UTILIZING STATED PREFERENCE IN ELECTRIC VEHICLE RESEARCH; EVIDENCE FROM THE LITERATURE

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1. Introduction

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 Kyoto protocol, Canada's goal was to achieve a 6% total reduction by 2012 compared to 1990 levels, however, emissions have increased by 24% since then (Simpson et al., 2011). Canada has also associated itself with the Copenhagen Accord, with a new commitment to reduce GHG emissions to 17% below 2005 levels by 2020 (Environment Canada, 2014). The government of Canada is targeting the transportation sector, specifically road transportation, as one of the largest sources of GHG emissions in Canada. In 2012, around 27% of Canada's emissions originated from domestic transportation of goods and people (Environment Canada, 2014). 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 (Electric Mobility Canada, 2010).

Accordingly, Electric vehicles[i] (EV) have been considered by many as a promising solution towards sustainable transportation and significant reduction in fossil fuel consumption (Daziano & Chiew, 2012). However, four years after the introduction of modern EVs, they have been uncompetitive with internal combustion engine vehicles (ICEV) in the Canadian marketplace. 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 to adopt EVs as their next vehicle purchase.

Efforts to identify the preference of consumers for a particular product have applied different survey methods; these include revealed preference (RP), and stated preference (SP). However, since the existing consumer market for EVs is still in its initial stages, RP technique cannot provide useful information with regards to consumer preference (Louviere et al., 2000). Also, EVs are still considered a new technology that is 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). 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).

The method of SP survey has long been applied to obtain people's preferences in response to different hypothetical situations (Hensher, Rose, & Greene, 2005). Train (1980) and Beggs et al. (1981) were among the first authors who applied such methods in the field of transportation research. Since then, the SP survey technique has emerged as one of the most challenging data collection method used within the choice modelling literature (Hensher et al., 2005). A number of efforts have been carried out to develop comprehensive SP guidelines that are to be used by academics and practitioners (e.g. Hensher et al., 2005; Louviere et al., 2000). Although these attempts provide useful information on the design and applications of SP surveys, yet these are not specifically targeted to the case of EV research. The existing literature on SP surveys in the context of EV research has emphasized data analysis and the mathematical side of choice modeling, while some important elements of SP surveys such as procedures relating to alternatives/attributes/levels selection have been under-emphasized. This study aims to fill in this gap while analyzing the previous practice of SP surveys in the context of EV research.

Even though, SP surveys have become the standard practice for evaluation of a new product such as the EVs, there are a number of associated disadvantages. SP data are hypothetical and may be affected by the degree of 'contextual realism' one establishes for the respondents (Louviere et al., 2000). As a consequence, they may not necessarily represent actual behavior of respondents in the real market. A number of strategies however exist to minimize hypothetical bias associated with SP survey, which will be discussed in this paper. To make the choice scenarios as close as possible to real world situation, special attention must be paid to identifying factors influencing choices. A review of these factors is the topic of the next section. The purpose of this review is to identify factors that have been found consistently in the previous research to affect consumer choice. This is followed by highlights of some limitations within the existing literature. Knowing these limitations opens windows for future work, and allows for more accurate interpretation of estimation results with regard to forecasting and policy analysis. Finally, a discussion on how to overcome these limitations is presented following by a number of recommendations regarding SP survey design.

2. Factors influencing the adoption of EVs

Diffusion of a new product depends on the fulfillment of expectations and needs of potential users. Studies of vehicle choice within the existing literature have examined choice as a function of several factors including; vehicle features (Brownstone, Bunch, & Train, 2000; Dagsvik, Wennemo, Wetterwald, & Aaberge, 2002; Jensen, A. F., Cherchi, E., & Mabit, 2013), socioeconomic characteristics (Egbue & Long, 2012; G. O. Ewing & Sarigöllü, 1998), travel pattern (Axsen & Kurani, 2013; Kurani, Turrentine, & Sperling, 1994), attitudinal factors (Hidrue, Parsons, Kempton, & Gardner, 2011; Krupa et al., 2014), and policies and/or regulations designed to encourage the purchase of cleaner fuelled vehicles (Hoen & Koetse, 2014; Potoglou & Kanaroglou, 2007; Ziegler, 2012).

2.1. Vehicle features

This section reviews the attributes of electric vehicles that significantly differ from their equivalents on an ICE-based vehicle (or not present on conventional vehicles at all) including; monetary (price, fuel cost, etc.), functional (range, acceleration, etc.) and charging attributes.

Monetary attributes: The majority of previous studies have focused on the monetary attributes of EVs, including purchase price, running cost, and financial incentives. Vehicle price has been an important attribute in almost all the previous studies. In a survey conducted among 1000 US residents, 92% of respondents stated that vehicle price would be an important or a predominant factor in the choice of their next vehicle purchase (Krupa et al., 2014). They also found that potential fuel cost saving is important to 86% of respondents. Based on the results, demand for EVs could remain low if pricing is uncompetitive with conventional vehicles.

However, some studies show that consumers might be willing to pay a premium for electric vehicles. One study by Ewing & Sarigöllü (1998) in Montreal found that one-third of respondents are willing to pay at least 1000$ CAD more for a cleaner vehicle. However, according to Hidrue et al. (2011), the cost of batteries must drop significantly before electric vehicles will find a mass market. Due to the growing advances in EV battery technology, it is expected that these costs will be reduced significantly in the coming years (Garcia-Valle & Peças Lopes, 2013). Lebeau et al. (2012) conducted a study in which they projected EV up-take for years 2012, 2030, and 2050. They found that although the market share of BEV and PHEV would increase to 15% and 29% respectively, the speed of penetration is very sensitive to vehicle price.

Throughout the previous studies, financial incentives has been a key factor in motivating people toward these new technologies. In a study conducted by Potoglou & Kanaroglou (2007), it was shown that monetary costs and purchase tax relief would encourage households to adopt an alternative fuel vehicle. In addition, according to electric mobility studies, EVs can provide large savings in fuel costs for their consumers (Garcia-Valle & Peças Lopes, 2013). However, the evidence presented in past studies shows that in general people are more sensitive to the money they pay upfront rather than future savings (Krupa et al., 2014).

Functional attributes: existing literature identified driving range as a crucial factor for the drivers. A recent study in Denmark showed that respondents chose EV half as many times after having a three-month experience with EV than before, mainly due to the limitation of range associated with an EV (Jensen et al., 2014). Driving range is of particular importance in travel behavior studies to identify if a household's driving pattern is compatible with EVs or not (Kurani et al., 1994). Previous studies argue that, despite recent advances in battery technologies of EVs, these vehicles are not still suitable for very long commutes such as vacation trips (Garcia-Valle, R., & Lopes, 2013).

Charging attributes: Another important aspect for the diffusion of electric mobility is the possibility for the potential users to charge their battery easily (Jensen et al., 2014). Long charging time and limited availability of fast charging facilities are currently considered as important limitations of EVs (Axsen & Kurani, 2013; Hackbarth & Madlener, 2013; Ziegler, 2012). Even if some previous research has shown that charging station infrastructure is seldom used and the car owners often charge at home (Golob et al., 1993), the psychological effect that one could charge an electric vehicle if needed helps to reduce the uneasiness or range anxiety and to increase the diffusion rate.

There is no doubt that the success of EVs will be highly dependent on convenient access to charging facilities. These charging facilities however need vast investment and the opposite argument is that this cannot happen until the numbers of EVs on the road increases (Garcia-Valle & Peças Lopes, 2013). Private parking space availability at home equipped with an electric socket is an alternative and convenient approach for providing charging facilities. This factor, however, is largely influenced by households' type of residence and their access to a private garage (Zito & Salerno, 2004).

2.2. Socioeconomic characteristics

Socioeconomic factors help to identify those societal groups that are compatible with future adoption of EVs. Segmentation analysis is beneficial to both policy makers and automotive stakeholders to assess the potential market penetration of EVs by identifying characteristics of households who are more likely to purchase such vehicles. It has been shown in the previous studies that the acceptance of EVs is affected by several individual factors such as educational level, annual income, and number of cars owned by the household, and these variables have been significant almost always and had impacts on the electric vehicle choices (G. O. Ewing & Sarigöllü, 1998; Hackbarth & Madlener, 2013; Hidrue et al., 2011; Potoglou & Kanaroglou, 2007).

Several studies revealed that younger, well-educated people have higher preferences for EVs (Hackbarth & Madlener, 2013; Hidrue et al., 2011; Ziegler, 2012). The cut-off age has usually been a value in the range of 45 to 55. Hoen & Koetse (2014) found that Second-hand car buyers are about twice as sensitive to price as new car buyers but WTP for driving range is similar between two groups. A number of studies have identified that households with higher income have stronger propensity for clean vehicles (Bunch et al., 1993; Potoglou & Kanaroglou, 2007). This result has been inconsistent with research findings conducted by McCarthy & Tay (1998) in which there was negative relationship between income and demand for fuel efficient vehicles. This is justified on the basis that a style of luxury is not compatible with fuel efficiency. McCarthy & Tay (1998) also studied the impact of ethnicity on vehicle type adoption. The result revealed that non-white buyers have higher demands for fuel-efficient vehicles.

Level of car ownership is another significant variables among past studies. Kurani et al. (1994) found that certain multi-vehicle households had a greater preference towards EVs and that the convenience of home recharging appeared an attractive feature of EVs. This result has been consistent throughout the literature with an exception of findings from Ewing & Sarigöllü (1998).

Several studies investigated interaction terms between individual characteristics such as age, education, income, etc., and all or some of the features of electric vehicles such as range, acceleration, etc. For instance, the interaction between commuting distance and fuel cost exhibited a great sensitivity to fuel cost for those who commute longer distances (Potoglou & Kanaroglou, 2007). Also, females are less sensitive to a limited range while high acceleration of EVs has been a positive factors for males (Bunch et al., 1993). Number of family members or number of children in the household are another determining factors affecting the choice of vehicle size (G. O. Ewing & Sarigöllü, 1998).

Location of living place has also significant impact on mobility behaviors and car dependency of households (Garcia-Valle & Peças

Lopes, 2013). Those living in urban areas (large or medium-sized town) have more mobility options (Cervero & Murakami, 2010). They have the opportunity of using a whole range of public transit and bicycle facilities. On the other hand, many rural areas or small town are only accessible by private car. Therefore, it is likely that the use of car is more important for rural groups than urban dwellers (R. Ewing & Cervero, 2001). This leads to the fact that the introduction of electric mobility in urban and rural areas requires different strategies (e.g. in making decisions about the optimum location of public charging facilities). Potoglou & Kanaroglou (2007) showed that the demand for adopting an energy-consuming vehicle (e.g. SUVs) reduced if respondents lived in a dense and diversified urban area. McCarthy & Tay (1998) also studied the geographical place of residence and its impact on vehicle type adoption. They found individuals in more densely populated areas had higher demands for fuel-efficient vehicles.

Hackbarth & Madlener (2013) found that, within an urban area, drivers with access to parking lot equipped with an electric socket are likely to be early adopters of EVs. But, those living in condos or apartment buildings do not have appropriate charging facilities at home and would be more dependent on public or semi-public infrastructures. For this reason, the wide acceptance of private EVs might be limited among those living in apartment buildings, that are likely to be single persons or couples without children or students (Garcia-Valle, R., & Lopes, 2013). In contrast, rural groups of families, seniors, and working couples make a large portion of car owners (Garcia-Valle & Peças Lopes, 2013).

2.3. Incentives and policies

Electric vehicle is still largely an incentive and regulation-driven product to become competitive in the current marketplace. In Canada, for example, there are financial incentives in some provinces for the purchase of certain BEVs and PHEVs (Electric Mobility Canada, 2010). Ontario province also has an incentive program for those who install an EV charging facility at home (Electric Mobility Canada, 2010). Previous research findings in Canada show that financial incentives such as price subsidies and tax-free purchases for clean vehicles are statistically significant (G. O. Ewing & Sarigöllü, 1998; Potoglou & Kanaroglou, 2007). Free parking and access to high occupancy vehicle (HOV) lanes were also significant factors in Hackbarth & Madlener (2013) study carried out in Germany but not significant in the Potoglou & Kanaroglou (2007) study. This result makes sense as Canada's roads are not well equipped with HOV lanes and parking costs in cities (with a few exception) are relatively inexpensive (Potoglou & Kanaroglou, 2007). Taxation of conventional vehicles and subsidization in electricity are other types of policies that may influence consumer behavior towards cleaner and more efficient vehicles (Ziegler, 2012). These policies and regulations are expected to reduce the gap between costs and willingness to pay for electric vehicles and increase the adoption of EVs in the future (Hidrue et al., 2011).

2.4. Attitudinal factors

Following the theory of planned behavior by Ajzen (1991), the main determining factors of behavioral intention are attitudes that are influenced by knowledge, experience, and social influence (Egbue & Long, 2012). In this context, Hidrue et al. (2011) investigated two significant variables in adoption of EVs; green life style and believing in gas price increase. Images of intelligence (e.g. fuel saving), responsibility, and support for the environment (e.g. reduced emissions) are other factors analyzed by Axsen & Kurani (2013), all associated with positive aspects of EVs. Environmental friendliness and concerns for climate change have been also identified as important variables in a number of other analyses (G. O. Ewing & Sarigöllü, 1998; Jensen, A. F., Cherchi, E., & Mabit, 2013; Ziegler, 2012). In a car ownership study in U.S., Weinberger & Goetzke

(2010) investigated the impact of ‘collective preferences’ on people’s decision to buy a car. They found that people who are exposed to relatively lower levels of auto ownership are more likely to own fewer cars, vice versa and other things being equal. These findings can be extended to the case of EV, where more exposure to EV users may increase potential adoption of EVs among consumers.

2.5. Travel pattern

Travel pattern expresses how a vehicle is used by an individual consumer and is helpful to measure a potential market for EVs based on people travel pattern. In an early study, Kurani et al. (1994) developed a qualitative study to explore the vehicle driving ranges that households are willing to consider given their routines, and potential impacts of BEVs on their travel behavior. They found that many multi-car households easily adapt to driving range limits of EVs. In a more recent survey conducted in US, it was found that the majority of respondents (71%) travel fewer than 20 miles per day - which is much lower than a minimum range offered by most PHEVs and BEVs. However, only 32% of respondents were interested in BEVs with a range between 0 and 100 miles (Egbue & Long, 2012). This result is an indication of ‘range gap’ between individual expectations of an EV range and the actual distance that they drive daily.

Hoen & Koetse (2014) found a large heterogeneity among respondents mainly due to differences in annual vehicle usage, in which those with higher mileage had lower preferences for EVs. This view is supported by Potoglou & Kanaroglou (2007) who found that long distance commuters were less interested in alternative fuelled vehicles. Contrary to these results, Hidrue et al. (2011) found that having at least one long trip per month (more than 100 miles) would increase respondent’s orientation toward EVs. The logic for this stems from the fact that EVs have better fuel economy than conventional vehicles.

3. Limitation of previous SP surveys

Last section reviewed previous studies that have used the device of hypothetical SP scenarios for studying vehicle type choice. In general, the characteristics that were found to affect consumers' choices were consistent across these studies. However, we identified some limitations relating to the contextual side of SP design. Although any weaknesses can be defensible within the scope of each particular study, it is the expansion of studies' results into the broader context that can be problematic.

- **Procedure of attribute selection is often ignored**

We found that the existing literature provides little guidance on selection of attributes for inclusion in SP surveys. Also, it is not convincing why some of the key attributes of vehicles are absent from various SP surveys and what governs the inclusion of others. Hidrue et al. (2011) is among a few authors who provided a brief description of why each attribute was included, however, they didn't provide any further information regarding values of ranges (or levels) chosen for each attribute. It is very important that SP surveys take into account the attributes that make EVs significantly different from conventional vehicles (Massiani, 2014). For instance, while many EV studies argued the importance of *charging time* for potential consumers of EVs (e.g. Hidrue et al., 2011; Potoglou & Kanaroglou, 2007), this attribute is not present in a number of SP surveys (Achtnicht, 2011; Dagsvik et al., 2002). The reason for that in many cases, however, is to reduce the cognitive burden associated with SP surveys. Dagsvik et al. (2002), for instance, limited the number of attributes to four, indicating that it would be difficult for respondents to deal with more than four attributes. The issue of cognitive burden, however, needs a full discussion as it depends on many other elements of SP surveys in addition to the number of attributes (Louviere et al., 2000).

- **Alternatives within the choice sets are not comprehensive**

The majority of previous SP surveys ignored the presence of competing technologies as alternatives in a single choice scenario. In many surveys, the respondents are usually asked to make a choice between the new purchase of an EV (i.e. HEV or PHEV or BEV) and a conventional ICE-based vehicle (e.g. diesel or gasoline) (e.g. Hidrue et al., 2011). Consequently, the estimated models may be biased as only one type of EV technology would dominate the estimated future market share while the others have not been taken into account (Al-Alawi & Bradley, 2013).

- **Variations among vehicle classes are often ignored**

Although several car ownership studies (not specifically in the context of EV) have shown the importance of vehicle class and size on consumers' choices (Mohammadian & Miller, 2003; Potoglou & Kanaroglou, 2007), this factor has been often ignored in various SP surveys. For instance, most EVs are now available in smaller vehicle classes, however, it is very likely that EVs become available in all other vehicle classes too. Hence, it is very important that vehicle class be integrated into SP design and modeling to set a correct market potential for each type of vehicle technology (Al-Alawi & Bradley, 2013).

- **Not enough attention has been paid to the background information of respondents**

Besides traditional socioeconomic variables (e.g. age, gender, education, etc.), the most relevant covariates in EV research are: garage availability (or household type as a proxy), vehicle purchase plan (first/replacement/second car), and geographical area (urban/suburban/rural). For instance, mobility behavior in small town and rural region differ from urban areas. In urban areas, people usually have access to a wider range of public transit and other alternative modes of transportation while in rural areas people are mostly dependent on private automobile. Also, ratio of apartment style buildings to single-family housing increases in urban areas, which limits the accessibility of people to a private garage (first priority for charging an EV).

4. Recommendations and conclusion

In this section, we present some recommendations for improving the utilization of SP survey in the context of EV research. The recommendations are based on the findings from literature review and limitations highlighted in the last section:

- **A balance between some competing objectives in SP design is favorable**

In an SP survey design, the analyst needs to meet some competing objectives, and balance them in a meaningful manner (Bunch et al., 1993). One important purpose of SP study is to elicit the maximum amount of information from respondents relating to the parameter attributes and choice outcome. This goal can be achieved by increasing numbers of alternatives, design attributes, and/or choice scenarios shown to each respondent. At the same time, choice complexity and cognitive burden that respondents experience in choice scenarios should be minimized. Survey burden and decision complexity can increase the variance of the random error term and thus reduce the efficiency of parameter estimation (Louviere et al., 2000). Larger designs potentially elicit more information, but often leave the analyst in a challenging trade-off between two desirable design properties (maximum information versus survey simplicity). This, however, can be achieved through a series of qualitative investigations prior to SP design such as interviewing and focus group, consulting with experts, and conducting pilot surveys.

- **SP scenarios should be as close as possible to real choice market**

A synthesis of strategies are presented here to minimize hypothetical bias associated with SP surveys[ii]; first, include those participants who have an initial intention to purchase a car in the future, as it gives a sample representative of the potential cur buyers (Massiani, 2014). Second, it is useful to highlight a few assumptions prior to choice scenarios to make them more similar to the car purchase situation (e.g. ask respondents to treat each scenario as their hard-earned money are on the line). Third, choice scenarios can be customized based on respondents' prior information regarding their current vehicle fleet. Fourth, it is more realistic to select attributes levels that reflect real market values (i.e. market condition) as well as possible future scenarios (e.g. reduction in EV purchase price or the expansion of charging stations). The level ranges may be wide enough to ensure potential forecasting flexibility, but narrow enough to ensure the level of survey believability by the respondents (Bunch et al., 1993).

- **Interpretation of unfamiliar attributes should be undertaken with caution**

This specifically applies to those attributes of EVs that people have no experience with, such as *range*, *charging time* and *public charging stations*. Although these attributes are considered as major barriers to fast adoption of EVs, the penalty that SP surveys find for these attributes are usually too high (Kurani et al., 1994). The analyst should consider the fact that many people want to have unlimited range and fast charging regardless of what their daily range needs are. They may, however, change their decision behavior when being exposed to more EV users or under the influences of new information. Also note that people don't often keep track of their daily driven distance as they would do for monetary expenses such as fuel and maintenance costs. Hence, they are likely to overestimate their daily driving distances when they make their choice in an SP survey. *CO2 emission* is another attribute that should be treated with more caution. This attribute is unique in being identified with a social good (i.e. emissions attribute is usually associated with images of social responsibility and support for the environment), and it is hard to say if respondents' stated preferences would remain the same in real choice decision (i.e. respondents may not behave in the same way they initially intended because of some socioeconomic constraints[iii]) (Bunch et al., 1993). Therefore, it is recommended that respondents' lack of experience with limited range and other unfamiliar attributes of EVs be taken into account when SP results are used for market sale prediction or policy analysis.

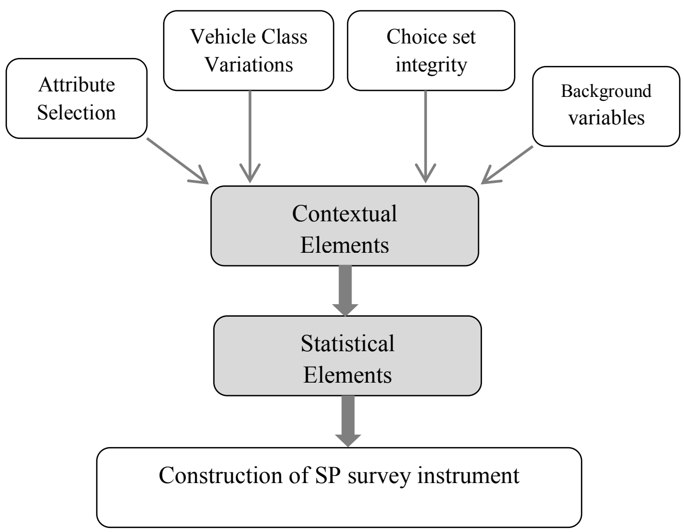

Figure 1: Conceptual framework for construction of an SP survey

In general, SP design can be viewed as integration of two main parts; contextual and statistical elements (Figure 1, highlighted in grey). While statistical requirements of SP design have been extensively discussed in the past (Hensher et al., 2005; Louviere et al., 2000; Train, 2002), less emphasis has been paid to the contextual elements of such design. A general framework to involve contextual elements more within the process of SP design is illustrated in figure 1. This study attempts to highlight some limitations within the existing literature and present some recommendations that could overcome these issues.

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[i] Electric vehicles or EVs refer to vehicles for which propulsive power is all or partially provided from electricity (Egbue & Long, 2012).

[ii] Note that several previous SP survey have applied one or combinations of these strategies. However, we recommend the utilization of all these strategies to ensure that hypothetical bias is minimized.

[iii] Public-good bias effect

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