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The spatial pattern of demand in the early market for electric vehicles: Evidence from the United Kingdom

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1. Introduction

The dominant position of the car to service personal mobility needs in the majority of economically developed nations has been firmly embedded over the past half century. The desire of citizens for car mobility stems from the substantial affordances which cars offer (Dant, 2004), allowing their users to attain transport speeds, flexibilities, and seamless movements which alternative modes of transport usually cannot provide (Schwanen and Lucas, 2011). The car mobility system is remarkably resistant to subversion, meaning a transition away from their personalised service is unlikely to occur in the near future (Urry, 2007; Wells and Xenias, 2015). While car use will likely be sustained in the future, there is a general awareness of the harms the system generates inclusive of economic, social, and environmental issues (Banister, 2005). Geels (2012) refers to some of these harms as destabilising pressures, which have the potential to produce shifts in system configuration to allow for a sustainable transport future to be realised (Geerlings et al., 2012).

One such potential shift in the configuration of the transport system relates to the integration of new propulsion and fuel technologies in cars (Banister, 2008). Electric Vehicles (EVs), which partially or entirely replace the internal combustion engine with an electric motor powered by electricity stored in an on-board battery pack, represent the leading technology to motivate this shift. EVs have the potential to offer considerable benefits to society such as enhancing the energy efficiency of vehicles, diversifying the energy input to the transport system, improving local air quality, and reducing the greenhouse gas (GHG) emissions of car mobility (Faria et al., 2012; Ma et al., 2012; Sandy Thomas, 2012; Wu et al., 2015). In the United Kingdom (UK), EVs represent the primary mechanism through which substantial reductions in the GHG emissions inventory for the transport sector will be realised in order to meet the legislated carbon targets (Climate Change Act, 2008). This is apparent in the Committee on Climate Change's (2015) Fifth Carbon Budget which estimates that 9% of all new vehicle sales in the UK will need to be EVs by 2020, increasing to 60% by 2030.

Realising the preferred emissions reduction trajectory of the Committee on Climate Change for the transport sector is contingent on the appearance of high levels of demand for EVs. This anticipated emergence and subsequent rapid growth in EV demand has generated a large expansion in research investigating issues related to EV technical improvement (Dijk and Yarime, 2010; Tuttle and Kockelman, 2012), citizen reaction (Egbue and Long, 2012; Axsen et al., 2013; Graham-Rowe et al., 2011), energy system integration (Pasaoglu et al., 2014; Robinson et al., 2013), and identifying the characteristics of drivers likely to adopt EVs during their initial diffusion (Plötz et al., 2014; Schuitema et al., 2013; Nayum et al., 2016; Higgins et al., 2017). The diffusion of EVs through national vehicle fleets is often discussed temporally, with models designed in order to predict future rates of adoption and to construct potential uptake trajectories (Shepherd et al., 2012; Zubaryeva et al., 2012a; Tran et al., 2013). Comparatively less attention has been paid to the manner in which EVs are diffusing spatially and how the uptake of EVs differs across geographical areas. This paper contributes to this area of study by exploring how the early demand for EVs (i.e. plug-in hybrid and pure battery electric vehicles) has spatially manifested across the local authorities of the UK through the application of spatial econometric modelling. The analysis examines the spatial variation in the demand for EVs and determines if this variation displays signs of geographical organisation. Moreover, the analysis investigates the association which is present between EV demand and the environmental context covering the socioeconomic, household, and transport system characteristics of the local authorities. Within this, the relationship between EV registrations and the installation of charging infrastructure is evaluated to consider if infrastructure investments are stimulating demand in the immediate and intermediate vicinity.

2. Existing literature

The topic of EV demand has attracted a substantial degree of academic attention over the past decade, likely due to the degree of importance placed on EVs in transport policy (Al-Alwai and Bradley,

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2013; Rezvani et al., 2015). Research has focused on how citizens will interpret the unique characteristics of EVs and their formation of preferences towards these vehicles. Applications of Discrete Choice Modelling (Train, 2009) have generally found that citizens are averse to the limited driving ranges and purchase price premiums of EVs, with the reduced environmental impact and improved operating costs of EVs unlikely to overcome these negative evaluations (Potoglou and Kanaroglou, 2007; Caulfield et al., 2010; Hidrue et al., 2011). Concentrating on the latent characteristics of individuals, research employing psychometric analysis has identified attitudes relating to environmental concerns (Ozaki and Sevastyanova, 2011; Morton et al., 2016) and personal value structures (Jansson et al., 2011) as relevant issues in EV evaluations. The integration of Discrete Choice Modelling and psychometric analysis is an area which has been proposed (Ben-Akiva et al., 2002) and can lead to the specification of more realistic models (Bolduc et al., 2008). Model integration of this nature has been pursued by Daziano and Chiew (2012), who propose the combination of observable and latent attributes previously identified as holding explanatory power concerning preferences towards EVs into an integrated model of EV demand.

With the market for EVs expected to grow substantially over the next 25 years, forecasting the demand for EVs represents an active area of inquiry. Current forecasts tend to present alternative adoption scenarios, demonstrating how alterations in the system parameters which are known to influence adoption (e.g. expectations concerning the reduction in EV purchase price premiums and expansions in EV driving range) can influence uptake trajectories. Musti and Kockelman (2011) simulate the evolution of household vehicle fleets in Austin, USA, over a 25 year period through the construction of alternative scenarios with their model indicating that two and three car households are most likely to integrate an EV into their household fleets while feebate[1] policies can discourage the adoption of vehicles with large footprints (e.g. Sports Utility Vehicles). Employing a conjoint adoption model, Eggers and Eggers (2011) produce a number of short-term (2009–2018) adoption scenarios for EVs and utilise a series of critical factors inclusive of purchase price, driving range, timing of EV market entry, and environmental evolution in their uptake trajectories. Modelling the demand for EVs to 2050, Shepherd et al. (2012) make use of a systems dynamics model to evaluate alternative market scenarios, with their results indicating that it is a combination of different elements, that cover the configuration of market conditions, which are important, and that considering single factors in isolation may lead to suboptimal recommendations. Recently, Brand et al. (2013) evaluate the impact of different fiscal transport policy mixes through the UK Transport Carbon Model (Brand et al., 2012) with their findings supporting the importance of feebates by suggesting that policies which offer financial rewards for low carbon vehicle choices while penalising the purchase of heavily polluting vehicles will lead to the most rapid expansion in EV sales.

While research that explores the distribution of EV sales over time allows for considerations relating to the effect of government policy mix, initial market conditions, and anticipated technical improvements to be modelled, investigations of this nature tend to overlook the dispersal of EV sales across space. Spatial analysis of EV demand allows researchers to investigate issues relating to the role of infrastructure deployment, situational contexts, and varying demographic arrangements. Researchers have begun to address these issues with Campbell et al. (2012) constructing a spatial cluster model in an effort to identify the residential location of citizens who are most likely to adopt an EV in the city region of Birmingham, UK. Their model is built using UK census data with the results indicating that potential EV adopters tend to concentrate in suburban locations. Campbell et al.'s model is extended by Namdeo et al. (2014) who combine demographic data with travel patterns to identify optimal locations for the installation of public EV charging infrastructure in the Tyne and Wear metropolitan area of the UK. The results of their analysis suggest that latent demand for EVs relating to two citizen groups who tend to reside in the inner city could be promoted through the placement of proximate charging points.

A series of works have demonstrated the insights which can be generated when combining spatial and temporal aspects of EV demand forecasting in an integrated analysis. Zubaryeva et al. (2012b) develop adoption scenarios for the European Union based on the factors likely to influence early demand expressed by experts in a multi-criteria assessment (Zubaryeva et al., 2012a). They find that lead markets for EVs are likely to be sited in large, densely populated urban areas in the economically prosperous member states. These findings hold parallels to the work of Higgins et al. (2012), who spatially forecast EV demand out to 2030 across the metropolitan region of Melbourne, Australia, with geographical differences in uptake being primarily motivated by driving distances, employment status, and household income. Similarly Kihm and Trommer (2014) model EV adoption trajectories to 2030 for the German market and find that EV registrations tend to concentrate in urban and suburban areas.

Recently, research has begun to examine the realised uptake of low emission vehicles, primarily through examinations of the geographic distribution of Hybrid Electric Vehicle (HEV) registrations. Saarenpää et al. (2013) conduct an analysis in which the spatial adoption of HEVs is compared to socioeconomic data in Finland. The analysis finds that HEVs have a higher propensity to be registered in areas which have populations that have a high degree of formal education, household income, and proportion of owner-occupied homes. Through the specification of a multinomial logit model of HEV demand across the census tracts of Windsor, Canada, Dimatulac and Maoh (2017) find that HEV uptake is associated with gender splits, employment type, education level, household size, and income. The demand for HEVs has also been examined using spatial econometric models, with the work of Liu et al. (2017) and Morton et al. (2017) finding that education level, car availability, household size, travel to work patterns, and personal incomes all have significant associations with uptake. Chen et al. (2015) build a Poisson log-normal conditional autoregressive model of non-hybrid EV adoption (i.e. plug-in hybrid and pure battery electric vehicles) across the census blocks of Pennsylvania, USA, with their findings suggesting that EV registrations tend to be lower in areas that have high densities of low income households and areas that have increased distance to the central business district. Moreover, Chen et al. (ibid.) identify persisting spatial autocorrelation in their model of EV demand, implying that other issues which are spatially clustered and that are challenging to include in spatial models (e.g. parking availability and pricing) may also be associated with EV uptake.

To summarise, research which involves the spatial modelling of EV demand has so far fallen into two categories. Firstly, predictive models have been produced which aim to estimate the likelihood of areas to include early EV adopters (Campbell et al., 2012; Namdeo et al., 2014) and how this likelihood of adoption alters over time (Zubaryeva et al., 2012b; Higgins et al. 2012; Kihm and Trommer, 2014). Secondly, explanatory models have been formatted with the goal of examining what area characteristics can be of use in accounting for the observed spatial variation in adoption (Saarenpää et al., 2013; Dimatulac and Maoh, 2017; Liu et al., 2017; Morton et al., 2017; Chen et al., 2015). The research presented in this paper sits within the second category and aims to extend current understanding regarding the spatial diffusion of EVs in the early market by determining the degree to which the socioeconomic, household, and transport characteristics of the areas as well as the presence of charging infrastructure in the immediate and intermediate vicinity can be of use in accounting for the spatial variation in EV adoption.

[1] Feebate policies generally include the provision of rebates for fuel efficient vehicles and surcharges for highly polluting vehicles.