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How open are Canadian households to electric vehicles? A national latent class choice analysis with willingness-to-pay and metropolitan characterization

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ABSTRACT

This paper reports on results developed from a 2015 national survey of Canadian consumers that sought to assess attitudes and preferences towards consumer electric vehicles. A latent class discrete choice model was developed based on stated preferences choices. Four classes emerged with each being oriented to one of the primary vehicle technologies considered. The dominant characteristics of the Internal Combustion Engine (ICE)-oriented class are purchase price sensitivity, EV scepticism and an apparent resistance to change; for the Hybrid Electric Vehicle (HEV)-oriented class it is reluctance to plug-in and an unusual combination of high environmental concern and an acceptance to burn gasoline; for the suburban-oriented Plug-in Hybrid Electric Vehicle (PHEV)-oriented class it is measured optimism about plugging-in combined with an orientation to a replacement vehicle for the next purchase; and for the younger and most urban Battery Electric Vehicle (BEV)-oriented class it is the highest optimism about electric vehicles and a focus on positive aspects such as rapid acceleration and minimized maintenance costs. By orientation of household mindset, approximately 40% are ICE, 30% are PHEV, 20% are HEV and 10% are BEV. These results suggest considerable openness to electric vehicles. Willingness-to-pay for vehicle and charging attributes and incentives were calculated and are highly useful in interpreting the latent classes. The results feature interesting geographical variation which is captured at the level of Canadian metropolitan areas.

1. Introduction

Despite apparent economic, energy, and environmental benefits, Electric Vehicles (EVs) are only very slowly beginning to gain a foothold in the global auto market (Al-Alawi and Bradley, 2013; Klöckner et al., 2013). As of mid-2017, a cumulative total of approximately 35,000 new EVs *"Battery electric vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV)"* have been sold in Canada in contrast to approximately 650,000 EVs in the United States. On a per capita basis, the U.S. market is approximately 2.5 times more advanced than the Canadian one. A majority of the Canadian sales have been supported by purchase price incentives that have been administered in the most populated provinces: Quebec, Ontario and British Columbia. Lagging EV sales in Canada are more

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noteworthy when it is considered that the national electricity generation profile is one of the cleanest in the world. 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 TCO_2e/GWh threshold (Kennedy, 2015). Canada is far below this threshold (167 tCO_2e/GWh). Canada makes for an interesting laboratory to study the consumer landscape for EVs. From coast-to-coast Canada covers 4 ½ time zones. It has two official languages, a diversity of ethnic groups, nearly forty metropolitan areas of varying sizes, regionally distinct weather patterns and an array of different terrain.

There have been extensive efforts to understand the adoption of EVs in varying contexts and using different methods. A clear pattern of research activities has emerged in the literature whereby consumer adoption/rejection of EVs is assessed on the basis of two broad theoretical foundations: economic theories of preference utilitarianism and behavioural theories (Axsen et al., 2015; Rezvani et al., 2015; Schuitema et al., 2013). The more frequent stream of research is rooted in preference utilitarianism theory and deals with the adoption of EVs as a rational choice process (Dumortier et al., 2015; Rezvani et al., 2015; Schuitema et al., 2013) linked to utility maximization (Buskens, 2015).

On the other hand, there is a growing stream of research that relates the adoption of EVs to behavioural aspects (Anable et al., 2011; Mohamed et al., 2016; Wang et al., 2014). Here, there is a more pronounced focus on consumers' personal beliefs, personality, perception and emotion as they relate to EV adoption. Other approaches have included the theory of planned behaviour (Egbue and Long, 2012; Mohamed et al., 2016; Moons and De Pelsmacker, 2012; Wang et al., 2014), normative theories (Moons and De Pelsmacker, 2012), consumer innovativeness (Schuitema et al., 2013), Diffusion of Innovation (DOI) theory (Morton et al., 2016) lifestyle theory (Axsen et al., 2015) and grounded theory (Caperello and Kurani, 2012; Graham-Rowe et al., 2012) to link EVs adoption behaviour to environmental, attitudinal, symbolic, emotional, and societal factors.

Evidence from previous studies provides a sketch of the characteristics of EV adopters, although it has been argued that a rather fragmented picture in the understanding of EV adoption has emerged (Rezvani et al., 2015). EV adopters have been revealed as middle-to-high income (Anable et al., 2011), environmentally concerned middle-aged households (Hidrue et al., 2011; Moons and De Pelsmacker, 2012; Wang et al., 2014; Ziegler, 2012), and with relatively higher education (Hidrue et al., 2011) and full time employment (Plötz et al., 2014). It has been also argued that males are showing more interest in EV technology (Anable et al., 2011; Plötz et al., 2014). A clear distinction is identified in the profile of consumers interested in PHEV and BEV as well (Anable et al., 2011; Plötz et al., 2014). Although these assessments hold part of the truth, it can be argued that there are some fundamental concerns. Firstly, the adopted theoretical perspective, and its procedural tools, can influence the identification of consumers' reaction to EVs (Axsen et al., 2015). The output from a quantitative choice model will not necessarily be confirmed by a qualitative modelling of behavioural aspects for the same users. Although both are aimed at depicting the heterogeneity of consumer adoption of EVs, they represent polar ends of a continuum in approach (Mohamed et al., 2016; Schuitema et al., 2013). Secondly, the circumstances of any behavioural/choice decision vary significantly across contexts. This justifies the imperative need for approaches that capture such variation, and incorporate both preferences and beliefs in a single model.

While not pretending to offer the final answer on such broader methodological questions, this study aligns with preference utilitarianism and uses a particular implementation of the latent class choice model, which is sensitive to how attitudes shape EV preferences. This paper's approach enhances the latent class choice approach of prior EV applications (Axsen et al., 2015; Hidrue et al., 2011) by following the method of Beck et al. (2013) that was applied in assessing the impacts of emissions charges on vehicle choice. In that study, specific Likert-based statements, intended to measure pertinent beliefs, enter directly into the class probability model along with respondent demographics to help allocate choice makers into latent classes. As such, Likert-based indicator variables do not enter into the class-specific sub-models in which utilities of the choice alternatives are estimated.

In comparing the approach of Beck et al. (2013) to EV studies that utilize the latent class choice model, some differences are worth noting. Axsen et al. (2015) uses a sequential approach to form constructs that relate to technology orientation, environmental lifestyle and an indicator of openness to new lifestyles and these constructs enter into the class membership model. Hidrue et al. (2011) avoid the issue of forming attitudinal constructs by asking respondents only about past observable changes in behaviours that relate to the environment. Also, their focus is essentially on BEVs versus conventional vehicles which ultimately results in only two latent classes. Though not focused on attitudes or EVs, Train (2008) carries out a methodologically oriented study where a latent class choice model assesses alternative vehicles powered by hydrogen.

It is worth highlighting other advanced discrete choice approaches that are applicable in the EV context. The mixed logit model has been applied frequently in the EV literature (Mabit and Fosgerau (2011), Hackbarth and Madlener (2013), Tanaka et al. (2014) but these implementations have not offered a mechanism to assess attitudes and beliefs and the general approach has been criticized as harder to interpret (Axsen et al., 2015). Beck et al. (2013) offer a good discussion of the advantages of the latent class choice model over the mixed logit and Shen (2009) has undertaken a comparison between the mixed logit model and the latent class choice model that reflects favourably on the latter. The latent class choice model also does not suffer from the Independence of Irrelevant Alternatives (IIA) property that the multinomial logit model possesses and which the nested multinomial logit model seeks to address (Potoglou and Kanaroglou, 2007).

The hybrid choice model (Bolduc et al., 2008), which has been less frequently used to this point, seeks to generate representative latent attitudinal constructs from a series of indicator variables that directly enter into the utility functions of choice alternatives. The hybrid choice model is conceptually more complex than the latent class model and unlike the latter, does not segment choice makers into discrete classes. In the latent class context, these offer rich potential for interpretation and comparison.

For the current study of Canadian households, the purpose is to understand the preferences for the two primary types of electric vehicles; Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs) relative to each other and against Hybrid Electric Vehicles (HEVs) and conventional Internal Combustion Engine vehicles (ICE) and in a way that is sensitive to household

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