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Uncertainty in the Demand for Electric Vehicles: An analysis of its location and governmental response

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Abstract

The introduction of Electric Vehicles (EVs) into the passenger vehicle market has, in recent years, become viewed as a primary solution to the significant carbon emissions attributed to personal mobility in the current transportation system. These vehicles range from those which can be viewed as existing within the current technological regime, such as hybrid vehicles, to those which, by their nature, exist on a different technological pathway and are categorized as disruptive innovations. The greatest emission reduction potentials currently exist in these disruptive innovation pathways, notably pure battery electric powertrain systems. The UK and EU Governments have played an active role in steering the development and market introduction of EVs. Policies have been formulated and introduced to engage the consumer by raising awareness of these alternative options, incentivise adoption through fiscal measures and establish the necessary infrastructure. However, a great deal of uncertainty remains regarding the effectiveness of these policies and the viability of the EV technology in the mainstream automotive market. This paper investigates the prevalence of uncertainty concerning demand for EVs. This is achieved through the application of a conceptual framework which assesses the location of uncertainty. UK and EU Government policy documents are assessed through a rapid evidence review alongside contributions from academia to determine how uncertainty has been reduced. Specific attention is paid to the complexities of governmental policy making in an uncertain environment and how policy makers have responded to this challenge. Preliminary results from the analysis are presented and discussed alongside an overview of the selected methodology utilised in the evaluation.

Introduction

Electric Vehicles (EVs) represent a category of vehicle which utilise advancements in battery technology to reduce energy demand and the carbon dioxide (CO₂) intensity attributed to passenger vehicle mobility. These technical advancements have been realised in a variety of different formats ranging from plug-in hybrid electric vehicles, which incorporate a small battery pack alongside a traditional internal combustion engine (ICE), to pure battery electric vehicles which operate solely from electricity. EVs are viewed as a primary means by which the UK and EU Governments will meet their commitments to reduce CO₂ emissions in the transport sector (OLEV, 2013; EC, 2012a). This sentiment is shared at a global level with industrialised and newly industrialised nations considering EVs as a technological mechanism which holds the capability of allowing political statements concerning energy efficiency to be achieved (IEA, 2011). Specifically focusing on the UK, legally binding legislation has been passed which requires CO₂ emissions to be reduced by 80% based on 1990 levels by 2050 (Climate Change Act, 2008) with five year carbon budgets established to ensure the UK is on a trajectory to meet this commitment (HMGov, 2009). EVs represent a form of disruptive innovation (Christensen, 1997; Zapata and Nieuwenhuis, 2010) meaning their introduction has the potential to destabilise existing market conditions. As a result of the disruptive characteristics of EVs, there is a significant degree of uncertainty surrounding the

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proposed transition to these vehicles (Stuben and Sterman, 2008; Savacool and Hirsh, 2009).

This paper investigates this issue of uncertainty by examining how it manifests in respect to demand for EVs. Specific attention is given to private household EV demand though passing references are also made concerning uncertainty in the fleet market. A conceptual framework which illustrates the different locations of uncertainty is developed and described. Each location represents a specific domain of uncertainty, where different actors operate, with the conceptual framework illustrating how these locations are connected. A rapid evidence review of UK and EU Government policy documents combined with research output from the academic sector is used to demonstrate how uncertainty has been addressed. To structure the analysis, two research questions have been formulated:

- What are the main locations of uncertainty in the demand for EVs?
- How has policy been used to reduce uncertainty in the demand for EVs?

The structure of this paper firstly presents the background to the concept of uncertainty and the approach employed to conceptualise it before stating where the policy and supporting documents relevant to this study were sourced. Following this, the conceptual framework assessing the location of uncertainty is developed and then applied in reference to EV demand. Having presented the results of the rapid evidence review, the research questions initially outlined are approached to demonstrate the contribution of the analysis. To conclude, the key points from the analysis are summarised followed by a brief discussion of how future research can provide additional contributions in this area.

Background and Approach

Uncertainty is a concept which is present to some degree in all forms of social system. As the world has become more complex and interrelated, uncertainty has become an important issue. A lack of appreciation for the implications of uncertainty can lead to significant costs to society (Meijer et al., 2007). In this regard, investigating the concept of uncertainty in reference to how it has exhibited in demand for EVs is likely to be a worthwhile endeavour.

Uncertainty manifests itself as any form of deviation from the unachievable ideal of complete deterministic knowledge of a system (Walker et al., 2003). The concept has been conceptualised in different formats, ranging from pure statistical approaches (Greenland, 2001) to the influence it has over human decision making (Tversky and Kahneman, 1974). Additionally, the concept of uncertainty has been examined in certain areas of transportation, with its influence over the estimation of greenhouse gas emissions from the transportation sector (Kioutsioukis et al., 2004; Int Panis et al., 2004) and its prevalence in traffic forecasts (Waller et al., 2001; de Jong et al., 2006) being well established. In this paper, the framework initially developed by Walker et al. (2003) forms the basis of the investigation. This framework defines uncertainty according to three main characteristics incorporated in an uncertainty matrix. Firstly, the location of uncertainty can be established through the development of a model of the relevant environment. Secondly, the level of uncertainty can be assessed on a continuum ranging from absolute determinism to total ignorance. Thirdly, the nature of uncertainty can be explored to assess if a particular instance of uncertainty is *epistemic*, and thus reducible through the acquisition of additional knowledge, or *variable* and thus reflecting a natural deviation present in the system. This paper specifically focuses on defining the locations of uncertainty in EV demand through an assessment of the topics which have been discussed in UK and ED Government policy and academic documents.

Walker et al.'s (ibid) framework has received widespread acknowledgement by the academic community. Refsgaard et al. (2007) conducted a review of fourteen methods for examining uncertainty in environmental modelling and determined that the uncertainty matrix was most effective at identifying and classifying uncertainty. Investigating how decision making in environmental management is affected by uncertainty, Ascough II et al. (2008) utilise the uncertainty matrix to determine the degree of epistemic uncertainty in a system in order to quantify how uncertainty can be reduced. Assessing uncertainty in the use of genetically modified organisms, Kraymer von Krauss et al. (2004) employ the level component of the uncertainty matrix to quantify expert judgements. Providing a critical assessment of the

uncertainty matrix, Warmink et al. (2010) extend the initially defined methodology through the inclusion of qualitative uncertainty and acknowledge the presence of ambiguousness in the nature of uncertainty. This extended uncertainty matrix is then applied to two case studies in environmental modelling with the results seeming to improve the process of identification and classification of uncertainty.

To develop a database of relevant governmental policy documents to allow for an assessment of how UK and EU policy makers have approached the issue of uncertainty, a rapid evidence review was conducted. In reference to UK documents, the internet portal gov.uk was used to identify relevant government documents. In addition, the Low Carbon Vehicle Partnership's resource library was reviewed to provide additional material such as supporting documents and consultancy reports. For EU documents, a similar procedure was followed with the EU bookshop internet portal being the principal source of documents. In all instances, the review process was exhaustive, with each portal searched in its entirety for documents concerning transport, energy demand and EVs. Documents were evaluated to identify areas of the text which were relevant to EV demand to determine how government policy has responded to the challenge of reducing uncertainty. Focus was given to documents which discussed EV consumer related issues though the analysis also included the other locations of uncertainty which are detailed in the conceptual framework outlined in the forthcoming section. To complement this, relevant academic literature was sourced from an extensive literature review previously conducted in EV demand (Morton, 2013a).

Conceptual Framework of Uncertainty

To determine the locations of uncertainty regarding demand for EVs, an overview of the relevant environment has been established. A framework of uncertainty which was initially outlined by Meijer et al. (2006) and subsequently applied to micro CHP (Meijer et al., 2007) is used as a starting point to develop a conceptual framework of the locations of uncertainty for EV demand. The structure of Meijer et al.'s (2006) framework is updated to account for the nuances of the EV market. These updates were informed by the points of discussion which were prominent from an assessment of the government policy documents. The framework is illustrated in Figure 1 and contains six primary components. Of the six primary components, four are internal to EV demand and comprise [1] consumers, [2] political, [3] infrastructure and [4] technological whilst two are external consisting of [5] economic and [6] societal.

Additionally, the conceptual framework of EV demand has been informed by the method specified by Walker et al. (2003), with the locations of uncertainty being further refined by considering uncertainty in reference to framework structure, internal components, how these components are related and the external inputs to the framework. In this paper, focus is given to framework structure and components by determining what are the locations of uncertainty for EV demand, how these locations are related and what represents and internal and external component of the framework. This distinction between internal and external components reflects the volitional control of policy makers, with internal components being controllable to some degree whilst external components are less controllable. In the next section, each of these components is briefly outlined followed by a discussion regarding the rationale for their inclusion and their expected influence. After this, a review of how UK and EU Government policy has been utilised to address these identified uncertainties is offered.

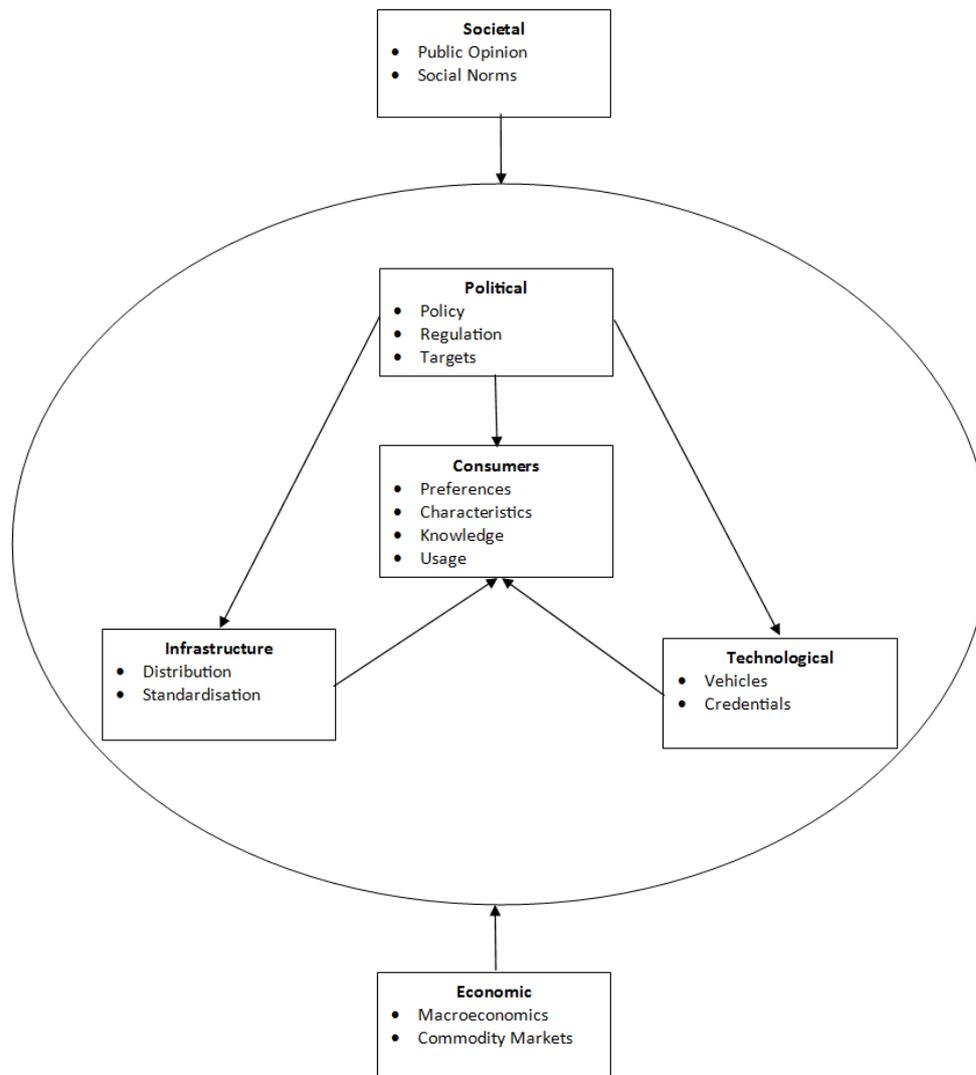


Figure 1: Conceptual Framework of the Locations of Uncertainty in Reference to EV Demand

Locations of Uncertainty

Whilst the fundamental locations of uncertainty regarding the development and introduction of new technologies are likely to share similarities, each innovation will have a unique uncertainty environment which accounts for its particular nuances. This section details the specific uncertainties which exist in reference to EV demand by applying the conceptual framework detailed in the proceeding section to the Government policy documents and academic literature sourced from the rapid evidence review.

1. Consumers²

Forming the focal point of the framework, consumers represent the principal component of interest with four aspects of consumer uncertainty being topical in reference to EV demand.

Firstly, consumers have preferences towards different vehicles based on the subjective utility they assign to different vehicle characteristics (Lave and Train, 1979). In reference to EVs, consumer preferences represent an area of significant uncertainty, with extensive research

² In this specific iteration of the model, the environment is being developed in reference to private household consumers. It is anticipated that the environment can be re-defined for fleet consumer demand with little effort required.

attempting to quantify preferences for the unique attributes of EVs (Beggs et al., 1981; Calfee, 1985; Dagsvik et al., 2002) and estimate likely market shares (Train, 1980; Bunch et al., 1995; Eggers and Eggers, 2011). This issue has received attention by the UK Government, with King (2007) exploring how consumers make choices between different cars. Findings suggest that encouraging consumers to select the appropriate class of car for their needs and ensuring that the car selected is best in class for CO₂ emissions holds an emissions abatement potential of 15% and 25% respectively. Similarly, the importance of understanding consumer preferences has been acknowledged at the EU level (EC, 2010a). Doubts have been raised regarding consumer willingness to pay for technology aimed at reducing car emissions (EC, 2005) whilst choice experiments have determined that consumers tend to upgrade range and reduce purchase price rather than increase top speed or improve recharge times in EVs when given the option (EC, 2012b).

Secondly, consumers can be categorised by their defining features to allow manufacturers and governments to target market interventions. The common characteristics of EV adopters represents an area of uncertainty, with low sales volumes (DfT, 2013a) meaning data on actual purchasers is difficult to attain. This has led researchers to employ research methods based on psychometric surveys (Borthwick and Carreno, 2012) and census data (Campbell et al., 2012) to assist in identifying likely adopters. The UK Government commissioned a report to examine the emerging EV market (Slater et al., 2009) with findings suggesting that early adopters have a higher willingness to pay for EVs, a premium of £2000 was viewed as being acceptable which is in keeping with other research findings (Potoglou and Kanaroglou, 2007), whereas mass market consumers were unwilling to pay extra to support new technologies. Moreover, early adopters of EVs tend to originate from multicar households and hold relatively high levels of household income and formal education (Morton, 2013b).

Thirdly, the degree of awareness consumers have regarding EVs and the degree to which knowledge needs to be improved to accelerate EV demand represents an aspect of consumer uncertainty. Increasing awareness of and knowledge concerning a product tends to be viewed as an effective strategy to increase adoption (Lavidge and Steiner, 1961). Axsen and Kurani (2008) examined consumer awareness of plug-in hybrid EVs in California and found that knowledge concerning the vehicles was markedly low and confusion between hybrid EVs and plug-in hybrid EVs was common. Taking a UK perspective, Lane (2005) found that awareness of the environmental consequences of car use among British drivers was high whilst knowledge concerning low carbon vehicles was categorized as moderate. However, these results are challenged by recent research which found that non adopters of EVs generally lacked knowledge regarding the difference between EVs and plug-in hybrid EVs, charging requirements, vehicle range and models available (Hutchins et al., 2013). Determining the required level of information to provide concerning EVs and the best format for this information to take is viewed as an important issue by the UK Government (DfT, 2009). King (2008) highlights the importance of providing consumers with easily understandable information regarding vehicle CO₂ emissions to allow them to make informed purchasing decisions. Recent research has demonstrated that miles-per-gallon remains the preferred metric of fuel efficiency for car buyers and also a proxy for environmental impact (Lane and Banks, 2010). The UK Government has expressed a commitment to diffusing knowledge concerning eco-labels, ensuring industry adoption and regulating the information provided to reduce the prevalence of unsubstantiated product claims (HoC, 2009). Research has examined the effectiveness of eco-labels with consumers tending to react to eco-labels at the model rather than the class level (Noblet et al., 2006) and information presenting on sliding scales found to be the most effective transmission method (Teisl et al., 2006). This issue has also gained traction at EU level (EC, 2007a; EC, 2010a) with mandatory minimum standards on promotional literature stating 20% of all vehicle advertisement space must be dedicated to fuel efficiency information (EC, 2007b). However, uncertainty still remains regarding the degree to which manufacturers are prioritising the importance of eco-labels in the purchasing environment.

Fourthly, with EVs representing cars with unique characteristics which are likely to affect driver behaviour, it remains unclear how drivers will use and fuel these vehicles. Specifically, uncertainty exists regarding car use alterations as drivers transition from ICE to EVs such as trip purpose, trip distance and the formation of charging habits. To address this issue, UK

and EU Governments have commissioned a series of public EV trials to explore usage patterns. The EU's green eMotion initiative involves a demonstration project which examines all aspects of the transition to EVs (EC, 2011a). This project runs between 2011 and 2015 and is set to trial 2,000 EVs across 14 locations. In the UK, the government established an Ultra-Low Carbon Vehicle Demonstrator programme which operated between 2009 and 2012 and utilised 350 low carbon vehicles across 8 consortia projects. Findings from the programme are that users tend to extend their daily range as they become more experienced with the vehicle (Cabled, 2010a), with two-thirds of journeys being less than 5 miles (Cabled, 2010b) and an average trip length of 5.1 miles compared to a national average of 7 miles (Carroll et al., 2013). In reference to vehicle charging, the average charge duration is less than 2 hours (Cabled, 2010a) with the vehicles being plugged-in 21.7% of the time. Additionally, users tended to let their batteries run down more with increased experience (Everett et al., 2011) whilst 10% of charging was conducted at public infrastructure points (Carroll et al., 2013).

2. Political

With the passenger vehicle market representing a sector of significant economic importance (Eddington, 2006), it proves to be an area which is actively managed by the UK and EU governments. The management strategy utilised is multifaceted, covering areas related to vehicle regulation, taxation and usage. Political behaviour and policy formation represent a specific location of uncertainty. In this framework, the issues of specific interest have been reduced to three main categories covering policy, regulation and targets.

In reference to EVs, the UK Government has stated an initial investment of £400 million between 2009 and 2015 (DfT, 2009) with an additional commitment of £500 million to 2020 (DfT, 2013b). To oversee the transition to EVs, the Low Carbon Vehicle Partnership (DfT, 2002) and the Office on Low Emission Vehicles (BIS, 2013) were established to act as communication platforms, to support research and development and coordinate funding. Similarly, the EU expressed its policy in reference to EVs under a European Strategy for Clean Energy Efficient Vehicles (EC, 2010; EC, 2010b; EC, 2011b) and has established the European Green Cars Initiative (EC, 2012c, EC, 2012d) which was launched in 2008 with a €5 billion funding commitment. These policies assist in reducing political uncertainty by demonstrating government commitment to EVs, allowing consumers to have confidence in prolonged government backing of the technology.

Secondly, government has the option to regulate the market environment by manipulating taxation and fiscal programmes. By altering the taxation scheme, the government can create incentives for the adoption of one vehicle type whilst reducing the merits of others. The UK was the first country to introduce vehicle circulation taxes (VED) based on CO₂ emissions. However, questions had been raised in the early years of implementation regarding the effectiveness of the scheme, with lack of driver awareness and insufficient differentiation in the tax bands cited as limitations (HoC, 2004; HoC, 2006). Recently, UK VED have been altered with the introduction of eight additional bands, which have increased the resolution and monetary separation of the scale, alongside a first year tax rate (the premium of which can be considered a purchase tax) aimed at penalising heavy emitting vehicles (HMTreasury, 2008). However, these changes have been criticised for lacking the ambition required to generate significant behavioural change and for being inadequately publicised with the general public who are still not aware this represents an environmental tax (HoC, 2008). Moreover, recent updates to UK company car tax (CCT) (HMTreasury, 2012) have reduced the incentive for fleets to purchase low emission vehicles by removing first year tax allowances, a move which may cause instability in the market and send mixed messages about the government's commitment to low emission vehicles (HoC, 2012a). However, the perceived ineffectiveness of these alterations to vehicle circulation and registration taxes could originate from consumers tending to consider these issues unimportant, with VED and CCT ranked least important in reference to purchase evaluation metrics among households and fleets in the UK (Lane, 2005).

Related to this issue of vehicle taxation is the increasing popularity of purchase incentives for EVs. These incentives are aimed at reducing the upfront costs of purchasing an EV which

are viewed as a significant barrier to demand (Beggs et al., 1981). Academic research has explored the effectiveness of these schemes at incentivizing adoption, with findings suggesting that the price of petrol is significantly more important over the adoption of hybrids vehicles compared to purchase incentives for US consumers (Diamond, 2009), subsidies produce no significant addition to market uptake over what is produced by vehicle regulation (Harrison and Shepherd, 2013) whilst the metric of assessing which vehicles qualify does not significantly influence adoption rates (de Haan et al., 2007). The UK Government has introduced a £5, 000 Plug-in Car Grant (PiCG) for vehicles emitting less than 75 gCO₂/km. Uncertainty exists regarding the effectiveness of this scheme, with questions raised regarding if the incentive is enough to spur demand (HoC, 2012a). Assessing the impact of the policy, research commissioned by the Department for Transport (Hutchins et al., 2013) found that the presence of the purchase grant was stated as being an important issue with 85% of household and fleet EV adopters who tended to consider the magnitude of the grant to be appropriate. However, non-adopters of EVs tended to find the purchase price to remain a significant barrier even with the incentive whilst general awareness of the scheme was regarded as being low. To ensure that purchase incentives operating in the EU comply with state-aid regulations and do not adversely affect the single market, the EU (2013a) has proposed guidelines to coordinate and harmonize schemes operating in the community. Incentives are to be technological neutral, be based on CO₂ tailpipe emissions and not to exceed the price premiums of the vehicles above a comparable conventionally fuelled alternative. These guidelines will give confidence to consumers purchasing EVs within the European community by ensuring that the magnitude of incentive does not significantly differ between member states.

Lastly, governments can sanction targets to operate in a market environment, which state a desired destination for specific aspects of the system. Targets can take a number of different forms, such as those which are technology neutral as opposed to targets which are focused on specific innovations, and can operate at varying levels ranging from national to local targets. In the automotive market, targets have been actively utilised with the UK Government specifying a 16% reduction in domestic transport emissions by 2020 (DfT, 2009) whilst the EU has expressed an objective to replace 20% of conventional transport fuels with alternatives by 2020 (EC, 2001). Specifically relating to cars, The UK Government, under their Powering Future Vehicles Strategy of 2002, stated a goal of having 10% of new car sales in 2012 emitting less than 100gCO₂/km (DfT, 2002) with an actual sales figure of 8.6% being achieved (DfT, 2013c). At the European level, the EU has established targets for average new car emissions being no greater than 130gCO₂/km by 2015 (EC, 2007c), decreasing to 95gCO₂/km by 2020 (EC, 2009) with a long term ambition of 70gCO₂/km by 2025 (EC, 2007). Official targets for EV sales are less clear, with the UK Government stating that adoption targets for EVs are not appropriate (HoC, 2012b) whilst the EU has expressed an objective to have between 8 and 9 million EVs on the road by 2020 (EC, 2013b). Taking a slightly different approach, the Committee on Climate Change has estimated how many EVs will be required in order to meet the UK's carbon budget commitments and has set a target of 240, 000 EVs and plug-in hybrid EVs on the road by 2015, increasing to 1.7 million by 2020 (CCC, 2009). However, with only 4, 100 EVs being registered in the UK in 2012 (DfT, 2013d), it is unlikely the first of these targets will be realised.

3. Infrastructure

In order for new fuels to become a viable market alternative, infrastructure to support them needs to be established. In the case of EVs, infrastructure is partly installed through an extensive high voltage and local distribution grid. However, uncertainty exists over whether additional provision is required, the quantity of this provision and its optimum location. This issue has been addressed in academic research with Campbell et al. (2012) assessing the spatial distribution of likely EV adopters to determine appropriate locations for infrastructure whilst Pridmore and Anable (2012) examine hot spots of adoption as a precursor to exploring the interaction with infrastructure availability. The EU considers this to be a significant issue and has set targets for infrastructure installation for all member states (EC, 2013c) with the UK required to install 1.2 million EV charge points with 122, 000 of these being publicly available by 2020. To provide a sense of the challenge these targets offer, only 3, 000 chargepoints have been installed in the UK by 2012 (HoC, 2012a).

The UK Government has stated its specific policy regarding the installation of EV infrastructure, rolling out a Plugged-in Places Initiative (PiP) which has installed charging posts in eight selected sites in an effort to develop front-running locations for EV adoption and to give consumer confidence in the ability to recharge EVs in public places (OLEV, 2011). The effectiveness of this initiative has been brought into question, with no significant relationship found between installed infrastructure and EV adoption (HoC, 2012a). Responding to this, the UK government commissioned research into the effectiveness of the PiP initiative with the findings indicating that 40% of households and fleets stated public charging infrastructure is an important issue but that awareness of the initiative during adoption was low and not a factor in the purchase decision (Hutchins et al., 2013). Recommendations are made to ensure infrastructure is installed at likely destinations and across the strategic road network.

A related issue to this concerns different vehicle manufacturers having selected different plug architectures to charge their EV battery packs. This can cause confusion with consumers, who may not be aware of the technical differences leading to challenges in selecting the best option for their situation. Linked to this, it is currently uncertain what the required mix between standard, fast and rapid charge points is and the role of more novel innovations such as inductive charging. To address this, the UK Government has expressed a desire for charge plug standardisation to mitigate this adoption barrier (HoC, 2012a). Responding to this, the EU has conducted stakeholder engagement and expert reviews to identify the most appropriate technical specification for charge points to ensure universal compatibility (EEGTF, 2011a).

4. Technological

The technical attributes of EVs have been repeatedly identified in empirical research as representing a significant barrier to EV demand. Consumers still tend to consider EVs to be cars of the future as opposed to viable options in the present market (Caperello and Kurani, 2012). In this paper, two specific aspects of technological uncertainty in demand for EVs are highlighted for discussion.

Determining the likely development curve and long-term viability of the technology is viewed as an important issue to inform policy makers and to improve consumer confidence in EVs (EC, 2010b). Roadmaps for the estimated improvements to EV technology (SMMT, 2002; IEA, 2011; Cluzel and Douglas, 2012) alongside scenarios of possible futures (AEA, 2009; GFEI, 2009) have been popular approaches. The UK Government commissioned an influential report which assessed the technical and economic viability of different powertrains (NAIGT, 2009). Findings from this report suggest that EVs will be viable in the mass market by 2020, though this will depend on breakthroughs in energy storage. At the European level, the future technological development of EVs has been assessed with an action plan to 2050 established (EEGTF, 2011b). The importance of harmonization of standards, installation of fast charge infrastructure and sustained support for research and development are highlighted as necessary in order to make EVs viable options. Ultimately, if EVs can reach comparative technical performance to conventional vehicles, consumers appear willing to shift to the technology platform (Eggers and Eggers, 2011).

Focusing on a specific technical aspect, questions have been raised concerning the environmental credentials of EVs (Graham-Rowe et al., 2012), with drivers concerned that the increased emissions in the production of EVs and in the generation of electricity diminish the appeal of the vehicles. Research conducted for the Low Carbon Vehicle Partnership demonstrated that, even with current UK electricity grid fuel mix, EVs are associated with significant life cycle emissions reductions compared to conventional cars (Gbegbaje-Das et al., 2013). Moreover, as more renewable energy comes online and the carbon intensity of the grid decreases, CO₂ emission savings attributed to EVs will increase. However, more research on this issue is required to develop better understandings of production emissions, end of life recycling emissions and emissions associated with the provision of infrastructure (Contestabile et al., 2012). This issue is repeated across a number of related technical areas, with EV demand being reduced by uncertainties surrounding EV battery life, claimed fuel efficiencies, achievable ranges and operational capabilities in cold weather conditions.

5. Economic

External to the EV market is the wider economic environment which comprises regional, national and international levels. This wider economic environment can have significant external effect over the EV market, most notably at the level of national markets which have minimal influence over global automotive manufacturers. The variability of the economic environment can introduce uncertainty into the EV market by two primary vectors.

The first of these vectors relates to the economic outlook evaluated by macroeconomic indicators. The recent worldwide financial recession, which has coincided significant reductions in new car registrations in Europe (ACEA, 2013), has provides an appropriate example of the vulnerability of the mainstream automotive industry to economic instability. At the consumer level, individuals are likely to become more uncertain during times of economic recession (Mishkin, 1978), leading to more conservative purchasing behaviour. With EVs representing a form of disruptive innovation (Christensen, 1997), it is likely the recession has discouraged a proportion of potential EV adopters from bearing the additional risk represented by these vehicles. However, reductions in the carbon intensity of new vehicles registered in the UK has been outperforming expectations (CCC, 2011) though concerns have been raised regarding whether or not this trend is likely to be sustained as the UK enters economic recovery.

A second vector of economic uncertainty likely to influence demand for and supply of EVs relates to international commodity markets. Notably, the variability and future projections of the price of oil is likely to substantially affect the viability of conventional ICE vehicles. Consumer expectations of future oil prices levels and the prospects for new oil reserves are likely to influence their perceptions of EVs (Sangkapichai and Saphores, 2009; Ozaki and Sevastyanova, 2011). Moreover, the availability of rare earth metals has emerged as an issue of concern (EC, 2005), which is reinforced by the current spatial concentration of producers (Humphries, 2010). Research activity has responded to this issue, with new worldwide reserves identified and catalogued (BGS, 2011; USGS, 2011). Additionally, regulations have been put into place to ensure that used batteries are recycled (BERR, 2009) which will likely stimulate the recovery and reuse of the rare earth metals embedded within them.

6. Societal

Positioned outside the EV market, society incorporates aspects which range from the comparatively stable issue of dominant ideology to relatively more variable aspects of political agendas. In reference to uncertainty in EV demand, two specific issues are of particular significance.

Firstly, with cars representing an aspect of society which is associated with a large degree of discourse, public opinion represents an important issue in the emerging market for EVs. Authors have assessed the nature of public opinion of EVs, with findings demonstrating that exposure to specialised media decreases attitudes towards clean fuelled vehicles (Gould and Golob, 1998) whilst increasing awareness of environmental issues assists in putting the regulation of vehicle emissions on the political agenda (Collantes and Sperling, 2008). Charting public opinion is an area of government activity, with the both UK and EU Governments having departments who assess the opinions of citizens (EC, 2012e). Specifically relating to transport, over two thirds of European citizens would be willing to compromise on car speed to reduce emissions whilst car price represents the least flexible issue (EC, 2011c). In the UK, drivers tend to be attracted to lower emission vehicles but are unwilling to reduce their car use (DfT, 2013e). Moreover, UK public opinion on using the tax system to encourage drivers to buy more fuel efficient vehicles is split whilst the main expressed barriers to EV adoption are reduced range and lack of public charging infrastructure (DfT, 2012). However, recent research examining social stratification in the automotive market (Anable, 2005) has demonstrated that significant variation exists in the attitudes of different segments of the market, which brings into question the robustness of measuring public opinion at the market level.

Secondly, the presence of commonly held frames of reference can display significant influences over human interaction and decision making. These frames of reference are generally referred to as social norms (Sherif, 1936) and form a primary aspect of social psychology (Cialdini and Trost, 1998). The incidence of norms in the automotive market has received academic attention with Lane and Potter (2007) describing their prominent position in cognitive models of decision making to conceptually demonstrate their influence over car buyer behaviour. Empirically applying the Value Belief Norm theory, Jansson et al. (2011) examined adoption of alternatively fuelled vehicles in Sweden and found that personal norms are a significant indicator. In a similar piece of research, Peters et al. (2011) applied an extension of the Theory of Planned Behaviour to explain vehicle CO₂ intensity and found that social norms are a significant determinant of personal norms in the car buying market.

Discussion

The structure of the conceptual framework is not exhaustive, but rather a simplified illustration of a complex system. Indeed, the components included and how they relate to each other is likely to prove an area of debate, with certain components capable of being defined in different formats. This is often referred to as model uncertainty and involves what is included in the model (and by extension, what is excluded), what represents and internal feature and what is external, how the different components of the model are connected and the magnitude of the relationships. Moreover, certain features of the modelled environment will be static and have set parameters whilst others will be dynamic. This dynamic aspect is itself an aspect of uncertainty, with different locations of uncertainty likely to increase or reduce in importance dependent on the stage of the market introduction.

Returning to the original research questions, this paper has taken an existing framework of uncertainty (Meijer et al., 2006), adapted it to account for the specific nature of EV demand and illustrated it using a structure defined by Walker et al. (2003). The main features of uncertainty in EV demand have been bounded into six different locations. These locations cover characteristics and preferences of consumers, attributes and potential of the technology, political strategy and commitment, infrastructure provision, economic variability and social dynamics. Table 1 summarises the main locations of uncertainty and the related governmental policy response.

To a certain degree, UK and EU Government policy has responded to all of the specified locations of uncertainty internal to the framework. Both governments have committed substantial funding to stimulating the market for EVs and have set targets to allow other actors operating in this market to form medium and long-term plans. Grants have been put in place to incentivize EV adoption with the taxation system adapted to provide additional advantage to EVs. The installation of EV charging infrastructure has been a proactive area, with the UK Government establishing an initiative to coordinate activity whilst the EU has put in place policy to ensure harmonisation of standards to prevent market fragmentation. The technical potential of the EV powertrain has been investigated, with the long-term viability of the technology pathway assessed and research and development targeted at improving characteristics of importance to consumers. However, the effectiveness of these policies have been brought into question, with commentators implying that uncertainty has not been mitigated enough to enhance demand with this view being supported by low levels of EV sales to date. This lack of policy effectiveness may originate in part from the uncertainty related to which government departments are responsible for what aspects of the transition to EVs. Indeed, the complexity of the situation requires a greater degree of department cooperation which may not fit with existing working practices.

Table 1: Summary of The Locations of Uncertainty in Reference to EV Demand and Associated Policy

Locations of Uncertainty	Government Policy Response
<i>Internal Sources of Uncertainty</i>	
Consumer	<ul style="list-style-type: none"> Quantitative and qualitative research concerning consumer preferences and characteristics Information campaigns – eco-labels and actonCO₂ EV trials to assess usage profiles
Political	<ul style="list-style-type: none"> Policy statements expressing support for the technology Funding commitments to accelerate adoption Establishment of institutions to oversee transition Target setting to establish transition pathways
Infrastructure	<ul style="list-style-type: none"> Installation of chargepoints in urban locations Standardisation of charging technical architectures
Technological	<ul style="list-style-type: none"> Assessments of long-term technical viability of EVs Development of technical roadmaps and scenarios Enforcement of technical standards to reduce green-washing
<i>External Sources of Uncertainty</i>	
Economic	<ul style="list-style-type: none"> Monetary and fiscal macroeconomic policy
Societal	<ul style="list-style-type: none"> Monitoring of public opinion

In reference to componts external to the framework, it is challenging for the UK and EU governments to respond to external uncertainty due to the inherent variability present in the economic and social systems. However, these governments have demonstrated their awareness of these issues, have attained an understanding of their likely influence over consumer demand for EVs and are monitoring the relevant indicators. In this sense, whilst reducing the exposure to external uncertainty might prove difficult, mitigating the possible consequences is a more realistic aim.

Summary

This paper has explored how the concept of uncertainty has manifested in reference to demand for EVs and detailed the UK and EU Government policy response. A conceptual framework containing six locations was developed to structure the discussion incorporating consumer, political, technological, infrastructure, economic and societal uncertainties. Government policy documents were sourced and evaluated to determine what efforts policy makers have so far made to reduce uncertainty in EV demand.

Results of the analysis have demonstrated that, in certain areas, UK and EU Governments have taken the lead in reducing uncertainty in EV demand through the enactment of policy. In the UK, purchase incentives for EVs have been introduced to mitigate the financial risks of EV adoption. This has been combined with a favourable registration and circulation taxation system to encourage the purchase of a low emission vehicle. The UK Government has been proactive in examining the need for and optimum location of EV charging infrastructure to provide reassurance to EV adopters.

In other areas, research conducted by academic institutes and consultancies have offered to primary contribution to the reduction of uncertainty. Assessments of the technological potential of EV powertrains have been conducted to demonstrate the long-term viability of the platform. Market research has taken place to assess the preferences of consumers and how they respond to novel EV attributes. Structural analysis has been employed to develop an understanding of the likely characteristics of early adopters and their spatial locations.

However, continued low sales figures for EVs are a prominent indicator that a significant degree of uncertainty still exists in the EV market. Criticisms have been levelled at the UK and EU Governments in reference to a lack of ambition, ineffective integration and collaboration across different department alongside a simplistic approach to consumer dynamics in policy development. It is evident that more focused research is required to improve the likelihood of realising a wide scale transition to EVs. The conceptual framework developed in this paper offers a starting point for this renewed research effort, by providing a novel perspective on how uncertainties can represent barriers to EV uptake and that the reduction of uncertainties can be considered a possible method of accelerating EV adoption.

Having charted the current locations of uncertainty in EV demand and explored the enacted political response, this project will move forward by addressing the level of these uncertainties and their natures. This will be achieved through stakeholder interviews with actors who are positioned in the outlined uncertainty locations. Moreover, it is hoped this exercise will assist in uncovering additional locations and aspects of uncertainty that so far have yet to be addressed.

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References

Due to the extensive nature of the references included in this paper, the production of a detailed reference list is not possible to meet the page limit. For interested readers, the reference list can be viewed at the following URL:

http://homepages.abdn.ac.uk/c.morton/pages/UTSG_Reference_List.docx

Alternatively, interested readers can contact the correspondence author directly to attain a complete copy of the references