Transportation Research Part D 52 (2017) 85–97

Contents lists available at ScienceDirect

Transportation Research Part D

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

Spatial effects on hybrid electric vehicle adoption

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ARTICLE INFO

Article history:

Keywords:
Hybrid electric vehicle
Technology adoption
Spatial effects

ABSTRACT

This paper examines spatial effects on hybrid-electric vehicle (HEV) adoption. This is in contrast to most existing analyses, which concentrate on analyzing socioeconomic factors and demographics. This paper uses a general spatial model to estimate the strength of 'neighbor effects' on HEV adoption—namely that each consumer's HEV-adoption decision can be influenced by the HEV-adoption decisions of geographic neighbors. We use detailed census tract-level demographic data from the 2010 United States Census and the 2012 American Community Survey and vehicle registration data collected by the Ohio Bureau of Motor Vehicles. We find that HEV adoption exhibits significant spatial effects. We further conduct a time-series analysis and show that historical HEV adoption has a spatial effect on future adoption. These results suggest that HEVs may appear in more dense clusters than models that do not consider spatial effects predict.

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1. Introduction

A hybrid-electric vehicle (HEV) contains an internal combustion engine and an electric propulsion system. This allows the vehicle's kinetic energy to be converted to electric energy that charges a battery when decelerating. This electric energy is used when the HEV subsequently accelerates to achieve better fuel economy. HEVs represent a rapidly developing transportation technology, which is widely accepted by customers compared to other types of non-conventional vehicles. Block and Harrison (2014) report that a total of about 3 million HEVs have been sold in the United States between 1999 and 2013. The Toyota Prius, which entered the United States market in the year 2000, led all HEV sales, representing a 41.8% market share (as of the end of the 2015 model year), followed by HEV versions of the Toyota Camry and Honda Civic.[1]

Predicting future HEV adoption is of interest for a number of reasons. Sioshansi and Denholm (2010, 2009) show that HEVs can introduce transportation-energy and -cost savings and associated emissions reductions relative to conventional vehicles. These efficiencies are of interest to policy makers. Another is that HEV adoption patterns can be used as a proxy for adoption of other more advanced transportation technologies that are not yet as mature as HEVs. This includes plug-in electric vehicles (PEVs). While HEV adoption is not a perfect proxy for PEV adoption, one can expect some similar adoption-dynamics between the two technologies. Egbue and Long (2012) and Plötz et al. (2014) note that initial adoption of a new vehicle technology tends to be dominated by technology enthusiasts or early adopters. At the same time, Axsen and Kurani (2012) note interpersonal influences between early adopters of vehicle technologies and subsequent adopters (when the technology becomes more widely adopted). We believe that studying such dynamics in the adoption of HEVs can provide

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[1] http://www.afdc.energy.gov/data/.

http://dx.doi.org/10.1016/j.trd.2017.02.014
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useful insights into the possible future trajectory of PEV adoption. Finally, Tuttle and Baldick (2015) explicitly state that because of the advanced nature of HEV technology and adoption dynamics, a number of studies use past HEV adoption rates as a baseline from which to project future PEV adoption.

PEV adoption raises additional concerns relative to HEV adoption, because PEVs include a grid-chargeable battery. The impacts of PEVs on the electric power system depends both on the rate at which they are adopted and the extent to which their owners are geographically clustered. As an example of this, Collins and Mader (1983) and Mohseni and Stevie (2009) analyze possible PEV adoption in two regions of the United States. They find that significant clustering of PEVs is possible, which can yield extremely high distribution-level loads that may require significant infrastructure investments. Proactive planning of such investments requires knowing the extent to which PEVs may be clustered and where such clusters may appear.

Most empirical studies of HEV adoption focus on the effects of socioeconomic and demographic factors only. These studies reveal some geographic clustering of HEV adoption, because people with similar socioeconomics and demographics tend to cluster. Nevertheless, these studies do not capture the direct neighbor effect, which is that each consumer's HEV adoption decision can be influenced by HEV adoption decisions of geographic neighbors. Thus, these studies may result in biased estimates that underestimate geographic clustering.

In this paper we explicitly study such neighbor effects on HEV adoption, to fill this gap in the existing literature. We use several variants of a general spatial model to estimate the strength of these neighbor effects. Using demographic data from the 2010 United States Census and 2012 American Community Survey and vehicle registration data from the Ohio Bureau of Motor Vehicles, we demonstrate that HEV adoption exhibits statistically significant spatial effects. We also conduct a time-series analysis and show that historical HEV adoption has a significant spatial effect on future adoption. The remainder of this paper is organized as follows. Section 2 surveys other HEV adoption studies. Section 3 discusses the structure of the spatial models used in our analysis. We detail the data used in our analysis in Section 4 and summarize our results in Section 5. Section 6 concludes.

2. Literature review

According to Musti and Kockelman (2011), unit vehicle price, vehicle type or class, and fuel economy are among the most important factors that affect vehicle-adoption decisions. Curtin et al. (2009) study the effects of economic considerations, environmental attitudes, and non-economic attitudes on HEV adoption. They conclude that although economic considerations have a significant influence on HEV purchase probabilities, environmental and other non-economic attitudes have an even larger impact. They also provide a model that can estimate HEV purchase probabilities of different households based on socioeconomic and demographic variables, including region (*i.e.*, urban versus rural) of residence. Although region of residence is included in this model, it does not explicitly capture spatial effects. Despite this, their study suggests some clustering of HEV adoption due to the clustering of individuals with similar socioeconomics and demographics. Gallagher and Muehlegger (2011) examine the relative efficacy of different incentive mechanisms, such as tax-based subsidies, on consumer HEV adoption. As with the work of Curtin et al. (2009), this analysis neglects spatial effects. Rezvani et al. (2015) provide a comprehensive overview of the drivers for and barriers against consumer adoption of PEVs. Their work focuses on consumers' perceptions of PEVs, as this is an important driver of technology adoption.

Axsen and Kurani (2011) conduct one of the few analyses of PEV adoption to date that captures spatial impacts. Their study focuses on investigating the effects of social interactions on influencing perceptions of PEVs. This is done by mapping social networks, which gives a social episode diary, ranking the influence of different interpersonal experiences, and assessing how interpersonal interactions affect attitudes toward PEVs. To map people's social interactions, they conduct a detailed four- to six-week study of the social networks of individuals from 10 households. The work of Axsen and Kurani (2011) has two important distinctions compared to ours. First, because they focus on the spatial impacts of social networks on PEV adoption, their study relies on a small data set. This is because they must construct each subject's social network, which is a time-consuming process. Because our study focuses on the spatial impacts of geographic networks (*i.e.*, the effects of HEV adoption by a spatial neighbor on an individual's adoption decision) we can use a much larger data set, which in our case covers the entire state of Ohio. This is, however, also a limitation of our analysis. We do not model the effects of HEV adoption by someone within an individual's social network that is not a geographic neighbor on vehicle-purchase decisions.

3. Structure of spatial models

Spatial analysis is successfully applied to many subfields of economics, including economic growth theory and regional and labor economics. According to Ward and Gleditsch (2008) the use of these techniques is motivated by interest in studying the interactions between social entities. This is because in many cases the outcomes of an individual's actions do not depend solely on that individual's attributes but also on the individual's physical location and interactions with others.

Paelinck and Klaassen (1979), Anselin (1988) describe spatial econometrics as a subfield of econometrics that deals with spatial interactions (*i.e.*, autocorrelations) and structure (*i.e.*, heterogeneity) in regression models for cross-sectional and panel data. LeSage and Pace (2009) identify two features that distinguish spatial from traditional econometric techniques:

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