apparent influence of electricity prices on EV adoption decisions. In regions with cost-effective and sustainable electricity sources, the operational cost savings of EVs compared to traditional vehicles may be less pronounced, potentially explaining the EPSP Index's reduced significance in our models.

Meanwhile, Ontario's reliance on nuclear energy, another low-carbon source, further complicates the relationship between electricity costs and EV adoption. The absence of data from Alberta, where electricity relies more on fossil fuels, prevents a complete understanding of how electricity prices across different energy contexts might influence EV adoption. Future research should seek to fill this gap by examining provinces with diverse energy sources to fully capture the nuanced effects of electricity costs on the economics of owning an EV.

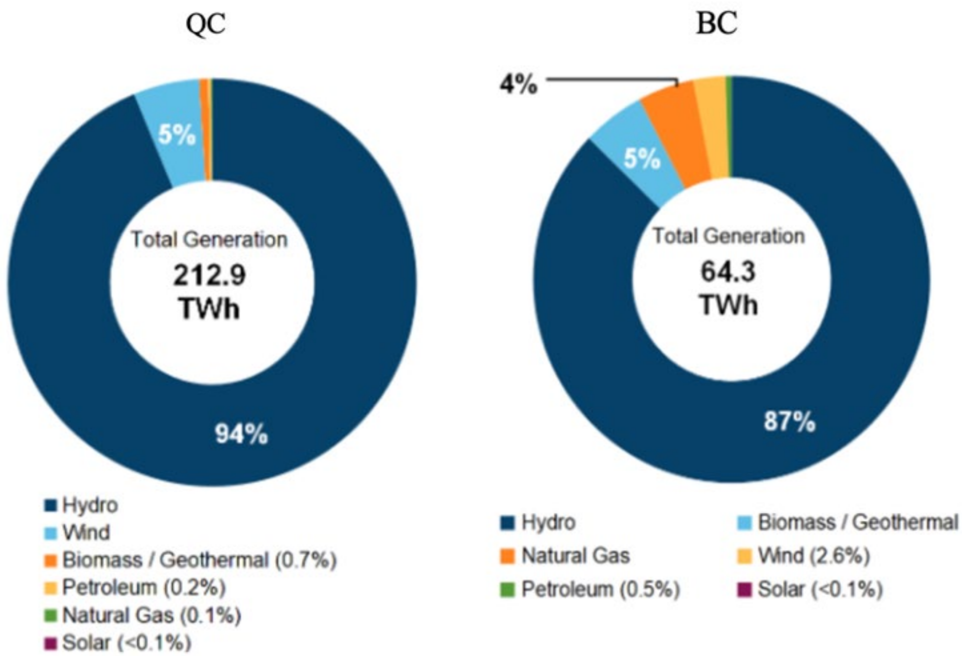

Figure 7. Electricity Generation by Fuel Type (2019), QC & BC
Source: Canada Energy Regulator. Canada's Energy Future Data Appendices.

5. CONCLUDING DISCUSSION

This study delivers an extensive examination of factors influencing the adoption of all Electric Vehicles (EVs), Battery Electric Vehicles (BEVs), and Plug-in Hybrid Electric Vehicles (PHEVs) in Canadian cities. Applying fixed-effects regression models, the research investigated key variables, such as gasoline price, electric power selling price (EPSP) index, minimum temperature, rebates, available public EV charging ports (APCP) in 2022, and GDP per capita.

The findings highlight that gasoline price, minimum temperature, rebates, and GDP per capita significantly impact the adoption of all three types of vehicles. However, the APCP does not significantly affect PHEV adoption, contrary to its positive influence on EV and BEV registrations. This divergence is likely attributed to PHEVs' dual fueling capability, which reduces their dependence on charging infrastructure. Meanwhile, the EPSP index was found to have an insignificant impact on the adoption of all vehicle types.

The findings emphasize the significance of economic incentives such as rebates and the central role of local environmental and socioeconomic factors in EV adoption. The findings offer crucial insights for policymakers, manufacturers, and consumers equally, highlighting the effectiveness of strategic targeting of market segments with higher minimum temperatures and the provision of economic incentives to promote EV adoption.

Delving into the economic perspective, the use of subsidies, such as rebates, to promote EVs can be seen in two lights. On one hand, subsidies can act as a catalyst, accelerating adoption and thus leading to economies of scale, greater research and development, and decreased unit costs over time. This could further enhance consumer adoption and reduce environmental externalities like greenhouse gas emissions. Highlighting the impact of these subsidies, our model indicates that, without them Canada might see approximately 4,400 fewer EV registrations each year. On the other hand, the short-term financial outlay required by governments to subsidize EVs might be seen as an undue burden on taxpayers, especially if not offset by long-term benefits. It is crucial, therefore, for economic analyses to weigh these costs against the anticipated long-term economic, environmental, and societal gains.

Despite existing literature suggesting the negative impact of electricity prices on EV adoption, the EPSP Index in this study was statistically insignificant. This could be attributed to the unique Canadian context, particularly the distribution of the population and power generation methods across different provinces. Provinces with high EV adoption rates also have low electricity prices due to extensive use of hydroelectric power, which might influence consumers' perception of the operational costs of EVs.

Future research could examine these overlooked factors, explore the lagged effects of the influencing variables, and potentially probe into non-linear relationships between these factors and EV adoption. This would offer a more comprehensive understanding of consumer decision-making in EV adoption.

Overall, this study offers vital insights into the factors influencing electric vehicle adoption in Canada. However, it addresses only a portion of the broader narrative around electric vehicles. The findings highlight the importance of formulating government policies that not only foster EV adoption but also align with wider goals to mitigate CO2 emissions. Understanding these determinants allows policymakers to create more effective strategies for encouraging the shift to electric vehicles, which is a crucial step towards fulfilling Canada's commitments to reduce carbon emissions and address climate change challenges. Such targeted policies can significantly contribute to the nation's environmental sustainability objectives.

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