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Policy making under uncertainty in electric vehicle demand

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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 dioxide emissions attributed to personal mobility. Moreover, EVs offer a means by which energy diversification and efficiency can be improved compared to the current system. The UK government and European Commission have played an active role in steering the development and market introduction of EVs. However, a great deal of uncertainty remains regarding the effectiveness of these policies and the viability of EV technology in the mainstream automotive market. This paper investigates the prevalence of uncertainty concerning the demand for EVs. This is achieved through the application of a conceptual framework that assesses the locations of uncertainty. UK and EU documents are assessed through a review of the published policy alongside contributions from academia to determine how uncertainty has been reduced. This assessment offers insights to decision makers in this area by evaluating the work done to date through a landscape analysis. Results have identified six different locations of uncertainty covering: consumer, policy, infrastructure, technical, economic and social issues.

1. Introduction

Electric vehicles (EVs) represent a vehicle category that uses advancements in battery technology to reduce the energy and carbon dioxide intensity attributed to passenger vehicle mobility. EVs are viewed as a primary means by which the UK and EU governments will meet their commitments to reduce carbon dioxide emissions in the transport sector (EC, 2012a; OLEV, 2013). Specifically focusing on the UK, legally binding legislation has been passed that requires greenhouse gas emissions to be reduced by 80% based on 1990 levels by 2050 (Climate Change Act 2008, 2008) with 5-year carbon budgets established to ensure the UK is on a trajectory to meet this commitment (HMGov, 2009). However, registration rates of EVs, while growing, still remain markedly low (Figure 1), which brings into question the capacity of EVs to provide substantial reductions to carbon dioxide emissions from the transport sector over the short and medium term. 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 proposed transition to these vehicles (Sovacool and Hirsh, 2009; Struben and Sterman, 2008).

This paper investigates this issue of uncertainty by examining how it manifests in respect to the demand for EVs. Specific attention is given to household EV demand, although passing references are also made concerning uncertainty in the fleet market. A conceptual framework that 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 potentially connected. A review of the published UK and EU government policy documents combined with research output from the academic sector is used to produce a landscape of this research area. To structure the analysis, two research questions have been specified.

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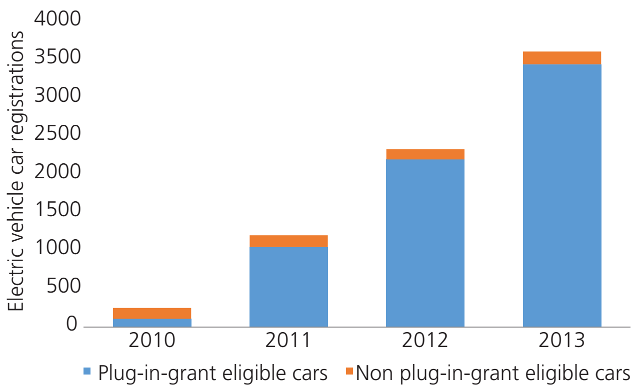

Figure 1. Registration rates of electric vehicles and the proportion qualifying for the £5000 plug-in car grant in the UK in 2013 (DfT, 2014a)

- 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?

This paper first 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 locations of uncertainty is developed and then applied in reference to EV demand. Having presented the results of the review of the published evidence, the research questions initially outlined are approached to demonstrate the contribution of the analysis. To conclude, the key points from the analysis are summarised.

2. Background and approach

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 applied 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 transport sector (Int Panis *et al.*, 2004; Kioutsioukis *et al.*, 2004) and its prevalence in traffic forecasts (de Jong *et al.*, 2007; Waller *et al.*, 2001) being well established. In an effort to provide a unified basis for the investigation of uncertainty, Walker *et al.* (2003) developed a matrix that defines uncertainty according to three main characteristics.

- The location of uncertainty can be established through the development of a model of the relevant environment.
- The level of uncertainty can be assessed on a continuum ranging from absolute determinism to total ignorance.
- 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 fluctuation present in the system.

In this paper, specific focus is given to defining the locations of uncertainty in EV demand through an assessment of the topics that have been discussed in UK and EU government policy documents and academic papers. Three primary databases provided the source of the policy documents inclusive of gov.uk, the Low Carbon Vehicle Partnership resource library and the EU Bookshop internet portals. In all instances, each portal was searched in its entirety for documents concerning transport, energy demand and EVs. To complement the identified policy documents, relevant academic literature was sourced from a recently completely thesis that investigates consumer demand in the emerging market for EVs (Morton, 2013).

3. Conceptual framework of uncertainty

To determine the locations of uncertainty prevalent in the market for EVs, a topology of uncertainty, which was initially outlined by Meijer *et al.* (2006) and subsequently applied to micro combined heat and power (Meijer *et al.*, 2007), is used as a starting point to develop a conceptual framework of uncertainty in EV demand. In this paper, the structure of Meijer *et al.*'s topology is updated to account for the nuances of the EV market. These updates are informed by the points of discussion, which are prominent from the assessment of the government policy documents reviewed in this paper. The framework includes six locations of uncertainty inclusive of

- consumer
- policy
- infrastructure
- technical
- economic
- social uncertainties.

The locations of consumer, policy and technical uncertainties are taken directly from Meijer *et al.*'s topology. In addition, the location of economic uncertainty is an expansion of Meijer *et al.*'s resource uncertainty, while the social and infrastructure uncertainties are unique to the conceptual framework presented in this paper.

With Meijer *et al.* choosing to describe their topology in a verbal manner, the conceptual framework developed in this paper is visually illustrated in Figure 2 to exhibit how the locations of uncertainty might be spatially represented. To assist in developing this illustration, the description of Walker

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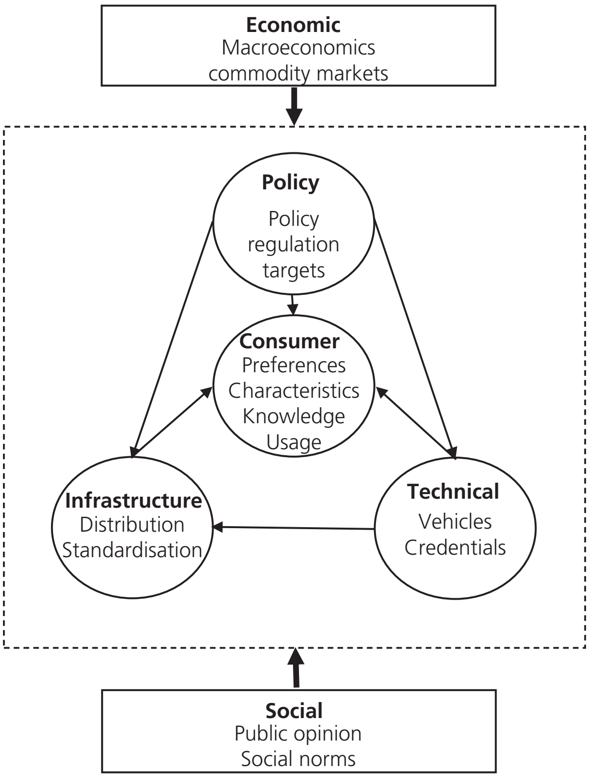

Figure 2. Conceptual framework of the locations of uncertainty in the demand for electric vehicles

et al. (2003) of uncertainty was used to consider how the framework might be structured, what represents an internal and external location and how these locations are potentially related. This distinction between internal and external location reflects the volitional control of policy makers, with internal locations being controllable to some degree while external locations are less controllable. With this in mind, the locations of economic and social uncertainty are selected to represent external aspects of the framework. How the locations are connected in the framework reflects the conceptual expectations of the authors with these hypothesised relationships not having been empirically tested.

4. Locations of uncertainty

This section details the specific uncertainties that 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 review of the published evidence.

4.1 Consumer uncertainty

Forming the focal point of the framework, consumer uncertainty represents the principal location of interest owing to the close proximity between consumers and demand. With adoption rates of EVs in the UK remaining markedly low (DfT, 2013a), an appreciation for consumer uncertainty may highlight issues limiting uptake. Four aspects of consumer uncertainty are of specific interest in reference to EV demand.

First, 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 attempting to quantify preferences for the unique attributes of EVs (Beggs *et al.*, 1981; Calfee, 1985; Caulfield *et al.*, 2010; Dagsvik *et al.*, 2002) and estimate likely market shares (Bunch *et al.*, 1995; Cluzel *et al.*, 2013; Eggers and Eggers, 2011; Train, 1980). This issue has received attention from 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 carbon dioxide 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), whereas 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).

Second, consumers can be categorised by their defining features to allow manufacturers and governments to target market interventions. The common characteristics of EV adopters represent an area of uncertainty, with low sales volumes meaning data on actual purchasers are 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 indicating that early adopters have a higher willingness to pay for EVs. A premium of £2000, which represents 1·6 years fuel expenditure for the average UK car (ONS, 2013), was viewed as being acceptable by early adopters, which is in keeping with other research findings (Potoglou and Kanaroglou, 2007), whereas mass market consumers were unwilling to pay extra to support new low-carbon technologies.

Third, the level 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

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increase adoption (Lavidge and Steiner, 1961). Axsen and Kurani (2009) 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. These results are supported by recent research, which found that non-adopters of EVs generally lack knowledge regarding the difference between EVs and plug-in hybrid EVs, charging requirements, vehicle range and models available (Hutchins *et al.*, 2013) leading to a situation where only 20% of UK drivers are familiar with EV technology (Cluzel *et al.*, 2013). King (2008) highlights the importance of providing consumers with easily understandable information regarding vehicle carbon dioxide emissions to allow them to make informed purchasing decisions. Recent research has demonstrated that miles-per-gallon remains the preferred metric of fuel efficiency with car buyers and also a proxy for environmental impact (Lane and Banks, 2010), although empirical analysis indicates that this metric is not optimal in conveying efficiency information (Anable *et al.*, 2009).

The UK government has expressed a commitment to diffusing knowledge concerning eco-labels, ensuring industry adoption and regulating the information provided (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), with information presented on sliding scales found to be the most effective transmission method (Teisl *et al.*, 2008). This issue has also gained traction at EU level (EC, 2007a, 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.

Fourth, EVs represent cars with unique characteristics that are likely to affect driver behaviour; it remains unclear how drivers will use and fuel these vehicles. 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 that examines all aspects of the transition to EVs (EC, 2011a). This project runs between 2011 and 2015 and is set to trial 2000 EVs across 14 locations. In the UK, the government established an ultra-low carbon vehicle demonstrator programme, which operated between 2009 and 2012 and used 350 low carbon vehicles across eight 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 8·05 km (5 miles) (Cabled, 2010b) and an average trip length of 8·21 km (5·1 miles) compared to a national average of 11·27 km (7 miles) (Carroll *et al.*, 2013). In reference to vehicle charging, the average charge duration is less than 2 h (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), while 10% of charging was conducted at public infrastructure points (Carroll *et al.*, 2013).

4.2 Policy uncertainty

With the passenger vehicle market representing a sector of significant economic importance (Eddington, 2006), it proves to be an area that is actively managed by the UK and EU governments. The management strategy utilised is multi-faceted, 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.

First, 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 support the establishment of EVs into the mainstream automotive market. 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 on clean and energy efficient vehicles (EC, 2010a, 2010b, 2011b) and has established the European green cars initiative (EC, 2012c, 2012d), which was launched in 2008 with a €5 billion funding pledge. In addition to these investments in EV demand in particular, UK and EU governments have expressed commitments to decarbonising transport more generally (DfT, 2009; EC, 2011c), which are incorporated into carbon dioxide emission reduction targets at the marco level (Climate Change Act 2008, 2008; EC, 2014). These schemes assist in reducing policy uncertainty by demonstrating government commitment to environmental sustainability in general and EVs in particular through prolonged financial backing.

Second, government has the option to regulate the market environment by manipulating taxation and fiscal programmes. Through an alteration of the taxation scheme, government can create incentives for the adoption of one vehicle type while reducing the merits of others. The UK was the first country to introduce vehicle circulation taxes (VED) based on carbon dioxide emissions. However, questions have 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, 2006). Recently, UK VED have been altered with the introduction of eight additional bands, which have increased

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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 highly 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 remain unaware that this represents a form of environmental taxation (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 that may cause instability in the market and send mixed messages about the UK 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 evaluations 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). The UK government has introduced a £5000 plug-in car grant (PiCG) for vehicles emitting less than 75 g of carbon dioxide per kilometre (gCO_2/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 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 (Hutchins *et al.*, 2013). However, non-adopters of EVs tended to find the purchase price to remain a significant barrier even with the incentive while general awareness of the scheme was regarded as being low. Moreover, doubts regarding the impact of purchase incentives have been raised in academic research, with findings suggesting that the price of petrol is significantly more important in reference to the adoption of hybrid vehicles compared to purchase incentives for US consumers (Diamond, 2009). Furthermore, in forecasting market developments, subsidies produce no significant addition to market uptake over what is produced by vehicle regulation (Harrison and Shepherd, 2013), whereas the metric of assessing which vehicles qualify for an incentive does not significantly influence adoption rates (de Haan *et al.*, 2007).

To ensure that purchase incentives operating in the EU comply with state-aid regulations and do not adversely affect the single market, the EC (2013a) has proposed guidelines to coordinate and harmonise schemes operating in the community. Incentives are to be technologically neutral, to be based on carbon dioxide tailpipe emissions and not to exceed the price premiums above a comparable conventionally fuelled alternative. These guidelines will likely reduce policy uncertainty 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. 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) while 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 100 gCO_2/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 130 gCO_2/km by 2015 (EC, 2007c), decreasing to 95 gCO_2/km by 2020 (EC, 2009) with a long-term ambition of 70 gCO_2/km by 2025 (EC, 2007b). Official targets for EV sales are less clear, with the UK government stating that adoption targets for EVs are not appropriate (HoC, 2012b) while 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 4100 EVs being registered in the UK in 2012 (DfT, 2013d), it is unlikely the first of these targets will be realised.

4.3 Infrastructure uncertainty

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, while Pridmore and Anable (2012) examined 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 member states (EC, 2013c), with the UK required to install 1·2 million EV charge points with 122 000 of these being publicly

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available by 2020. To provide a sense of the challenge these targets offer, only 3000 charge points 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). With these findings in mind, recommendations were 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 alternative 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). Furthermore, the EU has conducted stakeholder engagement and expert reviews to identify the most appropriate technical specification for charge points to ensure universal compatibility (EEGFTF, 2011a).

4.4 Technical uncertainty

The technical attributes of EVs have been repeatedly identified in empirical research as representing a significant barrier to EV demand, with consumers tending 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 technical uncertainty in the 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 in EV technology (Cluzel and Douglas, 2012; Cluzel *et al.*, 2013; IEA, 2011; SMMT, 2002) 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, although 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 (EEGFTF, 2011b). The importance of harmonisation 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 expressing concerns regarding the increased emissions in vehicle production and in the generation of electricity, which leads to diminished appeal for 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, carbon dioxide emission savings attributed to EVs will likely increase *ceteris paribus*. However, more research on this issue is required to develop a better understanding of production emissions, end-of-life recycling emissions, marginal generation and emissions associated with the provision of infrastructure (Contestabile *et al.*, 2012). Once a more evidenced understanding has been attained, this can be communicated to the general market to ensure the technical uncertainty associated with the environmental sustainability of EVs is mitigated. Similar issues are repeated across a number of related technical areas, with EV demand being potentially reduced by uncertainties surrounding EV battery life, claimed fuel efficiencies, achievable ranges and operational capabilities in cold weather conditions.

4.5 Economic uncertainty

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 in two primary ways.

The first aspect relates to the general economic situation, which is often evaluated by macroeconomic indicators. The recent

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worldwide financial recession, which has coincided with significant reductions in new car registrations in Europe (ACEA, 2013), provides an appropriate example of the vulnerability of the mainstream automotive industry to economic instability. At the consumer level, financial discussions are likely to become more uncertain during times of economic recession (Mishkin *et al.*, 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 since the recession (Figure 3) have been outperforming expectations (CCC, 2011), although concerns have been raised regarding whether or not this trend is likely to be sustained as the UK enters economic recovery.

A second aspect 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 affect the viability of conventional internal combustion engine vehicles substantially. Consumer expectations of future oil price levels and the prospects for new oil reserves are likely to influence their perceptions of EVs (Ozaki and Sevastyanova, 2011; Sangkapichai and Saphores, 2009). 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, 2013). 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.

4.6 Social uncertainty

Positioned outside the EV market, society incorporates aspects that 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 social issues are of particular significance.

First, with cars representing an aspect of society that is associated with a large degree of discourse, public opinion becomes an important issue in the emerging market for EVs. Authors have assessed the nature of public opinion of EVs, with findings demonstrating that negative exposure in specialised media reduces preferences towards clean fuelled vehicles (Gould and Golob, 1998), while increasing awareness of environmental issues assists in putting the regulation of vehicle emissions on the political agenda (Collantes and Sperling, 2008). With longitudinal evidence demonstrating significant variability in public opinion towards environmental issues (Dunlap, 1991), these fluctuations may lead to uncertainty regarding the level of public support for environmental sustainability policies in general and EVs in particular.

Charting public opinion is an area of government activity, with both the UK and EU governments having departments that assess the attitudes 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 while

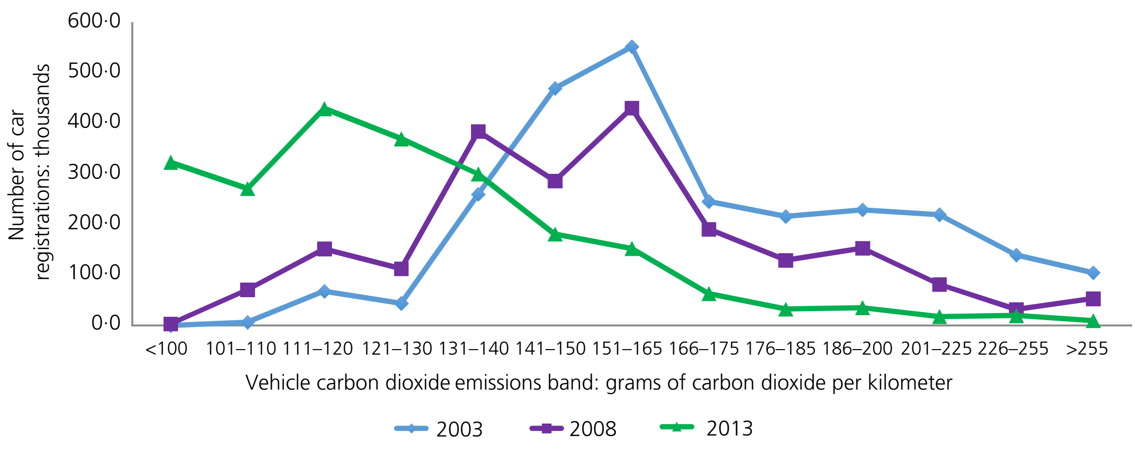

Figure 3. Distribution of new car registrations in the UK in respect to carbon dioxide emissions band in 2003, 2008 and 2013 (DfT, 2014b)

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car price represents the least flexible issue (EC, 2011d). 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, while the main expressed barriers to EV adoption are reduced range and lack of public charging infrastructure (DfT, 2012). However, research examining social stratification in the automotive market has demonstrated that significant variation exists in the attitudes of different segments of the market (Anable, 2005), which brings into question the robustness of measuring public opinion at the market, as opposed to segment, level.

Second, 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 EV market has received academic attention, with Lane and Potter (2007) describing their prominent position in cognitive models of decision making to demonstrate conceptually their influence over car buyer behaviour. Empirically applying the value belief norm theory, Jansson *et al.* (2011) examined the adoption of alternatively fuelled vehicles in Sweden and found that personal norms, such as perceived moral obligation, act as 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 carbon dioxide intensity and found that social norms are a significant determinant of personal norms in the car buying market. However, assessing how the social norms connected to EVs are likely to develop remains an unexplored area, leading to uncertainties regarding the social interpretation of these vehicles.

5. Discussion

This paper has taken an existing topology of uncertainty (Meijer *et al.*, 2006) and adapted it to develop a conceptual framework that accounts for the specific nature of uncertainty in EV demand. The main features of uncertainty in the EV market have been bounded into six different locations covering characteristics and preferences of consumers, attributes and potential of the technology, policy strategy and commitment, infrastructure provision, economic variability and social dynamics. Table 1 summarises the main locations of uncertainty and the related governmental policy response.

UK and EU government policy documents have been examined to determine the degree to which action has already been taken to mitigate uncertainty. Both governments have commited substantial funding to stimulate 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 incentivise EV adoption with the taxation ystem adapted to provide additional advatange to EVs. The installation of EV charging infrastructure has been a proactive area, with the UK government establishing initatives to coordinate activity while the EU has put in place policy to ensure harmonisation of standards to prevent market fragmentation.

Locations of uncertainty	Government policy response
Internal sources of uncertainty	
Consumer	■ Quantitative and qualitative research concerning consumer preferences and characteristics Information campaigns – eco-labels and act-on-CO_2 EV trials to assess usage profiles
Policy	■ 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	■ Installation of chargepoints in urban locations Standardisation of charging technical architectures
Technical	■ Assessments of long-term technical viability of EVs Development of technical roadmaps and scenarios Enforcement of technical standards to reduce green-washing
External sources of uncertainty	
Economic	■ Monetary and fiscal macroeconomic policy
Social	■ Monitoring of public opinion

Table 1. Summary of the locations of uncertainty in reference to the demand for electric vehicles and associated policy response

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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 a number of these policies has 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. Uncertainty remains regarding whether the level of the EV purchase incentive provided by the UK's PiCG is sufficient to spur demand effectively. Ambiguities concerning the validity of the credentials linked to the environmental impact of EV production and use alongside other technical issues are likely to be suppressing demand. While significant work has been conducted regarding consumer response to EVs at the market level, the idiosyncrasies of particular market segments remain underexplored with the consequence that market interventions cannot be tailored to the nuances of targeted segments, leading to a situation where policies may have indistinct effects. Moreover, the 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 calls for a greater degree of department cooperation, which may not fit with existing working practices.

Reflecting on the effectiveness of the conceptual framework in analysing the policy documents, it is important to acknowledge that the framework only represents a simplified illustration of a complex system. Indeed, the locations that it includes are likely to prove a topic of debate, with certain locations capable of being defined in different formats. Moreover, the links illustrated between the locations of the framework currently represent hypothesised connections, which require further testing to evaluate their validity. Indeed, one of the clear limitations of the framework's existing structure stems from its inflexibility, with potentially important aspects such as market competition, the emergence of alternative models of car ownership and mobility as well as the importance of substitute and complementary products being omitted. Furthermore, themes that cut across multiple locations such as environmental sustainability are difficult to account for yet hold clear importance in this market. With these considerations in mind, future research may want to consider how to improve the framework to increase its capability to incorporate a wider degree of aspects to improve the framework's usefulness.

6. Conclusion

EVs offer a possible means by which the transport sector can partially address the objectives of decreasing emissions of carbon dioxide while improving the levels of energy efficiency and energy security. This paper has attempted to provide insight regarding potential barriers that may be suppressing demand for EVs by exploring the market under the lens of uncertainty. This has been achieved through the application of a conceptual framework, which contains six locations of uncertainty inclusive of consumer, policy, technical, infrastructure, economic and social uncertainties. UK and EU government policy documents were sourced and evaluated to determine what efforts policy makers have so far made to reduce uncertainty in EV demand.

A number of uncertainties have been identified which, as yet, do not appear to have been effectively addressed by government policy. Notably, criticisms have been levelled at the UK and EU governments in reference to a lack of ambition, ineffective integration and collaboration across different departments alongside a simplistic approach to consumer dynamics in policy development. Conversely, effective policies have also been enacted in the EV market, with widespread adoption of eco-labels, clear messages on manufacturer targets in reference to average vehicle carbon dioxide emissions alongside significant financial commitments to supporting the development of the emerging market.

The conceptual framework has generally performed effectively in providing a lens through which to consider uncertainty in reference to EV demand, although there is still room for significant development. While no specific aspect of the framework is discussed in any great detail, one of the strengths of the approach taken in this paper is to allow a landscape perspective of the EV market to be attained, which demonstrates the current policy achievements while highlighting areas where additional work is required. Future research may want to consider how to introduce more flexibility into the framework's structure to allow for aspects to be included that do not easily fit into the existing locations. Moreover, with this paper presenting a somewhat static picture of uncertainty as it presently exists in reference to EV demand, researchers may want to consider how to introduce a dynamic aspect. While this framework has been adapted to explore the demand for EVs specifically, the approach has the potential to be amended to make it suitable for different application environments such as the diffusion of residential heat pumps, smart meters as well as industrial and manufacturing innovations. Indeed, further applications in alternative markets may reveal similarities in the uncertainties that are present in different innovation systems, potentially allowing for cross-cutting policies to address uncertainties in different market environments.

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