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A CONSUMER LATENT CLASS CHOICE MODEL TO ASSESS PROSPECTS FOR ELECTRIC VEHICLES IN CANADA

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Introduction

As of late 2015, a cumulative total of approximately 16,500 new plug-in vehicles have been sold in Canada in contrast to nearly 400,000 plug-in vehicles in the United States. On a per capita basis, approximately 2.5 times as many plug-in vehicles have been sold in the United States. A majority of the Canadian sales have been supported by substantial provincial incentives. Lagging relative EV sales in Canada are somewhat surprising when it is considered that the national electricity generation profile is one of the cleanest in the world (150 TCo2e/GWh) meaning that promised environmental benefits of EVs can largely be realized in the Canadian context (Kennedy 2015). Certainly there is evidence that "dirty" electricity generation will, to a varying extent, defeat the purpose of EV adoption (Holland et al. 2015) but almost all developed countries are below the accepted 600 TCo2e/GWh threshold (Kennedy 2015). Canada is far below this threshold, which strongly implies that there are Canadian barriers to consumer adoption unrelated to the environmental case for electric vehicles. Egbue and Long (2012) offer an overview of the types of barriers that apply to EV adoption while Anable et al (2011) consider the UK perspective on such matters.

The purpose of this analysis is to derive an improved understanding of how Canadian households view electric vehicles of varying types and whether they are seen, or could be seen, as viable household vehicles. The data for this analysis were derived from a sample of approximately 20,000 Canadian households accessed via an online survey panel. The survey was offered in both official languages. Participants were screened against three criteria: age (older than 18), whether respondent is one of the decision-makers in most or all important financial decisions made by the household, and whether the household is at least somewhat likely to purchase or lease a new or used vehicle sometime within the next several years.

The focal point from the survey, for the purposes of the choice model discussed below, is a consumer stated preference exercise (SP). This exercise represents the choice between four powertrain technologies: Internal Combustion Engine (ICE), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), and Battery Electric Vehicle (BEV). Each SP screen includes four main categories of attributes: cost, operational, charging, and non-cash incentives for a total of 11 attributes. Each respondent participated in four SP choice games where the attributes associated with the vehicles in each game are varied in accordance with an experimental design.

The analytical results derived in this paper are based on a latent class discrete choice model. See Hidrue et al. (2011) and Axsen et al. (2015) for other examples in this domain. The observed choice behaviour is based on the vehicle selections that household respondents are observed to make in the SP scenarios. These same scenarios provide information on how choice-makers respond to vehicle attributes. In a separate part of the survey, information is collected that captures demographics, driving patterns and vehicle ownership of the respondent households and also responses to attitudinal statements are collected. Each aspect is highly relevant to the development of the choice model. The latent class choice model is separated into two main components: a class probability model that captures the likelihood that a given household belongs to one of four latent classes and utility sub-models that summarize what is important for each latent class in their evaluations. The two subsequent sections of this paper are organized accordingly.

Description of class probability model results

The class probability model governs the assignment of individual households to the latent classes. Results of this analysis suggest that the best overall class probability model emerges using a combination of objective socio-economic and related variables and a series of subjective attitudinal statements. The latter group is very useful in refining the character of the classes.

Some of the important findings from the class probability model are as follows:

- Non-attitudinal variables contribute important insights to this sub-model.
- 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.
- There is a clear result 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 higher age in drawing households away from the ICE class.
- Speaking primarily French at home boosts the class probabilities of both the ICE and BEV classes.
- Female respondents 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.
- 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. 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.
- Those seeking a replacement vehicle are far less likely to be assigned to the BEV class.
- Current households with 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.
- 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 saving money on car purchase price.

The class probability model includes the most effective subset from a large list of attitudinal statements. Some of the interesting results in this regard are as follows:

- 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 to 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.
- 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.
- 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.” The BEV class has the strongest comfort level associated with this behaviour followed by the PHEV class.
- Regarding the ability of a battery warranty to alleviate concerns, the statement: “With an excellent battery warranty, I would not worry about buying an EV” 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.

- 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 little power in allocating households to the latent classes.

Description of the class utility model results

Each latent class has its own unique character as to how incremental changes in the attributes of the ICE, HEV, PHEV and BEV vehicles affect utility. A sub-model is associated with each latent class and can be interpreted essentially in the same way as a single, stand-alone multinomial logit model (MNL). It becomes immediately obvious that the existence of the classes permits considerable heterogeneity in parameters that would not be possible with a basic multinomial logit. But the results for the MNL *do* conform to expectations. Willingness-to-pay (WTP) results unify interpretation through a translation into dollar amounts. One tends to see larger WTP amounts for those classes with lower purchase price sensitivity.

Some significant results are:

- The purchase price variable is strongly negative and significant for each latent class suggesting that utility decreases as prices increase. The ICE class is considerably more 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.

- The cash incentive variable was made specific to the PHEV and BEV alternatives. 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, the cash incentive parameters are not "offsetting" the purchase price parameters. In utility terms, it is the ICE class that most highly values the cash incentives but this result is overwhelmed by a stronger result on purchase price. In WTP terms, members of the classes would tolerate less than a $1000 dollar increase in vehicle purchase price to benefit from a $1000 cash incentive. There is no class where the WTP for a $1000 cash incentive significantly exceeds $1000.

- Parameters on 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 miles to the point where the result is not significantly different from zero.

- For the parameter on 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, the HEV class treats gasoline range and electric range comparably with the former being valued somewhat more highly. By far the HEV class values most increasing the driving distance between gasoline fill-ups.

- A series of non-cash incentives (i.e. exemption from tolls, PHEV and BEV access to HOV lanes, free municipal parking) yield generally positive but not strong results in terms of influencing utility.

- The one non-cash incentive that the four classes all value is the battery warranty attached to all but the ICE option. 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.

- 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.

- In terms of charging time variables, the disutility associated with public charging time is much stronger than for home or workplace charging time. Time spent for the former is being directly associated with inconvenience. The ICE and the HEV classes appear to perceive the greatest disutility in this respect. The BEV class appears most tolerant with respect to public charging time and perhaps counter intuitively appears to actually derive utility as home/work charging time increases.

- WTP results suggest that the HEV class is most willing to pay for reductions in public charging time. The fact that the HEV class is largely composed of people who do not like the inconvenience associated with periodic charging does not mean that they are not evaluating the impact of this inconvenience. Results suggest that this class will be potentially most responsive to reductions in charging time given a greater willingness to pay for it.

- Related to charging time is the issue of the presence of charging infrastructure. This variable is specific to the plug-in alternatives and covers a wide range where charging stations are $1/10^{th}$ as available as current gasoline stations to being twice as available as current gasoline stations. The results are positive and significant for the plug-in classes but are insignificant for the HEV and ICE classes. The latter two classes are apparently more focused on public charging time than they are on finding the place to charge.

Conclusions

A latent class choice model applied to a large sample of Canadian households has been quite effective in discerning four distinct classes as it relates to the potential adoption of electric vehicles in Canada. The model has also been successful in characterizing these four classes and offering results to enable rich interpretations of the data. Three of these classes are "green classes" and can generally be linked in turn to HEV, PHEV, and BEV vehicles. A class oriented to ICE vehicles stands somewhat alone and distinct.

Clearly, within the "green" class there is a great deal of heterogeneity in preferences and behaviour. A simple set of two latent classes, with one of them defining the green class, is not sufficient to represent and understand this heterogeneity. There is evidence of a strong divide between ICE vehicle classes and green vehicle classes, where the latter category includes households oriented to HEVs. Households that own HEVs and plug-in vehicles do not want to go back to ICE vehicles. These results could suggest that policy incentives should be targeted at moving households towards hybrids and not just the plug-in classes of vehicles.

The ICE and HEV classes are similar in many ways. However, they have one very important difference in that the HEV class is the least price sensitive and the most willing to spend more money on a vehicle while the ICE class is the polar opposite. Where the ICE and HEV classes are similar is in having a dismissive attitude toward inconveniences associated with plugging in. Otherwise, the HEV class is more moderate in attitudes than the ICE class.

Results suggest that much of what defines vehicle choice in this context begins and ends with the price of the vehicle but those more willing to consider an EV are also more willing to look past price. Even with incentives, price remains an issue in most cases.

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