

**UNDERSTANDING THE PREFERENCES AND SUITABILITY OF CONSUMERS FOR
ELECTRIC VEHICLE ADOPTION IN CANADA**

**UNDERSTANDING THE PREFERENCES AND SUITABILITY OF CONSUMERS FOR
ELECTRIC VEHICLE ADOPTION IN CANADA**

By ELNAZ HAJ ABOTALEBI

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AUTHOR: Elnaz Haj Abotalebi

Bachelor and Master of Architecture Engineering (Iran, 2010)

Master of Urban Planning (University at Buffalo, NY, 2012)

SUPERVISOR: Professor Darren M. Scott

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Abstract

In Canada, road transportation accounts for more than one-fourth of secondary energy use, and thus is one of the main contributors to greenhouse gas (GHG) emissions (Environment Canada, 2016). With around 81% of Canadian households having at least one vehicle, the automobile is an important element of household mobility, while the transportation sector relies heavily on petroleum products for on-road use (Statistics Canada, 2016). Despite this situation, Canada has accepted to reduce its GHG emissions by 30% below 2005 levels by 2030 under the 2015 Paris agreement (Environment Canada, 2016). This emissions reduction goal, however, is unlikely to happen without transitioning to carbon-free alternatives, such as electric vehicles, for daily transportation. Despite many advancements in electric mobility, Canada still lags many other countries with respect to electric vehicle (EV) adoption among private consumers.

To address this issue, the present dissertation discusses details of a survey that was developed to investigate electric mobility prospects in Canada through a series of socioeconomic, attitudinal, and stated preference (SP) questions. The acronym “SPACE” (Survey for Preferences and Attitudes of Canadians towards Electric Vehicles) is used for the purpose of present thesis to identify the survey instrument. The SPACE dataset is then utilized to conduct econometric analyses (latent class modelling approach) of vehicle powertrain in Atlantic Canada, a lagging region in terms of EV uptake, and to compare results with those obtained for leading adoption provinces (Ontario and British Columbia). This comparison highlights potential differences and similarities in terms of openness towards EVs and willingness to pay for different vehicular features of EVs.

The thesis also investigates economic suitability of battery electric vehicles (BEV) for Canadian households to gain insights on characteristics of households for whom adopting a BEV would make economic sense.

Results of econometric analysis indicate that despite the very low penetration level of EVs, there is widespread openness to the idea of electric vehicles in Atlantic Canada, although less than leading adoption provinces. The main obstacles to the widespread adoption of EVs in Atlantic Canada can be explained as higher purchase prices of EVs relative to internal combustion engines (ICE), current and historical absence of financial incentives, limited exposure to EV, and inadequate charging stations. With economic suitability analysis, it was found that even with today's electric vehicles present in the market, that are considered to have high purchase price, a sizable share of Canadian households (18%) are economically suited to buy a battery electric vehicle. A bivariate ordered probit model is also utilized in the thesis to estimate annual mileage and vehicle ownership time, the most influential factors on economic suitability of BEVs. The bivariate probit model results show that multi-vehicle households with children in the suburbs have higher mileages, while education and income have positive impacts on both annual mileage and ownership time, and thus on increasing the economic suitability of BEVs. Together, results of present thesis would help policy makers and stakeholders to make targeted decisions regarding EV marketing in Canada, especially in lagging adoption regions like Atlantic Canada.

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Preface

The present dissertation is a compendium of five chapters that include an introduction, three research papers, and a conclusion. The research papers are either under-review or submitted for publication in peer-reviewed journals. All three articles focus on prospects for electric vehicle adoption among Canadian consumers using a survey (SPACE) dataset. The first research paper mainly review the process of design and implementation of SPACE that was conducted in May-June 2015. For this reason, there is some element of repetition among chapters, particularly as it relates to overlap in description of the survey and dataset used for the analysis.

For all three articles, the dissertation author conducted the literature reviews, stated preference design of the survey, census data collection, data cleaning, quantitative analysis of the dataset, model estimation, result interpretation and manuscript writing. In the first research paper, the dissertation author initiated and led the design of the survey questionnaire. She designed the stated preference scenarios using statistical methods, and conducted the McMaster University Ethics approval process. Dr. Darren Scott and Dr. Mark Ferguson are co-authored in all three papers. Dr. Scott supervised the whole process from the beginning through completion and submission by providing valuable feedback, developing research methodologies, and manuscript revising. Dr. Ferguson who is the project manager for ‘electric mobility’ research project provided professional contribution specifically in developing the first research paper that conducted critical appraisal and editing to the manuscript. Dr. Moataz Mohamed is also co-authored on the first paper

by contributing to the design of survey and also providing feedback on the first paper's manuscript.

The three research papers are as follows:

Chapter 2:

Abotalebi, E., Ferguson, M. R., Mohamed, M., Scott, D. M. 2018. Design of a Survey to Assess Prospects for Consumer Electric Mobility in Canada: A Retrospective Appraisal. *Transportation*, 1-28. <https://doi.org/10.1007/s11116-018-9952-x>

Chapter 3:

Abotalebi, E., Scott, D. M., Ferguson, M. R. 2019. Why is electric vehicle uptake low in Atlantic Canada? A comparison to leading adoption provinces. *Journal of Transport Geography* 74, 289-298. <https://doi.org/10.1016/j.jtrangeo.2018.12.001>.

Chapter 4:

Abotalebi, E., Scott, D. M., Ferguson, M. R. 2019. Can Canadian households benefit economically from purchasing battery electric vehicles? An investigation of the total cost of ownership based on consumer context. Submitted to *Transportation Research Part D: Transport and Environment*. Submitted.

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List of Abbreviations

AIC	Akaike Information Criterion
BEV	Battery electric vehicles
BIC	Bayesian Information Criterion
BC	British Columbia
CAA	Canadian Automobile Association
CO ₂	Carbon dioxide
EV	electric vehicles
GTHA	Greater Toronto and Hamilton Area
GHG	Greenhouse Gas
HOV	High occupancy vehicle
HEV	hybridized engine vehicles
ICE	Internal Combustion Engine vehicle
IEA	International Energy Agency
LC	Latent Class model
MNL	Multinomial Logit model
MNP	Multinomial Probit model
NB	New Brunswick
NL	Newfoundland and Labrador
NS	Nova Scotia
ON	Ontario
PEV	Plug-in Elective Vehicle
PHEV	Plug-in Hybrid Electric Vehicles
PEI	Prince Edward Island
QC	Quebec

RP	Revealed Preference
SPACE	Survey for Preferences and Attitudes of Canadians towards Electric Vehicles
SUV	Sport Utility Vehicle
SP	Stated preference
TPB	Theory of Planned Behaviour
TCO	Total Cost of Ownership
US	United States
WTP	Willingness To Pay

Chapter 1

Introduction

1.1 Background and research problems

In recent years, there has been increasing concern about Greenhouse Gas (GHG) emission and its impacts on climate change. This concern has led several national and international entities to develop and set policies to tackle GHG emissions. For instance, under the Copenhagen Accord, Canada is committed to reduce GHG emissions to 17% below 2005 levels by 2020 (Environment and Climate Change Canada, 2018). Canada has also associated itself with the 2015 Paris agreement, which is a new commitment to reduce GHG emissions by a certain level. With around 84% of Canadian households having at least one vehicle registered in their household, road transportation is one of the largest sources of GHG emissions. In addition to climate change, the problems with local air quality are attributable in large part to the consumption of fossil fuels by conventional motor vehicles (Black, 2010). There are also issues surrounding the finite nature of petroleum stocks and future security of energy supplies (Black, 2010).

As concerns over environmental impacts of transportation and mobility are increasing, there is the potential for electric mobility to have a positive and significant impact in Canada's sustainable transportation. The importance of electric mobility for Canada is that this country has one of the cleanest electricity generation profiles in the world, and yet has a very small market

share for electric vehicles (EVs) (about 0.6%) which lags relatively behind the US (close to 1%) and many European countries: Norway (29%), Netherlands (6.4%), Sweden (3.4%), France and United Kingdom (both close to 1.5%) (IEA, 2017). In 2012, about 73% of Canada's electricity was generated without use of Carbon dioxide (CO₂) emitting sources (such as hydro, nuclear, wind and solar) (Natural Resources Canada, 2018). It is also projected that by 2035, the share of wind and solar energy for electricity generation will increase by 7% with hydroelectricity remaining the dominant source of power production (Environment and Climate Change Canada, 2018).

With thriving automotive sector and clean electricity generation profile, there is an opportunity for Canada to take a leadership position in the penetration of electric vehicles (Plug 'n Drive, 2017). Battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and hybridized combustion engine vehicles (HEV) are examples of EV technologies. Among these options, BEVs use electricity as its main source of energy and contribute to a significant reduction of local air pollution (Garcia-Valle & Peças Lopes, 2013). PHEVs can be driven both on electric battery and gasoline mode or their combination, while HEV combines an internal combustion engine and one or more electric motors, but cannot be plugged into electricity facilities (Garcia-Valle & Peças Lopes, 2013).

Privately owned vehicles are indeed the largest contributors of GHG emissions in Canada. Therefore, to successfully understand the future diffusion of EVs in the passenger vehicle market, it is crucial to identify the characteristics of consumer segments that are most likely or are better suited to adopt an EV as their next vehicle purchase, and to determine vehicle features, policy

packages or governmental incentives that are most important to these segments (Axsen et al., 2015). The present thesis focuses on the design of a national survey instrument used to gather over 20,000 observations across Canada to provide high-quality data that enable several research works in the context of EV consumer preferences. With the use of this dataset, potential electric vehicle (EV) adoption among households in Atlantic Canada, in relation to leading adoption provinces (Ontario and British Columbia) is also investigated in this dissertation, followed by an economic analysis of battery electric vehicles for Canadian households and characteristics that make households suited for a BEV adoption.

Since the existing consumer market for EVs is still limited, revealed preference (RP) technique cannot provide useful information with regards to consumer preference (Louviere et al., 2000). Also, EVs are still considered as new technologies that are continuously evolving, and hence, to understand consumer adoption, one needs a wide range of variation of different attributes that currently is not found in real market (Daziano & Chiew, 2012). Stated preference (SP) data, on the other hand, can cover a much wider range of attributes and levels than RP data and technological shifts can be also taken into account (Louviere et al., 2000).

Design of experiments or experimental design is the technique used in this study for developing SP choice scenarios. Within each scenario, households are presented in a systematic way with automobile options, along with their defined attributes, and are asked to make a choice (Hensher et al., 2005). This technique provides quantified procedures for investigating the conditions under which potential auto buyers may purchase an EV as their next vehicle. Also, to

explore preference heterogeneity across the consumer segments, socioeconomic and environmental factors are taken into consideration (Brownstone et al., 2000). A national survey was designed and administered to a panel of Canadian households to gain better understandings of EV consumers and the variables that affect their preferences for EVs versus other vehicle alternatives. The acronym “**SPACE**” (Survey for **P**references and **A**ttitudes of **C**anadians towards **E**lectric **V**ehicles) is used for the purposes of this dissertation. The process of survey design and all details associated with it is described in full in chapter 2.

1.2 Research questions and objectives

The main goal of this study is to evaluate prospects for electric vehicle adoption among consumers in an effort to accelerate the EV adoption rate in Canada, and each objective is articulated in a way to move the undertaken research forward into this final goal. The thesis aims to provide estimates of consumer preferences for EVs, effective EV regulations and policies as well as economic suitability of battery electric vehicles. Both qualitative and quantitative strategies will be adopted to accomplish these objectives. Experimental design, discrete choice modelling, and economic analysis (total cost of ownership model) are major techniques that will be used in the present thesis, and are described in full in the methodology section of each chapter. The overall structure of the present dissertation is composed of three objectives as outlined below.

Objective 1

Objective 1 is to review the process that led to the development and construction of a national survey instrument used to gather 20,520 observations across Canada. This research chapter contributes to the literature by fully providing a comprehensive review of the survey including strategies and processes that were followed in efficiently gathering a large amount of useful EV-oriented data and information. Objective 1 is the foundation of the present thesis by developing the dataset that has given rise to two other research papers.

Objective 2

Objective 2 is to identify vehicle features and incentives that influence households' preferences towards electric vehicle (EV) in Atlantic Canada, a lagging region in terms of electric vehicle (EV) adoption. A latent class (LC) random utility model is used to segment Atlantic respondents based on their sociodemographic and environmental attitudes, and to estimate their willingness-to-pay for different vehicular features. A separate model is estimated for leading adoption provinces (Ontario and British Columbia), and compared to the Atlantic model. The results obtained from each model provide insightful information regarding the factors that make Atlantic lag behind.

Objective 3

Objective 3 investigates BEV suitability of a national sample – derived from implementation of SPACE - by comparing the total cost of ownership (TCO) for a BEV and an

equivalent Internal Combustion Engine vehicle (ICE) of similar vehicle class, under a series of incentive and purchase price scenarios. The study calculates the percentage of BEV-suited households and utilizes a bivariate ordered probit model to predict annual mileage and vehicle ownership period – the most influencing factors on the TCO outcome - by incorporating households' socioeconomic, vehicle fleet, and geographic variables.

1.3 Dissertation contents

The remainder of this dissertation is organized as follows.

Chapter 2 reviews the process of survey design and all details associated with collecting a national set of consumer stated preference data for Canada to quantify the determinants of electric vehicle purchases relative to other vehicle types. Since very few of EVs were sold in Canada at the time of survey implementation, it was impossible to collect revealed responses, and hence stated preference method was applied to focus on choices households would make under hypothetical scenarios of varied pricing and vehicle attributes. This chapter is a centerpiece for the overall thesis which act as inputs for other research chapters. The data collection took place in May 2015 and 20,520 observations were collected for ten provinces in Canada.

Chapter 3 focuses on the four provinces comprising Atlantic Canada to obtain insights into the consumer EV adoption gap observed between this region and a grouping of the leading English-speaking adoption provinces in Canada, namely British Columbia and Ontario. This research chapter investigates the differences of preferences and attitudes among potential consumers of the

two samples to find out why Atlantic Canada is lagging behind in terms of EV adoption, by performing latent class modelling approach. This modelling approach is selected for this analysis since it can link taste heterogeneity to attitudinal and socioeconomic characteristics of decision makers (Beck et al., 2013). It can also group respondents into distinct classes based on common characteristics which provide an appropriate framework for policy evaluation, interpreting the results and making decisions based on respondents' conditions. The results of this study will be useful for vehicle manufacturers in identifying market segments and for policy makers to frame effective incentives and regulations to promote adoption of EVs in this region of the country.

Chapter 4 analyzes the suitability of BEVs among Canadian households. Despite some barriers associated with BEVs (e.g. high purchase price and limited range), these vehicles have very low operating costs compared to internal combustion vehicles (ICEs), which can make economic benefits for their buyers in the long run. Given that, the study constructs a “total cost of ownership” (TCO) model in the consumer context by using data from a sample of prospective car buyers in Canada. This reveals the share of households who are suited for a BEV purchase under a series of incentive and price scenarios. This study also builds a bivariate ordered probit model to predict annual mileage and ownership period, the most influencing variables in the TCO model. The model incorporates a suite of socioeconomic, vehicle fleet, and geographic variables and is independent from the TCO model. Results of this study suggest targeted decisions regarding policy and marketing based on consumer conditions to further promote the adoption of BEVs in Canada.

The dissertation concludes in Chapter 5 by summarizing the contributions and novel aspects of the present thesis. It also provides possible directions for future research.

1.4 References

Axsen, J., Bailey, J., and Castro, M.A. 2015. Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics* 50, 190–201.

Beck, M.J., Rose, J.M., Hensher, D. 2013. Environmental attitudes and emissions charging: An example of policy implications for vehicle choice. *Transportation Research Part A: Policy and Practice* 50, 171–182.

Black, W. R. 2010. *Sustainable transportation: problems and solutions*. Guilford Press.

Brownstone, D., Bunch, D.S., Train, K. 2000. Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles. *Transportation Research Part B: Methodological* 34, 315–338.

Daziano, R.A., Chiew, E. 2012. Electric vehicles rising from the dead: Data needs for forecasting consumer response toward sustainable energy sources in personal transportation. *Energy Policy* 51, 876–894.

Environment and Climate Change Canada. 2018. *National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada*. Environment and Climate Change Canada, Gatineau, QC (Cat. No. EN81-4/1E-PDF).

Garcia-Valle, R., & Lopes, J. A. P. (2013). *Electric vehicle integration into modern power networks*. Springer Press, Berlin, Germany.

Hensher, D., Rose, J., William, W. 2005. *Applied Choice Analysis: A Primer*. Cambridge University Press, Cambridge, UK.

International Energy Agency (IEA). 2017. Global EV Outlook 2017: Two Million and Counting. IEA Publications, France.

Louviere, J., Hensher, D., Joffre Swait, J. 2000. Stated Choice Methods: Analysis and Applications. Cambridge University Press, Cambridge, UK.

Natural Resources Canada. 2018. Electricity Facts. <https://www.nrcan.gc.ca/energy/facts/electricity/20068> , Accessed 25 October 2018.

Plug 'n Drive. 2017. Driving EV uptake in the Greater Toronto and Hamilton Area. Plug 'n Drive, Toronto, ON.

Chapter 2

Design of a Survey to Assess Prospects for Consumer Electric Mobility in Canada: A Retrospective Appraisal

2.1 Introduction

Surveys are important for research that examines human behaviour. In the field of transportation, surveys are powerful means to obtain critical information for planning and policy making and can provide researchers and policy makers with high-quality data to evaluate changes in transportation systems and regulations in response to existing transportation problems. Surveys that seek to understand consumer preferences and attitudes towards electric and other alternative fuel vehicles have been prominent over the past 25 years, but their use has accelerated in the past decade. Interest in this field has been driven by the fact that electric vehicles (EV) offer a pathway to mitigate the consequences of vehicular emissions.

With the objective to investigate the consumer electric mobility landscape in Canada, a team of researchers and industry partners undertook an effort to develop a comprehensive survey instrument. The acronym “**SPACE**” (Survey for **P**references and **A**ttitudes of **C**anadians towards **E**lectric **V**ehicles) is used for the purposes of this paper to identify the survey instrument. **SPACE** was deployed in the spring of 2015 and focused on four main powertrain types: internal combustion engines (**ICE**), hybrid electric vehicles along the lines of the Toyota Prius (**HEV**), plug-in electric

hybrid vehicles (**PHEV** - e.g. Chevy Volt) capable of running on gasoline or electricity and battery electric vehicles (**BEV** - e.g. Tesla Model S, Nissan Leaf) powered strictly by electricity.

Canada makes for an interesting case study. It has one of the cleaner electricity generation profiles in the world, and yet has a very small market share for EVs which lags relatively behind the United States (US) and many European countries. While previous works provide valuable insights about EV consumer within Canadian context (e.g. Axsen et al., 2015; Ewing & Sarigöllü, 1998; Potoglou & Kanaroglou, 2007), the sample collected with SPACE is the first of its kind in Canada with a comprehensive national scope and with meaningful samples from all ten Canadian provinces, major metropolitan areas, and in both official languages. A stated preference (SP) experiment is at the core of SPACE and is supported by an array of information on demographics, residential location and context, current vehicle ownership and vehicle purchase intentions, travel patterns and an assortment of attitudinal information.

Table 2.1 An overview of selected EV Studies

Study	Geography	No. respondents	Design type	Labeled/unlabeled	No. attributes	No. scenarios/ Opt-out choice?	No. alternatives or fuel types
Bunch et al. (1993)	Southern California	692	Orthogonal	Quasi-labeled	7 fuel type, fuel availability, range, price, fuel cost, pollution, performance	5/ No	3 gasoline, alternative fuel, electric
Ewing & Sarigöllü (1998)	Montreal, Canada	881 Suburban driver commuters	Orthogonal	Labeled	8 price, maintenance cost, acceleration, range, refuelling rate, emission, commuting time, fuel and parking cost	9/ No	3 conventional, fuel-efficient, electric
Horne et al. (2005)	Canada	1150	Not Stated	Labeled	6 price, fuel cost, fuel availability, lane access, emissions, power	8/ Not Stated	4 gasoline, natural gas, hybrid/electric, hydrogen fuel cell
Potoglou & Kanaroglou (2007)	Hamilton, Canada	482 Future car buyers	Orthogonal	Quasi-labeled	8 price, fuel and maintenance costs, fuel availability, incentive, acceleration, pollution, vehicle size, fuel type	8/ No	3 gasoline, hybrid, alternative fuelled
Mabit & Fosgerau (2011)	Denmark	2146 New car buyers	Not Stated	Labeled	6 price, operation cost, range, refuelling frequency, acceleration, service dummy	12/ Not Stated	2 out of 5 conventional, hydrogen, hybrid, bio-diesel, electric
Hidrue et al. (2011)	US	3029 Future car buyers	D-efficient	Labeled	6 range, charging time, fuel cost, pollution, performance, price	2/ Yes	2 conventional, BEV
Achtnicht et al. (2012)	Germany	600 Future car buyers	Orthogonal	Quasi-labeled	6 price, fuel costs, engine power, emissions, fuel availability, fuel type	6/ Not Stated	7 gasoline, diesel, hybrid, gas, biofuel, hydrogen,
Ziegler (2012)	Germany	598 Potential car buyers	Not Stated	Quasi-labeled	5 price, power, fuel costs, emissions, service station availability, fuel type	6/ Not Stated	7 gasoline, diesel, hybrid, gas, biofuel, hydrogen, electric
Hackbarth & Madlener (2013)	Germany	711 New or potential car buyers	Orthogonal	Not Stated	8 price, fuel cost, emissions, range, fuel availability, refueling time, recharging time, policy incentives	15/ Not Stated	4 out of 7 gas, HEV, PHEV, BEV, BV, fuel cell, conventional
Beck et al. (2013)	Sydney, Australia	650 Recent car buyers	D-efficient	Labeled	9 price, fuel cost, emission charge, fuel efficiency, engine size, seating capacity, manufacturer	4-5/ No	3 petrol, diesel, hybrid
Jensen et al. (2013)	Denmark	369	Orthogonal	Labeled	6 price, fuel costs, performance (top speed), emissions, charging possibility, battery lifetime	8/ Yes	2 conventional, EV

Study	Geography	No. respondents	Design type	Labeled/unlabeled	No. attributes	No. scenarios/ Opt-out choice?	No. alternatives or fuel types
Hoen & Koetse (2014)	Netherlands	1903 Private car owners	Orthogonal	Unlabeled	8 fuel type, price, monthly costs, range, refueling time, additional detour time, number of brands/models, policy measure	8/ No	3 out of 6 conventional, hybrid, plug-in hybrid, fuel cell, electric, flex-fuel
Tanaka et al. (2014)	Japan and US	4202 (US) 4000 (Japan)	Orthogonal	Labeled	6 price, fuel cost, range, emissions, fuel availability, home plug-in construction fee.	8/ Yes	3 EV, PHEV, gasoline
Axsen et al. (2015)	Canadian provinces	1754 New car buyers	Orthogonal	Not Stated	5 price, fuel cost, range, home recharge access, recharge time	6/ Not Stated	4 conventional, HEV, PHEV, BEV
Helveston et al. (2015)	China and the US	667 (china) 415 (US)	Not Stated	Unlabeled	6 fuel type, range, brand, price, fast charging capability, fuel cost, acceleration	16/ No	3 out of 4 conventional, HEV, PHEV, BEV
Present study	Canada	20,520 future car buyers	D-efficient	Labeled	12 price, maintenance and fuel cost, gasoline and electric range, acceleration, cash and non-cash incentives, battery warranty, emission, charging time and availability	4/ Yes	4 ICE, HEV, PHEV, BEV

There are a number of novel aspects associated with the design of SPACE. First, the survey is administered among a large panel of Canadians with 20,520 observations from every corner of the country (e.g. all provinces, urban-rural settings, etc.), and hence provides more in-depth coverage of geographical variation in EV preferences than previous studies. Second, the implementation was sensitive to respondent context (Carlsson, 2010), with SP scenarios being customized per respondent (e.g. annual mileage, replacement or additional vehicle, and anticipated purchase price). Moreover, respondents encountered SP scenarios associated with their preferred vehicle body type. For instance, vehicle attribute characteristics shown to an economy buyer were different from those offered to a respondent interested in a luxury sedan. Finally, the survey instrument featured a good balance of objective socio-economics and information about perceptions, attitudes and beliefs in order to best understand what aspects were most heavily influencing preferences.

To this point, **SPACE** has given rise to four studies and with others in progress. Mohamed et al. (2016) utilized attitudinal and demographic components of this survey to assess behavioral intention towards EVs. Higgins et al. (2017) conducted a choice modeling analysis where respondents evaluated powertrain attributes that were specific to the vehicle body types they preferred for their next vehicle, and Mohamed et al., (2018) followed that up with an analysis on vehicle body type supported by structural equation analysis. Ferguson et al. (2018) leveraged a wide range of collected variables and the full national scope of the data to develop a latent class choice model for Canada.

Based on our literature review, Table 2.1 summarizes studies that have used surveys to help understand the preferences of consumers towards different types of EVs. All the reviewed studies are based on stated as opposed to revealed preference data and this is likely explained by the low market penetration of electric vehicles. Within the SP experiments of these studies, the number of powertrain alternatives ranges between two and seven and several have included a conventional vehicle (gasoline or diesel) along with one or more EV types. The number of attributes varied from five to eight, that generally include the monetary (price, fuel cost, etc.), functional (range, acceleration, etc.), charging infrastructure and policy-related attributes. There is also great variability in number of scenarios, type of experimental design, geography and sampling frame. However, aspects of survey design are only partially discussed in previous EV studies and are mainly reported as part of the analyses that these surveys support. As a result, the construction of the survey instrument that underlies the analysis often remains somewhat in the background.

The present paper contributes to the literature by providing an informative overview of the development of a comprehensive survey instrument that was applied in a Canada-wide data collection effort to yield useful EV-oriented data and information. The overview includes associated strategies, thought processes and significant decisions that were made in developing and implementing the survey. The aim is for some lessons that emerge to extend beyond those working within the EV domain. Another contribution is to address a gap in the EV-oriented literature where many surveys have been developed to this point around the world, but a thorough review of the thinking that went into these is not available, to the best of our knowledge.

The remainder of this paper is organized as follows. Section 2.2 provides an overview of the survey instrument and describes the content of SPACE and rationale for our target population. Having provided the necessary context, Sections 2.3 and 2.4 move on to explore, in some depth, the important decision-making that was linked to the survey development and the significant and novel aspects of the main survey instrument. As will be seen, Section 2.3 is more weighted to the important decisions and Section 2.4 is more weighted to novel aspects. A concluding section synthesizes the results of our retrospective look at the development of SPACE.

2.2 Overview of the Survey Instrument and Rationale for Target Population

SPACE is designed to investigate factors as they relate to the choice of vehicle powertrain. The main idea is to collect data on potential car buyers/leasers of all types, with an objective to capture a wide range of population segments and assess their interest in acquiring an electric vehicle across these segments. The sampling approach is thus not highly targeted compared to several past EV studies that recruited people, for example, on the basis of a vehicle purchase within the previous or the upcoming year following survey deployment or with a focus on new vehicle buyers (e.g. Hackbarth & Madlener, 2013; Mabit and Fosgerau, 2011; Aksen et al., 2015).

The design of SPACE is aligned with what we planned to do with the data as part of a larger project. For example, we intended to characterize the future potential for EVs in thousands of small geographies across Canada. The collection of 20,520 observations allows us to work with segments of the overall sample and still have a significant and meaningful sample within each segment. It also provides a great deal of flexibility to access the data and answer specific research questions

that may come up after the fact. Even with a large sample, it was decided not to allocate budget to people who stated little or no likelihood to acquire a vehicle. This has implications on the inclusion of our screening criteria as those with near zero intention of acquiring a vehicle in the “foreseeable” future were excluded from the survey (See section 3.2).

Table 2.2 provides an overview of the six primary survey sections and the specific elements included in each. The survey started with an introductory script emphasizing the aim and scope of the project as well as other general information about the survey including sections, expected completion time, and contact information. The first section contained the household *current vehicle inventory* and *travel patterns*. This section gathered vehicle-specific data on make, model, year, fuel type, residential parking circumstances, and number of registered vehicles for the household. A detailed hierarchical drop-down list of all makes and models available in the Canadian new and used vehicle markets was developed to assist participants in reporting their vehicles. We collected this information for up to four vehicles registered by a household. This section also collected data on the travel patterns of the household with an emphasis on two aspects: the degree of reliance on different mobility modes, and daily/monthly trip frequencies and driven distances for each vehicle. Note that the sample also included households without a vehicle at the time. These households skipped this section as vehicle inventory and travel patterns did not apply for them.

The second section covered the household *purchase/lease plan* including their expected vehicle type, price, and timing of purchase/lease. This part contained a variety of supporting questions, particularly, the ones that play a more critical role in an EV purchase/lease decision such

as replacement vs. additional car , and new vs. used car purchase (Massiani 2014). The time horizon for acquiring a vehicle as well as reasons and budget for their purchase/lease were investigated here. A Likert-scale matrix was included in this section to measure the importance of some vehicle attributes (e.g. cargo space, etc.). They were collected to obtain a separate viewpoint on vehicle attributes from the insight that would emerge from the SP scenarios.

Attitudinal statements comprised section five of SPACE and captured the behavioural intentions of participants to purchase an electric vehicle. We developed thirty items based on an extended theory of planned behaviour that were structured around six constructs related to EV purchase decision: environmental concern, attitude, social norm, personal moral norm, perceived behavioural control, and behavioural intention. Although independently the attitudinal factors provided comprehensive analyses of the behavioural factor influencing EV adoption (Mohamed et al., 2016), it also provided a strong ground that could be integrated in econometric analysis to explain heterogeneity within the sample (Ferguson et al., 2018).

The last part of our survey included *socioeconomic* questions, which collected potentially relevant variables that could influence the choice of vehicle powertrain, such as place of residence and housing type (single family housing vs. apartments). We also collected postal codes of the household residence and workplace which provided us with valuable information for a future geodemographic analysis. Note that for the most part, SPACE took advantage of closed-ended questions to reduce the amount of effort needed from respondents. The question types of each section are provided in Table 2.2.

Table 2.2 SPACE sections and question types

Survey sections	Question types	Survey elements
Survey start screen	One-page text	Introduction
Screening	Single-select questions	Age If a household decision-maker or not Likelihood to acquire a household vehicle in the future (replacement or incremental)
Section 1: Current vehicles and travel pattern	Drop-down lists and Single-select questions	Number of registered vehicles in household Make/model/year of vehicles Ownership status (e.g. owned or leased) Fuel type Household parking context and exposure to weather Access to electrical outlets Average number of trips per weekday/weekend per vehicle Average kilometers driven per weekday/weekend per vehicle Estimated monthly number of high mileage days Average annual kilometers
Section 2: Vehicle purchase/lease plan	Single-select questions and Likert-scale matrix	Number of years before vehicle replacement Number of years until next vehicle purchase/lease Replacement or incremental vehicle purchase/lease Reason for vehicle purchase/lease Expected purchase/lease price New or used Importance rating of key vehicle attributes
Section 3: Educational part	Three-page text and images	Introduction of four powertrains and the differences Detailed description of attributes used in the SP scenarios
Section 4: SP scenarios	Four SP scenarios	Each scenario is similar to Figure 2.3
Section 5: Attitudinal statements	Likert-scale matrices	Thirty attitudinal statements (largely linked to Theory of Planned Behaviour)
Section 6: Socioeconomics	Single-select questions and Textboxes	Province of Residence Sex of householder Postal code (home and work) Dwelling type Home ownership status Number of years living at current place of residence Marital status of Respondent Household size Number of adults (18+) in household Important travel modes per household member Relation between household members Employment status per household member Education per household member (18+) Number of licensed drivers Household income Language spoken most often at home

2.3 Significant Survey Design Decisions

In the course of developing this survey, there were some decisions made that involved choosing one direction over another. The purpose of this section is to discuss some of the most significant decisions in terms of the thinking that went into them.

2.3.1 In-house or Outsourced Data Collection

Surveys have moved from traditional means of data collection (e.g. mail-outs) to internet-based methods that are more efficient in many aspects ranging from actual collection to implementing as usable data. Associated with the maturation of internet surveys has been the rise of the survey panel where a firm will maintain a set of thousands of survey panelists who are willing to take internet surveys on different topics over time in exchange for incentives. The availability of survey panels means that researchers do not need to find ways to access actual lists of potential respondents (e.g. e-mails) which had been historically problematic. In the absence of a survey panel, it takes longer and there is more uncertainty involved, in researchers reaching a target number of responses and respondents may require repeated reminders.

A survey panel can provide a geographically comprehensive and representative sample for all states/provinces/regions in a shorter period of time across a country. SPACE has been deployed for this on a large scale across Canada. As further examples within the EV domain, Hidrue et al. (2011) used a panel to collect a national sample in the United States, and Hackbarth & Madlener (2013) did so for Germany. One other important advantage is that panelists have already expressed

a general willingness to participate in surveys and are often familiar with a range of survey types including those with choice experiments.

While the clear advantages of a survey panel are very attractive, one possible drawback is that the cost is likely to be higher than for traditional sample recruitment. Certainly, the use of a survey panel has to be well-budgeted ahead of time, especially if it will be a large survey. Another limitation is that panelists who are doing many surveys may compromise data quality by rushing through the questions to get to the end and receive the incentive. However, panel operators adopt policies such as removing careless respondents from the panel to increase the quality of survey responses. For instance, our panel operator dropped those respondents from the delivered data who finished the survey ‘too quickly’, i.e. in less than 30% of the median survey completion time. There are still issues in an online panel regarding inattentive and fully/partially-random responses, especially within the stated preference components of surveys (Petrik et al., 2016), and thus post-collection screening and cleaning is important (Meade & Craig, 2011).

Also, panels can be associated with ethical concerns from a university research perspective. There may be issues having to do with the level and type of incentives that are offered to respondents, loss of incentive for an incomplete survey, or concerns with an excessive number of questions that are mandatory as opposed to optional. Another potential drawback of online panels is the issue of representativeness (Szolnoki & Hoffmann, 2013) as raised in Blasius & Brandt’s (2010) study which found that their online sample was not representative of the population on some demographic and attitudinal characteristics. Results in Table 2.3 suggest that our panel operator

was able to deliver a sample that was reasonably representative of the population for characteristics that we could compare.

2.3.2 Conceptualization of Respondent and Implications for Screening

In SPACE, we stressed “households” as opposed to individual respondents. Respondents were required to represent their household and provide information on their household members. The acquisition of an expensive, relatively infrequently renewed item like a car can often be seen as a household decision. As such, while it was individuals who responded, those who did not consider themselves as primary household decision-makers (effectively household heads or maintainers) were screened out. This aspect was reinforced several times during the survey. For example, phrases such as “your next household vehicle” or “members of your household” were used as the survey progressed. The primary householder criterion aligns with the other screening criterion that excluded respondents aged less than 18. A potential limitation to both screens is that they de-emphasize young people who are important to the future of electric mobility.

The third criterion was the inclusion of households who had at least some intention to purchase/lease a vehicle (new or used) in the future. In contrast to previous works, respondents were not required to be recent or urgent car buyers (e.g. Achtnicht, 2011; Mabit & Fosgerau, 2011). Our sample, therefore, was more general as the only group we excluded were those who were ‘not at all likely’ to purchase a vehicle in the foreseeable future. We did not specify an exact timeframe for that purchase since it could potentially exclude some car buyers that consider a vehicle purchase

as a long-term decision. Also, those households currently without a vehicle were not excluded from our database, as opposed to studies (e.g. Hoen & Koetse, 2014) that included car owners only.

As Figure 2.1 below makes clear, a very large collection of panelists indeed (35,795) at least considered the completion of the survey. Of all those who considered the survey, only about 57% actually saw the survey through to completion and this translated to the 20,520 final respondents. About 8.6% evaluated the survey's letter of information and decided not to participate. About 17.6% were willing to participate but were screened out if they failed to meet any one of the criteria relating to age, being a household maintainer or being interested in acquiring a vehicle in the future. Finally, 16.5% decided to withdraw from the survey at some point after beginning to answer the questions or were eliminated from the final database by the panel operator if not passing quality control criteria. With regard to the latter, data were not shared by the survey operator to shed light on the nature and causes of withdrawals.

Of the 17.6% that were screened out, not being willing to acquire a vehicle in the future (11.6%) was about twice as important as not being a household head (5.9%) in influencing the screening outcome. The loss of potential respondents because they were aged less than 18 was essentially a non-factor in the screening (0.1%). In terms of how these screening results were applied, age was given first priority, household head was given second and the desire for a future vehicle was given third priority. Furthermore, the detailed time tracking option enabled by our panel operator gave us the ability to search for people that were unengaged in some sections of the survey to be eliminated from the final sample for certain types of analysis. Overall engagement can

be assessed through total time spent on the survey and tendency to “straight-line” answers to suites of attitudinal questions.

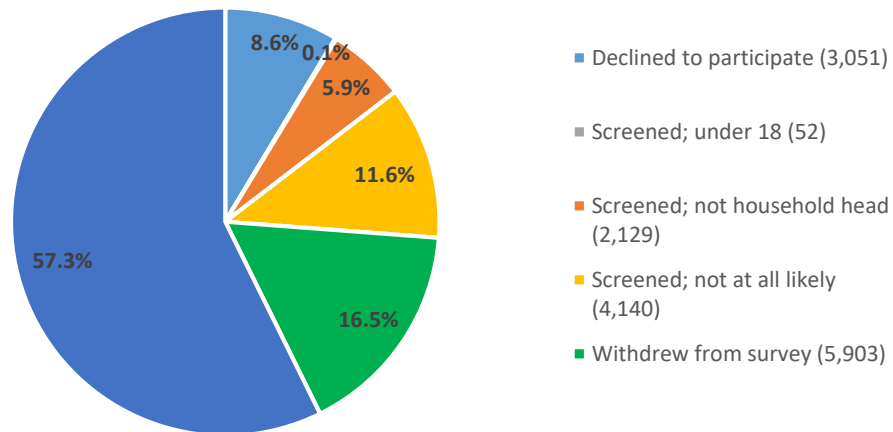


Figure 2.1 Inventory of outcomes for all panelists who considered the survey, the counts of respondents for each part are shown in parenthesis

Table 2.3 compares our sample with the 2016 Canadian census distribution of households (or household maintainers) across a range of variables. Education and marital status of the householders are derived from census 2011. Given the focus on people with an interest to acquire vehicle, there are “built-in” differences between the characteristics of our study population and the entire population of Canada. There is an over-representation of the more highly educated and two- or three-person sized households. Partly such households have a higher on-going intention to acquire a vehicle. But the higher educated are also more likely to participate in survey panels and sufficient recruitment of one-person household panelists seems challenging based on these results. Similar insights are likely to apply for income, where there is less representation from lower-income households. Under “Province”, it can be seen that the SPACE data collection was stratified

with the less-populated provinces more heavily sampled to ensure an adequate number of respondents from all provinces.

Table 2.3 Sample vs. Canadian households as derived from census.

Context		SPACE	Census
Age (householder)	18-24	4%	3%
	25-34	14%	14%
	35-44	18%	17%
	45-54	23%	20%
	55-64	22%	20%
	65+	19%	22%
Education (householder)	No certificate; diploma or degree	3%	17%
	High school diploma or equivalent	18%	22%
	College, trades certificate or diploma	34%	37%
	University certificate, diploma or degree at bachelor level or above	45%	23%
Marital status (householder)	Single	25%	18%
	Married or common law	69%	58%
	Other	6%	23%
Household income (CAD\$)	Less than \$25,000	5%	14%
	\$25,000 to \$49,999	16%	21%
	\$50,000 to \$99,999	37%	33%
	\$100,000 and more	29%	32%
	Refused	14%	--
Language spoken most often at home	English	77%	67%
	French	18%	21%
	Other	5%	12%
Household size	1	18%	28%
	2	45%	34%
	3	17%	15%
	4	14%	14%
	5 or more	7%	8%
Dwelling type	Single detached house	65%	54%
	Townhouse or semi-detached	12%	12%
	Apartment or condo	21%	34%
	Other	1%	1%
Dwelling tenure	Owner	78%	68%
	Renter	22%	32%
Province	Newfoundland and Labrador	3%	1%
	Prince Edward Island	1%	0.4%
	Nova Scotia	5%	3%
	New Brunswick	4%	2%
	Quebec	22%	23%
	Ontario	29%	38%
	Manitoba	5%	4%
	Saskatchewan	4%	3%
	Alberta	12%	12%
British Columbia	15%	13%	

2.3.3 Educating Respondents on Powertrains and Vehicle Attributes

At the time (mid-2014) when survey development was initiated, the research team was of the opinion that most respondents would likely have at least some misconceptions about the main vehicle types under study and many would have no knowledge about plug-in electric vehicles (Krause et al. 2013). It was clear at the time anecdotally that such misconceptions applied at dealerships let alone among consumers! In the philosophical discussions which were held about the survey, the research team came to the conclusion that this survey might well influence potential car buyers who previously had incomplete information about them. It was decided that there was not much we could do about that but that it was better in any case for respondents to improve their knowledge about EVs as the survey progressed. Current knowledge about EVs was not assessed at the beginning of the survey though some information about general environmental attitudes was collected including the connections between vehicles and the environment.

Measures were taken to adequately educate respondents so that they could make informed choices within the SP section of the survey grounded on correct information. The introductory script of the survey introduced the term “electric mobility” and that it was our research mandate to investigate the topic but definitions were not provided. In retrospect, and as cautioned by Dillman (1978), this introductory script could have been written in a manner that was more "powertrain neutral." It is possible that our script attracted a disproportionate share of respondents with an interest in electric vehicles. At the start of the SP section, the survey instrument clarified the types of powertrains that respondents would consider. Figure 2.2 illustrates what was briefly presented

and how we covered basic knowledge about how the vehicles were powered, what types of behaviours were required of the owner, and some implications of driving these vehicles. Gasoline vehicles were explained in a similar way. Further details about vehicles types became clear as we described the attributes associated with vehicles (Figure 2.4) that would be assessed by the respondent during the SP scenarios. These were treated as a second layer of fundamental information about these vehicles and covered aspects such as fuel/charging costs and battery range among several others.

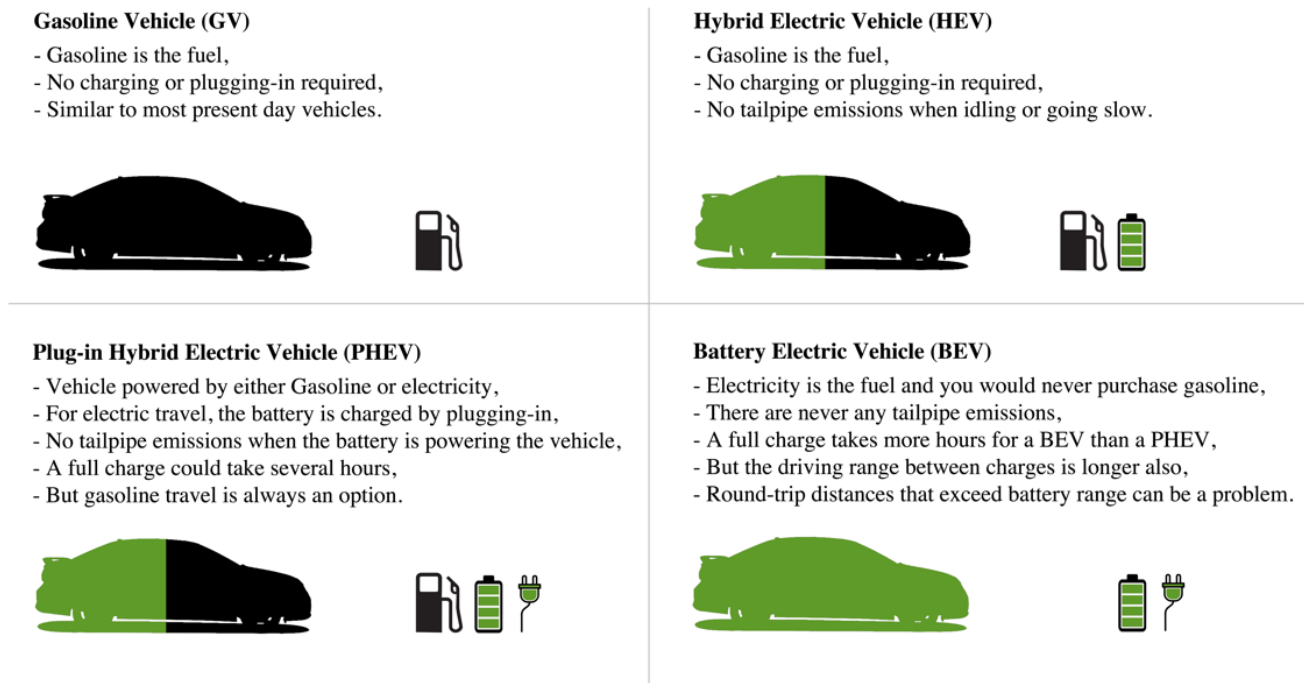


Figure 2.2 Educational materials; four powertrains and their features.

2.3.4 Selection of SP Attributes and Levels

Given the continuing small market penetration of EVs, the Stated Preference (SP) approach has remained the most widely applied methodology and the primary source of data for obtaining people's preferences towards such vehicles (Abotalebi et al., 2015). In an SP scenario, respondents choose or rank their most preferred options, with these options being characterized through a series of attributes and assigned "levels" for these attributes in accordance with an experimental design (Louviere et al., 2000). The selection and quantity of attributes for SP scenarios is an important consideration (Hensher et al., 2005; Louviere et al., 2000). Monetary attributes (i.e. purchase price and fuel, maintenance or operational cost) have been included in almost all reviewed studies, as well as charging time/availability and vehicle range (See Table 2.1 and Liao et al., 2017). Other attributes such as emissions and various forms of incentives have been considered less often.

The selection of SP attributes for the present study was jointly guided by the literature (Table 2.1) and feedback from partners. We sought specifically to understand the importance of technical EV attributes that include range, charging time, fuel/maintenance cost savings, emission reduction, and performance; as well as the impact of policy measures including the quality of the battery warranty, government cash incentives, and various non-cash incentives (e.g. access to high occupancy lanes, free municipal parking and exemptions from tolls). Overall, 12 attributes were included in each SP scenario covering all the items under study. On the SP screen, attributes appeared in four main categories; cost, operational, non-cash incentives, and charging (Figure 2.3). This was preceded by another screen informing respondents about the attributes included in the SP

scenarios (Figure 2.4). The information from Fig. 4 was accessible as pop-up text via icons in Figure 2.3. Hence, there was an opportunity to refresh one’s memory about the attributes once the scenarios were under way.

(Scenario 1 of 4: Intermediate Sedan Category)
 Please **MOUSE OVER** any of the 18 picture icons on this screen for more information

















Charging		 Gasoline	 Hybrid	 Plug-in Hybrid	 Battery Electric	None of these four vehicles
Charging Station Availability		-----	-----	Twice as available as current gas stations	10% as available as current gas stations	
Charging Time	Public 	2 hr & 48 min	2 hr & 56 min	
	Home/Work 	2 hr	5.25 hr	
Incentives						
Non-cash incentives				- HOV access	- Free Municipal Parking	
Battery Warranty - Years/Km			3 yrs / 58000 km	8 yrs / 160000 km	5 yrs / 96000 km	
Operational						
Gasoline Range		700 KM	875 KM	525 KM	0 KM	
Battery Range		0 KM	0 KM	90 KM	250 KM	
Performance/Acceleration (0 to 100 km/h)		9 Sec	4.5 Sec	13.5 Sec	9 Sec	
Annual CO ₂ Tailpipe Emissions		1.76 tonnes	0.88 tonnes	0.44 tonnes	0.00 tonnes	
Cost						
Vehicle Cost (Price - Cash Incentives)		18750-0= \$18750	25000-0= \$25000	25000-10000= \$15000	50000-5000= \$45000	
Annual Maintenance Cost		\$641.25	\$641.25	\$641.25	\$320.00	
Fueling/Charging Cost per Year		\$1137.50	\$812.50	\$325.00	\$325.00	
For the Replacement Vehicle, I would choose		<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
For a 2 nd household Vehicle, I would choose		<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 2.3 A sample stated preference choice scenario

A few salient points about the chosen attributes are worth noting. First, purchase price and government cash incentives appeared as a single line item on the SP screen, as a “net” purchase price calculation, even though they were treated as two distinct attributes in the experimental design. The highest level for cash incentives reflected the maximum (\$10k) offered in Canada at the time. Subsequently, even higher incentives (up to nearly \$15k) were offered in Canada and our experimental design would have benefitted from capturing the same.

Interestingly, range was treated in our implementation as two distinct attributes: gasoline and battery range. The results from a national analysis (Ferguson et al., 2018) showed the utility of this approach. For example, willingness-to-pay analysis found that HEV-oriented households placed a very high per km value on gasoline range while those inclined towards BEVs shunned consideration of gasoline range and instead highly valued per km increases in electric range.

Third, we distinguished between charging times for home/work and public stations, with the latter generally being associated with faster rates of charging in the experimental design since public charging is typically more “opportunistic” and time-constrained in nature. The approach to separate and independently explore the primary charging contexts differed from previous EV surveys, with the exception of Jensen et al. (2013) where home, work, and public stations were presented as distinct attributes.

Carefully review these scenario attributes which will influence the upcoming vehicle choices that you will be asked to make.

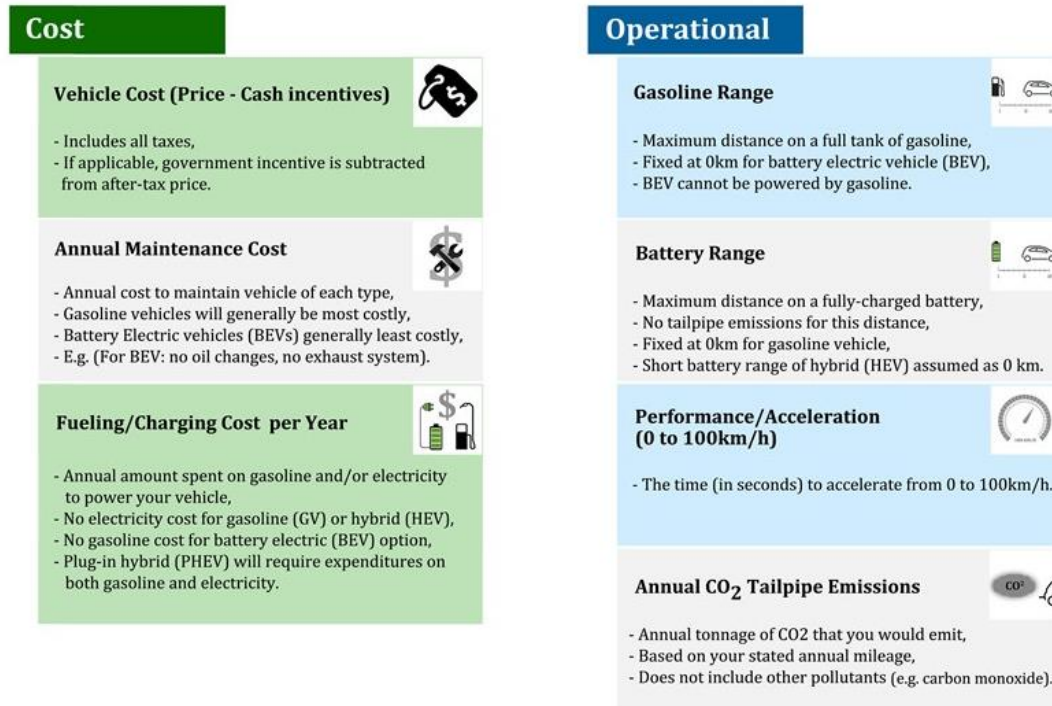


Figure 2.4 Survey overview material on selected SP vehicle attributes

2.3.5 SP Alternatives and their Identification to Respondents

As our research mandate was to focus on electric vehicles, we included EV-related technologies, hybrid (HEV), plug-in hybrid (PHEV) and battery electric vehicles (BEV), to compete with internal combustion engines (ICE) in SP scenarios. Within the literature, a considerable range of powertrains/fuel types are utilized (Table 2.1). With the exception of Potoglou & Kanaroglou (2007), ICE and BEV define two of the powertrains in all studies reviewed. Other fuel types such as natural gas, hydrogen, and biofuel that are included in a number of studies

(Achtnicht, 2011; Hackbarth & Madlener, 2013; Ziegler, 2012) were not included in SPACE as these were judged outside our EV-oriented mandate and are not widely available within the Canadian vehicle market. HEV and PHEV were only considered in a subset of past studies, however when included, they achieved considerable predicted market shares sometimes larger than BEVs (Axsen et al., 2015; Hackbarth & Madlener, 2013; Helveston et al., 2015; Massiani, 2014).

Apart from types and number of alternatives, another important decision was the presentation of alternatives on the SP screen, whether in a labeled or unlabeled form. Some previous works designed their choice sets as unlabeled experiments (Helveston et al., 2015; Hoen & Koetse, 2014; Ziegler, 2012), while the choice of fuel type was nevertheless incorporated in their modeling analyses as the dependent variable. The term quasi-labeled has been used for such experiments (Ziegler, 2012), meaning that while the names of alternatives convey no information to the respondents, their attributes and levels are designed in a way that relates exactly to one powertrain or fuel type.

On a labeled choice, however, vehicle powertrains can be identified before reviewing the attributes associated with each alternative (Hidrue et al., 2011; Jensen et al., 2013; Mabit & Fosgerau, 2011; Tanaka et al., 2014). As such, the name each alternative carries can have a significant influence on the choices that respondents make. For instance, some people may select a BEV simply because of their pro-environmental attitudes, without consideration of attributes associated with that alternative. While the trade-offs between attributes are somewhat downgraded

in this approach, labeled experiments are more in line with choices people make in the real world where a number of branded goods or services are considered (Hensher et al., 2005). Indeed, the label given to each alternative adds an extra level of realism to SP surveys. Also, labeled alternatives are preferred when the focus is on prediction and forecasting (Hensher et al., 2005).

In SPACE, the SP scenarios consisted of four fixed ‘labeled’ alternatives illustrated with a related visual design (Figure 2.3). Respondents were required to make a choice between these four alternatives for the primary choice context, which most often was for a replacement vehicle. A secondary choice context was also examined but this choice was for five alternatives including an opt-out option. The reasoning for this had to do with context sensitivity and is thus discussed in Section 4.4.

2.3.6 Choice of Design Technique for SP Scenarios and Implications

D-efficient or Efficient experimental design was employed for generation of our SP scenarios (Hensher et al., 2005; Street, Burgess, & Louviere, 2005). *Orthogonal* and *D-efficient* design are the two main design types used in previous EV studies (See Table 2.1). Although *orthogonal* has been used most often within EV research, evidence from the literature demonstrates the outperformance of efficient design (Bliemer & Rose, 2011; Carlsson & Martinsson, 2003; Rose & Bliemer, 2008). Bliemer & Rose (2011), for example, tested the impact of different experimental design types (i.e. orthogonal vs. efficient) on the estimation results, and found that efficient design lowered standard errors in the estimation of parameters. The efficiency of experimental design can be further improved, if there is *a priori* information available about coefficients of attributes (e.g.,

price, range, etc.), perhaps through the literature, pilot surveys, or secondary data (Bliemer & Rose, 2011; Huber & Zwerina, 1996; Rose & Bliemer, 2008).

The pre-known information about an attribute, the so-called “prior,” is an initial value used as a coefficient when computing utilities for each alternative in a SP scenario (Carlsson & Martinsson, 2003; Huber & Zwerina, 1996). In the present study, we conducted a pilot survey using an orthogonal design (Louviere et al. 2000), based on priors being equal to zero (we assumed no information was available). A subset of the estimated coefficients from the pilot survey were used as priors for our final survey. We only used those coefficients that were statistically significant with expected signs. For instance, the estimated coefficient for the *price* attribute was a significant, negative value, and hence was used as a prior to generate an efficient design for our final survey. We assigned no prior to those attributes that had insignificant or counterintuitive coefficients, as it could result in a negative impact on the efficient design (Bliemer & Rose, 2011).

The Ngene program was used for both pilot and final surveys to generate choice scenarios for each of seven vehicle classes (See Table 2.4). In the experimental design, 48 scenarios were divided into 12 blocks, and each respondent was randomly assigned to one of these blocks, with 4 distinct scenarios. The design steps in Ngene begin by specifying the functional form of the utility for each alternative and choice probabilities are calculated for each scenario. This process is possible when priors are used, so the analyst can check for the potential ‘dominancy’ of a certain alternative, which is considered as an issue for a more traditional orthogonal design (Bliemer & Rose, 2011). This ensures that there is a reasonable balance between utilities of all alternatives

within an SP scenario, so that respondents actively “trade-off” when deciding on their choices (Huber & Zwerina, 1996).

The efficiency of the design is assessed by the D-error which is the most widely used measure of the goodness-of-fit for experimental design (Rose & Bliemer, 2008). The D-error does not have a unit and its magnitude depends on the units of the design attributes (Rose & Bliemer, 2008). In practice, it is almost impossible to find a design with zero D-error; therefore, researchers are satisfied if the design has a sufficiently low D-error, depending on the units of the design attributes. This is called a D-efficient design (Huber & Zwerina, 1996; Rose & Bliemer, 2008). If the error is large, the steps should be repeated by changing the variables or priors. In SPACE, we developed the experimental design based on attribute levels associated with each vehicle body type (See section 4.1), and the design with minimized D-error was used after several iterations, similar to the approach adopted by Hensher et al. (2011).

2.3.7 Respondent Cognitive Burden

One challenge in the design of a survey that seeks to be comprehensive is to gather as much high-quality information about respondents as possible while appropriately managing cognitive burden (Stopher, 1998). Generally, surveys are not seen as enjoyable by many respondents, so the degree to which a survey instrument is perceived as difficult, time consuming, or stressful is highly relevant. Partly the burden can be managed through economical and simple wording of questions and proper sequencing of questions.

Historically, cognitive burden has been discussed as an issue for SP scenarios (e.g. Achtnicht, 2011; Bunch et al., 1993; Potoglou & Kanaroglou, 2007), but the requirements for other survey components are considerable and impose some burden on the respondents. It also has to be considered that there are survey section interdependencies in burden: for example, if a respondent is tired or frustrated at the beginning of an SP section, this can only hurt the ultimate quality of the SP data.

In assessing the question of survey completion times for SPACE, it became clear in retrospect that there were issues of differential survey burden across respondents. For example, SPACE collects several pieces of information over several questions on each vehicle in the household. The questions gathered data such as daily trip and mileage patterns and other aspects. Estimates were also asked regarding vehicles for which the respondent may not have been the primary driver. A similar dynamic, though less onerous, was at play in the gathering of information about household members. Respondents were required to provide this information and some other similar inquiries (See Table 2.2) for up to seven household members and as many as four vehicles registered by their households. Hence, a respondent with many family members and several vehicles had more to manage.

Figure 2.5a suggests that the questioning associated with vehicles seemed to add more respondent burden than the questioning associated with household members and broadly that more vehicles and more household members added to completion time. However, another important factor in assessing the relationship is the age of the respondent as is seen in Figure 2.5b. There is

evidence that regardless of the number of vehicles in the household, younger people completed the survey faster. Each age group shows that a large number of vehicles imposes a burden but, this burden is of a large absolute magnitude for older respondents. Older people seemed to get more “bogged down” in the questions on vehicles and even with relatively few vehicles. Bear in mind that these results are medians and there would be many examples of larger burden differentials on a respondent-by-respondent basis.

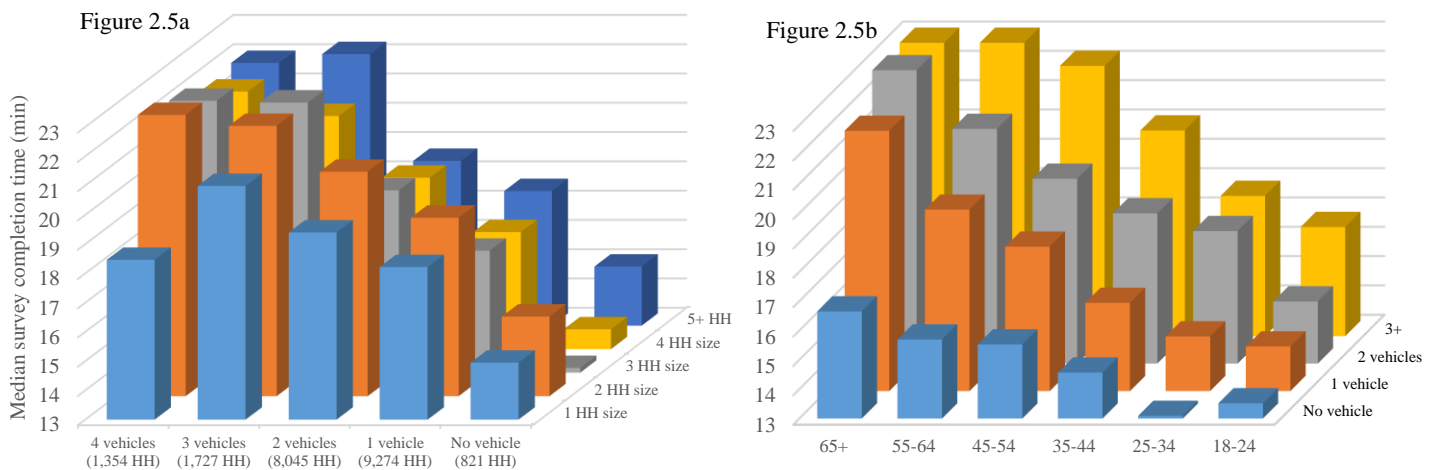


Figure 2.5 Median survey completion time by combination of household size, number of vehicles and age groups

Within the SP section, we decided on fewer scenarios (four per respondent) to further manage cognitive burden. This also provided an opportunity to include more attributes (12 attributes) per scenario to best capture the range of factors taken into account in an actual vehicle

purchase. We might have opted for a fewer number of attributes similar to most previous EV studies (See Table 2.1), but this was not judged as in line with the real-world complexity of a vehicle purchase decision. Appealing visual design along with informative pop-up text for all graphic icons on the SP screen were additional elements that sought to reduce per-scenario burden for the respondents. Also, as previously noted, we included attributes in four main categories: cost, operational, non-cash incentives, and charging (Figure 2.3) to assist respondents in sorting through the attributes to offset the additional burden in this respect.

There were other aspects to respondent burden in the survey. Attitudinal questions (i.e. thirty Likert scale items), were dispersed in groups through the survey to reduce monotony. Another strategy was to leave socioeconomic inquiries to the end, as survey panelists see these types of questions a lot and are more comfortable with them.

Overall, there is evidence from the results here that the research team, as with several past studies, viewed the issue of survey burden too much from the viewpoint of the choice experiment and overlooked ways that additional burden was being added for some respondents in other sections of the survey. In retrospect, for example, we could have reduced the number of questions that asked about all vehicles in the household. We could have focused more specifically on the respondent's vehicle and asked about other household vehicles only for the more important points (e.g. annual km driven).

2.4 Novel Aspects of the Survey Design

While the previous section highlighted certain design dilemmas and some challenging decisions that were made, the current section focuses on novel features of the survey. For these, a consensus was reached among team members that implementation would improve the survey instrument and perhaps have our effort stand out from other work in the field.

2.4.1 Vehicle Body Type Conceptualization

The preferred vehicle body type of households shaped the implementation of our SP experiments. In many previous SP surveys, respondents were exposed to the attribute levels that were not specifically designed for their vehicle body type of interest. This reduces the ability of respondents to relate to scenarios they evaluate. In SPACE, the attribute levels were anchored realistically on a single vehicle body type that respondents were asked to identify prior to the SP experiment. Seven vehicle classes: economy, intermediate sedan, full sedan, luxury sedan, minivan/crossover, sport utility vehicle (SUV), and pick-up truck were presented to respondents. Related images and approximate prices were provided that corresponded to a conventional gasoline version of each type (Table 2.4). The respondents' selected vehicle body type applied to all scenarios and was used as the basis to derive attribute levels per alternative (Table 2.5). This method added to the relevance and realism of the attribute levels being evaluated by the respondent (Beck et al. 2013; Rose and Bliemer 2008). For instance, a household interested in an economy size vehicle would see matching price or fuel cost levels in scenarios.

While the factor of vehicle body type has been included in a number of previous EV studies, it was either treated as an attribute within scenarios (Potoglou & Kanaroglou, 2007a) or the same attribute levels were utilized across different vehicle types. Our segmenting of the vehicle market into seven classes opened up the opportunity to investigate how preferences for EVs change according to households’ preferred vehicle body types as in the study by Higgins et al. (2017).

Table 2.4 Base values for SP scenarios








Body Type Image	Vehicle Size	Purchase Price (\$)	Maintenance Cost (\$/km)	Acceleration (sec to reach 100 km/hr)	Gasoline Range (km)	CO ₂ Tailpipe Emissions (tonnes/km)	Fueling/Charging Cost (\$/km)
	Economy	22,000	0.051	8.8	700	0.000143	0.07
	Intermediate	25,000	0.051	9.0	700	0.000141	0.07
	Full sedan	35,000	0.060	7.2	800	0.000182	0.08
	Luxury sedan	59,000	0.072	6.5	700	0.000202	0.09
	Minivan	33,500	0.069	5.0	700	0.000234	0.14
	SUV	30,000	0.072	9.0	670	0.000234	0.09
	Pickup truck	40,000	0.081	6.6	750	0.000444	0.13

Table 2.5 Relative attribute levels used in SP scenarios

Attributes	Alternatives			
	ICE	HEV	PHEV	BEV
Purchase price (\$)	-25%, Base	Base , +50%	Base , +50%, +100%	Base , +50%, +100%
Cash incentive (\$)	0	0	0, 5000, 10,000	0, 5000, 10,000
Maintenance cost (\$/km)	Base	-25%, Base	-50%, -25%, Base	-25%, -50%, -75%
Acceleration (sec to reach 100 km/hr)	Base	-50%, Base , +50%	-50%, Base , +50%	-50%, Base , +50%
Battery range (km)	-	-	30, 60, 90	150, 250, 350
Gasoline range (km)	Base	-25%, +25%	-25%, +25%	-
CO ₂ tailpipe emissions (tonnes/km)	-25%, Base	-50%, -25%	-75%, -50%	0
Fueling/charging cost (\$/km)	Base , +20%, +40%	-20%, Base	-60%, -40%, -20%	-80%, -60%
Public charging time (hr)	-	-	0.15, 1.5, 2.75	0.25, 3, 5.65
Home/work charging time (hr)	-	-	2, 3, 4	3.5, 5.25, 7
Fueling/charging station availability	All gas stations	All gas stations	10%, Same, Twice	10%, Same, Twice
Battery warranty	-	-	3 yrs/58,000 km, 5 yrs/96,000 km, 8 yrs/160,000 km	3 yrs/58,000 km, 5 yrs/96,000 km, 8 yrs/160,000 km
Non-cash incentives	-	-	HOV lane access, Free parking, Free toll roads	HOV lane access, Free parking, Free toll roads

Same = same number of stations as number of current gas stations; Twice = twice as many stations as current number of gas stations; HOV lane access = high occupancy vehicle lane access.

2.4.2 Emphasis on Detailed Geography and Location

Geography played a significant role in the conceptualization of SPACE. Fundamental in this regard, was our collection of 6-digit postal codes that could fairly precisely locate our respondents, and identify the spatial context in which they would assess electric mobility. For example, whether potential EV buyers are more concentrated in the central cities or suburban areas, also, whether or not EVs are more preferred among single-family housings with access to a private garage as opposed to apartment occupants where charging circumstances may have been less

favourable. Such segmentation analysis can be conducted at the small census area level (dissemination area) using locational and other variables from SPACE. Such a fine level of spatial detail is not common within the EV literature. Campbell et al. (2012) is one of the few studies that derived a geographically-oriented segmentation system, though solely through the use of census data; by means of variables such as income, age, and home ownership that were considered important in characterizing the adoption of alternative fuel vehicles.

Capturing the locational context of households permits consideration of research aspects such as: optimum locations for public charging infrastructure, identification of places with high demand for home EV charging and resulting impact on the electricity distribution network. Information on workplace location (i.e. postal code or nearest major intersection) was also collected to derive a sense of the spatial scope of daily activities and implications for EV range.

2.4.3 Emphasis on Collection of Attitudes

An extensive suite of Likert-based attitudinal statements was included in SPACE to support survey analysis from multiple aspects. The focus of the statements was to extend the Theory of Planned Behaviour (TPB), developed in 1991 by Ajzen et al. Among other studies, Egbue & Long (2012), Lane & Potter (2007), and Moons & de Pelsmacker (2012) applied TPB in their EV analysis, though within different research contexts since the extended TPB can be customized based on the objectives of each study (Mohamed et al., 2016).

In SPACE, suites of attitudinal statements were developed to capture several behavioural constructs and intentions as they relate to EV adoption behavior. The captured attitudes acted as a primary outcome factor in the structural equation analysis of Mohamed et al (2016) that offered independent behavioural analysis of EV purchase intentions, and were used to model choice outcomes in the SP analysis of Ferguson et al. (2018). The inclusion of attitudinal statements combined with an emphasis to support multiple analysis approaches is rare in the previous works. The attitudinal component offers the possibility to be used as an explanatory role in choice modelling related to the SP analysis and is also useful in carrying out detailed geographical and psychographic-based market segmentation analysis. These offer insights into how attitudes vary over space. Altogether, the SP section and attitudinal part worked as complementary in understanding consumer behaviours towards EVs.

A list of attitudinal statements can be found at Mohamed et al. (2016) along with details of analysis. The developed model includes six constructs: environmental concern, attitude towards adopting EVs, subjective norm, perceived behavioural control, personal moral norm, and EV adoption intention. One possible improvement is the inclusion of one more construct to measure the level of public awareness on EVs. This aspect emerged from our industrial partners later on but was not emphasized during survey development.

2.4.4 Context Sensitivity

The implementation of the SP experiments in the survey instrument was rather novel in that it was sensitive to the respondents' specific circumstances; annual mileage, purchase plan (i.e. incremental or replacement vehicle), preferred vehicle body type and anticipated purchase price. In the EV literature, this is referred to as *customized* design, and was applied in a number of studies (e.g. Bunch et al., 1993; Hidrue et al., 2011; Potoglou & Kanaroglou, 2007). In SPACE, the levels associated with tailpipe emissions, fueling/charging cost, and maintenance cost were adjusted based on respondent's annual mileage and preferred vehicle body types reported earlier in the survey. Fueling/charging cost, for example, can vary a lot across vehicle body types.

The choice box at the bottom of the SP screen (see Figure 2.3) was also customized according to a respondent's previously provided information. In the example of Figure 2.3, the respondent had earlier identified that the household sought a replacement vehicle as opposed to an incremental vehicle. For this reason, the first row of the choice box dealt with the powertrain that would be selected for the replacement vehicle. As a potential source of further useful data, we gave the respondent a second, more speculative, choice to make as to what powertrain they would choose in the event that they did, for whatever reason, decide to add an incremental vehicle. Note that this incremental vehicle is labelled in Figure 2.3 as the "2nd household vehicle." This indicates that the respondent had earlier identified that the household currently operated one single vehicle. Because this choice context was a secondary and low-probability one, the option to choose no vehicle for that choice context was provided. For each respondent, the presentation at the bottom of the SP

screen would adjust to their household circumstances. For the minority of households that preferred an incremental vehicle, the first choice would relate to that circumstance and the second choice with the opt-out option would relate to a replacement scenario.

To summarize, the first and primary choice context was implemented as a *forced choice*, meaning that respondents had no choice for declining all four vehicles presented per scenario. But the secondary choice context permitted an opt-out and offered five options from which to choose. In the case of a younger household, contemplating their first vehicle purchase, the secondary choice context would have been for a replacement vehicle. The opt-out option was clearly needed for this non-plausible scenario. While most secondary choice contexts were at least plausible, they were lower probability scenarios.

For the primary choice context, the one that respondents had said they were more likely to consider, we saw the “opt out” option is in some ways being similar to a “prefer not to answer” option and thus decided against it. The thinking was that it was better to get some insight on preferred powertrains than none. It was important, for example, to know that a respondent gravitated to an ICE vehicle. To the extent that even the primary choice context was not desirable for some respondents (e.g. maybe they tended to buy cheaper, used vehicles in real life) there was the option to identify such respondents and remove from analyses as necessary (See Table 2. Section 2: Vehicle purchase/lease plan). Meanwhile, we had more insight about their vehicle preferences than we would have otherwise, had we included an opt-out in the primary choice context.

2.5 Conclusions

This paper has reviewed the process that led to the development of a national survey instrument to assess consumer prospects for electric vehicles in Canada. The survey was deployed in the spring of 2015 to collect a consumer data set from over 20,000 households across Canada. The benefit of hindsight has offered us an opportunity to assess the process and what has been learned as it relates to the development of a survey instrument. Actual data collected, including information on respondent completion durations by survey section, has assisted in the overall assessment.

Arguably, the most important survey decision was made in 2013, long before the survey instrument was constructed. At that time, the research team identified that a privately managed consumer survey panel offered an unparalleled opportunity to explore, in considerable detail, Canadian preferences and attitudes toward electric vehicles. It was anticipated that a well-constructed national sample, if large enough, would also provide meaningful sub-samples at the level of Canadian provinces, regions, metropolitan areas and even at the intra-urban level. Planning and budgeting well in advance were certainly important elements in the comprehensive nature of the sample that was facilitated. The decision to go with a survey panel removed traditional researcher anxiety about issues such as response rates and the ultimate number and nature of observations that the team would have at their disposal. However, survey panels are not without risk. Costs are higher and there can be issues with developing a representative sample since some types of respondents (e.g. single-person households, the less educated, etc.) are harder to capture

as survey panelists. Some of the collected data may be suspect, and hard to diagnose as such, when survey-hardened respondents answer inattentively.

To capture geographical locations, we collected detailed six-digit postal codes from survey respondents. As such, an important research theme to focus on detailed spatial variation in vehicle powertrain preferences was enabled and the extensive nature of the panel itself supported this emphasis. That nature of the panel also dictated that we would deal with individual survey respondents. We would not be able to gather data from “*households*” per se but we did conceptualize that respondents could be asked, subject to screening criteria, to act as representatives of the household and would provide information about the household as a whole. This focus on household “*heads*” had the effect, for better or worse, to weed out young adults still living with their parents.

Several components of the survey were novel. First, our implementation of vehicle attributes in choice experiments was done in such a way as to be sensitive to the vehicle body types that households preferred for their next vehicle. As such, luxury car buyers were not seeing scenarios, for example, that might have seemed more appropriate for an economy car buyer. Past EV literature had tended to outline more generic approaches. The choice scenarios also benefitted from several aspects that were implemented to be context-sensitive to the earlier answers of respondents. Another novel aspect was that the survey simultaneously emphasized in-depth choice experiments and an extensive collection of Likert-based attitudinal indices. Among other benefits,

the two approaches offered redundancy in measuring behavioural intention toward acquiring electric vehicles.

The research team paid considerable attention to cognitive burden in the development of the survey. An important focus was not overwhelming respondents as they made their way through the choice experiments. Ordering of survey sections was an important consideration as was the core nature of the stated preference scenarios themselves. Interestingly, the research team only really realized in retrospect that “do loops” built into the survey based on the number of registered household vehicles and the number of household occupants created some significant differential burdens in completing the survey. The survey was much more onerous for some people depending on their circumstances. We would expect future survey implementations by the research team to be more sensitive to this aspect.

Lessons were learned from the experience of developing SPACE. One was that the development of a comprehensive survey instrument is quite labour intensive and numerous iterations are required especially when partners and stakeholders play a role. The process is not to be taken lightly. It is very important to consider carefully all the aspects that are to be covered and even so, it is likely in retrospect that overlooked questions will be identified. While SPACE was quite comprehensive, there were omissions and probably the most significant was in not thoroughly assessing respondent knowledge about electric vehicles. This was an aspect that partners were requesting after the fact, since it is useful information to benchmark over time, but the collective team including partners did not clearly identify this at the outset. Nevertheless, some attitudinal

statements included in the survey gave some sense about aspects such as knowledge of current charging infrastructure and places where EVs could be bought.

Another surprising oversight had to do with gathering written comments from respondents. While we asked respondents to contact the research team with any comments or questions, it would have been much better to include a comment box directly within the survey. Subsequent work with our other surveys has shown that some respondents are willing to write significant passages about the topics examined in surveys. Not directly including this functionality greatly reduced the amount of qualitative information that we gathered. With respect to other survey respondents, the type that typically would be less likely to leave detailed comments, it was learned that it is a good idea to time track respondents as this gives a good sense of whether questions are being considered carefully. This aspect is particularly important with the rise of the survey panel where people may respond to a large volume of surveys.

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2.7 References

Abotalebi, E., Mahmoud, M., Ferguson, M.R., Kanaroglou, P. S. 2015. Utilizing Stated Preference in Electric Vehicle Research ; Evidence from the Literature. In Proceedings of the 50th Annual Canadian Transport Research Forum Conference 1–19. Montreal, Quebec, Canada.

Achtnicht, M. 2011. German car buyers' willingness to pay to reduce CO2 emissions. *Climatic Change* 113, 679–697.

Ajzen, I. 1991. The theory of planned behaviour. *Organizational Behavior and Human Decision Processes* 50, 179–211.

Axsen, J., Bailey, J., Castro, M.A. 2015. Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics* 50, 190–201.

Beck, M.J., Rose, J.M., Hensher, D. 2013. Environmental attitudes and emissions charging: An example of policy implications for vehicle choice. *Transportation Research Part A: Policy and Practice* 50, 171–182.

Blasius, J., Brandt, M. 2010. Representativeness in online surveys through stratified samples. *Bulletin de méthodologie sociologique* 107, 5-21.

Bliemer, M.C.J., Rose, J.M. 2011. Experimental design influences on stated choice outputs: An empirical study in air travel choice. *Transportation Research Part A: Policy and Practice* 45, 63–79.

Bunch, D.S., Bradley, M., Golob, T.F., Kitamura, R., Occhiuzzo, G.P. 1993. Demand for clean-fuel vehicles in California: A discrete-choice stated preference pilot project. *Transportation Research Part A: Policy and Practice* 27, 237-253.

Campbell, A.R., Ryley, T., Thring, R. 2012. Identifying the early adopters of alternative fuel vehicles: A case study of Birmingham, United Kingdom. *Transportation Research Part A: Policy and Practice* 46, 1318–1327.

Carlsson, F. 2010. Design of stated preference surveys: is there more to learn from behavioral economics. *Environmental and Resource Economics* 46, 167–177.

Carlsson, F., Martinsson, P. 2003. Design techniques for stated preference methods in health economics. *Health Economics* 12, 281–294.

Dillman, D. 1978. *Mail and telephone surveys: the total design method*. New York, NY, United States.

Egbue, O., Long, S. 2012. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy Policy* 48, 717–729.

Ewing, G.O., Sarigöllü, E. 1998. Car fuel-type choice under travel demand management and economic incentives. *Transportation Research Part D: Transport and Environment* 3, 429–444.

Ferguson, M., Mohamed, M., Higgins, C. D., Abotalebi, E., & Kanaroglou, P. 2018. How open are Canadian households to electric vehicles? A national latent class choice analysis with willingness-to-pay and metropolitan characterization. *Transportation Research Part D: Transport and Environment* 58, 208–224.

Hackbarth, A., Madlener, R. 2013. Consumer preferences for alternative fuel vehicles: A discrete choice analysis. *Transportation Research Part D: Transport and Environment* 25, 5–17.

Helveston, J.P., Liu, Y., Feit, E.M., Fuchs, E., Klampfl, E., Michalek, J.J. 2015. Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the US and China. *Transportation Research Part A: Policy and Practice* 73, 96–112.

Hensher, D.A., Beck, M.J., Rose, J.M. 2011. Accounting for Preference and Scale Heterogeneity in Establishing Whether it Matters Who is Interviewed to Reveal Household Automobile Purchase Preferences. *Environmental and Resource Economics* 49, 1–22.

Hensher, D., Rose, J., William, W. 2005. *Applied Choice Analysis: A Primer*. Cambridge University Press, Cambridge, UK.

Hidrué, M.K., Parsons, G.R., Kempton, W., Gardner, M.P. 2011. Willingness to pay for electric vehicles and their attributes. *Resource and Energy Economics* 33, 686–705.

Higgins, C.D., Mohamed, M., Ferguson, M.R. 2017. Size matters: How vehicle body type affects consumer preferences for electric vehicles. *Transportation Research Part A: Policy and Practice* 100, 182–201.

Hoen, A., Koetse, M.J. 2014. A choice experiment on alternative fuel vehicle preferences of private car owners in the Netherlands. *Transportation Research Part A: Policy and Practice* 61, 199–215.

Huber, J., Zwerina, K. 1996. The Importance of Utility Balance in Efficient Choice Designs. *Journal of Marketing Research* XXXIII, 307–317.

Jensen, A.F., Cherchi, E., Mabit, S.L. 2013. On the stability of preferences and attitudes before and after experiencing an electric vehicle. *Transportation Research Part D: Transport and Environment* 25, 24–32.

Krause, R.M., Sanya, R.C, Lane, B.W., Graham, J.D. 2013. Perception and reality: public knowledge of plug-in electric vehicles in 21 U.S. cities. *Energy Policy* 63, 433-440.

Lane, B., Potter, S. 2007. The adoption of cleaner vehicles in the UK: exploring the consumer attitude-action gap. *Journal of Cleaner Production* 15, 1085–1092.

Liao, F., Molin, E., van Wee, B. 2017. Consumer preferences for electric vehicles: a literature review. *Transport Reviews* 37, 252–275.

Louviere, J., Hensher, D., Joffre Swait, J. 2000. *Stated Choice Methods: Analysis and Applications*. Cambridge University Press, Cambridge, UK.

Mabit, S.L., Fosgerau, M. 2011. Demand for alternative-fuel vehicles when registration taxes are high. *Transportation Research Part D: Transport and Environment* 16, 225–231.

Meade, A.W., Craig, S.B. 2011. Identifying careless responses in survey data. In *Proceedings of the 26th Annual Meeting of the Society for Industrial and Organizational Psychology*. Chicago, Illinois, United States.

Massiani, J. 2014. Stated preference surveys for electric and alternative fuel vehicles: are we doing the right thing? *Transportation Letters* 6, 152–160.

Mohamed, M., Higgins, C.D., Ferguson, M., Réquia, W.J. 2018. The influence of vehicle body type in shaping behavioural intention to acquire electric vehicles: A multi-group structural equation approach. *Transportation Research Part A* 116, 54–72.

Mohamed, M., Higgins, C., Ferguson, M., Kanaroglou, P. 2016. Identifying and characterizing potential electric vehicle adopters in Canada: A two-stage modelling approach. *Transport Policy* 52, 100–112.

Moons, I., de Pelsmacker, P. 2012. Emotions as determinants of electric car usage intention. *Journal of Marketing Management* 28, 195–237.

Petrik, O, De Abreu e Silva, J. Moura, F. 2016. Stated preference surveys in transport demand modeling: disengagement of respondents. *Transportation Letters: The International Journal of Transportation Research* 8, 13-25.

Potoglou, D., Kanaroglou, P.S. 2007a. An Internet-Based Stated Choices Household Survey for Alternative Fuelled Vehicles. *Canadian Journal of Transportation* 1, 36–55.

Potoglou, D., Kanaroglou, P.S. 2007b. Household demand and willingness to pay for clean vehicles. *Transportation Research Part D: Transport and Environment* 12, 264–274.

Rose, J.M., Bliemer, M.C.J. 2008. Stated preference experimental design strategies. In: Hensher, D.A., Button, K.J. (Eds.), *Handbook of Transport Modelling, Second Edition*. Emerald Group Publishing Ltd., Bingley, UK. pp. 151–180.

Stopher, R.P. 1998. A review of separate and joint strategies for the use of data on revealed and stated choices. *Transportation Journal* 25, 187-205.

Street, D.J., Burgess, L., Louviere, J.J. 2005. Quick and easy choice sets: Constructing optimal and nearly optimal stated choice experiments. *International Journal of Research in Marketing* 22, 459–470.

Szolnoki, G., Hoffmann, D. 2013. Online, face-to-face and telephone surveys—Comparing different sampling methods in wine consumer research. *Wine Economics and Policy* 2, 57–66.

Tanaka, M., Ida, T., Murakami, K., Friedman, L. 2014. Consumers' willingness to pay for alternative fuel vehicles: A comparative discrete choice analysis between the US and Japan. *Transportation Research Part A: Policy and Practice* 70, 194–209.

Ziegler, A. 2012. Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: A discrete choice analysis for Germany. *Transportation Research Part A: Policy and Practice* 46, 1372–1385.

Chapter 3

Why is Electric Vehicle Uptake Low in Atlantic Canada? A comparison to Leading Adoption Provinces

3.1 Introduction

Between 2010 and mid-2018, cumulative electric vehicle (EV) sales in Canada increased from 1,500 to 70,000 vehicles with an even split between plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) (Schmidt, 2018). At the provincial level, however, approximately 97% of these sales have taken place in the provinces of British Columbia (12,587 vehicles), Ontario (26,143 vehicles), and Quebec (27,906 vehicles), which equates to 6 EVs per 1,000 households in these provinces. Other provinces, especially the four comprising a region known as Atlantic Canada, are well behind with respect to sales. As of mid-2018, a cumulative total of only 385 electric vehicles (or 0.4 EVs per 1,000 households) have been sold in Atlantic Canada (Nova Scotia – 169; New Brunswick – 156; Prince Edward Island – 25; Newfoundland and Labrador – 35).

The present study focuses on the four provinces comprising Atlantic Canada to obtain insights into the consumer EV adoption gap observed between this region and a grouping of the leading English-speaking adoption provinces in Canada, namely British Columbia and Ontario. The objective of this paper is to understand why Atlantic Canada lags behind these leading provinces. The study assesses attitudes and preferences of households towards EV adoption to

further our understanding of attributes and policies that play critical roles in households' decisions towards EV purchases. Differences in willingness-to-pay for each vehicle attribute along with distinctions in the mindset of households towards available powertrains in both lagging and leading areas are investigated in the current analysis.

This paper is one of the first EV studies to examine a lagging adoption region and provides comparisons with a model obtained from leading EV adoption provinces, which provides valuable context to judge consumer acceptance of electric vehicles in Atlantic Canada. We focus on the differences in preferences and attitudes among potential consumers of the two samples to find out why Atlantic Canada is lagging behind in terms of EV adoption. Also, our study is one of the few works to include all available EV technologies as alternatives in the stated preference (SP) survey. We have also included a new vehicular feature (i.e., battery warranty) and a combination of vehicle attributes that has rarely been used throughout the literature. Since few EVs have been purchased in Canada, especially in the Atlantic provinces, a stated preference (SP) survey technique is applied in the current analysis to quantify the determinants underlying purchasing EVs relative to other vehicle types.

The remainder of this paper is organized as follows. Section 3.2 reviews briefly past studies that have investigated EV preferences, concluding that none have investigated a region lagging in terms of EV adoption. The study area is presented in Section 3.3, followed by an overview of the stated preference (SP) survey and data set used in the investigation in Section 3.4. The latent class modelling approach and the determination of number of classes are described in Section 3.5. The

modeling results are discussed in Section 3.6. Concluding remarks are presented in the final section.

3.2 Studies Exploring EV Preferences

Previous EV studies have examined vehicle choice as a function of different vehicle attributes (e.g., Brownstone et al., 2000; Potoglou and Kanaroglou, 2007), incentives (Bjerkan et al., 2016; Helveston et al., 2015; She et al., 2017; Zhang et al., 2016), regulations and policies (Lutsey and Sperling, 2012; Massiani, 2015), infrastructure (Bailey et al., 2015), socioeconomics (Campbell et al., 2012; Carley et al., 2013), social network and attitudes (Axsen and Kurani, 2013; Beck et al., 2013; Ferguson et al., 2018; Rezvani et al., 2015), driving patterns (Franke and Krems, 2013; Khan and Kockelman, 2012; Pearre et al., 2011), and locational variables (Ferguson et al., 2018).

From a modeling perspective, most previous EV studies have used discrete choice methods to estimate consumer preferences for electric vehicles or their specific features (Table 3.1). Of these methods, the EV literature is dominated mostly by multinomial (Ewing and Sarigöllü, 1998), nested logit (Potoglou and Kanaroglou, 2007), and mixed logit models (Hackbarth and Madlener, 2013; Hoen and Koetse, 2014; Jensen et al., 2013). Hidrue et al. (2011), Axsen et al. (2015), and Ferguson et al. (2018) are examples of the few studies that have estimated EV preferences among consumers using latent class (LC) models. An important advantage of LC models over other discrete choice methods is that respondents can be grouped into different preference classes based on their attitudes and socioeconomic characteristics (Beck et al., 2013; Hidrue et al., 2011). For instance, Axsen et

al. (2015) specify five distinct latent classes where 23% of their sample is oriented towards conventional vehicles, 28% and 16% are hybrid electric vehicle (HEV)-leaning and HEV-oriented respectively, 25% are PHEV-oriented, and 8% are plug-in electric vehicle (PEV)-enthusiast. In a similar analytical approach, Ferguson et al. (2018) found 40% of a national Canadian sample as being oriented towards internal combustion engine vehicles (ICE), while 20%, 30% and 10% of the sample were HEV-, PHEV- and BEV-oriented respectively.

Regarding vehicle attributes and their impacts on EV preferences, Axsen et al. (2015) found high prices and range limitations as the main barriers to adopting EVs in their Canadian sample, and that PHEVs are the most popular among other powertrains followed by hybrid and internal combustion vehicles (Axsen et al., 2015). EV infrastructure is another crucial feature hindering the diffusion of electric mobility (Jensen et al., 2014). Long charging time and limited availability of fast charging facilities have been repeatedly considered as important limitations of EVs (Axsen and Kurani 2013; Hackbarth and Madlener 2013; Ziegler 2012). Financial incentives have also been shown to motivate people towards EVs as a new technology. Potoglou and Kanaroglou (2007) found that monetary costs and purchase tax relief would encourage households to adopt an alternative fueled vehicle.

Acceptance of EVs is also affected by several socioeconomic (Potoglou and Kanaroglou, 2007) and attitudinal factors (Ewing and Sarigöllü, 1998; Hackbarth and Madlener, 2013; Hidrue et al., 2011). For instance, Potoglou and Kanaroglou (2007) found that younger people and those with a university degree are more likely to adopt an alternative fueled vehicle, and that the demand

for high energy consuming vehicles, such as vans or sport utility vehicles (SUVs), diminished if respondents lived in dense and diversified urban areas. Hidrue et al. (2011) found that being younger, having a higher education (bachelor degree or above), and having a green lifestyle increased people's orientation towards EVs, while income and being a multi-car household did not have a significant impact on being in the EV class.

While the EV literature features several studies exploring EV preferences around the globe, no study was found with a focus on a lagging adoption region and the reasons behind that. One exception is a report by Pollution Probe – a prominent non-profit organization – that studied Canadian lagging regions, including Atlantic Canada, in terms of EV deployment. The report is particularly focused on regional and inter-regional challenges and opportunities, which were obtained through stakeholder discussions in each region (Pollution Probe, 2018). The present study builds on the insights obtained from the Pollution Probe report by providing statistical inferences obtained from consumers' attitudes and preferences and contributes to the collective understanding of the issue and strategies that can help to address the problem of low EV uptake in this lagging adoption region.

Table 3.1 Selected EV studies by region.

Study and Region	EV Alternatives	Modeling Approach	Key Aspects
<i>Europe</i>			
Dagsvik et al. (2002) Norway	BEV	Random utility models for ranking data	Estimated several alternative structural demand models based on probabilistic theories of individual choice behavior.
Lebeau et al. (2012) Belgium	BEV, PHEV	Choice-based conjoint	Examined the market share for EVs in 2012, 2020, and 2030.
Ziegler (2012) Germany	BEV, HEV	Multinomial probit	Due to the high numbers of alternatives, this study used the multinomial probit model for estimation, and also considered the effect of environmental awareness variables.
Hackbarth and Madlener (2013) Germany	BEV, HEV	Mixed logit	Added PHEV as a choice alternative, and driving range, recharging time, and incentives as vehicle attributes.
Jensen, et al. (2013) Denmark	BEV	Mixed logit	Examined before/after experience.
Hoen & Koetse (2014) Netherlands	BEV, HEV, PHEV	Mixed logit	Included a wider range of car attributes and alternatives.
<i>United States</i>			
Brownstone et al. (2000)	BEV	Mixed logit	Jointly modeled SP and RP vehicle choices.
Hidrué et al. (2011)	BEV	Latent class	Offered respondents an EV-equivalent of their preferred conventional vehicle to control for extraneous features.
Axsen & Kurani (2013)	BEV, HEV, PHEV	--	Extended in-depth survey methods by applying a “vehicle design game.”
Krupa et al. (2014)	PHEV	Ordinal logistic regression	Provided policy-makers and auto manufacturer with useful information to better promote PHEVs.
<i>Canada</i>			
Ewing and Sarigöllü (1998) Montreal, QC	BEV	Multinomial logit	Analyzed the issue of how economic instruments could increase demand for low-emission vehicles.
Potoglou and Kanaroglou (2007) Hamilton, ON	HEV	Nested logit	Provided neighborhood characteristics as covariates of households’ vehicle choices in an urban environment.
Axsen et al. (2015) Western provinces	BEV, HEV, PHEV	Latent class	Constructed consumer segments based on “lifestyle theory.”

BEV = battery electric vehicle; EV = electric vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; RP = revealed preference; SP = stated preference.

3.3 Study Area

Atlantic Canada includes the provinces of Nova Scotia (NS), New Brunswick (NB), Prince Edward Island (PEI), and Newfoundland and Labrador (NL) (Figure 3.1). In 2016, 2.33 million people lived in these provinces (Statistics Canada, 2016). As shown in Table 3.2, the region's population is aging (ratio of people age 65 and older is above the national average) and has annual incomes below the Canadian average. Also, significant discrepancies exist between rural and urban areas of the region, with rural communities having access to fewer economic opportunities, which has led to out-migration and very slow population growth (Natural Resources Canada, 2009). Only a few large urban centers offer public transit (Halifax Regional Municipality, Cape Breton Regional Municipality, Moncton, Saint John, Fredericton, Charlottetown, and St. John's) meaning that Atlantic Canadians depend more on private vehicles for mobility purposes than Canadians overall (Table 3.2).

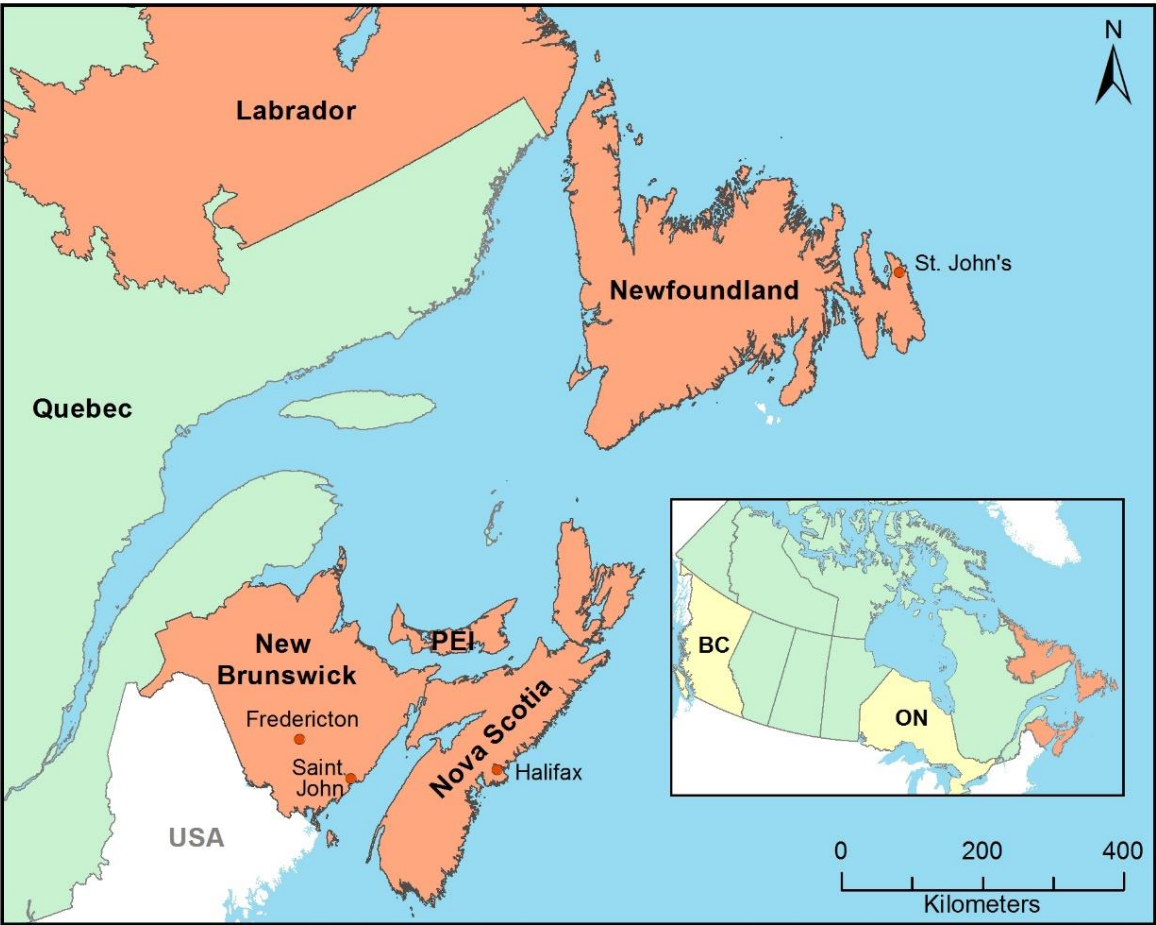


Figure 3.1 Study area (BC = British Columbia, ON = Ontario)

Table 3.2 Demographic characteristics by province (Source: Statistics Canada, 2016).

	New Brunswick	Nova Scotia	Prince Edward Island	Newfoundland and Labrador	Ontario	British Columbia	Canada
Population, 2016	747,000	924,000	143,000	520,000	12,852,000	4,400,000	35,152,000
Population change, 2011-2016 (%)	-0.5	0.2	1.9	1	4.6	5.6	5
Population density, (persons/km ²)	10.5	17.4	25.1	1.4	14.8	5	3.9
Ages 0-14 (%)	15	14	16	14	16	15	17
Ages 15-64 (%)	65	66	65	66	67	67	67
Ages 65+ (%)	20	20	19	19	17	18	17
Median household income (2015 \$)	59,300	60,800	61,200	67,300	74,000	70,000	70,300
% using public transit to get to work, 2016	2.3	6.4	1.3	2.5	14.6	13.1	12.4

3.4 SPACE Survey

The data for this analysis come from a survey developed to measure Canadian households' preferences and attitudes for electric vehicles and to assess their sensitivities to various attributes of said vehicles. SPACE (Survey for Preferences and Attitudes of Canadians towards Electric Vehicles) was administered in May-June 2015 to a panel of approximately 20,000 Canadian households. It was stratified with the less populous provinces more heavily sampled to ensure that an adequate number of respondents from all provinces was provided. For instance, the less-populated provinces of Atlantic Canada, which are investigated in this study, were proportionally over-sampled. Also, the survey was made available in both of Canada's official languages – English and French.

SPACE started with three screening questions to ensure that the realized sample would match the target population. Respondents needed to be 18 years or older, have some intention to purchase a vehicle within the next several years, and be one of the decision makers in their households. The latter question was to emphasize a respondent's role as household representative. Additionally, we removed respondents who were 'not at all likely' to buy a vehicle in the foreseeable future to ensure a sample representative of potential car buyers (Abotalebi et al., 2018). Our sample, therefore, was more general unlike some previous studies where respondents were required to be recent or urgent car buyers (e.g., Achtnicht, 2011; Mabit and Fosgerau, 2011). Also, we did not specify an exact timeframe to purchase a car since it could potentially exclude some buyers who consider vehicle purchase as a long-term decision. Households currently without a vehicle were not excluded from our database, as opposed to studies that included car owners only (e.g., Hoen and Koetse, 2014). In total, 2 139 observations from the Atlantic provinces (the lagging region) and 9 400 observations from the leading adoption provinces were used in the final analysis.

A stated preference (SP) experiment was at the core of SPACE to obtain household preferences in response to different hypothetical situations (Hensher et al., 2005). This was supported by an array of information on demographics, residential location and context, current vehicle ownership and vehicle purchase intentions, travel patterns, and an assortment of attitudinal information (Abotalebi et al., 2018). SP methods are widely used in marketing and have been applied in cases where the market share of the product is very limited, as with the case of EVs with

close to zero market penetration in Atlantic Canada. Also, future scenarios and new variables can be included and tested within SP experiments (Louviere et al., 2000).

In the SP scenarios, we specifically sought to understand the importance of technological EV attributes including range, charging time, fuel/maintenance cost savings, emission reduction, and performance; as well as the impact of policy measures including quality of battery warranty, cash incentives, free municipal parking, HOV lane access, and toll-free roads.

Each scenario consisted of four “labeled” alternatives, internal combustion (ICE), hybrid (HEV), plug-in hybrid (PHEV), and battery electric vehicles (BEV), illustrated with their related visual design. A clear explanation of each alternative was also provided to respondents in the educational section prior to the SP scenarios (Ferguson et al., 2018). Respondents were presented with four such scenarios and were asked to make a choice between four alternatives.

A D-efficient experimental design was developed to generate SP scenarios based on the results from a pilot survey conducted prior to the main survey to provide us with some pre-known information about attributes, the so-called “priors,” and to make adjustments to the whole survey (Bliemer and Rose 2011). The Ngene program was used to generate 48 choice scenarios for each seven vehicle classes. These scenarios were divided into 12 blocks, and each respondent was randomly assigned to one of these blocks, with 4 distinct scenarios.

The most important aspect of the SP experiments was being context sensitive to the respondents’ specific circumstances: annual kilometers, preferred vehicle size, and anticipated

purchase price. In SPACE, the attribute levels were anchored realistically on the vehicle sizes that respondents specified prior to the SP experiment. Respondents could choose between seven vehicle classes (Economy, Intermediate, Full Sedan, Luxury, SUV, Minivan, and Pickup truck) presented to them with related images and approximate prices corresponding to the ICE market (Table 3.3). The respondents' selected vehicle size applied to all scenarios and was used as a reference point to derive attribute levels of the alternatives (Table 3.4). This method added to the relevance and realism of the attribute levels being evaluated by the respondent (Beck et al., 2013; Rose and Bliemer, 2008). For instance, a household interested in an economy size vehicle was faced with its matching price or fuel cost levels.

For the households without a vehicle at the time of survey, 15,000 km annually (i.e., average annual kilometers reported in the survey) was used. The approximate price of selected vehicle size was used as a reference point and the prices of all alternatives were pivoted off that value specified by the experimental design. Table 3.4 displays our SP alternatives, attributes, and their levels.

Table 3.3 Base values for the SP scenarios.








Body Type Image	Vehicle Size	Purchase Price (\$)	Maintenance Cost (\$/km)	Acceleration (sec to reach 100 km/h)	Gasoline Range (km)	CO ₂ tailpipe Emissions (tonnes/km)	Fueling/charging Cost (\$/km)
	Economy	22,000	0.051	8.8	700	0.000143	0.07
	Intermediate	25,000	0.051	9.0	700	0.000141	0.07
	Full sedan	35,000	0.060	7.2	800	0.000182	0.08
	Luxury sedan	59,000	0.072	6.5	700	0.000202	0.09
	Minivan	33,500	0.069	5.0	700	0.000234	0.14
	SUV	30,000	0.072	9.0	670	0.000234	0.09
	Pickup truck	40,000	0.081	6.6	750	0.000444	0.13

Table 3.4 Attribute levels for the experimental design.

Attributes	Alternatives			
	ICE	HEV	PHEV	BEV
Purchase price (\$)	-25%, Base	Base , +50%	Base , +50%, +100%	Base , +50%, +100%
Cash incentive (\$)	0	0	0, 5000, 10,000	0, 5000, 10,000
Maintenance cost (\$/km)	Base	-25%, Base	-50%, -25%, Base	-25%, -50%, -75%
Acceleration (sec to reach 100 km/h)	Base	-50%, Base , +50%	-50%, Base , +50%	-50%, Base , +50%
Battery range (km)	-	-	30, 60, 90	150, 250, 350
Gasoline range (km)	Base	-25%, +25%	-25%, +25%	-
CO ₂ tailpipe emissions (tonnes/km)	-25%, Base	-50%, -25%	-75%, -50%	0
Fueling/charging cost (\$/km)	Base , +20%, +40%	-20%, Base	-60%, -40%, -20%	-80%, -60%
Public charging time (hr)	-	-	0.15, 1.5, 2.75	0.25, 3, 5.65
Home/work charging time (hr)	-	-	2, 3, 4	3.5, 5.25, 7
Fueling/charging station availability	All gas stations	All gas stations	10%, Same, Twice	10%, Same, Twice
Battery warranty	-	-	3 yrs./58,000 km, 5 yrs./96,000 km, 8 yrs./160,000 km	3 yrs./58,000 km, 5 yrs./96,000 km, 8 yrs./160,000 km
Non-cash incentives	-	-	HOV lane access, Free parking, Free toll roads	HOV lane access, Free parking, Free toll roads

Same = same number of stations as number of current gas stations; Twice = twice as many stations as current number of gas stations; HOV lane access = high occupancy vehicle lane access.

3.5 Methods

3.5.1 Latent Class Choice Model

The dependent variable in our model is a household's stated choice of vehicle fuel type among four alternatives for their next vehicle purchase. The latent class (LC) choice model is the modeling approach used for this analysis. The LC model is preferred to the multinomial logit model (MNL) as it is not constrained by the IIA property and can also capture discrete segmentation of the data set (Walker and Li, 2007). The LC model can link taste heterogeneity to attitudinal and socioeconomic characteristics of decision makers rather than only specifying a random distribution to a given parameter as is the case with the mixed logit model (Beck et al., 2013). Hence, the LC model seeks to identify consumer segments that primarily differ according to their overall attitudes and preferences, and provide an appropriate framework for interpreting results, proposing policies, and making decisions based on respondents' taste heterogeneity.

The LC model is also preferred to the multinomial probit model (MNP) for the current analysis as it is free from unwarranted distributional assumptions (e.g., normal distribution in the MNP models) (Ryan et al., 2008). The LC class-specific choice model takes on whatever form is most appropriate for each class (e.g., logit, probit, random parameter logit, etc.) and can vary across classes (Walker and Li, 2007).

The LC model consists of two parts: a class membership model and a class-specific choice model. The probability that a decision maker with characteristics X_n chooses alternative i is presented as:

$$P(i|X_n) = \sum_{s=1}^S P(i|X_n, S)P(S|X_n)$$

where $P(i|X_n, S)$ is the probability of choosing alternative i conditional on attributes and decision maker characteristics X_n , and being a member of class S , and $P(S|X_n)$ is the probability that the decision maker with characteristics X_n belongs to class S (Walker and Li, 2007). The class assignment is not deterministic, but is modelled as a probability across classes.

3.5.2 Determining the Number of Latent Classes

The number of classes is not determined endogenously. Instead, a series of models with varying numbers of classes are estimated and a trio of statistics are used to compare different models. The statistics that aid the selection of the number of classes are the Bayesian Information Criterion (BIC), Akaike Information Criterion (AIC), and pseudo R^2 . In general, the higher these values, the better is the model according to the statistics (Walker and Li, 2007). Non-statistical criteria are also applied when selecting the number of classes. Since the focus is on understanding the heterogeneity underlying different segments, each class must be clearly distinct in terms of behaviors of decision makers assigned to that class.

Table 3.5 shows statistics to select the optimum number of latent classes for both the “Atlantic” and “Leading” models. With an increase in the number of classes, the model performs better in terms of statistical criteria (i.e., pseudo R-square, AIC, and BIC), but the classes become more identical with four or more classes. For the Atlantic sample, the 3- and 4-class models are very close with respect to their estimation results. However, the model with 3 classes provides better results, since the differences between classes are more identifiable and meaningful. The same analysis was conducted for the leading sample, though the model with four latent classes provided the best fit and was selected for the final analysis.

Table 3.5 Latent class model statistics for assessing the optimum number of classes

Number of Classes	Number of Parameters	BIC	AIC	Pseudo R ²
<i>Atlantic Model</i>				
2	50	-21,286	-20,990	0.313
3 (selected)	84	-19,676	-19,179	0.375
4	118	-19,283	-18,585	0.397
<i>Leading (ON and BC) Model</i>				
3	84	-71,747	-71,115	0.319
4 (selected)	118	-68,184	-67,254	0.357
5	152	-66,708	-65,513	0.374

AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion.

3.6 Results

3.6.1 Descriptive Statistics

The respondent-specific variables used in the latent class model and their descriptive statistics are found in Table 3.6. Participants were also asked to choose the vehicle they would next purchase with regard to size. Figure 3.2 shows the preferred vehicle sizes in all Atlantic and leading

provinces. In Newfoundland and Labrador, there is a greater proportion for larger vehicles (i.e., SUVs, vans, and pickup trucks) and lower demand for fuel-efficient vehicles. This trend is reversed in Nova Scotia where close to half of its respondents chose an economy or intermediate size vehicle. Luxury or full sedan is relatively more popular in Ontario.

Table 3.6 Variable definitions and statistics

Variable	Definition	Atlantic Canada (%)	ON and BC (%)
Age < 45	1 if householder is < 45 years old; 0 otherwise	36	36
Female householder	1 if householder is female; 0 otherwise	58	54
University degree	1 if householder has achieved a university degree; 0 otherwise	70	73
Multicar household	1 if household owns at least two cars; 0 otherwise	53	49
Homeowner	1 if household is owns its home; 0 otherwise	80	78
Economy size	1 if household's next vehicle purchase is an economy size vehicle; 0 otherwise	17	18
Keeping vehicle < 3 years	1 if the amount of time that the household usually keeps a vehicle < than 3 years; 0 otherwise	9	8
High income	1 if household's income is greater than \$100,000; 0 otherwise	40	43
Newfoundland	1 if household lives in the province of Newfoundland and Labrador; 0 otherwise	25	-
		Mean Score	
Environment- supportive score (out of 25)	Respondents were asked about their attitudes on two qualitative criteria: environment- and EV-supportive. The statements were measured on a five-point Likert scale. For each category, a score was calculated for each respondent according to their responses (where 1 equals Strongly Disagree, 3 equals Neutral, and 5 equals Strongly Agree) and was used as a covariate in our final model See Mohamed et al. (2016) for a list of the attitudinal statements used in the SPACE survey.	10.13	11.82
EV-supportive score (out of 35)		22.46	24.32

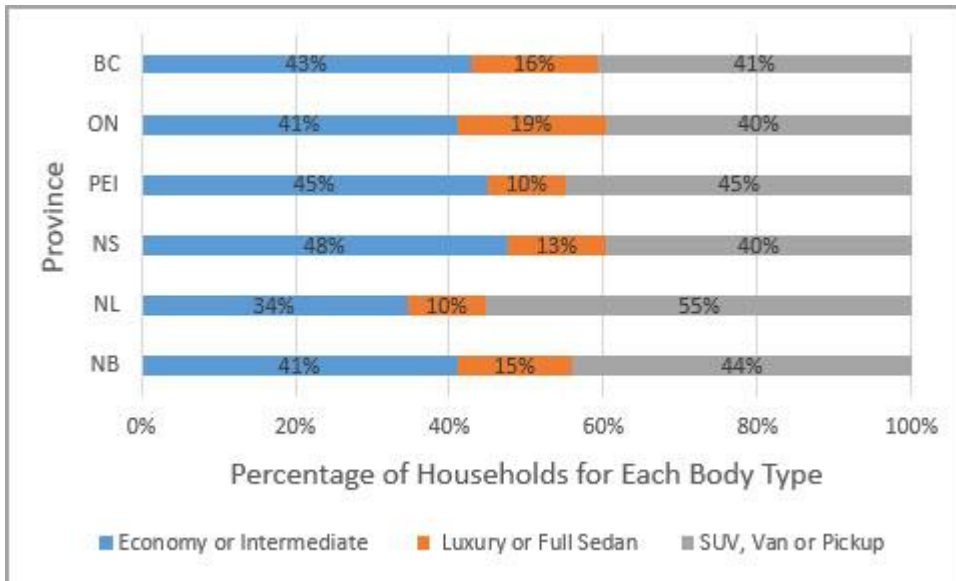


Figure 3.2 Vehicle body type preferences by province

3.6.2 Class membership sub-model

Table 3.7 summarizes the results for the class membership for both the “Atlantic” and “Leading” models. The class membership results for the Atlantic model show that being of younger age (< 45), having a university degree, and planning to buy an economy car increase a respondent’s PEV-orientation. For the Leading model, the factors of younger age, being female, and possession of a university degree decrease the chance of membership in the ICE-oriented class. In both models, people with higher scores for non-ICE technologies have a higher tendency to choose a plug-in electric vehicle as their next purchase, indicating the importance of attitudes in determining class assignment. In the Atlantic model, being a homeowner and having a tendency to keep vehicles less than three years are associated with being included in the ICE-oriented class. The latter factor

reflects less opportunity to benefit from EV fuel savings in the long run. Higher income and having access to multiple cars were statistically insignificant in both the Atlantic and Leading models. The class membership results show that Atlantic people closely follow similar sociodemographic and attitudinal characteristics as people living in the Leading adoption provinces.

Our analysis on provincial differences within Atlantic Canada shows that respondents living in Newfoundland and Labrador are less likely to buy a plug-in electric vehicle. This is most likely due to isolation and a lower level of urbanization in this province compared to the rest of the Atlantic provinces. We already saw that people living in Newfoundland and Labrador have less tendency towards an economy or intermediate vehicle size, which is the typical body type of most available EV models (Figure 3.2).

Table 3.7 Latent class membership model results

HEV-oriented (reference)	Atlantic model		Leading (ON and BC) model		
	Class 1: ICE-oriented	Class 3: PEV- oriented	Class 1: ICE-oriented	Class 3: PHEV-oriented	Class 4: BEV-oriented
Constant	3.708***	-4.41***	3.593***	1.386***	-2.635***
Age < 45	0.04	0.34**	-0.270***	-0.295***	0.048
Female householder	0.035	0.191	-0.319***	0.116	-0.135
University degree	-0.045**	0.164**	-0.412***	0.210***	0.040
Multicar household	0.099	0.082	0.045	-0.008	-0.217
Homeowner	0.302*	0.246	-0.015	-0.049	-0.176
Economy size	0.549***	0.363**	-0.031	-0.112	0.309***
Keeping vehicle < 3 years	0.39*	-0.013	0.441***	0.397***	0.311**
High income	-0.201	-0.104	0.036	0.014	-0.156
Newfoundland	0.398***	-0.199*	-	-	-
Environment supportive score	-0.074***	0.066***	-0.013*	0.006	0.009*
EV supportive score	-0.125***	0.113***	-0.144***	0.057***	0.089***

***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively.

3.6.3 Class specific sub-model

Table 3.8 presents the results for the class-specific model. In the Atlantic model, it can be seen that respondents in Class 1 (40% of the sample) have a propensity towards conventional vehicles. Members of Class 2 (30% of the sample) are more oriented towards HEVs, and Class 3 (30% of the sample) exhibits greater interest for PEVs, which include both PHEV and BEV technologies. The plug-in oriented class is the only class for which availability of charging stations and home charging time are significant determinants of vehicle choice. For the Leading sample, a four-latent class model is formed in which 40% are ICE-oriented and 20% are HEV-oriented. The plug-in oriented members are grouped into two distinct latent classes of PHEV-oriented and BEV-oriented, which make up 30% and 10% of the Leading sample, respectively. Clearly, as can be seen in Table 3.8, the LC modelling approach is statistically preferred to the MNL approach in both models as it has an improved log likelihood and much higher goodness of fit.

Across all classes, most of the parameters have expected signs and most of the alternative specific constants are significant. The coefficient on price is statistically significant and negative in all classes. Purchase price is clearly an important indicator of vehicle choice, as one would expect. Cash incentive is another important predictor of purchasing an EV, which is positive and strongly significant in all classes. Maintenance cost, however, turns out to be insignificant for all three classes of the Atlantic model while it is a significant and negative parameter in the Leading model. This difference is most probably due to the unfamiliarity of Atlantic households with different aspects of EVs, including fewer moving parts that lower maintenance cost.

Battery warranty is significant in all classes of the Atlantic model with the expected positive sign. Interestingly, the battery warranty is not significant for the BEV-oriented class of the Leading model. High occupancy vehicle (HOV) lane access is insignificant across all classes in the Atlantic model, while it is significant and positive for the PHEV-oriented class of the Leading model. A similar result is observed for free parking, a parameter that is significant for the PHEV- and BEV-oriented classes of the Leading model, while it is not significant for a comparable class in the Atlantic model (i.e., PEV-oriented).

Gasoline range is significant for all classes except for the BEV-oriented class of the Leading model. Electric range, on the other hand, is insignificant across all classes of the Atlantic model, while it is significant for plug-in oriented classes of the Leading model. This result is another sign indicating that Atlantic households are perhaps less familiar with different attributes of a plug-in electric vehicle, including its range.

All coefficients for charging time either at home or at public stations have the expected signs. However, only the home charging time is significant for the PEV-oriented class in the Atlantic model. Public charging time, on the other hand, is only significant for the ICE- and HEV-oriented classes of the Atlantic model. This trend is relatively reversed in the Leading model where households of plug-in oriented classes are not much worried about home charging time. This is most likely due to better familiarity of the households of the Leading provinces about EV charging at home and the possibility of charging overnight – a factor that can neutralize the impact of time.

Table 3.8 MNL and latent class-specific choice model results

	Atlantic models				Leading (ON and BC) models				
	MNL	Class 1: ICE- oriented	Class 2: HEV- oriented	Class 3: PEV- oriented	MNL	Class 1: ICE- oriented	Class 2: HEV- oriented	Class 3: PHEV- oriented	Class 4: BEV- oriented
Probability of Membership		0.4	0.3	0.3		0.4	0.2	0.3	0.1
ICE constant	0.7522***	3.27***	1.803**	-1.91***	0.856***	2.976***	1.129**	-0.463**	-2.79***
HEV constant	0.3764***	0.932	3.8***	-1.49***	0.583***	1.073***	3.176***	0.591***	-2.53***
PHEV constant	0.3674***	0.508	1.781***	0.27*	0.521***	0.467**	1.165***	1.885***	-1.38***
Purchase price (1000 \$)	-0.0364***	-0.12***	-0.06***	-0.04***	-0.036***	-0.118***	-0.02***	-0.06***	-0.03***
Cash incentive (1000 \$)	0.0247***	0.061***	0.053***	0.019***	0.034***	0.077***	0.034***	0.058***	0.036***
Maintenance cost (\$/year)	-0.0579	0.154	-0.038	-0.075	-0.002***	-0.003***	-0.005***	-0.003***	-0.004**
Acceleration (sec to reach 100 km/h)	-0.0113***	0.019	-0.01	-0.02***	-0.010***	-0.029***	0.003	-0.01***	-0.03***
Gasoline range (km)	0.0004***	0.0004	0.001***	0.001***	0.0004***	0.001***	0.001***	0.001***	0.0002
Battery warranty	0.0614***	0.147**	0.084*	0.064**	0.055***	0.120***	0.094***	0.125***	0.015
Electric range (km)	0.0003	0.0008	0.001	0.0006	0.001***	0.002**	0.001	0.002***	0.001*
Free parking	0.0124	0.292*	-0.189	0.013	0.078***	0.043	0.096	0.128***	0.132**
HOV lane access	0.03	0.227	0.079	0.001	0.043**	-0.045	-0.223**	0.085**	0.052
Fueling/charging station availability	0.0414*	0.092	-0.006	0.047*	0.024**	-0.011	0.015	0.029	0.030
Public charging time (hr)	-0.027***	-0.0756*	-0.0732*	-0.0096	-0.031***	-0.08***	-0.096***	-0.034***	-0.053***
Home/work charging time (hr)	-0.0461***	-0.028	-0.009	-0.036*	-0.021***	-0.003	-0.092**	-0.020	-0.030
Log likelihood	-13,072		-9,506		-46,662		-33,517		
McFadden R ²	0.03		0.375		0.03		0.357		

***, **, * indicate statistical significance at 1%, 5%, and 10%, respectively. Note: BEV is the reference for the alternative specific constants.

While charging station availability is significant for the PEV-oriented class in the Atlantic model, it is not a point of concern for any classes of the Leading model. The reason may lie behind the fact that these stations are already widespread in the Leading provinces while this is not the case for Atlantic Canada.

To summarize the Atlantic class assignment model, the main defining characteristics of the ICE-oriented class is high purchase price sensitivity and a general interest in monetary attributes including cash incentive, free parking, and battery warranty. The members of this group show the signs of “conservancy or reluctance to change” in their attitudes. The ICE-oriented members of the Leading model are also sensitive about higher electric range, rapid acceleration, and lower maintenance costs of EVs. This shows “a bit of enthusiasm” towards EV technologies among ICE-oriented households of the Leading provinces compared to their counterparts in Atlantic Canada.

The socioeconomics of the PEV-oriented group in the Atlantic model are mostly the opposite of its ICE-oriented class. The members of the plug-in group are younger, better educated, and possess progressive attitudes. The prominent characteristic of the plug-in class is much less sensitivity to vehicle purchase price. They are people who are “thinking bigger” when it comes to the future purchase of a vehicle even though they may not be in a position to afford it yet. This class is more pre-occupied with performance aspects of a vehicle (e.g., rapid acceleration) and the convenience afforded by charging at home. They are, however, less worried about whether public charging might work out for them if they owned an EV. In contrast the HEV-oriented class of the Atlantic model is not performance-oriented and they are much more pre-occupied with losing time

to public charging. The HEV group contains 30% of the Atlantic sample which suggests a large share of “green-thinking” people in Atlantic Canada.

In summary, it can be seen from the coefficients of some important attributes such as purchase price and acceleration that the PEV-oriented class of the Atlantic model hovers somewhere in between the two plug-in oriented classes of the Leading model. In other words, Atlantic PEV-oriented members possess some characteristics that are ahead of the PHEV-oriented class of the Leading model in terms of plug-in electric vehicle acceptance, while they do not appear as enthusiastic about BEV technologies as the BEV class of the Leading model. The lack of a BEV-oriented class is an important characteristic that makes Atlantic Canada distinct from the leading adoption provinces.

3.6.4 Willingness-to-pay

Table 3.9 shows respondents’ willingness to pay (WTP) for vehicle attributes, which is what consumers (members of each latent class) are willing to pay for a one-unit improvement in an attribute. For each latent class, WTP is calculated by dividing an attribute’s coefficient by the absolute value of the coefficient of a vehicle’s purchase price and multiplying the result by 1000 since purchase price is expressed in thousands of dollars. Constants of latent classes are converted into WTP terms because they are indicative of the base level of attractiveness that each class associates with the four powertrain alternatives. In both models, the ICE- and HEV-oriented classes are the least interested in BEVs. The PEV-oriented class of the Atlantic model, which includes enthusiasts of both plug-in electric vehicle technologies (i.e., PHEV and BEV), appears more

interested in PHEVs than BEVs. The PEV class of the Atlantic model, however, shows similar negativity towards both ICEs and HEVs. The PHEV-oriented class in the Leading model prefers HEVs to BEVs, while its BEV-oriented class is strongly attracted to BEVs.

As one would expect, respondents in all classes have a positive WTP associated with cash incentive and battery warranty. However, the classes vary in their sensitivity to these attributes. For instance, people in the Atlantic HEV-oriented class place a higher value on cash incentive and the PEV-oriented class is willing to pay more per level increase in the battery warranty. The members of the Atlantic plug-in class are less pre-occupied with public charging time and more concerned with acceleration and home charging time, while the HEV-oriented group is more worried about charging time at stations.

With regard to charging availability, members of the Atlantic PEV-oriented class place higher value on charging station availability, while in the Leading model, members of both PHEV- and BEV-oriented classes are less worried about access to charging stations. PHEV- and BEV-oriented classes of the Leading model are also more concerned with free parking as opposed to their counterparts in the Atlantic model.

Table 3.9 Willingness to pay

	Atlantic model			Leading (ON and BC) model			
	Class 1: ICE- oriented	Class 2: HEV- oriented	Class 3: PEV- oriented	Class 1: ICE- oriented	Class 2: HEV- oriented	Class 3: PHEV- oriented	Class 4: BEV- oriented
ICE constant	\$27,337	\$30,211	-\$51,555	\$25,116	\$47,340	-\$7,863	-\$83,093
HEV constant	\$7,791	\$63,691	-\$40,317	\$9,060	\$133,163	\$10,050	-\$75,206
PHEV constant	\$4,240	\$29,855	\$7,295	\$3,946	\$48,847	\$32,028	-\$40,965
Purchase price (1000 \$)	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000	\$1,000
Cash incentive (1000 \$)	\$512	\$891	\$510	\$647	\$1,423	\$980	\$1,067
Maintenance cost (\$/year)	-	-\$631	-\$2,016	-\$24	-\$195	-\$46	-\$126
Acceleration (sec to reach 100 km/h)	-	-\$175	-\$572	-\$242	-	-\$242	-\$743
Gasoline range (km)	\$4	\$9	\$12	\$7	\$23	\$9	\$7
Battery warranty	\$1,225	\$1,412	\$1,726	\$1,011	\$3,937	\$2,127	\$433
Electric range (km)	\$7	\$16	\$15	\$15	\$19	\$31	\$32
Free parking	\$2,440	-	\$346	\$360	\$4,015	\$2,172	\$3,934
HOV lane access	\$1,892	\$1,317	\$25	-	-	\$1,417	\$1,733
Charging station availability	\$770	-	\$1,274	-	\$635	\$492	\$888
Public charging time (hr)	-\$630	-\$1,226	-\$259	-\$674	-\$4,025	-\$571	-\$1,057
Home charging time (hr)	-\$234	-\$148	-\$959	-\$28	-\$3,840	-\$333	-\$892

Note: BEV is the reference for the alternative specific constants.

Comparing the WTP values in both models, there are some broad similarities of Atlantic Canada to the Leading provinces, but there are some crucial distinctions, which help to explain some of the slow uptake. With respect to various aspects of EVs, households in the Leading model are willing to pay more for public charging time, whereas Atlantic households are more concerned about charging time at home. However, we suspect that when the PEV-oriented households become more advanced in their thinking about EVs, they may pay more attention to public charging time. In the Leading model, the BEV-oriented group is focused on this aspect. However, the PEV-

oriented group in the Atlantic model appears to be more sensitive towards charging station availability than households in the Leading model.

Contrary to the Leading model, electric range was not a significant attribute in the Atlantic model where households in the PEV-oriented class were willing to pay about half (\$15) the amount that similar households in the Leading model would pay for a kilometer of added range (\$31-\$32). Alternatively, Atlantic households are more interested in gasoline range than their counterparts in the Leading model. The reason that electric range is less highly valued in the Atlantic model may be that Atlantic Canadians in general drive less (or at least less far) as there are no sprawling metros, and this may affect perceptions about gasoline versus electric range.

Concerning battery warranty, Atlantic PEV-oriented households are willing to pay an additional \$1,726 to improve the warranty by one level. While this is somewhat lower compared to the PHEV-oriented class in the Leading model, it is much higher than that of the BEV-oriented class, which is willing to pay only \$433.

Free parking was insignificant for Atlantic Canadians while it was an important attribute in the Leading model with \$2,172 and \$3,934 WTP, respectively, for the PHEV- and BEV-oriented groups. The very low WTP value for free parking in Atlantic Canada compared to the values in the Leading model is most probably due to parking being less expensive in Atlantic Canada than in the larger urban centers in the Leading provinces (Ontario and British Columbia). Cash incentive was also a more important attribute in the Leading model compared to the WTP measures in the Atlantic model. Furthermore, the Atlantic Canada plug-in oriented class discounts the importance of a cash

incentive by almost half of its value – that is, such households are only willing to pay \$510 for every \$1000 of cash incentive.

3.7 Discussion and conclusions

This paper provides evidence on the choice of vehicle powertrain among households of a lagging adoption region (Atlantic Canada) in relation to leading adoption provinces (Ontario and British Columbia). The study uses socioeconomic, attitudinal, and stated preference data obtained from SPACE, a 2015 national survey. The parameters of a latent class model have helped to garner insights about how personal perceptions towards various attributes and cash and non-cash incentives shape the choice of vehicle type in Atlantic Canada.

With respect to vehicle attributes, high purchase price, limited charging stations, and long charging time either at home or at public stations are negatively perceived among potential Atlantic EV consumers. Also, households are sensitive to financial incentives targeting EV buyers meaning that EVs are to some extent an incentive-driven product to become competitive with gasoline vehicles in Atlantic Canada (as we write this paper, there are no cash incentives offered to EV buyers in this region). Provincial incentives are indeed among the most important components of the differing adoption rates across regions in Canada. Related to this is the lack of a major metropolitan area or a “core area” in Atlantic Canada where an EV diffusion process can gain a foothold.

The quality of the battery warranty and fast acceleration of EVs are also positively perceived among Atlantic consumers, while driving range is not a significant attribute. Atlantic households are not sensitive towards minimized maintenance cost and non-cash incentives including free parking for EV owners. While both home and public charging time are negatively perceived among Atlantic households, people in the PEV-oriented class are more sensitive towards charging time at home.

In the Leading model, a distinct class for BEV-oriented households was able to form. In Atlantic Canada, this was not the case. The BEV-oriented class in the Leading model possessed some characteristics that were not present or observed in the Atlantic sample. For instance, the Leading BEV-oriented class was associated with fairly intense urbanization of some large metropolitan areas, which is not occurring in Atlantic Canada. Our trials showed that a 4th Atlantic latent class was not BEV-oriented, most probably due to a higher level of uncertainty of the Atlantic sample about EVs. The complete current and historical absence of government incentives may provide some explanations for that. Related to this are themes of remoteness being a factor. There is evidence that the most remote province, Newfoundland and Labrador, is quite ICE-oriented relative to the rest of Atlantic Canada and meanwhile, Atlantic Canada itself is remote compared to Canada's urban heartland.

The class membership results show that there is a larger HEV orientation in Atlantic Canada – 30% as opposed to 20% in the Leading model. However, plug-in classes (PHEV- and BEV-oriented) account for a total of 40% in the Leading model, but only 30% in Atlantic Canada. Hence,

the plug-in orientation is simply less prevalent in Atlantic Canada. The ICE-oriented class (40%) remains the same as the Leading model.

Despite the very low penetration level of EVs, there is widespread openness to the idea of electric vehicles in Atlantic Canada. As to why the existing market shares is nothing close to these numbers, it cannot be said that uptake is low because people are unreceptive to electric vehicles. Based on the results, a good share of households ARE indeed receptive, though not to the extent of the leading English-speaking adoption provinces in Canada. However, the results suggest that receptive people exhibit less conviction and perhaps more uncertainty about EVs than the similar group in the Leading model.

The main obstacles to the widespread adoption of EVs can be explained as higher purchase prices of PHEVs and BEVs relative to ICE, lack of financial incentives, limited exposure to EVs, and inadequate charging stations across the Atlantic provinces. For instance, at the time of writing, there are only two fast chargers built in the province of Nova Scotia. Other barriers include limited public awareness and knowledge about EVs, lack of supply and service providers at local dealerships, and lack of a supportive market strategy.

Receptivity in Atlantic Canada is demonstrated by a large PEV-oriented class, which is more upscale, better educated, and younger with progressive attitudes. Since this class has a high share of younger people who are less established, income does not differentiate well. These results can be used to target specific population segments for EV marketing and to take prioritized provincial actions to accelerate EV uptake in Atlantic Canada. For instance, younger adults and

educated people are a good target, but income and homeownership may be less important than one might expect.

We should acknowledge that the present work is limited to the stated preference responses of potential consumers. More qualitative research methods such as research groups or interviews can add further insights to better understand what makes regions like Atlantic Canada lag behind. Future studies can focus on other lagging adoption regions in Canada (e.g., the Prairies) and also worldwide to gain more insights towards the EV mindsets in those regions and to provide context for comparing the results.

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3.9 References

Abotalebi, E., Ferguson, M.R., Mohamed, M., and Scott, D.M. 2018. Design of a survey to assess prospects for consumer electric mobility in Canada: a retrospective appraisal, *Transportation*, 1-28.

Achtnicht, M. 2011. German car buyers' willingness to pay to reduce CO2 emissions. *Climatic Change* 113, 679–697.

Axsen, J., Bailey, J., and Castro, M.A. 2015. Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics* 50, 190–201.

Axsen, J., Kurani, K.S. 2013. Hybrid, plug-in hybrid, or electric—What do car buyers want? *Energy Policy* 61, 532–543.

Bailey, J., Amy Miele, A., Axsen, J. 2015. Is awareness of public charging associated with consumer interest in plug-in electric vehicles? *Transportation Research Part D: Transport and Environment* 36, 1–9.

Beck, M.J., Rose, J.M. Hensher, D.A. 2013. Environmental attitudes and emissions charging: an example of policy implications for vehicle choice. *Transportation Research Part A: Policy and Practice* 50, 171–182.

Bjerkan, K.Y., Nørbech, T.E., Nordtømme, M.E. 2016. Incentives for promoting battery electric vehicle (BEV) adoption in Norway. *Transportation Research Part D: Transport and Environment* 43, 169–180.

Bliemer, M.C.J., Rose, J.M. 2011. Experimental design influences on stated choice outputs: an empirical study in air travel choice. *Transportation Research Part A: Policy and Practice* 45, 63–79.

Brownstone, D., Bunch, D.S., Train, K. 2000. Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles. *Transportation Research Part B: Methodological* 34, 315–338.

Campbell, A.R., Ryley, T., Thring, R. 2012. Identifying the early adopters of alternative fuel vehicles: a case study of Birmingham, United Kingdom. *Transportation Research Part A: Policy and Practice* 46, 1318–1327.

Carley, S., Krause, R.M., Lane, B.W., and Graham, J.D. 2013. Intent to purchase a plug-in electric vehicle: a survey of early impressions in large US cities. *Transportation Research Part D: Transport and Environment* 18, 39–45.

Dagsvik, J.K., Wennemo, T., Wetterwald, D.G., Aaberge R. 2002. Potential demand for alternative fuel vehicles. *Transportation Research Part B: Methodological* 36, 361-384.

Ewing, G.O., Sarigöllü, E. 1998. Car fuel-type choice under travel demand management and economic incentives. *Transportation Research Part D: Transport and Environment* 3, 429–444.

Ferguson, M., Mohamed, M., Higgins, C.D., Abotalebi, E., Kanaroglou, P. 2018. How open are Canadian households to electric vehicles? A national latent class choice analysis with willingness-to-pay and metropolitan characterization. *Transportation Research Part D: Transport and Environment* 58, 208–224.

Franke, T., Krems, J.F. 2013. What drives range preferences in electric vehicle users? *Transport Policy* 30, 56–62.

Hackbarth, A., Madlener, R. 2013. Consumer preferences for alternative fuel vehicles: a discrete choice analysis. *Transportation Research Part D: Transport and Environment* 25, 5–17.

Helveston, J.P., Liu, Y., McDonnell Feit, E., Fuchs, E., Klampfl, E., Michalek, J.J. 2015. Will subsidies drive electric vehicle adoption? Measuring consumer preferences in the US and China. *Transportation Research Part A: Policy and Practice* 73, 96–112.

Hensher, D., Rose, J., William, W. 2005. *Applied Choice Analysis: A Primer*. Cambridge University Press, Cambridge, UK.

Hidrué, M.K., Parsons, G.R., Kempton, W., Gardner, M.P. 2011. Willingness to pay for electric vehicles and their attributes. *Resource and Energy Economics* 33, 686–705.

Hoen, A., Koetse, M.J. 2014. A choice experiment on alternative fuel vehicle preferences of private car owners in the Netherlands. *Transportation Research Part A: Policy and Practice* 61, 199–215.

Jensen, A.F., Cherchi, E., de Dios Ortúzar, J. 2014. A long panel survey to elicit variation in preferences and attitudes in the choice of electric vehicles. *Transportation* 41, 973–993.

Jensen, A.F., Cherchi, E., Mabit, S.L. 2013. On the stability of preferences and attitudes before and after experiencing an electric vehicle. *Transportation Research Part D: Transport and Environment* 25, 24–32.

Khan, M., Kockelman, K.M. 2012. Predicting the market potential of plug-in electric vehicles using multiday GPS data. *Energy Policy* 46, 225–233.

Krupa, J.S., Rizzo, D.M., Eppstein, M.J., Lanute, D.B., Gaalema, D.E., Lakkaraju, K., Warrender, C.E. 2014. Analysis of a consumer survey on plug-in hybrid electric vehicles. *Transportation Research Part A: Policy and Practice* 64, 14–31.

Louvière, J., Hensher, D., Joffre Swait, J. 2000. *Stated Choice Methods: Analysis and Applications*. Cambridge University Press, Cambridge, UK.

Lutsey, N., Sperling, D. 2012. Regulatory adaptation: accommodating electric vehicles in a petroleum world. *Energy Policy* 45, 308–316.

Mabit, S.L., Fosgerau, M. 2011. Demand for alternative-fuel vehicles when registration taxes are high. *Transportation Research Part D: Transport and Environment* 16, 225–231.

Massiani, J. 2015. Cost-benefit analysis of policies for the development of electric vehicles in Germany: methods and results. *Transport Policy* 38, 19–26.

Mohamed, M., Higgins, C., Ferguson, M., Kanaroglou, P. 2016. Identifying and characterizing potential electric vehicle adopters in Canada: a two-stage modelling approach. *Transport Policy* 52, 100–112.

Natural Resources Canada. 2009. Canadian Vehicle Survey: 2009 Summary Report. Natural Resources Canada, Ottawa, ON (Cat. No. M141-18/2009E-PDF).

Pearre, N.S., Kempton, W., Guensler, R.L., Elango, V.V. 2011. Electric vehicles: how much range is required for a day's driving? *Transportation Research Part C: Emerging Technologies* 19, 1171–1184.

Pollution Probe. 2018. Accelerating the Deployment of Zero Emission Vehicles : Atlantic Canada and the Prairies. Pollution Probe, Toronto, ON.

Potoglou, D., Kanaroglou, P.S. 2007. Household demand and willingness to pay for clean vehicles. *Transportation Research Part D: Transport and Environment* 12, 264–274.

Rezvani, Z., Jansson, J., Bodin, J. 2015. Advances in consumer electric vehicle adoption Research: a review and research agenda. *Transportation Research Part D: Transport and Environment* 34, 122–136.

Rose, J.M., Bliemer, M.C.J. 2008. Stated preference experimental design strategies. In: Hensher, D.A., Button, K.J. (Eds.), *Handbook of Transport Modelling, Second Edition*. Emerald Group Publishing Ltd., Bingley, UK. pp. 151–180.

Ryan, M., Gerard, K., Amaya-Amaya, M. 2008. Discrete choice experiments in a nutshell. In: Ryan, M., Gerard, K., Amaya-Amaya, M. (Eds.), *Using Discrete Choice Experiments to Value Health and Health Care*. Springer, Netherlands, pp. 13–46.

Schmidt, E. 2017. Electric Vehicle Sales Update Q2 2018, Canada. <https://www.fleetcarma.com/electric-vehicles-sales-update-q2-2018-canada/>, Accessed 18 October 2018.

She, Z.Y., Sun, Q., Ma, J.J., Xie, B.C. 2017. What are the barriers to widespread adoption of battery electric vehicles? A survey of public perception in Tianjin, China. *Transport Policy* 56, 29–40.

Statistics Canada. 2016. Data Products, 2016 Census. <https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/index-eng.cfm>, Accessed 18 October 2018.

Walker, J.L., Li, J. 2007. Latent lifestyle preferences and household location decisions. *Journal of Geographical Systems* 9, 77–101.

Zhang, Y., Qian, Z., Sprei, F., Li, B. 2016. The impact of car specifications, prices and incentives for battery electric vehicles in Norway: choices of heterogeneous consumers. *Transportation Research Part C: Emerging Technologies* 69, 386–401.

Ziegler, A. 2012. Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: a discrete choice analysis for Germany. *Transportation Research Part A: Policy and Practice* 46, 1372–1385.

Chapter 4

Can Canadian Households Benefit Economically from Purchasing Battery Electric Vehicles? An Investigation of the Total Cost of Ownership Based on Consumer Context

4.1 Introduction

Battery electric vehicles (BEVs) are a promising means of reducing greenhouse gas (GHG) emissions, especially in Canada, where 80% of its electricity is generated from non-GHG emitting sources (Natural Resources Canada, 2018). However, the country has a very small market share for electric vehicles (EVs) (about 0.6%), lagging behind the United States (close to 1%) and especially many European countries – Norway (29%), the Netherlands (6.4%), Sweden (3.4%), France and United Kingdom (both close to 1.5%) (IEA, 2017). Since road transportation in Canada is a major contributor to the country's GHG emissions, electric vehicles have a role to play in reducing such emissions if Canada is to meet its emission reduction target of 30% below 2005 levels by 2030 (Environment and Climate Change Canada, 2018).

BEVs are certainly less expensive to fuel and operate, but they are more expensive to purchase. A recent survey among electric vehicle owners across the Greater Toronto and Hamilton Area (GTHA) found that, on average, electric vehicle drivers save \$1,900 per year in fuel and maintenance costs compared to owners of internal combustion engine vehicles (ICEs) (Plug 'n

Drive, 2017). Other studies suggest that BEVs are likely to be cost-efficient depending on a household's vehicle usage and length of vehicle ownership (Hagman et al., 2016; Letmathe and Soares, 2017; Wu et al., 2015). However, few studies – none in Canada – have dealt with the economic suitability of BEVs in an effort to identify characteristics of households for whom BEVs are cost efficient. This is perhaps due to the challenging analysis of economic factors because of constant changes in the prices of gas, electricity, and BEV batteries (Hagman et al., 2016).

Given higher initial cost and lower operating cost of BEVs, the present study aims first to identify Canadian households that are economically suited for purchasing a BEV. For the purpose of this study, we call these households 'BEV-suited households'. For this task, we construct a total cost of ownership (TCO) model in the consumer context by using data from a sample of prospective car buyers in Canada. The TCO model is calibrated according to a household's specific situation: annual mileage, ownership period, and preferred vehicle class. This reveals the share of households that are suited for a BEV purchase under a series of incentive and price scenarios.

The second part of our analysis uses a bivariate ordered probit model to examine determinants of annual mileage and ownership period (both collected as ordered responses in the survey underlying our analysis), which are the most influential factors when calculating TCO. In terms of independent variables, the model incorporates a suite of socioeconomic, vehicle fleet, and geographic variables. While acting separately from the TCO model, the bivariate ordered probit model could be used to derive inputs to the TCO equation to predict total cost of BEV ownership under different scenarios of price and socioeconomic profiles. Note that our analysis focuses only

on battery electric vehicles (BEVs) that are powered solely by electricity, as the economic analysis for other types of EVs, such as plug-in hybrid vehicles (PHEVs), is different (Hagman et al. 2016).

The remainder of this paper is structured as follows. The following section reviews past studies that have considered the economic suitability of households to purchase EVs. The survey data and methods are described in Section 4.3. This is followed by the results in Section 4.4. The conclusion and policy implications are presented in Section 4.5

4.2 Studies Considering Economic Suitability

Since modern BEVs were introduced less than a decade ago, few studies address the economic analysis of these vehicles. To analyze the economic suitability of BEVs, the TCO model has been applied in previous studies to compare the actual costs of owning a vehicle across different powertrain technologies (e.g., Hagman et al., 2016; Letmathe and Soares, 2017; Wu et al., 2015). Both Letmathe and Soares (2017) and Wu et al. (2015) provide comprehensive overviews of studies using TCO models for assessing different powertrains and vehicle classes. Such analyses have found that BEVs can be considered cost-efficient depending on users' specific conditions (Al-Alawi and Bradley 2013; Hagman et al. 2016; Wu et al., 2015).

For Germany, Wu et al. (2015) compared the total cost of ownership across competing vehicle powertrains at present and in the future. Their results suggest that the cost efficiency of electric vehicles depends on annual mileage and different vehicle classes. They found that for low-mileage usage cases, ICEs remain the most cost-efficient option until 2025, whereas in the case of

long driving distances, an electric vehicle can make more economic sense due to lower operating costs compared to an equivalent ICE.

Hagman et al. (2016) conducted an economic analysis to investigate the possible discrepancy of the TCO among different vehicle drive trains, and found that BEVs have a competitive TCO with other powertrains due to lower operating costs. This study used some fixed assumptions regarding annual mileage, length of ownership, and driver profile.

The work by Plötz et al. (2014) is among the few studies that provide user-specific TCO calculations. They used the driving behaviour of their sample to identify households for whom electric vehicles make economic sense in Germany. They calculated the total cost of ownership for each household in their sample according to their driving profiles, and found that electric vehicles could be cost efficient for 5% of their sample. They also found that full-time workers and those living in small to medium-sized cities were the best candidates for purchasing electric vehicles. However, similar to Hagman et al. (2016), their study used fixed assumptions for the length of ownership and vehicle class segment.

Besides TCO studies, the importance of economic factors is well documented elsewhere throughout the literature. Both purchase price and fuel cost were identified as critical factors influencing vehicle purchases (e.g., Ferguson et al., 2018; Potoglou and Kanaroglou, 2007). In a survey conducted among 1,000 US residents, Krupa et al. (2014) found that 92% of respondents stated that vehicle price would be an important or a predominant factor in the choice of their next

vehicle purchase. They also found that potential fuel cost savings was important to 86% of respondents.

Hidrué et al. (2011) found that economic concerns, such as fuel cost savings, are more important for electric vehicle buyers than reducing carbon dioxide (CO₂) emissions. In a European analysis among 40 participants in the United Kingdom and after a 7-day driving experience with an electric vehicle, Graham-Rowe et al. (2012) found that drivers were more concerned with the financial implications of purchasing an electric vehicle than with other factors. Similar to Hidrué et al. (2011), they found that most drivers prioritize personal utility over environmental benefits.

From our review of the literature, we found that existing studies concerning the economic suitability of BEVs have different methodological approaches and fail to take user's specific conditions (e.g., annual mileage, length of ownership, etc.) into consideration. Most studies defined a number of major driving distances and/or ownership period cases and compared the TCO of competing powertrains for each case. For instance, Wu et al. (2015) calculated the TCO for each combination of three vehicle classes and three use cases (i.e., short, medium, and long travel distances) for each vehicle powertrain, and assumed a fixed ownership period for all cases. Similarly, Letmathe and Soares (2017) considered three typical annual mileage driver profiles to conduct their economic analysis (i.e., occasional, normal, and frequent drivers).

Our study differs from other studies within the TCO literature by comparing explicitly the TCO for BEVs and equivalent ICEs of similar vehicle class in the consumer context by using data from a sample of prospective car buyers in Canada. Specifically, compared to Plötz et al. (2014),

we consider the stated ownership periods as well as preferred vehicle classes of households for their next vehicle purchase when calculating TCO. The inclusion of vehicle class segment is of special importance since Higgins et al. (2017) found the significant role this factor plays in the choices of potential consumers. Hence, our analysis is more sensitive towards households' vehicle purchase plan situations compared to previous analyses.

Additionally, we conceptualize BEVs as a household's primary vehicle, which can bring long-term economic advantages for those who travel higher mileages. This is unlike some other studies (e.g., Khan and Kockelman, 2012), which assumed that BEVs would act as the secondary vehicle or the vehicle that is used less often or for shorter trips. To our knowledge, this is the first study to be conducted among a sample of potential car buyers in Canada. This is also the first study to this point in time that utilizes a bivariate ordered probit model to estimate both annual mileage and ownership period – the most influential factors in the TCO model.

In the current analysis, we aim to answer two research questions. First, how does the total cost of owning a BEV compare to that of ICEs of a similar vehicle class across a sample of prospective car buyers in Canada? This determines BEV suitability for our sample of potential car buyers in Canada, and is conducted under a series of incentive and price scenarios. Second, what are the determinants of annual mileage and ownership period, which are the most influential factors on the TCO outcomes? To address this question, we aim to simultaneously model these two variables based on households' specific characteristics. This part of the analysis links a household's specific characteristics/situation to the TCO model.

4.3 Data and Methods

There are two parts to our analysis: first, we identify ‘BEV-suited’ households in our sample by conducting an economic evaluation. We calculate the TCO of a BEV for all households according to their annual mileages, ownership period, and preferred vehicle classes, and compare this to the total cost of owning an equivalent ICE. The outcomes are calculated for the years 2018, 2020, 2025, and 2030, as well as for different cash incentive scenarios: none, \$5,000, \$10,000, and \$15,000.

The second part of the analysis estimates a bivariate ordered probit model with “annual mileage” and “ownership period” as dependent variables. The explanatory variables are a series of socioeconomic, vehicle fleet, and geographic variables. Note that the bivariate model is independent from the TCO model.

4.3.1 Survey Data

The data for this analysis come from the **Survey for Preferences and Attitudes of Canadians towards Electric Vehicles**, or ‘**SPACE**’, which was designed to investigate electric mobility prospects in Canada through a series of socioeconomic, attitudinal, and stated preference (SP) questions. It was administered in May and June 2015 to a panel of 20,520 Canadian households, and was made available in both English and French to cover both official languages in Canada. Our sample includes respondents of age 18 or above who are one of the primary decision makers of their households and are likely to buy a vehicle in the foreseeable future. Even though individual

respondents completed the survey, their roles as the household representative were emphasized several times throughout the survey.

SPACE contains information on a respondent's household vehicle fleet and driving patterns data from all ten provinces in Canada. We use three properties of the households' information to conduct the economic analysis: the stated annual mileage of the primary vehicle, number of years a household holds a vehicle or ownership period, and preferred vehicle class for the next purchase. Note that the sample also included households without a vehicle at the time. However, they were eliminated from further analysis as their annual mileage was not revealed. In total 19,707 households are used for our analysis.

4.3.2 Total Cost of Ownership Model

To answer our first research question, we determine the economics of both BEVs and ICEs in terms of TCO, which is a metric that goes beyond the initial costs of a vehicle and considers other costs over the vehicle's holding period (Wu et al., 2015). The comparison of two TCO values for each household in our sample allows us to determine those households for whom purchasing a BEV is cost efficient. The study estimates the costs for purchasing and operating each powertrain for all households in our database taking into account their specific conditions: annual mileage, the ownership period, and preferred vehicle class (Table 4.1). The TCO for household h is given by

$$TCO_h = (PP_h - I) + C_h \times VKT_h \times T_h + PP * \frac{r}{1-(1+r)^{-N}} \quad (1)$$

where PP_h stands for purchase price and C_h is the operating cost per km for the households' preferred vehicle class, I is the incentive for BEVs, T_h is the ownership time in years, r is the interest rate, and N is the finance years. For the interest rate, we assume an annual rate of 5%, which is the average interest rate (mid-2018) for personal loans in Canada for a 5-year finance term (Bank of Canada, 2018; Letmathe and Soares, 2017). The values for annual mileage (VKT_h) and ownership time (T_h) are specific to each household (h) in our database (Table 4.1). Also, the preferred vehicle class of each household determines the purchase price (PP_h) and operating cost (C_h) for each comparable powertrain as shown in Table 4.2.

The home charging installation cost of \$1,500 plus sale tax is determined based on the province of residence because sales tax varies across provinces in Canada. Operating cost (C_h) accounts for both fuel and maintenance/repair costs, which are expected to be lower for BEVs, since they have fewer moving parts meaning that no oil or filter changes are required.

The TCO literature recognizes that other costs influence the actual cost over the period of ownership including insurance and cost of depreciation (Al-Alawi and Bradley, 2013; Wu et al., 2015). A limitation of our research is that our TCO model does not account for these variables for the following reasons. Regarding the depreciation rate, due to scarcity of used BEVs, the historical data were insufficient to derive the resale value of these vehicles in the Canadian market. Also, for insurance cost, its calculation depends on several factors (e.g., driver's neighborhood, history, etc.), which were lacking in our data set. It is, however, worth mentioning that the literature found that

the total cost of ownership is influenced largely by differences in purchase price, fuel and maintenance costs rather than other costs (Dumortier et al., 2015).

We also acknowledge that we did not consider driving range when analyzing BEV economic suitability. While higher annual mileages appear to be in favour of BEVs' total cost of ownership, in some cases, long distances can become bothersome due to the limited ranges of BEVs. In reality, however, there are rare instances where the required driving distance exceeds the electric range (Wu et al., 2015). For instance, less than 7% of households in our sample stated a daily driving distance above 200 km, while about 90% of our sample stated a daily driving distance of 150 km or less, which can be covered with an average BEV without the need to charge between trips. However, we acknowledge that occasional long driving distances (e.g., vacation trips) are not considered in the present study. Also, there are several differences between the vehicles that are compared in the present analysis with regards to appearance, interior space, design, range, and some other features.

To derive conclusions based on future price scenarios, we computed TCO for the years of 2018, 2020, 2025, and 2030. Due to uncertainties regarding the purchasing price and operating costs in the present and future, we derived those values from different sources including literature (Letmathe and Soares, 2017; Wu et al., 2015) and expert forecasts (Canadian Automobile Association, 2017). Experts predict BEVs to reach price parity with ICEs by 2035, although the rates remain different for various BEV models (Wu et al., 2015; Plötz et al., 2014). We also concluded from the empirical data that the price of BEVs is expected to decrease mainly due to

drop in the price of batteries (Wu et al., 2015). We assume a decrease in the purchasing price of BEVs by \$1,000 per year for the Tesla Model S (Full/ Luxury Sedan) and \$500 per annum for the Nissan Leaf (Economy/Intermediate) and Kia Soul EV (SUV/Van/Pickup). We also assume that the purchasing price of ICEs increase slightly due to regulated improvements regarding fuel economy and CO2 emission regulations (Letmathe and Soares, 2017). The price values of future scenarios are presented in Table 4.2.

Table 4.1 Input parameters for the TCO model: household specific variables

Household Parameter	Definition
Annual mileage	Number of kilometres that a household’s primary vehicle is driven in a year
Ownership period	Amount of time, in years, that a household typically holds a vehicle
Preferred vehicle class	Economy/intermediate; full/luxury sedan; SUV/Van/Pickup

Table 4.2 Input parameters for the TCO model: market variables (prices exclude sale tax)

Market Parameters	Economy/ Intermediate	Full/ Luxury Sedan	SUV/Van/Pickup
<i>ICE</i>			
Make and model	Honda Civic EX	BMW 535ix	Ford Escape S
Purchase price ($PP_{h/ICE}$), 2018	\$24,500	\$67,500	\$25,300
PP_{ICE} , 2020	\$25,000	\$69,000	\$26,000
PP_{ICE} , 2025	\$26,000	\$72,000	\$27,000
PP_{ICE} , 2030	\$27,000	\$75,000	\$28,000
Operating cost, 100 km ($C_{h/ICE}$)	\$9.50	\$10.50	\$10.00
<i>BEV</i>			
Make and model	Nissan Leaf S	Tesla Model S	Kia Soul EV
Purchase price ($PP_{h/BEV}$), 2018	\$37,000	\$95,000	\$36,000
PP_{BEV} , 2020	\$36,000	\$93,000	\$35,000
PP_{BEV} , 2025	\$33,500	\$88,000	\$32,500
PP_{BEV} , 2030	\$31,000	\$83,000	\$30,000
Operating cost, 100 km ($C_{h/BEV}$)	\$2.36	\$2.88	\$2.56

4.4 Results

4.4.1 Share of BEV-suited Households

Equation (1) is used to obtain the share of BEV-suited households – those with a lower TCO for their preferred class of BEV ($TCO_{BEV} < TCO_{ICE}$). Figure 4.1 presents the results, which show sensitivity towards changes in cash incentive (0, \$5,000, \$10,000, and \$15,000) and purchasing price (years of 2018, 2020, 2025, and 2030) for three preferred vehicle classes. Without incentive, 16%, 12%, 15%, 19%, and 16% of households are BEV-suited in Ontario, Quebec, British Columbia, the Prairies, and Atlantic Canada, respectively. Clearly, an incentive makes BEVs more cost-effective, yielding a higher number of BEV-suited households in Canada.

For the economy/intermediate class, a linear trend is observed in all five regions/provinces with respect to incentive, where Quebec yields the highest share of BEV-suited as incentive increases. For the full/luxury sedan segment, results show that BEVs are not economically suited for a large share of households choosing this vehicle class, although this class accounts for 40% of our sample and thus is an important market segment. Even a cash incentive up to \$5,000 would not affect the share of BEV-suited households in this segment, but when the incentive goes up to \$15,000 there is an increase in the share of BEV-suited households in all regions/provinces, with the highest rise being in Ontario (an increase of 2% to 7%). For the SUV/Van/Pickup segment, we can see that an increase in the incentive up to \$10,000 has an increasing linear impact in the share of BEV-suited households in all five regions/provinces. However, the impact is less when the incentive increases from \$10,000 to \$15,000.

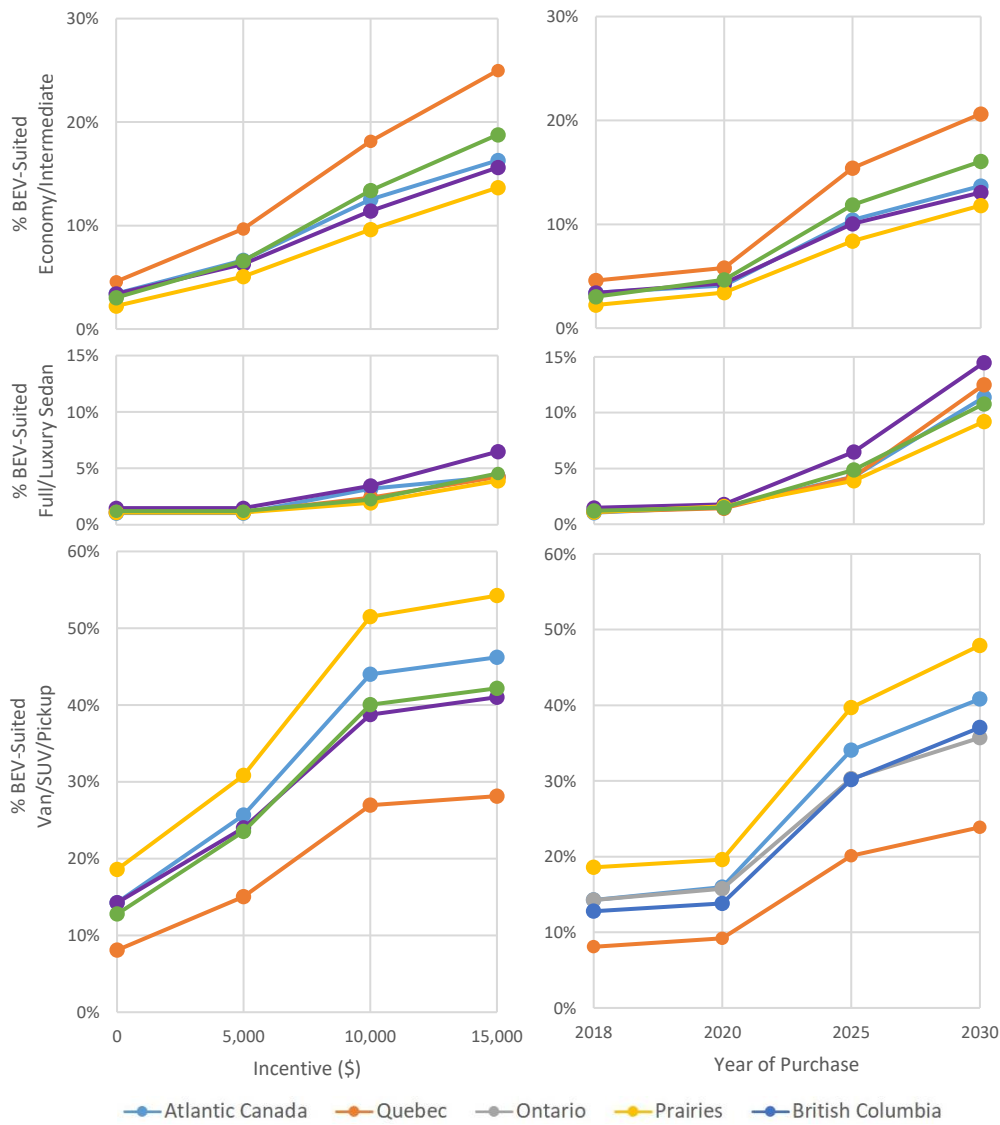


Figure 4.1 Share of BEV-suited households sensitive towards incentive and purchase price values segmented by province/region and preferred vehicle class

A similar analysis is conducted for future purchasing price without considering incentive (Figure 4.1). The analysis shows that BEVs improve in their competitiveness in all vehicle classes until 2030, which is in line with the results of Letmathe and Soares (2017). However, the suitability of BEVs improves slightly until 2020 across all vehicle segments. For the full/luxury sedan, an improvement in BEV competitiveness is relatively slow up until 2025. We can conclude from this result that in the short run (until 2020), financial incentives are important policy tools that can play a role in increasing BEV economic suitability, and hence in accelerating the market share of these vehicles.

4.4.2 Bivariate Ordered Probit Model

Existing literature on TCO indicates that mileage and ownership period are by far the most influential factors influencing TCO outcomes (Hagman et al., 2016; Letmathe and Soares, 2017; Wu et al., 2015). Using a bivariate ordered probit model, we investigate determinants of these factors. This modeling approach is selected for two reasons, First, the two dependent variables are available as ordered-responses (Table 4.3) and second, there is a significant negative correlation between dependent variables (Table 4.4). The negative correlation coefficient indicates that as mileage increases, the time of keeping vehicle decreases, which makes sense. As a vehicle is used more often, it is expected to last for a shorter period of time. A positive aspect of our bivariate ordered probit model is that it is independent from the TCO model and market parameters (e.g., purchase price, operating cost, etc.) that are subject to change due to fast technological progress and changes in policy measures. The bivariate ordered probit model makes it possible to link a

household's specific characteristics/situation to the TCO model through those characteristics that are found to influence mileage and ownership period.

For each household h , k and t represent the annual mileages and ownership period respectively. The bivariate ordered probit equation is written as:

$$y_{1h}^* = \beta_1 x_{1h} + \varepsilon_{1h}, y_{1h} = k \quad \text{if } \mu_{1,k} < y_{1h} \leq \mu_{1,k+1}$$

$$y_{2h}^* = \beta_2 x_{2h} + \varepsilon_{2h}, y_{2h} = t \quad \text{if } \mu_{2,t} < y_{2h} \leq \mu_{2,t+1}$$

$$[\varepsilon_{1h}, \varepsilon_{2h}] \sim \text{bivariate normal}, -1 < \rho_{\varepsilon_1 \varepsilon_2} < 1$$

where y_{1h}^* is the propensity for household h to make certain mileage in an average year and y_{2h}^* is the propensity to own a car for a given period of time, both of which are latent variables. The observed counterparts to y_{1h}^* and y_{2h}^* , are y_{1h} and y_{2h} which represent annual mileage and ownership period, respectively. The x s are vectors of explanatory variables, and β s are corresponding vectors of parameters that are estimated along with the threshold values, the μ s, for each equation. The random terms ε_{1h} and ε_{2h} are assumed to be normally distributed with a correlation $\rho_{\varepsilon_1 \varepsilon_2}$ between them. Estimates are obtained by maximum likelihood function using NLOGIT software.

Table 4.3 Independent variables, their definitions, and statistics

Variable	Definition	% or Mean
<i>Dependent variables</i>		
Annual mileage (km)	0-5,000	15%
	5,001-10,000	25%
	10,001-15,000	23%
	15,001-25,000	25%
	25,001-40,000	10%
	40,000+	2%
Ownership time (years)	1 – 3	10%
	4 – 6	35%
	7 – 9	27%
	10+	28%
<i>Independent variables</i>		
<i>Householder Age:</i>		
Young adults 18-24	1 if householder's age group is young adult; 0 otherwise	4%
Adulthood 25-34	1 if householder's age group is adulthood; 0 otherwise	14%
Middle age 35-54	1 if householder's age group is middle age; 0 otherwise	63%
Older age 55+	1 if householder's age group is older age; 0 otherwise	20%
Female householder	1 if householder is female; 0 otherwise	55%
Retired householder	1 if householder is retired; 0 otherwise	26%
Household income	A categorical variable with six levels ranging from "Less than \$25,000" to "Greater than \$150,000"	\$87,500
Number of children	Number of children less than 18 years old in the household.	0.45
<i>Education of householder:</i>		
No certificate	1 if householder carries no certificate; 0 otherwise	3%
High school diploma	1 if householder's education is high school diploma; 0 otherwise	18%
College degree	1 if householder's education is college degree; 0 otherwise	34%
Bachelor's degree or above	1 if householder's education is bachelor's degree or above; 0 otherwise	45%
Number of vehicles	Number of registered vehicles in the household	1.68
Leased	1 if household's primary vehicle is leased; 0 otherwise	7%
<i>Preferred vehicle class:</i>		
Economy/intermediate	1 if preferred vehicle class is economy/intermediate; 0 otherwise	18%
Full/luxury sedan	1 if preferred vehicle class is full/luxury sedan; 0 otherwise	40%
SUV/van/pickup	1 if preferred vehicle class is SUV/van/pickup; 0 otherwise	42%
<i>Province:</i>		
Newfoundland and Labrador	1 if household lives in Newfoundland and Labrador; 0 otherwise	3%
Prince Edward Island	1 if household lives in Prince Edward Island; 0 otherwise	1%
Nova Scotia	1 if household lives in Nova Scotia; 0 otherwise	5%
New Brunswick	1 if household lives in New Brunswick; 0 otherwise	4%
Quebec	1 if household lives in Quebec; 0 otherwise	22%
Ontario	1 if household lives in Ontario; 0 otherwise	29%
Manitoba	1 if household lives in Manitoba; 0 otherwise	5%
Saskatchewan	1 if household lives in Saskatchewan; 0 otherwise	4%
Alberta	1 if household lives in Alberta; 0 otherwise	12%
British Columbia	1 if household lives in British Columbia; 0 otherwise	15%
<i>Level of urbanization:</i>		
Low	1 if urban-rural index is 0 to 3; 0 otherwise	12%
Medium	1 if urban-rural index is 4 to 6; 0 otherwise	53%
High	1 if urban-rural index is 7 to 10; 0 otherwise	35%

The dependent variables, annual mileage and ownership period, along with independent variables are defined in Table 4.3. Geographical variables are captured by province as well as level of urbanization according to the location where a household resides. For that, we use an index of urbanization called the “urban-rural index,” which ranges from 0 to 10. It is derived based on a household’s locational position in a geographic dissemination area (Ferguson et al., 2018) where higher values are associated with a more urbanized area (Higgins et al., 2017). With respect to vehicle fleet, the number of cars, type of ownership, and households’ preferred vehicle classes are investigated. Socioeconomic variables include age, sex, income, number of children, and education.

Table 4.4 summarizes the results of the bivariate ordered probit model. The effect of household income on annual mileage is positive, which is in line with the results obtained in Cervero and Kockelman’s (1997) study which found that income affected vehicle usage even more so than number of vehicles in a household. Ownership period is also positively affected by household income suggesting that households with higher income tend to keep their vehicles for longer period of time. Both results make sense as households with higher income are expected to make more leisure trips and to buy more durable and expensive vehicles.

Number of children has a positive impact on annual vehicle mileage. This result reflects the additional mobility needed for households with children and echoes the result obtained in Cirillo and Liu’s (2013) study in which household size positively affected vehicle usage. Number of children has a negative impact on ownership period suggesting that households with more children

tend to switch their primary vehicle more often. This finding is most likely due to the households' need for more spacious vehicle types as the household size expands.

With regard to the household head's characteristics, education has a positive impact on annual mileage, which is in line with the results of Cirillo and Liu's (2013) study in which householders with a higher education level had higher vehicle usage. Ownership period is also positively influenced by education of householder. Retired householders are less likely to have higher mileage most probably because they generally make fewer trips than employed people (Scott et al., 2009). Retired householders are, however, expected to hold their vehicles longer. Similarly, a female householder is associated with lower mileage and a longer holding period.

While a household head's age has an insignificant impact on vehicle usage (Cervero and Murakami 2010), its impact is strongly significant for ownership period. The results show that there is a positive non-linear relationship between the age of household head and ownership period.

Regarding vehicle fleet variables, there is a positive relationship between annual mileage and number of vehicles registered by the household, which is similar to the result obtained in Cervero and Kockelman (1997). This relationship is also positive for the ownership period, most probably because multi-vehicle households keep their primary vehicle for a longer period of time since they add to their fleet rather than replacing.

Results also show that if the primary vehicle is leased, higher annual mileage and lower ownership period are anticipated, most likely because leasers switch their vehicles more often and hence have a shorter holding period.

With respect to vehicle class, a household interested in an economy/intermediate vehicle is expected to have lower annual mileage compared to other classes. Also, households choosing an economy/intermediate vehicle are associated with longer ownership period, perhaps because such households are attracted by better fuel economy over the ownership period, and thus keep their vehicles longer.

Table 4.4 Estimation results for bivariate ordered probit model of annual mileage and investment time

Variable	Annual mileage (km)	Ownership time (years)
Constant	0.920***	0.658***
<i>Household age (ref = Young adults 18-24):</i>		
Adulthood 25-34	-0.021	0.185***
Middle age 35-54	-0.009	0.419***
Older age 55+	-0.025	0.434***
Female householder	-0.254***	0.105***
Retired householder	-0.251***	0.054**
Household income	0.051***	0.004*
Number of children	0.071***	-0.060***
Education of householder	0.039***	0.029***
Number of vehicles	0.050***	0.110***
Leased	0.168***	-0.722***
<i>Preferred vehicle size (ref = SUV/van/pickup):</i>		
Economy/intermediate	-0.277***	0.205***
Full/luxury sedan	-0.089***	0.079***
<i>Province (ref = Ontario):</i>		
Newfoundland and Labrador	-0.060	-0.334***
Prince Edward Island	0.077	-0.386***
Nova Scotia	0.082**	-0.249***
New Brunswick	0.117***	-0.229***
Quebec	0.055**	-0.340***
Manitoba	-0.193***	0.095**
Saskatchewan	-0.106***	-0.048
Alberta	-0.138***	0.108***
British Columbia	-0.226***	0.190***
<i>Level of urbanization (ref = Low):</i>		
Medium	0.096***	-
High	-0.095***	-
<i>Threshold values (annual mileage in km):</i>		
5k - 10k and 10k - 15k	0.821***	-
10k - 15k and 15k - 25k	1.448***	-
15k - 25k and 25k - 40k	2.316***	-
25k - 40k and 40k+	3.139***	-
<i>Threshold values (ownership time in years):</i>		
4 to 6 and 7 to 10	-	1.216***
7 to 10 and 10+	-	1.980***
Correlation coefficient	-0.064***	-
SUMMARY STATISTICS		
N	19,707	
Log likelihood function	-56194	
Restricted log likelihood	-57952	
McFadden Pseudo R-squared	0.031	

***, **, * indicate statistical significance at 1%, 5% and 10% significance level, respectively.

The results of geographical variables show that the level of urbanization has a significant, non-linear impact on vehicle usage (Ewing and Cervero, 2001). Households living in a medium urbanized area (suburbs) are associated with higher mileage compared to those in areas characterized by a low level of urbanization (rural areas). In contrast, those living in places with a higher level of urbanization (downtown core or central business district) are associated with lower mileage due to shorter distances in between destinations compared to rural areas. Changes in urban levels of household location were also investigated in Cirillo and Liu's (2013) study in which households living in dense urbanized areas tend to drive less.

With regard to province, households living in Nova Scotia, New Brunswick, and Quebec are associated with higher annual mileage compared to Ontario. This finding is in line with commuting distance results as the average daily commuting distances in these provinces are among the longest in Canada (Statistics Canada, 2016). The coefficients for Newfoundland and Labrador and Prince Edward Island were insignificant.

With respect to ownership period, the Atlantic provinces and Quebec (i.e., all provinces east of Ontario) have a shorter holding period, while the western provinces, Manitoba, Alberta, and British Columbia, are associated with longer ownership period. The shorter vehicle ownership period in the Atlantic provinces can be due to proximity to the ocean, which decreases a vehicle's longevity. The coefficient for Saskatchewan was insignificant.

4.5 Conclusion and Policy Implications

In Canada, battery electric vehicles (BEVs) lag far behind their gasoline counterparts in terms of market share. The high initial price of BEVs is considered as one of the main barriers to adopting these vehicles (Lebeau et al., 2012). In this study, we analyzed the economic suitability of BEVs for Canadian households according to their specific conditions using TCO model. We also investigated household characteristics and geographic determinants of annual mileage and ownership period by estimating a bivariate ordered probit model.

Applying the TCO calculations for all users in our sample, we find that even with today's electric vehicles present in the market, that are considered to have high purchase price, 18% of Canadian households are BEV-suited.

Yet, the question still remains as to why the market share of BEVs in Canada is nothing close to this number? Part of the answer certainly comes from a low awareness and lack of information regarding the economic benefits of BEVs over the period of ownership. Dumortier et al. (2015) found that increasing consumers' awareness about the total cost of owning an electric vehicle has a potential to raise consumers' preferences toward these vehicles. The present study aims to provide such information along with profiles of households that are suited for a BEV purchase by investigating the most influential factors in the TCO model, annual mileage and ownership period.

We find that a household with higher income that lives in areas with a medium level of urbanization (suburbs) and has an educated, middle-aged household head is more likely to benefit economically from a BEV purchase. This information along with the results of the TCO model can make prospective buyers aware of the savings they could make through the years of ownership if their mileage is high enough, and thus increase the possibility of switching to a BEV for their next purchase (Dumortier et al. 2015).

Based on our results, we make three remarks concerning policy. First, consumers should become more knowledgeable about the potential benefits of BEVs according to their preferred vehicle classes and typical driving patterns. Previous surveys have found that a vast majority of consumers have little knowledge about the specifics of plug-in electric vehicles such as the real costs over years of ownership, electric charging locations and operation, available incentives, and maximum ranges covered by these vehicles (Krause et al. 2013; Kurani et al. 2016). Providing prospective car buyers with relative advantages of BEVs through information has the potential to further increase the market share of BEVs (Hagman et al., 2016). Second, marketing strategies could be targeted towards those consumers with higher annual mileages and longer ownership periods based on the results obtained from our bivariate ordered probit model. For instance, households with higher social status who live in suburban areas are good starting points for both marketing and information campaigns. Third, financial incentives should be granted to BEV buyers, at least in the short run (until 2020), to increase the cost efficiency of these vehicles

compared to equivalent ICEs. This can be achieved through both purchase rebates and tax credits (Zhang et al., 2016).

We acknowledge that our study focuses on cost factors only. Other determining factors such as range, charging time, and environmental aspects, or a combination of these factors, could be the topic of future studies to compare BEVs with conventional vehicles. Another limitation is the consideration of only three models of BEVs. It would be interesting to study other available models and compare those to equivalent ICEs within the Canadian market. Also, the seven vehicle classes investigated in the current analysis were grouped into three larger segments due to the lack of a wide variety of BEV models in the market. For instance, as we write this paper, there is no plug-in electric pickup available in the global auto market.

The findings in this paper could provide policy makers and marketing strategists with the most effective policy measures and BEV education campaigns based on consumer characteristics/situations in order to increase BEV uptake in Canada. With increasing improvements being made to BEV batteries to extend their ranges, by providing financial incentives to temporarily reduce the initial costs gap, and by educating people about their own driving patterns and also BEVs' long-term economic benefits, we expect a rapid BEV adoption rate in the near to medium term in Canada. The results of this study provide some reasons for that optimism.

4.6 Acknowledgements

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4.7 References

Al-Alawi, B.M., Bradley, T.H. 2013. Total cost of ownership, payback, and consumer preference modeling of plug-in hybrid electric vehicles. *Applied Energy* 103, 488–506.

Bank of Canada. 2018. Interest rates. <https://www.bankofcanada.ca/rates/daily-digest/>, Accessed 25 October 2018.

Canadian Automobile Association (CAA). 2017. Driving Costs Calculator. <https://www.caa.ca/carcosts/>, Accessed 25 October 2018.

Cervero, R., Kockelman, K. 1997. Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D: Transport and Environment* 2, 199–219.

Cervero, R., Murakami, J. 2010. Effects of built environments on vehicle miles traveled: evidence from 370 US urbanized areas. *Environment and Planning A* 42, 400–418.

Cirillo, C., Liu, Y. 2013. Vehicle ownership modeling framework for the state of Maryland: analysis and trends from 2001 and 2009 NHTS data. *Journal of Urban Planning and Development* 138, 1–11.

Dumortier, J., Siddiki, S., Carley, S., Cisney, J., Krause, R.M., Lane, B.W., Rupp, J.A., Graham, J.D. 2015. Effects of providing total cost of ownership information on consumers' intent to purchase a hybrid or plug-in electric vehicle. *Transportation Research Part A: Policy and Practice* 72, 71–86.

Environment and Climate Change Canada. 2018. National Inventory Report 1990-2016: Greenhouse Gas Sources and Sinks in Canada. Environment and Climate Change Canada, Gatineau, QC (Cat. No. EN81-4/1E-PDF).

Ewing, R., Cervero, R. 2001. Travel and the built environment: a synthesis. *Transportation Research Record: Journal of the Transportation Research Board* 1780, 87–114.

Ferguson, M., Mohamed, M., Higgins, C.D., Abotalebi, E., Kanaroglou, P. 2018. How open are Canadian households to electric vehicles? A national latent class choice analysis with willingness-to-pay and metropolitan characterization. *Transportation Research Part D: Transport and Environment* 58, 208–224.

Graham-Rowe, E., Gardner, B., Abraham, C., Skippon, S., Dittmar, H., Hutchins, R., Stannard, J. 2012. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: a qualitative analysis of responses and evaluations. *Transportation Research Part A: Policy and Practice* 46, 140–153.

Hagman, J., Ritzén, S., Janhager Stier, J., Susilo, Y. 2016. Total cost of ownership and its potential implications for battery electric vehicle diffusion. *Research in Transportation Business & Management* 18, 11–17.

Hidrue, M.K., Parsons, G.R., Kempton, W., Gardner, M.P. 2011. Willingness to pay for electric vehicles and their attributes. *Resource and Energy Economics* 33, 686–705.

Higgins, C.D., Mohamed, M., Ferguson, M.R. 2017. Size matters: how vehicle body type affects consumer preferences for electric vehicles. *Transportation Research Part A: Policy and Practice* 100, 182–201.

International Energy Agency (IEA). 2017. *Global EV Outlook 2017: Two Million and Counting*. IEA Publications, France.

Khan, M., Kockelman, K.M. 2012. Predicting the market potential of plug-in electric vehicles using multiday GPS data. *Energy Policy* 46, 225–233.

Krause, R.M., Sanya, R.C, Lane, B.W., Graham, J.D. 2013. Perception and reality: public knowledge of plug-in electric vehicles in 21 U.S. cities. *Energy Policy* 63, 433-440.

Krupa, J.S., Rizzo, D.M., Eppstein, M.J., Lanute, D.B., Gaalema, D.E., Lakkaraju, K., Warrender, C.E. 2014. Analysis of a consumer survey on plug-in hybrid electric vehicles. *Transportation Research Part A: Policy and Practice* 64, 14-31.

Kurani, K.S., Caperello, N., TyreeHageman, J. 2016. *New Car Buyers' Valuation of Zero-Emission Vehicles: California*. Institute of Transportation Studies, University of California, Davis, California (Research Report UCD-ITS-RR-16-05).

Lebeau, K., Van Mierlo, J., Lebeau, P., Mairesse, O., Macharis, C. 2012. The market potential for plug-in hybrid and battery electric vehicles in Flanders: a choice-based conjoint analysis. *Transportation Research Part D: Transport and Environment* 17, 592–597.

Letmathe, P., Soares, M. 2017. A consumer-oriented total cost of ownership model for different vehicle types in Germany.” *Transportation Research Part D: Transport and Environment* 57 314–335.

Natural Resources Canada. 2018. Electricity Facts. <https://www.nrcan.gc.ca/energy/facts/electricity/20068>, Accessed 25 October 2018.

Plötz, P., Schneider, U., Globisch, J., Dütschke, E. 2014. “Who will buy electric vehicles? Identifying early adopters in Germany.” *Transportation Research Part A: Policy and Practice* 67, 96–109.

Plug ‘n Drive, 2017. *Driving EV uptake in the Greater Toronto and Hamilton Area*. Plug ‘n Drive, Toronto, ON.

Potoglou, D., Kanaroglou, P.S. 2007. Household demand and willingness to pay for clean vehicles. *Transportation Research Part D: Transport and Environment* 12, 264–274.

Scott, D.M., Newbold, K.B., Spinney, J.E.L., Mercado, R.G., Páez, A. and Kanaroglou, P.S. 2009. New insights into senior travel behavior: the Canadian experience. *Growth and Change* 40, 140-168.

Statistics Canada. 2016. Data Products, 2016 Census. <https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/index-eng.cfm>, Accessed 25 October 2018.

Wu, G., Inderbitzin, A., Bening, C. 2015. “Total cost of ownership of electric vehicles compared to conventional vehicles: a probabilistic analysis and projection across market segments. *Energy Policy* 80, 196–214.

Zhang Y., Qian Z., Sprei, F., Li, B. 2016. The impact of car specifications, prices and incentives for battery electric vehicles in Norway: choices of heterogeneous consumers. *Transportation Research Part C: Emerging Technologies* 69, 386-401.

Chapter 5

Conclusions and Future Research

This dissertation investigated prospects for electric vehicle adoption among Canadian consumers. The aim was to develop a decision-making framework to accelerate the EV adoption rate in Canada, by providing quantitative estimates of consumer preferences, regulations and policies, and economic suitability of electric vehicles. Overall, the results of this research are useful for policy makers as the profiles of households with preference towards EVs as well as those who are economically suited to purchase an EV are obtained here. This thesis suggests that policy makers and car manufacturers should focus on specific group of users with relative preferences towards EVs based on the results of this thesis. For instance, households with high socio-economic status who are younger and possess progressive attitudes are a good target. Also, households who live in suburbs and have higher mileages are the most suited to purchase a battery electric vehicle from an economic point of view.

We suspect that the low rate of EV adoption in Canada is because of the existence of some lagging EV adoption regions (i.e., Atlantic Canada and Prairies). A detailed investigation of the EV adoption gap between Atlantic and leading provinces in Canada provides valuable information regarding consumers' mindsets and preferences. This thesis finds that the lack of government incentive, uncertainty and limited awareness or exposure to EVs are some reasons for the low adoption in Atlantic Canada. Hence, information campaigns are important policy tools that could

make consumers more knowledgeable about potential benefits of EVs. Also, financial incentives are still an important policy tool that could increase the attractiveness/cost efficiency of EVs, at least in the short run.

5.1 Contributions and novel aspects

There are several main contributions and novel aspects associated with this dissertation as follows.

1) Comprehensive overview of SPACE

Chapter 2 reviews important survey design dilemma and challenges in the course of developing and implementing the survey that are rarely discussed in the previous works. The use of survey panel, screening criteria, household conceptualization, the selection of alternatives, attributes and levels for SP scenarios, and the way cognitive burden was managed are all important decisions in the process of survey design while were not extensively discussed in the past works. Based on results of literature review, aspects of survey design are only partially discussed in previous EV studies and are mainly reported as part of the analyses that these surveys support. As a result, the construction of the survey instrument that underlies the analysis often remains somewhat in the background. Chapter 2 contributes to the literature by providing an informative overview of the development of a comprehensive survey instrument that was applied in a Canada-wide data collection effort to yield useful EV-oriented data and information. The overview includes associated strategies, thought processes and significant decisions that were made in developing and implementing the survey. The aim is for some lessons that emerge to extend beyond those working

within the EV domain. Another contribution is to address a gap in the EV-oriented literature where many surveys have been developed to this point around the world, but a thorough review of the thinking that went into these is not available, to the best of my knowledge.

2) A comprehensive stated preference survey

The sample collected with SPACE is the first of its kind in Canada with a comprehensive national scope and with large samples from all ten Canadian provinces, major metropolitan areas and in both official languages. A stated preference (SP) experiment is at the core of SPACE and is supported by an array of information on demographics, residential location and context, current vehicle ownership and vehicle purchase intentions, travel patterns and an assortment of attitudinal information, a combination of which that is rarely observed in the previous studies.

3) Emphasis on Geography and Location

The survey is administered among a large panel of Canadians with 20,520 observations from every corner of the country (e.g. all provinces, urban-rural settings, etc.), and hence provides more in-depth coverage of geographical variations in EV preferences than previous studies. Collection of 6-digit postal codes can precisely locate our respondents, and identify the spatial context in which they would assess electric mobility. Based on that, the “level of urbanization” index was developed, which is used as one of the determinants of households’ annual mileages estimated using a bivariate ordered probit model discussed in chapter 4.

4) Context Sensitivity and vehicle body type conceptualization

There is an emphasis to the context, whereas SP scenarios are *customized* based on the unique experience of each respondent: annual mileage, vehicle size, vehicle purchase plan, and vehicle anticipated price. The levels associated with tailpipe emission, fueling/charging cost, and maintenance cost were adjusted based on respondent's annual mileage and preferred vehicle size reported earlier in the survey. Respondents were faced with SP scenarios associated with their preferred vehicle body type that they specified earlier in the survey. This method added to the relevance and realism of the attribute levels being evaluated by the respondent (Beck et al. 2013; Rose and Bliemer 2008). For instance, a household interested in an economy size vehicle was faced with its matching price or fuel cost levels.

5) EV demand in a lagging adoption region

Atlantic Canada is a lagging region in terms of EV uptake while has not yet been investigated in that aspect. Until now, there is no evidence of such a study having been undertaken in a lagging adoption region around the globe. The results of chapter 3 provide a better understandings about why Atlantic Canada lags behind in relation to leading adoption provinces, and give insights about vehicle attributes and policies that are important to potential EV buyers. These results can be used to target specific population segments for EV marketing and to take prioritized provincial actions

to accelerate EV uptake in Atlantic Canada since the study finds widespread openness to the idea of electric vehicles among Atlantic consumers.

6) A comparison of Atlantic Canada and leading adoption provinces

We also compare the Atlantic model results with those of a separate latent class model obtained from leading adoption provinces to further expand our understandings towards the attributes and incentives that play roles in households' decisions toward an EV purchase. The class membership results show that there is a larger share of HEV orientation in Atlantic Canada – 30% as opposed to 20% in the model obtained from leading provinces. However, plug-in classes (PHEV- and BEV-oriented) account for a total of 40% in leading provinces, but only 30% in Atlantic Canada. Hence, the plug-in orientation is simply less prevalent in Atlantic Canada. Based on the results, Atlantic households seem more uncertain about battery electric vehicles (BEVs) compared to consumers in leading adoption provinces, and thus a BEV-oriented class was not able to form in the Atlantic latent class model.

7) The construction of “Total cost of ownership” (TCO) model

This study calculates and compares the TCO for commercially available BEVs and a comparable size of an ICE based on consumer context by using data from a sample of prospective car buyers in Canada. The study takes into consideration households' specific situation: annual mileage, ownership time and preferred vehicle class, and reveals the share of households who are suited for a BEV purchase under a series of incentive and price scenarios. Such analysis has not been

prominently featured in the literature, and no studies were found to analyze the Canadian market in this respect.

8) A bivariate ordered probit model to predict annual mileage and ownership time

This is the first study, to my knowledge, to utilize a bivariate ordered probit model to predict annual mileage and ownership period, the most influencing variables in the TCO model. The model incorporates a suite of socioeconomic, vehicle fleet, and geographic variables and is independent from the TCO model.

5.2 Future research

Although the research makes a number of contributions, several important questions for future research can be discerned:

1) Development of survey-oriented studies in other types of transportation research

Although the information provided in the present thesis about the development and implementation a survey instrument can go beyond the EV research domain, it is worthwhile to see similar works in other types of transportation research. A shortage of survey-oriented studies is currently evident throughout the transportation literature, whereas the focus of most studies are on final analysis of survey data than aspects of survey design itself.

2) A comparison of our survey instrument (SPACE) with similar surveys in the context of electric mobility and the outcomes that emerged from each can provide further knowledge about techniques and strategies that are most useful to be adopted by researchers. This can also reveal

the best practices to further reduce cognitive burden and design a survey that is less labour-intensive.

- 3) Some variables that are not included in the current study are worth investigating in more depth. For instance, whether occupants of single detached dwellings with space for home charging infrastructure might be more willing to adapt an EV comparing with occupants of multi-storey apartments.
- 4) Identifying the locations of households (postal codes) is a critical part of SPACE as it opens up opportunities for future studies with a more focused geographical analysis of potential EV adopters. One possible research objective using postal codes could be to estimate the optimum locations of public charging stations, and identify the places with high demand in terms of home EV charging and its impact on the electricity distribution network.
- 5) More qualitative research methods such as research groups or face-to-face interviews can add further insights to better understand factors that play role in consumer EV adoption in Canada generally and in lagging adoption regions specifically.
- 6) Future studies could consider focusing on other lagging adoption regions in Canada (e.g., the Prairies) and also worldwide to gain more insights towards the EV mindsets in those regions and to provide context for comparing the results.
- 7) Studies of other decision factors such as range, charging time, environmental aspects rather than economic factor or a combination of these factors can provide further insights about suitability of BEVs compared to conventional vehicles among Canadian consumers.

5.3 References

Beck, M.J., Rose, J.M. Hensher, D.A. 2013. Environmental attitudes and emissions charging: an example of policy implications for vehicle choice. *Transportation Research Part A: Policy and Practice* 50, 171–182.

Rose, J.M., Bliemer, M.C.J. 2008. Stated preference experimental design strategies. In: Hensher, D.A., Button, K.J. (Eds.), *Handbook of Transport Modelling, Second Edition*. Emerald Group Publishing Ltd., Bingley, UK. pp. 151–180.