Modelling the Determinants of Hybrid Vehicle Distribution in the Windsor Census Metropolitan Area

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Introduction

Like most North American cities the Windsor Census Metropolitan Area (CMA) has progressively grew to exhibit a sprawled urban form. Earlier studies indicate that urban sprawl is responsible for longer commute and the alarming rates of tailpipe emissions associated with internal combustion engines. The latter have been the predominant technology used to power vehicles in Canada and elsewhere around the world.

While certain transportation policies has been geared towards combating sprawl, the introduction and penetration of hybrid electric vehicles (HEV) in the market to replace internal combustion engine vehicles is seen as one of the solutions for reducing harmful emissions. The question as to what factors affect people's decision to own HEVs is not a trivial one especially that the market share of HEV technology is fairly low to date. However, there is a need to understand the process governing the way HEVs are distributed over space despite their current low numbers in the market.

In this paper, we investigating what factors potentially affect the adoption of HEVs in the Windsor Census Metropolitan Area (CMA). The objective of the analysis is to establish a statistical model that can explain the significant locational factors influencing the prevalence

(i.e. occurrence) of owned HEVs in certain census tracts of Windsor CMA. Data on owned HEVs by census tract of residence is employed in the analysis. A multinomial logit model (MNL) is specified and estimated to predict the probability of finding a HEV in one of the census tracts comprising the study area. Zonal and vehicle characteristics are used to model the logit probabilities. To our knowledge, the approach followed here to model the determining factors that govern the presence of owned HEVs at a particular location has not been attempted in previous studies.

The remainder of this paper is divided into the following sections. The subsequent section delivers a summary of recent related literatures on the subject. This is followed by a section which highlights the data used in the analysis and also discusses the statistical method used in the analysis. Next, the results from the estimated model are presented and explained. Lastly, the final section gives a conclusion to our study.

Literature Review

Several studies to date have been conducted to assess the consumer preference towards different types of alternative fuel vehicles (AFV). Most of these studies made use of stated preference experiments to evaluate how various vehicle-specific attributes, such as purchase and maintenance costs, max range, acceleration, refueling time, and pollution emission, influence consumers' vehicle choice. Ewing & Sarigollu (2000) use these factors within a multinomial logit model in order to estimate potential AFV adoption in Montreal. Results show that refueling time is insignificant compared to other attributes such as costs and performance. Probable incentives like road pricing and carbon taxes alone are found to be ineffective in AFV preference.

Along with vehicle-specific attributes, Potoglou & Kanaroglou (2007) also use socio-demographic and economic qualities, such as age, gender, education, and household income, in exploring AFV preference in Hamilton, Ontario. Interaction between respondents' and vehicles' characteristics, and government AFV incentives are also examined. Using a nested multinomial logit model, the authors found that respondents with university degrees are more likely to prefer clean vehicles than conventional vehicles, and high-income households are more willing to pay in order to acquire the potential benefits like tax-free purchase that come with AFV. Caulfield et al. (2010) also use a

nested multinomial logit model to examine how vehicle cost, carbon dioxide emissions, and vehicle registration tax would encourage Irish consumers to purchase AFV. Results found that vehicle cost has negative significant impact on AFV choice and high-income households are likely to choose AFV, which is in line with the findings of Potoglou & Kanaroglou (2007). However, carbon dioxide emissions and vehicle registration tax have weak effect on respondents and males are unlikely to choose AFV, other things being equal in the model.

Similar to previous studies, Qian & Soopramanien (2011) use stated choice conjoint analysis to define household and vehicle specific qualities that influence AFV acceptance in China. Again, a nested multinomial model is used, and the findings are in line with the mentioned studies; household income has significant effect on AFV preference, and individuals who frequently long-distance commute are less likely to choose AFV due to lack of refueling facilities.

Recent studies like Hackbarth & Madlener (2013) and Hoen & Koetse (2014) also use vehicle-specific qualities such as initial and operating cost, driving range, refuel time, fuel availability, and probable policies in their stated choice experiments in order to identify the characteristics of consumers that are most susceptible to AFV preference. Both studies use the mixed logit modelling approach to assess the likelihood of AFV preference in their respective study areas, and found that AFV purchase price and their limited driving range have negative significant impact on consumers' choice decision. Hackbarth & Madlener (2013) found that German consumers see refueling time as a weak factor towards AFV choice, while both financial and non-monetary government incentives like vehicle tax and special parking areas have great effect on AFV adoption. On the other hand, Hoen & Koetse (2014) describe refueling time to have a negative effect towards Dutch consumers' choice of AFV and limited policy incentives for AFV are not enough to overcome their negative preferences.

There are also studies that focus primarily on hybrid electric vehicles (HEV) and/or plug-in electric vehicles (PHEV) in the United States (US). Sangkapichai & Saphores (2009) explore Californians' interest in HEV through stated preference phone survey. A heteroskedastic ordered choice model is estimated to explain the respondents preference of HEV. Similar to previously mentioned studies, higher education and household income have great positive effect on HEV

adoption. Plausible solo occupancy access in high occupancy vehicle (HOV) lanes when using HEVs is also significant. He et al. (2012) analyze individuals' choices of HEV using consumer profile attributes and vehicle usage from US National Household Travel Survey and Vehicle Quality Survey data. A hierarchical choice model is used. Conforming to the previously mentioned studies, high household income and high education level have significant influence on probable HEV drivers. Likewise, Li et al. (2013) explore the factors influencing consumers' HEV preference using a nationwide online survey of American vehicle owners. A bivariate probit model is jointly used with vehicle and driving attributes to estimate the market penetration of HEV. Results suggest that rural residents are less likely to purchase HEVs, as well as male respondents, which is in line with the findings in Caulfield et al. (2010). Respondents who often generate long-distance commute are less favourable towards HEV choice. Tanaka et al. (2014) also conducted discrete choice analysis using data from stated preference surveys in the United States and Japan to estimate individuals' willingness to pay for PHEV and electric vehicle (EV). An error component multinomial logit model along with vehicle attributes, such as purchase cost, fuel cost, driving range, emission reduction, and fuel availability is used to evaluate PHEV and EV acceptance in both countries. Findings show that American respondents are more sensitive to fuel cost reduction and charging station availability than Japanese respondents are. However, both countries are significantly affected by purchase price subsidies, driving range limitation, and emission reduction.

Ozaki & Sevastyanova (2011) report a case study of HEV adoption in the United Kingdom based on revealed preference data. Toyota Prius owners, as well as sales assistants, are questioned regarding the revealed purchase motives of HEVs. Some of the answers are due to financial and policy-related benefits, promoting environmentalism and social preferences, and technological interests. The majority of the Toyota Prius buyers are educated, and have stable income. In contrast to findings from two other recent studies by Caulfield et al. (2010) and Li et al. (2013), most Prius owners are men who are 50 years old and above. Similarly, Tal et al. (2013) target the group of plug-in electrical vehicles (PEV) owners in California to expand the knowledge on the characteristics of these individuals. The survey is designed for Nissan

Leaf, Chevrolet Volt, and Tesla Roadster owners and their qualities are compared to general population in California. Findings indicate that most respondents live in major Californian metropolitan regions, and their household income is higher than the general population. Surprisingly, there is a high correlation between PEV and solar panel ownership.

One can argue that using stated preference (SP) or revealed preference (RP) data alone can be subject to errors due to implausible forecasts predicted by SP models, and multicollinearity found among attributes used in RP models. Brownstone et al. (2000) use a mixed logit model the vehicle choice process in California using data derived from SP and RP. Variables considered in the model are primarily vehicle characteristics such as purchase and fuel cost, maximum range, and performance. Results show that number of drivers per household is significant in potential AFV ownership, and possible AFV vehicle share is found to be very low compared to conventional vehicles.

There are also studies conducted that tries to understand the motivation behind HEV purchase, which are different from the ones mentioned above. Heffner et al. (2007) explore the symbolic meanings being created by HEV owners in California using ethnographic interviews. Most decisions are found to be influenced not just by practical concerns, such as possible savings and other incentives, but also by the need to express ones' self, which is not considered in the other studies. Graham-Rowe et al. (2012) conducted semi-structured interviews with a random sample of drivers in the United Kingdom after loaning them PEVs for one week in order to identify the possible qualities that may encourage households to embrace PEV ownership. This study is different from other SP experiments cited before because the respondents can give a much valid opinion towards PEV preference after using one for several days. Negative significance of purchase cost and limited range remained key determining factors as in the case of other studies.

The statistical analysis in this study builds upon these previous efforts by developing a model using demographic and socio-economic characteristics of the census tracts for the Windsor census metropolitan area (CMA), as well as their interactions with attributes of HEV present in the area in order to understand what factors greatly influence HEV ownership in the study area.

Data and Methodology

The datasets analyzed in this study are acquired from various sources. Vehicle related data for the Windsor CMA region are attained from R.L. Polk and Company. The records include vehicle specific information of all registered vehicles found in the area in 2010. The data include information about model year, make, and type of a specific vehicle registered in the area. Other characteristics such as fuel type and vehicle category (i.e. domestic or import) are also available in the dataset. In addition, fuel economy information, which is derived from United States Department of Energy, are also incorporated into the Polk dataset. Each vehicle is georeferenced to its respective census tract zone. The entire population of private vehicles is found to be 199,436; however, only 348 vehicles (about 0.17%) is considered hybrid electric vehicles (HEV). The distribution of HEV in Windsor CMA is presented in Figure 1. Likewise, the distribution of HEV based on vehicle classes is showed in Table 1.

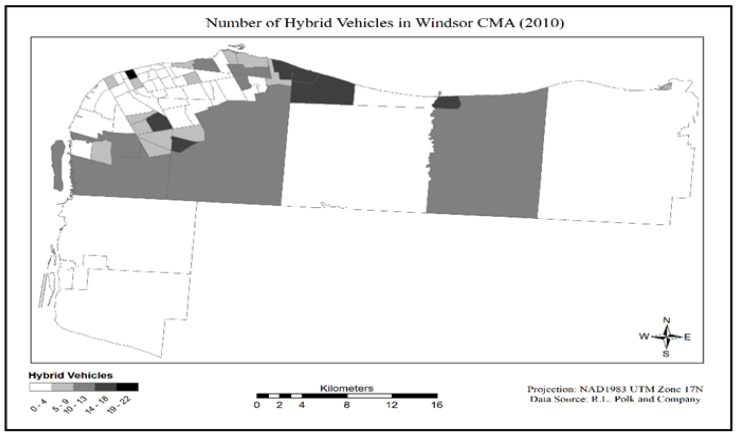

Figure 1: HEV Distribution in Windsor CMA

Table 1: HEV Class Distribution

Vehicle Class	*Domestic*	*Import*	*Grand Total*
Compact Cars	0	23	23
Large Cars	0	1	1
Midsize Cars	31	129	160
Sport Utility Vehicle	94	28	122
Subcompact Cars	0	36	36
Two Seaters	0	6	6
Grand Total	**125**	**223**	**348**

Moreover, several demographic variables from the 2011 Canadian National Household Survey (NHS) are examined to identify what particular census tract attributes have great influence on HEV adoption. Some of these variables represent the age, gender, level of education, and occupation of individuals residing in certain census tracts. The dataset has global non-response rate (GNR) of 28.1%, which indicates low risk of non-response bias and inaccuracy. Nonetheless, some census tracts do not have demographic information. Eliminating these zones is not an option because there are HEV present in these areas. Their demographic variables are estimated by taking the weighted average of the values of their respective neighboring census tracts. Weights are based on adjacent proximity queen structure.

Relationship between urban form and HEV ownership in Windsor CMA is also explored. Here, a mixed density index (MDI_i) is generated and tested. MDI_i is calculated using the following equation:

$$MDI_i = \frac{(E_i \times P_i)}{(E_i + P_i)}$$

where E_i is employment density and P_i is population density of census tract i. A higher MDI_i value suggests a better job-housing balance in the zone. Also, the impact of land use mix is examined via a Land Use Mix (LUM) index. For this, the 2011 DMTI Spatial Land Use Data for the Windsor CMA is used to calculate the LUM_i index for any given zone i. The following formula is used to estimate the LUM_i of each census tract:

$$LUM_i = -\frac{1}{K}\sum_{k=1}^{K} P_k \ln(P_k))$$

where P_k is the proportion of specific land use with respect to total land area and K is the total number of land use present in the census tract. LUM_i values range from 0 to 1 with values closer to 0 suggesting areas with mixed land use (i.e. high level of heterogeneity) and those closer to 1 suggesting areas with single use (i.e. high levels of homogeneity).

While we could have used a multinomial logit model to examine the revealed choices of households for selecting a particular class of vehicle which include the HEV class, such approach would prove inadequate given the very low market share of HEV in the study area (i.e. 0.17%). To fulfill the objective of this study and be able to provide a good insight into the determining factors that influence the choice of HEVs in our study area, we opted for a different modeling approach. Considering the population of HEV vehicles in the study area, our approach is focused on modeling the probability Pr(i) of finding HEV h among one of the 70 zones i that comprise the study area.

Given the large number of choices (i.e. 70 alternative zones), we formulated our choice set by selecting nine random zones from the 70 zones and adding them to zone where the true choice occurred. Next, a multinomial logit model is estimated to explain the potential HEV choice decision process among the 10 formed alternatives. The probability $P(i)$ of locating a HEV on a specific zone is modelled based on the choice utility V_i^h which is a linear in parameter function of various socio-economic factors X_i in census tract i, as well as their interactions with different vehicle attributes S_h:

$$P(i) = \frac{\exp(V_i^h)}{\sum_j \exp(V_j^h)}$$

The specification of the deterministic and systematic utility function V_i^h is based on various hypotheses that are inspired by the literatures and real world observations. A list of the utilized variables is shown in Table 2. To begin with, it is hypothesize that zones with people holding post-secondary certificates has positive influence towards HEV ownership because they tend to have stable jobs, and are more knowledgeable of the potential benefits of HEV adoption. Moreover,

census tracts with high proportion of high-income households, primarily those who make at least $60,000 a year, are expected to play positive and significant role in HEV preference because the purchase

Table 2: Description of Explanatory Variables

Variable	Description
MHIGHEDU	Proportion of the male population in each census tract with post-secondary certificates
MNGT	Proportion of the total population in each census tract with management related occupation
INCHIGH	Proportion of the total population in each census tract with household income of at least $60,000
AGE4064	Proportion of the total population in each census tract aged 40 to 64
WCHILD	Proportion of the total population in each census tract with at least 1 child in a household
OUTSUB	1 if census tracts is located in outer suburbs, 0 otherwise
MDI	Mixed density index of each census tract
LUM	Land use mix of each census tract
INT1	Interaction term between *MHIGHEDU* and imported sport utility vehicle
INT2	Interaction term between *MNGT* and sport utility vehicle
INT3	Interaction term between proportion of total population in each census tract with health related occupation and fairly new imported vehicles (model year from 2007 to 2010)
INT4	Interaction term between the *INCHIGH* and very new imported vehicles (model year from 2009 to 2010)
INT5	Interaction term between *AGE4064* and fairly old vehicles (model year 2000 to 2008)
INT6	Interaction term between *WCHILD* and imported SUV, and midsize vehicles

price of a HEV is less likely to be an impeding factor. In addition, individuals who live in outer suburban areas are more inclined to adopt an HEV because they are more likely to generate high levels of vehicle kilometers traveled (VKT), and they could greatly benefit from HEV's excellent fuel efficiency. On the other hand, it is expected that zones with high number of middle age people (i.e. ages 40 to 64 years old), as well as households with at least one child, will be less likely attractive destinations for HEV because of its high purchase price. One could argue that the money could be invested in something else that could benefit the whole family instead. Significance of different interaction terms between zonal demographic factors and vehicle attributes are also checked. These assumptions are justified using their estimated parameters' statistical significance and anticipated signs.

Results

The estimation results from the multinomial logit model is presented in Table 2, with all of the parameter coefficients and their corresponding t-statistics and p-values. The results suggest a well behaved model with a total ρ^2 value of 0.126. The estimation is conducted in the NLOGIT 4.0 Econometric Software.

It is found that census tracts with high proportions of men with post-secondary certificates are less likely to have HEVs. In a way, this result disproves the hypothesis that individuals with high education are inclined to owning HEVs. A possible explanation to this difference is that men prefer large and powerful vehicles. This claim is supported by the positive significant interaction term between men with post-secondary certificates, and imported sports utility vehicles (SUVs). This outcome illustrates that the feasibility of HEV adoption in zones with many high-educated males increases if the HEVs are imported SUVs.

The choice probability of new imported HEV (model year 2009 and 2010) increases in zones with high percentage of households with high income, primarily $60,000 or more. The same could be said about areas with high proportions of individuals with management related professions; however, managers are more likely to choose SUVs in general. On the other hand, the contingency of owning fairly new imported HEVs (model year 2007 or higher) in census tracts increases

with high proportion of people with health related occupations. These results prove the hypothesis that people with high paying jobs are likely to choose HEV because they are less concern with its substantial purchase price. Another possibility is that people in the health profession are more conscientious about the negative environmental impacts of driving conventional internal combustion engine vehicles.

Table 3: Estimated Results

Parameters	***Beta***	***S.E.***	***t-stats***	***P-value***
$\beta_{MHIGHEDU}$	-0.04177	0.02211	-1.89	0.0588
β_{MNGT}	0.06619	0.03018	2.19	0.0283
$\beta_{INCHIGH}$	0.03195	0.00758	4.22	0.0000
$\beta_{AGE4064}$	-0.14679	0.02917	-5.03	0.0000
β_{WCHILD}	-0.04006	0.01206	-3.32	0.0009
β_{OUTSUB}	0.50218	0.17518	2.87	0.0041
β_{MDI}	0.00143	0.00023	6.16	0.0000
β_{LUM}	-0.02194	0.01067	-2.06	0.0398
β_{INT1}	0.13569	0.05969	2.27	0.0230
β_{INT2}	0.08616	0.03949	2.18	0.0291
β_{INT3}	0.18834	0.05019	3.75	0.0002
β_{INT4}	0.02090	0.00959	2.18	0.0293
β_{INT5}	0.06238	0.02992	2.09	0.0371
β_{INT6}	0.04347	0.01462	2.97	0.0029
$L(0)$		-801.300		
$L(\beta)$		-700.511		
ρ^2		0.126		

When it comes to census tracts with high percentage of middle-aged individuals, specifically ages 40 to 64, the likelihood of HEV adoption in general decreases, but the probability of choosing older HEV models (model year 2000 to 2008) increases. This result supports the

hypothesis that people who belong to this age group are possibly repelled by HEV's high purchase price, other things being equal. It could also mean that people in this age group did their investment in the early 2000s when they were younger albeit such conclusion will require further investigation. Areas with high proportion of households with at least one child have negative effect on HEV preference. However, the result show that they are more inclined to HEV ownership if the HEVs are SUVs and midsize vehicles, which are the typical vehicle type for households with children.

In case of census tracts located in outer suburban areas, the results suggest that HEV locational preference tends to increase in these areas. This result is in line with the 2010 distribution of HEV in Windsor CMA. Moreover, zones with high mixed density index have positive and significant effect on HEV adoption. This means that people in areas with high job-housing balance are more prone to own HEVs. It could be because people who are more environmentally oriented tend to reside in more balanced areas and as such are more likely to gravitate towards more environmentally friendly vehicles.

With regards to land use mix, the results suggest that census tracts that area more homogenous (i.e. single use) are less likely to attract HEVs. This is expected since areas with homogenous land uses pertain to neighborhoods with single use in sprawled areas. Those neighborhoods house large and young families who will prefer to own minivans for their travel needs.

Conclusion

This paper focused on modeling the hybrid electric vehicle (HEV) segment, and identifying the locational factors that make a census tract more or less attractive to house HEVs in Windsor CMA. The results reinforce some of the previous findings from the literatures. It is found that education, gender, income, profession, and urban form have significant effect on HEV preference.

The achieved results provide a good benchmark for more extensive work on the topic. Analysis for other Canadian metropolitan areas will be needed to perform comparisons of the most significant factors influencing the locational preference of HEVs. Eventually, a larger sample size of HEVs could provide more flexibility in the modeling especially if more vehicle attributes could be introduced. Without

doubt, the analysis conducted in this paper provides good insight into the process as it relies mainly on commercially acquired data such as the Polk data and Census data that are available for various Canadian metropolitan areas. In that sense, comparative analysis of more recent Polk data could be performed to assess the market penetration of HEVs in Canadian markets.

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