

# A Short Example - Canadian Behaviours for the Design of Electric Vehicle Powertrain Combinations

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## Abstract

This paper is a very short demonstration of consumer attitudes towards EV powertrain and body type combinations in Canada. There is a focus on the impact of incentives and the modelling of purchase price, operating cost, incentive, and vehicle age importance in vehicle purchasing decisions. Additionally, powertrain combinations are compared against survey questions to provide a sense of whether underlying biases or concerns impact how consumers may design vehicles, even in realistic but hypothetical scenarios.

## 1. Introduction

The transportation sector represents one of the single largest contributors to greenhouse gas emissions (GHGs) and other pollutants in Canada. The uptake of electric vehicles (EVs), to date, has been limited. Various authors have explored attitudes towards EVs and have generally found purchase cost, range anxiety, and battery maintainability to be the primary barriers to purchase (see Mohamed (2018)). In this paper, as a part of the *McMaster Institute for Transportation and Logistic's* study on *The Social Costs and Benefits of Electric Mobility in Canada*, we aim to understand how consumers would design and purchase a vehicle of their preferred body type (sub-compact, Luxury Sedan, SUV, etc.) at a realistic price point. This paper presents a small number of results from the survey itself in addition to some basic discrete choice modeling, looking at the impact of purchase, price, operating cost, incentives, and body types. First, we will review the data collection process and aspects of the collection instrument, then present the data analysis, followed by some of the survey results and how the vehicles designed compare, lastly some conclusions are drawn.

## 2. Data Collection

Data was collected via an electronic survey completed by a third-party firm. A total of ~20,000 observations were collected, including repeat respondents from

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Build & Price Your Next Household Vehicle (Luxury)		Scenario Assumptions							
Work in the Design Zone below to adjust slider bars for age of vehicle, gasoline range and battery range. When happy with a vehicle and its price, choose from cash, lease or finance to finalize design.		Public Charging Experience: Excellent Incentives (New PHEVs/BEVs only): \$14,000							
<p><b>The Design Zone (how to use: step-by-step).</b></p> <p>Age of Vehicle (Years) <input type="range"/> New 2 6</p> <p>Gasoline Range (km) <input type="range"/> 0 500-700 1,000+</p> <p>Battery Range (km) <input type="range"/> 0 40-50 85-100 300-350 425-500</p> <p>NOTE: (e.g. 85-100 battery range) left number for 5yr old vehicle; right number for new vehicle.</p>		<p>Current Car Type: N/A</p> <p>BEV PHEV HEV ICE N/A</p> <p><b>Increase battery range and/or gasoline range to design a vehicle.</b></p>							
<p><b>Performance, Maintenance, &amp; Charging Outcomes</b></p> <p>Performance &amp; Acceleration <input type="range"/> N/A Reduced Average Enhanced</p> <p>Visits to Mechanic / # of parts to maintain <input type="range"/> N/A Less Typical More</p> <p>30+ Minute Public Charging Sessions <input type="range"/> N/A Never Optional On Occasion More Frequent</p>		<p>Tailpipe Emission Reduction ●●●●● N/A</p> <p><b>Monthly Cost Impacts</b></p> <p>Charging Cost N/A</p> <p>Gasoline Savings N/A</p> <p><b>Net Savings N/A</b></p> <p><b>Vehicle Price / Monthly Payments</b> Including Taxes and Applicable Incentives</p> <table border="1"> <thead> <tr> <th>Cash</th> <th>Lease (3 Yr)</th> <th>Finance (5 Yr)</th> </tr> </thead> <tbody> <tr> <td>N/A</td> <td>N/A</td> <td>N/A</td> </tr> </tbody> </table> <p>Cash Lease Finance</p>		Cash	Lease (3 Yr)	Finance (5 Yr)	N/A	N/A	N/A
Cash	Lease (3 Yr)	Finance (5 Yr)							
N/A	N/A	N/A							

Figure 1: Initialized Vehicle Design Scenario

a version of the survey conducted in 2015. A total of 16,901 respondents are included in this analysis dataset after removing repeat respondents and other responses inline with other works that have used this dataset as their basis. While other works focus on the results of the full survey (reference, reference, mitl report), this analysis looks at the experimental section added for the 2018 iteration of the survey, referred to as the *Vehicle Design Scenarios* (VDS).

Respondents were asked to go through two VDSs where they would choose a set of powertrain features (gasoline and electric range) that produce a vehicle, at a price, they would be willing to purchase. It is worth noting that as a part of the respondent screening process, only responses that had some degree of intention of purchasing a vehicle in the near future (as opposed to zero intent) were asked to complete the survey. In each of the two scenarios, respondents were given a number of assumptions to respond to, including: the ease or challenge they could charge their EVs (Charging stations being nearby, no wait time to plug in, and fast charging times - or not), a range of government cash incentives applied to the purchase price (\$0, \$7000, and \$14000), and whether or not respondents would be able to readily charge their vehicles at home with minimal need for public charging otherwise. These assumptions could not be changed by the respondent.

Inside of the VDS respondents, were able to assess how the performance, maintainability, and charging outcomes of the vehicle designed would change as the age, gasoline range, and electric range values were changed to create different configurations. Additionally, respondents were given information on the tailpipe emissions, in respect to a standard internal combustion engine, information on the estimated cost to charge their vehicle (based on the capacity of existing battery technology and their specified annual kilometres driven), and how much they may, potentially save on gasoline. The final piece of information given is

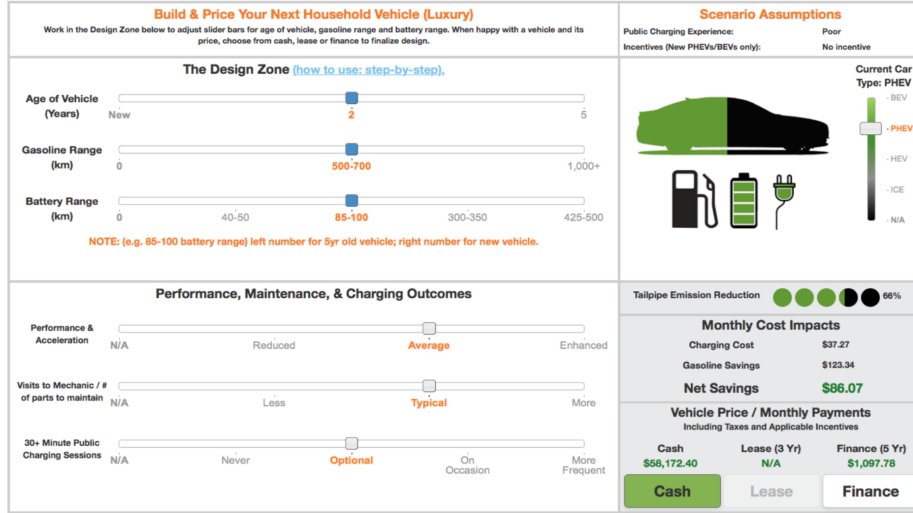


Figure 2: Vehicle Design Scenario with Configuration

an approximation of the vehicle purchase price (based off of existing vehicles and black book values are used to estimate the value of used vehicle prices), after tax and incentives, which is also presented as lease and financing payments. The standard initialization of the VDS, Figure 1, begins with all sliders set to zero values. Respondents are able to adjust the age and range sliders as many times as they perceived necessary, but are required to move either the gasoline or electric range sliders at least once to complete a vehicle configuration and choose a payment method to proceed. Once a configuration has been selected, Figure 2, the aforementioned fields are populated and adjust in real-time as the respondent alters their configuration.

### 3. Data Analysis

After cleaning the data of bad responses, as defined by too few slider changes (less than 1) in the VDS or completing the VDS too fast or too slowly ( $\pm 3$  standard deviations of the mean), we analyze the 16, 758 remaining responses. As discussed above, respondents were asked about the type of vehicle they would be interested in purchasing in the future, in addition to their annual kilometerage. These values were used to influence the purchase price of the vehicle (which varies by the body type and the powertrain) and informed the operating cost calculation (which estimates the monthly cost to operate the vehicle based on how far the respondent drives), discussed in detail in Appendix 1.

#### 3.1. Initial Outcomes

The purchase price and operating cost of vehicles, in addition to the percentage of vehicles designed by powertrain designation, is reviewed in Table 1.

Table 1: Purchase Price, Operating Cost, and Proportion of Vehicles Designed

Vehicle Powertrain	Purchase Price~ (\$)		Operating Cost* (\$)		Proportion (%)
	Mean	Median	Mean	Median	As Selected
<b>Gasoline Only</b>					
ICE	26163.31	23730.00	97.06	96.53	18.20
HEV	41579.87	37070.00	55.65	55.34	2.78
<b>Gasoline &amp; Electricity</b>					
PHEV SE	36084.92	33933.90	71.41	70.73	13.00
PHEV LE	39960.16	38321.74	62.71	65.12	53.65
PHEV LG	34113.51	29290.00	50.25	50.24	2.63
<b>Electricity Only</b>					
BEV SE	32653.75	26530.43	33.14	34.31	5.74
BEV LE	31007.28	25764.00	32.49	31.15	4.01

*Note:*

~ Approximate cost to purchase a class-representative vehicle, inclusive of tax

\* Approximate cost to operate (drive) a class-representative vehicle for 1,000km

Of particular interest is the popularity of the long-electric range plug-in hybrid electric powertrain, with 53.65% of respondents *designing* this option. The ICE and PHEV short-electric round out the top three selections, with the remaining powertrains accounting for only 15% of designs. Predicted to be of great influence is how the operating cost was presented to respondents; rather than in ambiguous terms of per-so-many-kilometres, a clear cut monthly dollar value was defined. The PHEV long-electric is not the cheapest vehicle to purchase, and is actually considerably more expensive than the most of the other powertrain combinations. This is a curious result which will require further validation and testing. Of concerns noted, is that for respondents who were fatigued at this stage of the data collection (the VDS was towards the end), only moving the sliders once or twice may have been enough for them and were not interested in vesting the time to generate a more reflective response. Further data cleaning could be enacted to review this phenomena, which further consideration of the time spent and changes made variables. The variance in vehicle purchase price by body type and powertrain is shown in Figure 3 and the variance in purchase price by powertrain, incentive, and vehicle age is shown in Figure 4. The boxplots clearly demonstrate that vehicle purchase price decreases for new vehicles with the incentive levels, but notably incentives do not impact the value of used vehicles. Rather, the purchase prices fall due to depreciation. The VDS took into active consideration the relative cost of different vehicle body types and has integrated these variances into the experiment, as presented.

Exploring the data of the boxplots more with more depth, we look at Table 2 for the breakdown by incentive, age, and powertrain. A surprisingly result is how marginal the variations between incentive groups are in the proportion of

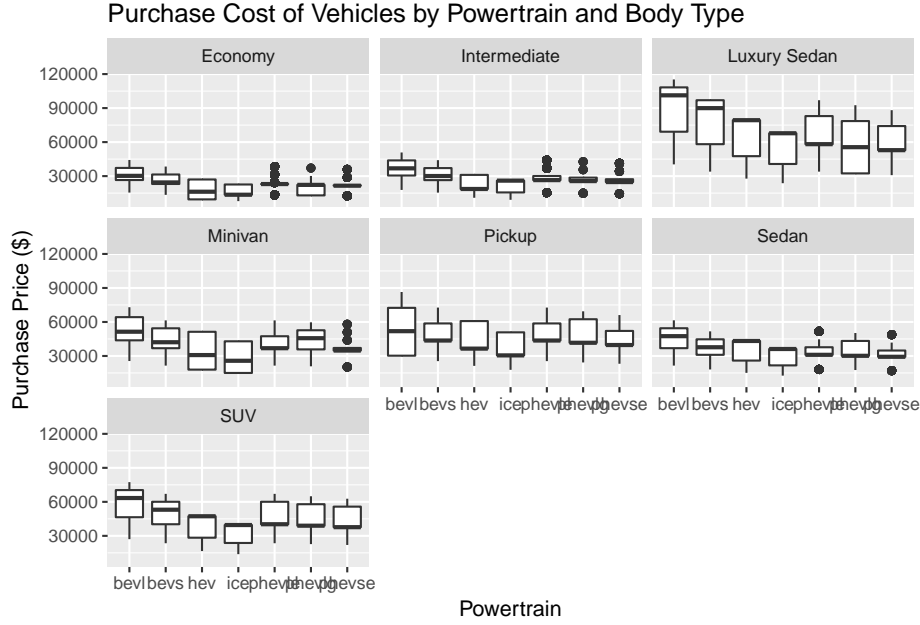


Figure 3: Purchase Cost Variance by Body Type

vehicles designed. While this table does not break out the results to include the seven body types, there is virtually no meaningful change as a result of increasing incentives, seeing less than a .4% change for the fully electric BEVs and less than 1% for the PHEVs at the maximum \$14 000 incentive level.

To further evaluate and analyze the data, a very brief discrete choice model is looked at (see Train (2009)).

### 3.2. Estimating an Initial Model

First, a multinomial logit model will be estimated. The initial model is estimated as  $depvar = \beta + pp$ , while a second model is estimated as  $depvar = \beta + pp + oc$ . Simply the dependent variable, the powertrain selection, is estimated to be a function of the purchase price and the operating cost. The model output confirms (albeit from a derived dataset), the alternatives (i.e., powertrains) frequencies. The results, in Table 3, are otherwise underwhelming. It is not expected that the coefficients would be positive, implying that as the values increase so too does the utility. While potentially true for purchase price, it seems suspicious in terms of operating cost. After the dataset has been validated, a proportional ordinal logistics regression should be estimated in addition to mixed logit models using the polr and gmn packages.

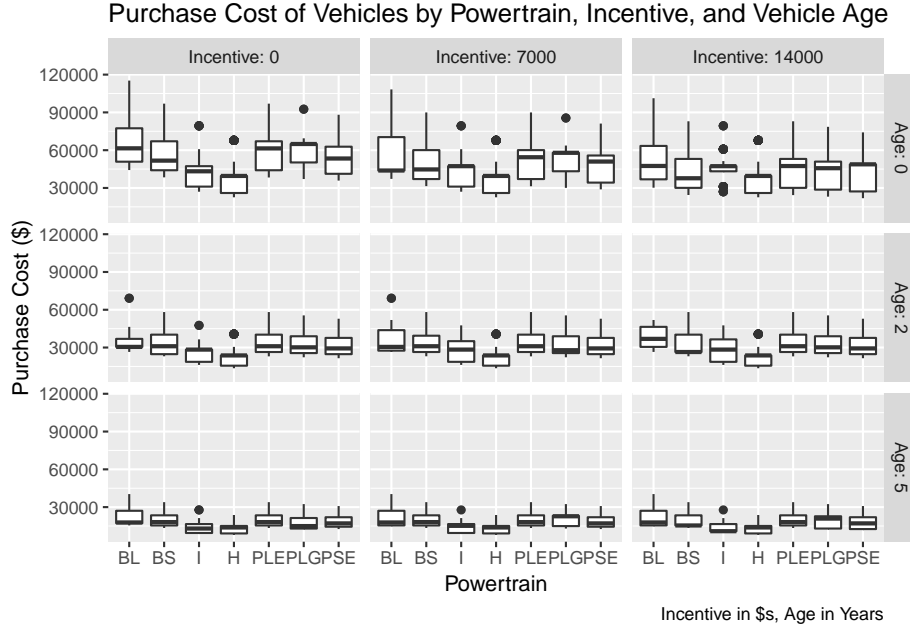


Figure 4: Purchase Cost Variance by Powertrain, Incentives, and Vehicle Age

#### 4. Conclusions

Significant time needs to be spent reflecting on the data analysis and data capture to ensure the validity of these results. It is circumspect that purchase price and operating cost would both be positively related, given the expectation that as operating cost decreased the utility would have increased. The same may be true of purchase price, but there are more variables at play, including for some individuals, a more expensive vehicle may in of itself be of higher utility. Other body types, such as minivans and pickup trucks are naturally more expensive than compact sedans. Regardless, more time is required to analyze the data to determine the validity of the results.

#### 5. Acknowledgements

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#### 6. Appendix

##### 6.1. Purchase Price and Operating Cost Calculations

Purchase price (pp) is determined by the bodytype (Economy, Intermediate, Sedan, Luxury Sedan, SUV, Minivan, Pickup) and the powertrain (i.e., technology

Table 2: Mean Purchase Price of Vehicle by Powertrain, Incentive, and Vehicle Age

Powertrain	Average Purchase Price (\$)			Proportion (%)
	New Vehicle	2 Year Old Vehicle	5 Year Old Vehicle	As Selected
<b>\$0 Incentive</b>				
ICE	35930.25	21052.50	12236.01	6.73
HEV	48626.75	38038.00	27395.80	1.00
PHEV SE	39118.97	39688.13	37737.69	4.47
PHEV LE	47478.40	43207.25	31437.84	17.51
PHEV LG	29966.67	31832.85	39836.52	0.79
BEV SE	27343.83	39472.29	34484.52	1.74
BEV LE	24239.20	30076.62	37246.88	1.21
<b>\$7 000 Incentive</b>				
ICE	36112.58	20883.05	12280.12	5.87
HEV	50695.07	38032.88	27143.62	0.92
PHEV SE	32464.60	32476.54	30405.86	4.46
PHEV LE	43317.27	39128.35	36987.74	17.70
PHEV LG	39102.64	39025.98	34280.83	0.87
BEV SE	40009.38	31832.16	33172.03	1.86
BEV LE	28266.41	34166.15	34468.11	1.20
<b>\$14 000 Incentive</b>				
ICE	35954.55	21141.04	12055.25	5.61
HEV	50168.36	38034.24	26888.45	0.86
PHEV SE	30856.02	39827.62	46632.97	4.06
PHEV LE	33208.34	38773.15	34874.95	18.43
PHEV LG	34068.44	33121.63	37770.84	0.97
BEV SE	23492.37	34608.95	27400.65	2.14
BEV LE	30603.00	36044.98	28650.61	1.60

type: ICE; Hybrid; PHEV - Short Electric, Long Electric, Long Gas; and, BEV: Short Range, Long Range). ICE and Hybrid are the cheapest options, respectively, across all bodytypes. pp is affected by three age levels: New, 2, and 5 years old. New = approximate MSRP value of the powertrain + bodytype configuration; 2 = 65% retained value; and, 5 years = 35% of retained value. pp is affected by three incentive levels: \$0, \$7000, and \$14000. Offered only to new vehicles of the powertrains: Phevse, Phevla, Phevlg, bevs, bevl.

Operating Cost (oc) is determined by the bodytype-powertrain combination, the cost of electricity, and the cost of gasoline (87 Octane / regular). Electricity rates are determined by whether respondents have access to home charging or not. Those with access paid 13 cents / kWh, those without paid 26 cents / kWh to approximate the cost of needing to use public / 3rd party charging systems. Cost of gasoline was determined by the January 2018 average cost of gasoline across Canada's top 20 municipalities, as per reporting by Statistics Canada (Gas = \$1.17 per litre). This value does not vary across alternatives. oc is calculated as a function of the average cost to travel 1000km in a series of reference vehicles, from full tank to empty on average combined fuel economy. This per 1000km value is then multiplied by the midpoint of the ranges of stated annual kilometres travelled by the respondent (e.g., 5000-10000km = 7500km), in an attempt to

Table 3: Initial logit models

Variable	Initial Model		Second Model	
	Estimate	p-value	Estimate	p-value
bevl:(intercept)	-1.5199	0.0000	-0.7799	0.0000
bevs:(intercept)	-1.1635	0.0000	-0.4323	0.0000
hev:(intercept)	-1.9016	0.0000	-1.4284	0.0000
phevl:(intercept)	1.0609	0.0000	1.4569	0.0000
phevlg:(intercept)	-1.9479	0.0000	-1.4091	0.0000
phevse:(intercept)	-0.3513	0.0000	-0.0553	0.2598
pp	0.0000	0.0117	0.0000	0.0082
oc	NA	NA	0.0114	0.0000

approximate the actual cost to operate that specific respondent may incur. A separate sheet is available without the per-respondent cost calculation.

## References

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