

Electric Vehicles in Canada: A National Analysis of Consumer Preferences, Willingness-To-Pay, and Market Segmentation

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Summary

This paper reports on the results of a large 2015 survey of Canadian consumers that sought to assess attitudes and preferences towards consumer vehicular electric mobility options. A stated preference experiment was carried out as part of this survey and the collected responses were analyzed via a latent class discrete choice model that identified segments with very distinct characteristics. Four classes emerge from the analysis with each class being oriented to one of the primary vehicle technologies. The dominant characteristics of the ICE-oriented class are purchase price sensitivity and EV scepticism; for the HEV-oriented class it is time sensitivity and a resulting reluctance to plug-in; for the PHEV class it is measured optimism about plugging-in combined with pragmatism; and for the BEV class it is true optimism about electric vehicles and a focus on positive aspects such as rapid acceleration and minimized maintenance costs.

Keywords: Canada, latent class choice model, stated preference, BEV, PHEV

1 Introduction

This paper offers results from a national level investigation into consumer attitudes toward electric mobility in Canada. A variety of approaches have been used to address this field of research [1]. The approach taken in this study is that there is a continuum of electric vehicle technologies including: Hybrid Electric Vehicles, Plug-in Electric Vehicles, and Battery Electric Vehicles. While all three vehicle types are associated with reduced tailpipe emissions [2], there are significant differences in the behaviours required from consumers to adopt/operate these vehicles. In this study, these three electrified vehicle options are placed alongside the conventional gasoline vehicle in a stated preference (SP) choice experiment with the objective to understand the most important reasons why a household would prefer one technology over another. The data collected via the SP experiment are subsequently analyzed with a latent class discrete choice model. This somewhat under-utilized technique is very useful in combining the advantages of choice modelling and segmentation to yield rich characterizations of how Canadian households view electric mobility. Various forms of discrete choice modelling have been used for prior studies of electric mobility [3][4][5][6] but relatively few [7] [8] to this point have utilized the latent class choice model.

2 Methodology

The data for this analysis were derived from a sample of 20,520 Canadian households captured via an online survey panel. The objective was to develop a representative sample of Canadian households and this objective was assisted by the fact that the survey was offered both in English and French (Canada's two official languages). The sample design was stratified in the sense that proportionally more observations were sampled from the less-populated provinces. The aim was to ensure adequate counts of household observations in as many provinces as possible. Even so, due to the limits of the survey panel, only 182 observations were collected from the province of Prince Edward Island, for example. Figure 1 summarizes the final observation counts by province and highlights their location.

The philosophy for the survey design was to be inclusive with respect to households to facilitate a good overview of the national consumer landscape on electric mobility. Other related research, for example, has restricted sampling to those who have acquired vehicles in the last one to five years [6] [8]. For this survey, only households that expressed little intent or interest to purchase/lease another vehicle in the foreseeable future were omitted. Households did not need to currently own/lease a vehicle to be included in this survey.

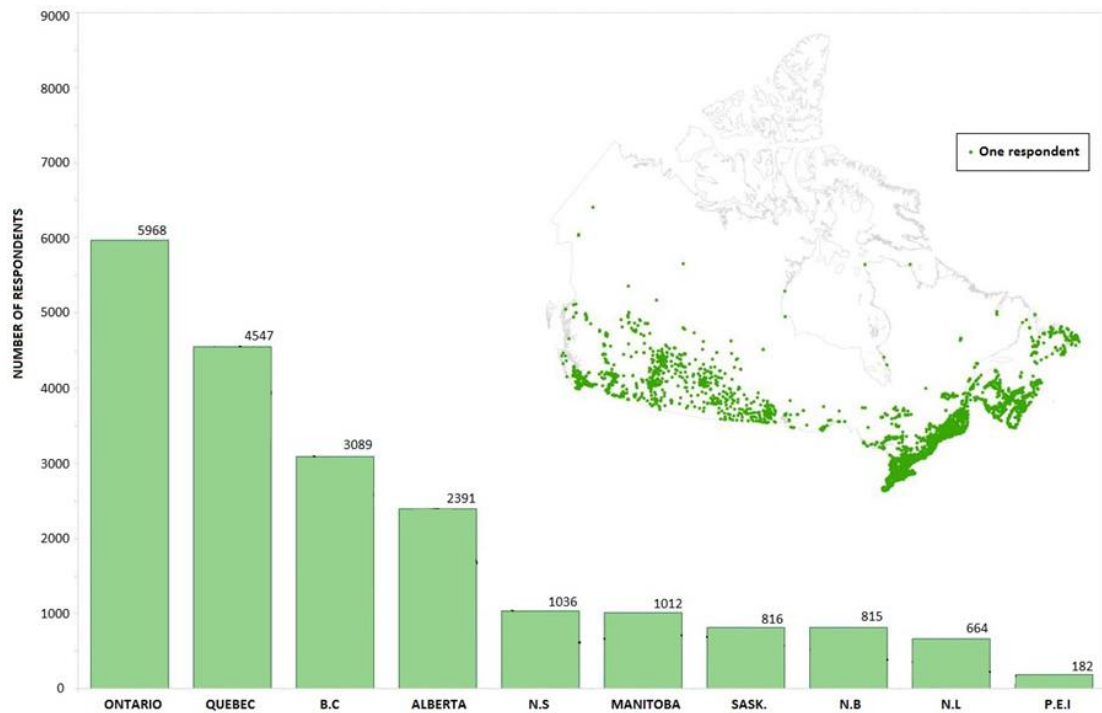


Figure1: Distribution of Respondents by Canadian Province

The survey was structured into seven sections: screening questions, household vehicle inventory, household vehicle purchase plans, educational material on vehicle technologies and their attributes, stated preference experiments for next household vehicle, attitudinal statements, and household spatial, demographic, and socioeconomic characteristics.

The results in this paper are derived from a stated preference (SP) exercise. Each respondent provided vehicle selections derived from four scenarios similar to the one shown in Figure 2. A given scenario offered versions of four vehicles (gasoline (ICE), hybrid electric (HEV), Plug-in hybrid (PHEV) and battery electric (BEV)). Each SP screen included four main attribute categories: cost, operational, charging, and non-cash incentives for a total of 11 attributes. To configure the numeric levels of attributes in each scenario, an appropriate experimental design was implemented using attribute levels defined in Table 1.

The SP scenarios were tailored to reflect travel patterns and vehicle type preferences of each respondent. Values attached to fuel cost, maintenance cost, and annual emissions were calculated on the fly, based on the annual travelled distance reported by participants, as well as with consideration to a participant's preferred vehicle type/size (i.e. economy, or SUV). An educational section was offered prior to the SP exercise to inform participants on the features/attributes of all vehicle technologies. Time spent on the total survey, the

educational section and the actual SP exercise was tracked. After omitting respondent who spent inadequate time on the SP section, 17953 households were retained for the choice modelling exercise to follow.

Table 1: Relative Attribute Levels Used in Choice Scenarios

Attributes		ICE	HEV	PHEV	BEV
Purchase Price (\$)	Percentage to ICE	100 75	150 100	200 150 100	200 150 100
Annual Maintenance Cost (\$)	Percentage to ICE	100	100 75	100 75 50	75 50 25
Annual Fuel Charging Cost (\$)	Percentage to ICE	140 120 100	100 80	80 60 40	40 20
Acceleration (0 to 100km/h secs)	Percentage to ICE	100	150 100 50	150 100 50	150 100 50
Tailpipe Emissions (tonnes)	Percentage to ICE	100 75	75 50	50 25	0
Cash Incentive (\$)	Absolute	0	0	0 5000 10000	0 5000 10000
Gasoline Range (km)	Percentage to ICE	100	125 75	125 75	0
E-Range (km)	Absolute	0	0	30 60 90	150 250 350
Public Charging Time (hrs)	Percentage	--	--	1100 600 100	2*PHEV levels
Home/Work Charging Time (hrs)	Percentage	--	--	100 75 50	200 150 100

(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	50000-50000=\$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						

Figure 2: A typical stated preference scenario

2 Results of Latent Class Choice Model

Although all components of the latent class choice model are estimated simultaneously, it is useful to separate discussion of the results into two model components. Initially, the results of the class probability model are described followed by those of the class-specific utility models.

At the outset, it is useful to note that the best performing model that could be developed consisted of four latent classes. Each latent class took on something of the character of one of the four alternatives in the choice model. As such, there is an ICE-oriented class, an HEV-oriented class, a PHEV-oriented class and a BEV-oriented class. Each class evaluates the choice process in its own way as is seen below.

2.1 Class Probability Model

The class probability model, which is implemented as a multinomial logit model, is based on a wide range of explanatory variables all of which vary over choice-makers. Key components of the results relate to demographics and attitudinal variables collected through the survey.

2.1.1 Level of Urbanization

Map patterns of EV choice behaviour from the survey show apparent greater affinity for plug-in vehicles in urbanized areas. How the results manifest themselves on the map can be due partly to pure geographic effects and partly due to the fact that urban people are different from rural people in their preferences. To test this element, an urbanization index was developed for all small census areas in Canada, appended appropriately to survey respondent data and applied within the class probability model. Results for the urbanization index suggest that there is indeed a separate and distinct geographic effect. Membership in the BEV class shows a positive relationship to the level of urbanization and to a lesser extent this is true as well of the PHEV class. Membership in the ICE and HEV classes, on the other hand, is not sensitive to this factor. In short, the level of urbanization associated with the place of household residence matters in evaluating a plug-in vehicle but not otherwise. The fact that it matters most for the BEV class could reflect a good match between the current range capabilities of a BEV and the needs of daily urban driving.

2.1.2 Age and Education

The basic demographics of age and education have relatively strong effects on class membership while effects due to household income were insignificant. This latter result confirms findings from a recent Canadian study [8]. There is a clear outcome that younger and better-educated households are more likely to be assigned to the plug-in classes than to the ICE and HEV classes. High levels of education are stronger than age in drawing households away from the ICE class.

2.1.2 Language

In the Canadian context, language is an important consideration, particularly in terms of whether primarily French-speaking people choose differently than primarily English speaking people. Results on this variable have clear implications for how adoption in the province of Quebec compare to the rest of the country. In this regard it is quite intriguing that the ICE class and the BEV class receive a similar boost to their membership probability if a household speaks primarily French at home. Many would not be surprised to hear of this result for BEVs given the emphasis on electric vehicles in Quebec and the clean hydro-electric generation profile there. That the ICE class receives a similar boost from speaking the French language is perhaps less expected. The PHEV class also receives a slight boost in membership probability if French is spoken while the HEV class is least compatible in this regard.

2.1.3 Sex of Respondent

This research has emphasized the importance of the household concept in the choice of vehicle powertrains, but the gender of the actual respondent from the household has some bearing on the household's class assignment. Female representatives are least associated with the ICE class and most associated with the HEV class. An added level of pragmatism combined with risk aversion seems to be at play where ICE is seen as less environmentally responsible and HEV is seen as the best way to achieve better environmental outcomes while not taking risks with new technologies.

2.1.4 Time Until Next Vehicle Purchase

The urgency with which households are looking to acquire their next vehicle has some bearing on the class probability results. If the next vehicle purchase is several years out then this increases the probabilities associated with the two plug-in classes to a similar degree. It decreases the likelihood of being in the ICE class. This variable has not been employed in prior EV choice models to the best of our knowledge. The result offers some evidence that the cumulative totals of plug-in vehicles on the road may be slowed by a lack of urgency from those most likely to prefer such vehicles.

2.1.5 Replacement or Incremental Household Vehicle

Related to the question of when the next buy is to be made is the question of whether the household will acquire a replacement vehicle or an incremental vehicle. A fairly strong result emerges that those seeking a replacement vehicle are far less likely to be assigned to the BEV class. Conversely, it suggests that households adding incremental vehicles are more BEV-oriented which is consistent with an observation in Norway [9] that EVs tended to show up in multiple vehicle households, possibly as a means to combat driving range limitations. It is important to note that this relationship does not extend to PHEVs based on the current results.

2.1.6 Ownership of Hybrid Vehicle

An interesting research question is whether ownership of a green vehicle increases the likelihood that a household will continue to own green vehicles in the future or move to a more advanced type of green vehicle. In this large sample of Canadian households, data were collected about vehicles currently owned in each household and it was possible to identify 356 that currently own hybrid vehicles. About 60% of these vehicles were in a household that also owned a non-hybrid vehicle. Accordingly, a variable was created that estimated the proportion of vehicles in a household that were hybrid. Results suggest that current households with a high proportion of hybrids are strongly and significantly less likely to be assigned to the ICE class. When having made a move toward green vehicles, households appear unlikely to go back to an ICE-oriented mentality. Since so many households with hybrids also own ICE, it is probably true that membership in the HEV latent class does not preclude further acquisition of ICE vehicles in the future. Secondarily, hybrid owners are also shown as less likely to be assigned to the plug-in classes relative to the HEV class. This implies a barrier to moving on to a plug-in vehicle but an apparently smaller one than moving on to an ICE vehicle.

2.1.7 Effect of Vehicle Size/Style

Finally, among the non-attitudinal variables, class membership is driven by preferences about the size/style of vehicle to purchase in the future. If the intent is for the household to acquire an economy vehicle then the BEV class receives a substantial boost in its probability while the PHEV class receives a modest boost. The ICE class receives a larger boost than PHEV while the HEV class is not impacted. The results suggest that despite the best efforts of Tesla, BEVs are still appealing more to those interested in small, economy vehicles. But many who opt for economy vehicles are still seeing ICE vehicles as a good choice while the same cannot be said for the HEV class who seem generally less interested in driving a very small vehicle.

2.1.8 Attitudinal Variables

The class probability model includes a half-dozen targeted attitudinal statements that have been specified from a much larger list of such statements. The strongest differentiating effects are provided by the statement **“I am willing to spend more money to buy an EV.”** The ICE class is far more likely to disagree with this statement while there is less differentiation among the green vehicle classes. It is the hybrid class that is actually most willing in this regard and this result is consistent with results to be described in the utility portion of the model.

Strong impacts are generated by another financially-oriented statement **“In the long-term, I think owning an EV is more cost effective than owning a conventional vehicle.”** Agreement with this statement leads to a reduced probability of membership in the ICE class and a largely increased probability of assignment to the BEV class. The PHEV class is less optimistic than the BEV class in this regard and the HEV class has more in common with the green classes than the ICE class. The BEV class in particular is much more comfortable with the idea of deferring savings over the lifetime of the vehicle while the ICE class views the concept with suspicion and would rather save upfront through as small a purchase price as possible.

Another pair of statements deal with required charging behaviour of plug-in vehicles. Strong differentiation between classes is generated by the statement **“I am willing to tolerate some periodic battery charging inconvenience for the benefits of driving an EV.”** Clearly, only some segments of the population have come to terms with the idea of plugging in, particularly in the public charging context that is primarily inferred by this statement. The BEV class has the strongest comfort level associated with this behaviour followed by the PHEV class. The ICE and HEV classes can essentially be grouped together in having little enthusiasm for plugging in. The HEV class may be “greener” than the ICE class but this does not mean that they are willing to purchase a vehicle that must or should be plugged in. Although the ICE class appears

slightly more receptive to the idea of home charging than the HEV class, the two can essentially be grouped for the statement **“Plugging in an EV at my home is not practical.”** The PHEV and BEV classes can also be grouped as tending to more strongly disagree with this statement. Overall, results suggest that attitudes about home charging are less divisive than those about public charging.

Of the two remaining attitudinal statements, one deals with the ability of a battery warranty to alleviate fears while the other touches on environmental aspects. **“With an excellent battery warranty, I would not worry about buying an EV”** again separates the plug-in classes from the ICE and HEV classes. A good battery warranty is more likely to alleviate concerns for the plug-in classes and especially so for the BEV class. The ICE class stands out as being least placated by a good battery warranty, which makes sense in that they are least used to being dependent on a battery. But also the ICE class has various concerns related to plug-in vehicles as other statements have indicated. More environmentally oriented is the statement: **“I feel that I ought to buy an EV to help replace uncertain foreign oil with made-in-Canada electricity.”** Strong agreement with this statement significantly reduced the probability of membership in the ICE class and boosted the probabilities to a greater extent for the BEV class and somewhat less for PHEV. Again the ICE class is the biggest outlier. There is a sense that the ICE class dwells more on the first part of this statement while the other classes are more attracted to the idea of replacing oil with cleanly generated electricity. Frequency distributions indicated that this statement resonated most strongly in Quebec, which is dependent on imports of foreign oil while at the same time having an abundance of cleanly generated electricity.

It is important to note that a series of attitudinal statements were individually tested to assess the importance of environmental responsibility and attitudes toward climate change. These statements had minimal power in allocating households to the latent classes. A pair of “importance” statements that assessed the significance that households attached to certain vehicle attributes did a slightly better job of capturing a sense of environmental responsibility. Households that attach a great deal of importance to reducing emissions from their vehicle, as measured on a five point Likert scale, are considerably less likely to be assigned to the ICE class and are interestingly most likely to be assigned to the HEV class. The importance of good mileage to a household provides significant, but somewhat less, differentiation. Those households least concerned with mileage are more likely assigned to the ICE class. The plug-in classes demonstrate more affinity with good mileage than they do with reducing emissions.

2.2 Utility Models by Latent Class

The class-probability sub-model that has just been described defines membership in the latent classes and it bears repeating that a single household can be a blend of multiple latent classes. However, each latent class has its own unique character as to how incremental changes in the attributes of ICE, HEV, PHEV and BEV vehicles affect utility and these are captured in sub-models – one for each class. In the discussion of these models below, the emphasis is on the differing patterns of willingness-to-pay (WTP) that are evident within and between the four latent classes that have been derived. The critical attribute on which WTP calculations are based is vehicle purchase price. Results are in dollars and ultimately it becomes possible to assess what increases in purchase price would be welcomed by households if a vehicle attribute incrementally improved. Conversely, results will suggest what decrease in purchase price would be expected if a vehicle attribute got incrementally worse.

2.2.1 Purchase Price

As the most important vehicle attribute in the WTP analysis, it makes sense to discuss the performance of purchase price in the models first. This variable is strongly negative and significant for each latent class suggesting, not surprisingly, that utility decreases as prices increase. The rate of change varies widely between the four classes. The ICE class is considerably more purchase price sensitive than the other three. The latter are grouped more closely together with the HEV being the least price sensitive and PHEV the most of the three. Since EVs are presently more expensive than conventional vehicles, price sensitivity is a real obstacle for the ICE segment. On the other hand, purchase price sensitivity alone does not suggest any intrinsic aversion to the idea of driving an EV.

One important note is that high price sensitivity tends to translate into lower WTP results for other variables. If a class is price sensitive, it is much more difficult to induce people into paying more for a car due to an improvement in one of its attributes. In terms of how WTP results are reported, another important note is that any counterintuitive results are not reported in the tables below while insignificant but intuitive results

for the attribute in question **are flagged with an asterisk**. In some of the cases, as will be seen, the lack of a significant parameter difference from zero is not problematic.

2.2.2 Cash Incentive

The cash incentive variable was made specific to the PHEV and BEV alternatives. This aligns with how provincial EV cash incentives have been applied in Canada. Since increased cash incentives are viewed favourably the results are positive and again strongly significant across the classes. With the exception of the BEV latent class, however, the cash incentive parameters are not “offsetting” the purchase price parameters (see Table 2). This indicates that the effect of cash incentives is typically somewhat “dampened” in the choice process on a dollar-for-dollar basis.

In utility terms, it is the ICE class that most highly values the cash incentives but this result is overwhelmed by a reluctance to give ground on purchase price. Of course from the perspective of someone in the ICE class, this cash incentive comes with “strings attached” in that they would need to purchase a plug-in vehicle to benefit. Impacts of the cash incentive may be lessened also by the fact that it operates at the upper end of the price range for a given vehicle; even after incentives the associated vehicle may be viewed as expensive.

Table 2: Tolerated Increase in Vehicle Purchase Price per \$1000 cash incentive

	ICE class	HEV class	PHEV class	BEV class
Cash Incentive	\$607	\$573	\$902	\$1,019

2.2.3 Annual Maintenance Costs

Annual vehicle maintenance costs are negatively associated with utility as expected and the results appear fairly uniform across the classes with the exception of the BEV class, which is more sensitive to an increase in these costs. This group of people may be attracted to the relative simplicity of BEV vehicles and the fact that there are many fewer moving parts to maintain. The same cannot be said for the other three vehicle types, including PHEV, which are quite complex in comparison. Those that are less sensitive to maintenance costs are likely more willing to tolerate a more complex vehicle or perhaps are not really appreciating the simplicity of a BEV. In WTP terms (Table 3), the BEV class is by far most willing to pay more for a vehicle that features low maintenance costs and the ICE class is by far the least willing.

Table 3: Tolerated Increase in Vehicle Purchase Price per \$100 reduction in Annual Maintenance Costs

	ICE class	HEV class	PHEV class	BEV class
Annual Maintenance Cost	\$159	\$684	\$316	\$1,124

2.2.4 Performance/Acceleration

The performance of a vehicle in the stated preference experiment was captured by the time in seconds to accelerate from a standing start to 100 km. With the exception of the result on the HEV class, results across the other three classes were negative and significant indicating that an increase in 0 to 100 time (i.e. decreased acceleration) was viewed negatively. The negative result, in utility terms, was actually strongest for the INCE class. In WTP terms though (Table 4), the BEV-class is most accommodative of an increased purchase price in exchange for improved acceleration and the HEV class appears least focused on this issue, possibly because they are much more focused on issues like range and fuel economy.

Table 4: Tolerated Increase in Vehicle Purchase Price per one-second reduction in 0-100km/h time

	ICE-class	HEV-class	PHEV-class	BEV-class
Performance (0-100km/h)	\$223	\$44*	\$235	\$437

2.2.5 Electric Range versus Driving Range

The range variables associated with the distance that can be travelled on a tank of a gasoline, or on a full charge, yield interesting results. Independent sets of parameters are estimated on range fueled by gasoline versus range fueled by electricity. The PHEV alternative is unique among the four vehicle types in that it is portrayed as having a range on both. Gasoline range is generally positive and significant across the classes

indicating that the distance between gasoline fill-ups is valued highly. The one exception is the BEV class, which apparently discounts gasoline-powered kilometres to the point where the result is not significantly different from zero. For electric range, the results are again generally positive and significant across the classes but in this case it is the HEV class where the result is not significant since electric miles are being discounted.

In WTP terms (Table 5), the HEV class treats gasoline range and electric range comparably with the former being valued somewhat more highly. By far the HEV class most values increasing the driving distance between gasoline fill-ups. In general, it is fair to say that electric range is more highly valued than gasoline range and this difference is particularly stark in the case of the BEV-class.

Table 5: Tolerated Increase in Vehicle Purchase Price per km Extra Range

	ICE-class	HEV-class	PHEV-class	BEV-class
Gasoline Range	\$6.24	\$21.91	\$9.69	\$4.44
Electric Range	\$13.18	\$16.89	\$31.22	\$29.86

2.2.6 Non-Cash Incentives

A series of non-cash incentives, made specific to the PHEV and BEV alternatives, yields generally positive but often not significant results in terms of influencing utility. In general, results are weak or counter-intuitive in utility terms for the HEV class, suggesting that members are paying more attention to other factors in their evaluation of vehicle powertrains.

With respect to a free municipal parking incentive for those who drive plug-in vehicles, the results are positive and significant for all except the HEV class. For the three other classes, this would seem to be an incentive that people would be willing to pay for via increased vehicle purchase price. The results for an exemption on tolls are not noteworthy. Partly this may reflect that tolls roads are less prominent in Canada than in many other countries. One strong result is that the PHEV class, which is quite urbanized, derives a significant boost in utility from having HOV access. This is true to a lesser extent for the BEV class. The ICE class responds as well indicating that HOV access could be a factor that members would evaluate in a plug-in vehicle.

Table 6: Tolerated Increase in Vehicle Purchase Price if Non-cash Incentives Apply

	ICE-class	HEV-class	PHEV-class	BEV-class
Free Municipal Parking	\$1,376	-	\$1,832	\$1,958
No Tolls	\$1,222	\$2,987*	-	\$1,074*
HOV access	\$509*	-	\$2,265	\$1,121*

2.2.7 Battery Warranty

The four classes all value a battery warranty, made specific in the experiment to all but the ICE alternative. The battery warranty has been captured in the analysis as three categorical levels which combine mileage and duration and this warranty applies to all but ICE vehicles. The WTP results in Table 7 reflect increases in vehicle purchase price that would be paid to increase the quality of the warranty by one level. Of note is the fact that the ICE class as well is quite responsive to a good battery warranty. Interestingly, the one class that seems *less* responsive to the quality of the battery warranty is the BEV class, perhaps indicating that they are most sold on the idea of a battery as a durable and effective source for propulsion and are least worried about how it will perform over time. The HEV and PHEV classes are willing to pay the most for an improved battery indicating that concerns about the long-term performance of batteries may act as a significant barrier to purchasing a BEV.

Table 7: Tolerated Increase in Vehicle Purchase Price per Battery Warranty Tier

	ICE-class	HEV-class	PHEV-class	BEV-class
Battery Warranty	\$929	\$3,153	\$2,302	\$800

2.2.8 Charging Time

In terms of charging time, the disutility associated with public charging time is much stronger than it is for home/workplace charging time. Time spent for the former is being directly associated with inconvenience. The ICE and HEV classes perceive similar and strong disutility for public charging time but of the two, the HEV class would be far more willing to pay for reduced public charging time. The PHEV and BEV classes can be grouped as perceiving a weaker disutility for increased public charging time with the BEV class being more willing to pay for time savings.

With respect to home/work charging time, results are generally not significant though increased charging time appears to be seen as a disutility that three of the classes would be willing to pay to address. There is a significant result for how the BEV class views home charging time and it appears to suggest that the BEV class derives good feelings, and does not perceive inconvenience, about the idea of their vehicle being plugged in at home or work for even long periods of time. This interesting but potentially counter-intuitive result shows up as a negative value in Table 8 below.

Among the WTP results, potentially the most interesting result is that the HEV class is most willing to pay for reductions in public charging time. The class probability model has indicated that the HEV class is partly defined by people who do not like the inconvenience associated with periodic charging. Overall, the result seems to suggest that it is the time involved in public charging that the HEV class is most concerned about.

Table 8: Tolerated Increase in Vehicle Purchase Price per Hour Reduction in Charging Time

	ICE-class	HEV-class	PHEV-class	BEV-class
Public Charging Time	\$531	\$1,971	\$409	\$738
Home/Work Charging Time	\$174*	\$1,020*	\$80*	-\$1,341

2.2.9 Charging Station Availability

Related to charging time is the issue of the presence of charging infrastructure. This variable is specific to the two plug-in alternatives and three levels of availability are considered. Charging stations are 10% as available as gasoline stations, equally available or twice as available. The results are positive and significant for the plug-in classes but are insignificant for the HEV and ICE classes. The HEV and ICE classes are evidently more focused on public charging time as a limiting factor and are not seriously considering limitations of where one can charge in public. The fact that the plug-in classes are attaching relatively more weight to the relative presence of charging infrastructure makes sense.

Table 9: Tolerated Increase in Vehicle Purchase Price per Tiered Increase in Public Charging Station Availability

	ICE-class	HEV-class	PHEV-class	BEV-class
Charging Station Availability	-	\$317*	\$694	\$1,122

2.2.10 Base Willingness-To-Pay

The alternative-specific constants associated with each latent class play a significant role in defining the classes. These capture components of systematic utility that cannot be specifically linked to incremental changes in the other model attributes. Since these are all part of the same model, their relative magnitude can be compared within and between latent classes. To some extent, the constants may capture utility components due to fueling/charging costs or emissions reduction. These factors were part of the choice experiment but significant impacts due to their incremental variation could not be identified.

In Table 10, the constants are converted into dollar terms using the WTP method. Results are indicative of the base level of attractiveness that each class associates with the four powertrain options, other things being equal. As such, the ICE and HEV classes appear least enthusiastic about BEVs. The PHEV class may prefer HEVs to BEVs. Interestingly, the BEV class appears almost as negative on HEVs as they do for ICE.

Table 10: Base Utilities Expressed in WTP terms

	ICE-class	HEV-class	PHEV-class	BEV-class
ICE Constant	\$23,528	\$28,614	-\$205	-\$44,642
HEV Constant	\$8,927	\$84,698	\$13,322	-\$38,620
PHEV Constant	\$3,474	\$28,983	\$32,194	-\$18,914
BEV Constant	\$0	\$0	\$0	\$0

3 Conclusions

This research has employed a comprehensive, far ranging survey data set collected from the Canadian population as the basis for a set of vehicle choice experiments. It has focused on households as the primary choice-making entity for vehicle purchases and filters have not been strict. Only households with little intent to purchase a vehicle in the future have been excluded. On this basis, a national latent class choice model has been developed and ultimately, households have been assigned into four latent classes, each of which has its own unique character. Many households are blends of these primary classes while some households can be directly associated with a single, dominant latent class.

The first latent class is ICE-oriented and is pre-occupied with financial considerations. There is a strong reluctance to pay more for a car, whether an EV or not, and there is scepticism with the idea that an EV will pay for itself over time. Cash incentives for plug-in vehicles are discounted by this class. Less concern is shown for high mileage and lower emissions than other classes but this class is likely considering an economy vehicle for the next vehicle purchase. With respect to plug-ins, this class shows little enthusiasm for the idea of plugging in at present but showed responsiveness to potential improvements in public charging time and is somewhat swayed by a strong battery warranty. Speaking French primarily at home increases likelihood of membership in this class.

The second latent class is HEV-oriented and, in contrast to the ICE class, is the least price sensitive of all the classes but does heavily discount cash incentives for plug-ins. In demographic terms, the HEV class is least likely to be French-speaking and is more likely to be associated with female respondents. While the HEV class is least sensitive to price it appears the most sensitive to time. Members have no enthusiasm to lose time with via public charging. Accordingly, with respect to plug-ins, this class is highly focused on improvements in public charging time and in the battery warranty. Of all the classes, this one feels strongest about the importance of reducing their vehicular emissions but, in contrast to other classes, they choose to do so by valuing gasoline range very highly. Not surprisingly, hybrid vehicles are more likely to be currently owned by this class.

The PHEV and BEV oriented classes share many similarities and but there are a few differences. Members of the BEV class comes across as “true converts” with respect to plug-in mobility while the PHEV class is clearly more likely than the BEV class to consider the hybrid vehicle option. In terms of similarities, both classes are younger, better educated and more urban. Both classes show less urgency to pursue their next vehicle purchase, which may temper the acceleration of EV adoption, but are receptive to cash incentives for plug-ins. Both classes are paying the most attention to electric range and less attention to gasoline range and both are wary of the availability of charging stations. On the latter point, results for the ICE and HEV classes suggest that members have not yet gotten to the point where they worry about charging station availability. Electric range, public charging time and battery concerns rate far more heavily for them at this juncture.

In terms of differences, the PHEV-oriented class has much more concern with batteries and associated warranties than the BEV class and is more sensitive to price. The PHEV class does not share the same indifference for gasoline range that the BEV class does. The BEV class is more likely to be pursuing an economy vehicle for the next vehicle purchase and is much more associated with an incremental, as opposed to replacement vehicle, for the next purchase. Relative to other classes, the BEV class is most pre-occupied with aspects such as minimal maintenance costs and rapid vehicle acceleration. They pay the most attention to the positive features of BEV vehicles while other classes pay much more attention to perceived negative features. Finally, they are more likely to speak primarily French at home.

Having characterized the basic nature of these classes, it is critical to note that their prevalence in the general population is not strongly related to existing patterns of car sales. Current cumulative plug-in sales in Canada have been somewhat dismal but the PHEV and BEV oriented classes are heavily represented in the survey

data. Results suggest that large numbers of Canadian households appear very open to the concept of electric mobility. An ICE-oriented orientation is not the majority in the survey data.

As to why the possible market shares suggested in the choice scenarios are not matched in reality, important explanations include dealership bias in favour of ICE vehicles and the simple fact that plug-in vehicles remain substantially more expensive. A good basic working knowledge of the range of electrified vehicular options that are available remains lacking in many people and this does not help real-world plug-in sales. Finally, it has to be acknowledged that a choice experiment such as this one measures behavioural intention as opposed to actual behaviours.

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References

- [1] Rezvani, Z., Jansson, J., & Bodin, J. (2015). Advances in consumer electric vehicle adoption research: A review and research agenda. *Transportation Research Part D*, 34, 122-136. doi:10.1016/j.trd.2014.10.010
- [2] Holland, S. P., Mansur, E. T., Muller, N. Z., & Yates, A. J. (2015). *Environmental Benefits from Driving Electric Vehicles?* Cambridge : National Bureau of Economic Research.
- [3] Potoglou, D., & Kanaroglou, P. S. (2007). Household demand and willingness to pay for clean vehicles. *Transportation Research Part D: Transport and Environment*, 12(4), 264-274. doi:10.1016/j.trd.2007.03.001
- [4] Hoen, A., & Koetse, M. (2014). A choice experiment on alternative fuel vehicle preferences of private car owners in the Netherlands. *Transportation Research Part A*, 61, 199-215.
- [5] 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 U.S. and China. *Transportation Research Part A*, 73, 96-112.
- [6] 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. doi:10.1016/j.trd.2013.07.002
- [7] 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(3), 686-705. doi:10.1016/j.reseneeco.2011.02.002
- [8] Axsen, J., Bailey, J., & Castro, M. (2015). Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. *Energy Economics*, 190-201. doi:10.1016/j.eneco.2015.05.003
- [9] Klockner, C. A., Nayum, A., & Mehmetoglu, M. (2013). Positive and negative spillover effects from electric car purchase to car use. *Transportation Research Part D: Transport and Environment*, 21, 32-38. doi:10.1016/j.trd.2013.02.007

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