Journal of Transport Geography 60 (2017) 59–67

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

The spatial distribution of hybrid electric vehicles in a sprawled mid-size Canadian city: Evidence from Windsor, Canada

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ARTICLE INFO

Article history:
Received 17 March 2016
Received in revised form 22 February 2017
Accepted 24 February 2017
Available online xxxx

Keywords:
HEVs
Vehicle ownership
Discrete choice modeling
Canada

ABSTRACT

Technological advancements in recent years have allowed hybrid electric vehicles (HEVs) to improve in terms of associated tailpipe emissions and fuel efficiency. As a result, the demand for HEVs in Canada has been on the rise, but the market share is still negligible. In this paper, the population of HEVs in the Windsor Census metropolitan area (CMA), Ontario, Canada for the year 2010 is considered to study the determinants that led to the observed spatial distribution of this class of vehicles across the different census tracts within the CMA. Vehicle-specific characteristics along with locational variables are employed in the analysis. Locational factors are based on census tract profile attributes (namely socio-economic factors) that were acquired from the 2011 Census National Household Survey (NHS). Other variables used in the analysis include mixed density index, average commuting distance and a measure of spatial clustering. Discrete choice modeling is used to explain the residential location of HEV owners in the CMA. Moran's I statistics analysis suggests that the spatial distribution of HEV owners exhibits a clustering pattern. This was also reinforced by the significance of the spatial term used in the choice model. Area-based socio-economic factors pertaining to the size of population, gender, type of occupation, education, size of household of the people living in an area, and income explain the spatial prevalence of HEVs. Also, areas housing long distance commuters as well as areas with mixed density tend to house HEV owners.

1. Introduction

Dependency on automobiles over the past six decades, coupled with urban sprawl, has led to longer commutes in most Canadian cities. The last twenty-five years witnessed increasing concern over global climate change and greenhouse gas emissions due to increased transportation activities. While certain transportation policies have been geared towards combating sprawl to reduce the number of vehicle kilometers traveled (VKT), the introduction and penetration of hybrid electric vehicles (HEVs), since the beginning of the new millennium is seen as one of the solutions for reducing greenhouse gas emissions (He et al., 2012; Li et al., 2013). HEVs have better fuel economy compared to their conventional gasoline-based counterparts. In that respect, the adoption of HEVs can lead to better efficiency in the long run, especially that the demand for private vehicles will continue to grow in the future.

An HEV is characterized as a more efficient conventional vehicle because it utilizes an electric motor besides a conventional gasoline engine to aid its propulsion (Maness and Cirillo, 2012). One of the key features of an HEV is its ability to generate electric energy as a result of the regenerative braking process (U.S. Department of Energy, 2012). The latter process converts energy that is typically wasted while coasting and braking into electricity and stores it in the electric battery empowering the electric motor of the vehicle. Another positive feature is the "power-assist" which provides additional power to the conventional engine to reduce gasoline demand when the vehicle accelerates. A third feature that distinguishes HEVs from their conventional counterparts is the "idle-off" mechanism which turns of the conventional engine when the HEV stops. Given the potential benefits of HEVs, it is important to understand the factors that affect people's decisions to own these types of vehicles, especially in sprawled commuter sheds. An example of the latter is the Windsor Census metropolitan area (CMA) in Ontario, Canada (Maoh and Tang, 2012). As a sprawled region, Windsor's shares of HEVs in the years 2010 (0.17%) and 2013 (0.28%) were negligible.

While the majority of the existing studies on HEV adoption have relied on stated preference choice surveys (Potoglou and Kanaroglou, 2008), little has been done to analyze revealed HEV adoption, especially in sprawled mid-size Canadian cities. An exception can be found in the recent work of Bansal et al. (2015) for the U.S. The work in this paper addresses this shortcoming by analyzing the factors that explain the observed spatial pattern of HEVs in Windsor, Canada. In so doing, the paper makes two distinct contributions to the existing transport geography literature. Firstly, the paper attempts to define the role of built

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http://dx.doi.org/10.1016/j.jtrangeo.2017.02.010
0966-6923/

environment factors on the adoption of HEVs in a sprawled urban environment with a strong auto-oriented culture. Secondly, the performed analysis uses a different method than the one used in Bansal et al. (2015) to model the spatial distribution of HEVs at the census tract level. To our knowledge, such approach to study the spatial distribution of HEVs has never been attempted in past research. Our approach is focused on modeling the residential location of HEV owners in the city. We contend that the locational pattern of HEV owners in Windsor exhibit a spatial pattern (e.g., clustering). Therefore, locational and socio-economic factors can be used to explain the aforementioned pattern.

The remainder of this paper begins with a Literature review section, which provides an account of the current state of knowledge on vehicle ownership modeling. Next, a "Methods of analysis" section is provided to describe the datasets used in the analysis and to highlight the statistical methods used to model the data. Results and discussion section presents the results from the performed analysis and discusses the obtained results. Finally, the last section provides a conclusion to the study and proposes some direction for future research.

2. Literature review

Although the current market share of non-conventional gasoline-based vehicles remains negligible, several studies have been conducted to evaluate consumer preference towards different types of vehicle technologies such as alternative fuel vehicles (AFVs) and HEVs. These studies are motivated by the foreseen benefits that these vehicles can bring, including their fuel efficiency, dependency on renewable energy sources and potential environmental benefits. In what follows, we provide an overview of the types of data that have been employed to study consumer preference towards owning vehicles. This will be followed by a discussion on the type of statistical methods that have been used to model consumer's vehicle type preference.

2.1. Types of data

There are usually two types of data used to assess consumers' vehicle preferences: revealed preference (RP) and stated preference (SP) data. RP data are typically used to explain actual choice behaviors towards the current alternatives in the market. This type of data is influenced by current market constraints and characteristics of the decision maker, which provide reliable market demand assessments. However, given the scarcity of non-conventional vehicles including the hybrid electric vehicles (HEV), in the current market, few studies have utilized RP data to understand the factors influencing vehicle choice decisions.

For example, Haan et al. (2006) surveyed new HEV owners, specifically Toyota Prius 2, during the first nine months of introducing these vehicles in the Swiss market. The authors suggested that certain socio-demographic attributes like household income and level of education have positive and significant influences on HEV ownership. They also noted that HEVs have not been accepted by the majority of consumers, and their market share is mostly powered by early adopters. Ozaki and Sevastyanova (2011) conducted a similar study where recent HEV owners in the United Kingdom were administered with a questionnaire survey to understand their reasons behind HEV adoption. The authors found that most HEV owners were educated with stable income. Incentives, as well as social and technological interests, also have positive influences on their choice decisions.

Gallagher and Muehlegger (2011) also explored how various monetary and non-monetary incentives can increase the number of different AFVs in the U.S. market. It was observed that there has been a strong relationship among tax incentives, gasoline prices, and HEV preference. The amount and the type of tax stimuli had a significant influence on consumers' behavior towards HEV ownership. They also found that some non-monetary incentives like single-occupant access to high occupancy vehicle (HOV) lanes had insignificant effect on HEV preference; however, other studies indicated that HOV privileges could stimulate HEV adoption, especially in California (see for example: Shewmake and Jarvis, 2014; Sangkapichai and Saphores, 2009). In addition to practical benefits like potential savings and incentives, Heffner et al. (2007) conducted interviews to investigate personal and social symbolism affecting the vehicle purchase decisions of Californian HEV owners. The authors noted that consumer perceptions of vehicle image, such as environmentalism, maturity, and intelligence, were some of the reasons for owners' HEV adoption.

On the other hand, SP data are often used to forecast the demand for new or yet to exist in the current market. According to Potoglou and Kanaroglou (2008), vehicle type choice models have been widely used to assess the future demand for conventional and alternative fuel vehicles. The authors provided an extensive review of the state of knowledge on the topic, with an emphasis on the type of data used, various modeling approaches, and critical explanatory variables. It is noted that the demand for AFVs has been studied through SP surveys.

A pioneering effort on the latter topic can be found in the work of Ewing and Sarigöllü (2000), who analyzed the factors affecting the choice of clean fuel vehicles in Montreal, Canada with the help of SP experiments. The significance of vehicle performance, purchase cost, different government subsidies, as well as consumers' attitudes towards environmental issues were utilized to evaluate the future demand for such vehicles. It was found that though perceived environmental impacts were important, vehicle purchase cost and performance were more important when purchasing a new vehicle.

Potoglou and Kanaroglou (2007) found that incentives alone were ineffective in promoting AFVs in Hamilton, Ontario. Along with vehicle-specific attributes, demographic and socio-economic (e.g., age, gender, level of education, and household income) factors were utilized to assess the potential of purchasing AFVs via an SP survey. The results reinforced and complemented the findings reported in the case of AFV adoption in Montreal; purchase cost and performance emerged as key determinants. The study also suggested that individuals with high level of education and high income households were more likely to choose AFVs than conventional vehicles. Similar findings had been reported elsewhere in the literature (see for example: Bansal et al., 2015).

2.2. Types of discrete choice models

Various types of discrete choice models, alongside SP surveys, have been the dominant methods to determine and analyze the future ownership of new vehicle types around the world. In a recent study, Lin and Greene (2010) explored the potential market distribution of plug-in hybrid vehicles (PHEVs) by comparing them with other vehicle technologies in the U.S. Using a Nested Multinomial Logit (NMNL) model, the authors found that PHEVs are greatly influenced by technological attitude, recharging availability, and vehicle usage intensity. The conducted study was later extended to further evaluate the effects of recharge accessibility on PHEV market using the Market Acceptance of Advanced Automotive Technologies (MA3T) model (Lin and Greene, 2011a). Results suggested that advancements of recharge technology would be greatly influenced by reduction in battery cost and would likely increase PHEV demand. The authors further extended their modeling work to assess and understand the significance of vehicle usage (i.e., daily vehicle miles traveled) on PHEV energy consumption (Lin and Greene, 2011b). It was established that the variations in vehicle usage over time significantly affect PHEV energy impact, especially the ones with larger batteries.

The NMNL model had also been used by Qian and Soopramanien (2011) to analyze the likelihood of various groups of consumers to adopt AFVs in China. It was argued that some types of AFVs can be perceived as conventional vehicles by Chinese consumers wanting to own a new vehicle. Different NMNL model specifications were introduced and estimated. Covariates, such as purchase cost, vehicle performance, and household income, had significant effects on AFV adoption, which support prior research. Results showed that individuals were more likely to