Programme Area: Light Duty Vehicles

Project: Consumers and Vehicles

Title: Quantifying Consumer Behaviour

Abstract:

This project was undertaken and delivered prior to 2012, the results of this project were correct at the time of publication and may contain, or be based on, information or assumptions which have subsequently changed. This is the first of two reports that accompany the Consumer Choice Model from the Consumers and Vehicles project. This first report is about deriving the coefficients of consumer choice. It presents an overview of consumer choice modelling, details the design of the choice experiment and analysis of the results and development of the coefficients of consumer choice for the model. Finally, key parameters of consumer choice are quantified against the eight market segments developed in the 'Identification of Relevant Consumer Segments' report. The key parameters presented in Section 5 quantify the effect various factors have on the price consumers are willing to pay for plug-in vehicles. These factors include: availability of infrastructure, vehicle acceleration, electric range and whether the choice is for a first or second car in the household.

Context:

The Consumer and Vehicles project looked at the potential long-term performance and cost of plug-in vehicles. It examined consumer reactions and behaviours in buying and using them. It explored supporting infrastructure, and included in-depth surveys with 3,000 consumers and real-world testing with 40 drivers.

ETI Consumers and Vehicles

Work Package 1.4-8A: Quantifying Consumer Behaviour

Version 1

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Acknowledgements

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Acronyms

ASC	Alternative Specific Constant
BEV	Battery EV
EV	Electric Vehicle
GB	Great Britain
PHEV	Plug in Hybrid Electric Vehicle
PIV	Plug in Vehicle
WTA	Willingness to Accept
WTP	Willingness to Pay

1 Executive summary

Over the coming years, policymakers and vehicle manufacturers will play a major role in decarbonising the passenger car market, through regulation and new incentives and the development of new technologies. However, the fate of these new technologies and overall progress in reducing emissions from passenger cars will continue to rest with individual consumers, who will make buy cars that are attractively priced and which fit with their lifestyles and transport needs. The consumer research programme conducted within the ETI"s Plugged In Places Economics and Infrastructure project has provided the most detailed insight to date on consumer attitudes to plug-in vehicles. This report contains the results of a quantitative survey of 2,700 buyers of new or nearly new cars, and shows how consumers are likely to respond to new technologies with their benefits and limitations.

Our findings suggest that predictions of uptake based solely on the economic „offer" of plug-in vehicles miss the critical role of consumers in the decision making process, and are likely to strongly overestimate the market for PIVs. Our results show that consumers respond strongly to differences in vehicle prices, running costs, but non-financial attributes such as range and the availability of infrastructure also play a key role. Different consumer groups also show strong preferences for or against plug-in vehicles, even when differences in price and functionality are taken into account.

Key findings

- Consumers respond strongly to changes in vehicle range for electric vehicles, but only up to a range of 240km (150 miles). They are willing to pay £2,300 to increase electric range from 160km to 240km, but only a further £300 to increase from 240km to 320km.
- Consumers are willing to pay £1,300 for an extra 50km of range for a battery electric vehicle. This is significantly lower than the cost to vehicle manufacturers of providing it (c. £3,500 for 50km at current battery costs).
- The availability of home charging is valued at £3,000-£4,000 by consumers, much higher than the cost of providing it.
- The availability of workplace charging alone (without home charging) had almost zero value to consumers for battery electric vehicles, but was worth over £3,000 for plug-in hybrids. This suggests that home charging is an essential requirement for consumers considering a pure EV, but prospective PHEV buyers understand the flexibility provided by the hybrid drivetrain.
- The WTP for public charging is also very low compared with private infrastructure. This finding contradicts the notion that a lack of *public* infrastructure is the main barrier to deployment of PIVs.
- Consumers appear to care very little about CO_2 emissions, even in early adopter groups. However, respondents were very sensitive to running costs, willing to pay £500 extra for a car with £100 per year in running cost savings.
- Respondents were willing to pay c.£1,400 for a 20% improvement in acceleration in any vehicle type. Recently released electric vehicles have strong acceleration characteristics, particularly at low speeds, and consumers would seem to be willing to pay for this benefit.

Our analysis also shows what consumers are willing to pay to buy a plug-in vehicle over a typical car, when differences in range and infrastructure availability are taken into account.

- Many consumers responded favourably to plug-in hybrid vehicles. 16% of private consumers were willing to pay more for a plug-in hybrid with a 64km range than for a typical car, even if only home charging were available.
- If work charging and extensive public infrastructure were available (in addition to home charging), nearly half of private consumers (44%) would be willing to pay more for a PHEV than a conventional vehicle.
- In contrast, the majority of respondents responded negatively to pure electric vehicles in all but the Pioneer (early adopter) group. Only 2% of consumers in our survey would be willing to pay more for a BEV with a 160km range if only home charging were available.
- This negative attitude persists even if consumers are offered workplace and public charging infrastructure, with only 14% of private consumers willing to pay more than for a BEV over a conventional car.
- Attitudes towards both PHEVs and BEVs are significantly more positive for second car purchases, though all consumers (including the early adopters) continue to prefer a PHEV to a BEV based on current vehicle characteristics.

Implications for policymakers and vehicle manufacturers

- Based on current consumer attitudes, the market for plug-in vehicles is likely to be dominated by plug-in hybrids rather than pure electric vehicles. However, only the early adopters in our group are willing to pay the current price premium for plug-in vehicles. This suggests that price remains the major barrier to mass-market adoption.
- For battery electric vehicles, mass-market consumers currently have a strong bias against the technology, and this will lead to low take up even if the vehicles reach price parity.
- Manufacturers should consider prioritising cost reduction over increasing vehicle range, since consumers are willing to pay less than the cost of providing the additional rage (at current battery prices).
- None of our consumer groups placed significant emphasis on CO_2 emissions. This suggests that marketing of plug-in vehicles should focus on financial benefits such as lower fuel costs and taxes rather than emissions.
- Programmes for infrastructure deployment should focus on home and workplace charging, where its value to consumers is higher than the cost of providing it. Our results also suggest that the cost of providing widespread public infrastructure is significantly higher than its perceived value to consumers.
- Analysis of public infrastructure requirements should account for the fact that the plug-in vehicle market is likely to be dominated by hybrids rather than pure electric vehicles.
- Current policies, such as the Plug-in Car Grant, congestion charging exemption, and taxes such as company car tax and VED, currently treat all plug-in cars equally. While this technology-agnostic approach is justified in the short term, pure electric cars are likely to require more support than plug-in hybrids if they are to be equally attractive to the mass market.

2 Quantifying consumer behaviour

2.1 Background

This report is one of two final reports delivered under Work Package 1.4-8A in the Plug In Vehicle Economics and Infrastructure Project (PIVEIP). It details the results of the consumer choice modelling conducted as part of a wider market research programme. We discuss the design of a choice experiment carried out on 2,700 buyers of new and nearly new cars in November 2010, and the insights gained into consumers" buying preferences for plug-in vehicles and how these preferences vary across the population.

The results from the choice experiment are a key component in Element Energy"s Electric Car Consumers Model (ECCO), also developed as part of the PIVEIP. Results and analysis based on this model are contained in a separate report delivered under Work Package 1.4-8B.

2.2 Understanding consumer choice

2.2.1 Introduction

Over the coming years, policymakers and vehicle manufacturers will need to play a major role in decarbonising the passenger car market. Policymakers are responsible for driving progress in low carbon vehicles, for example through EU targets for new vehicle emissions, and through incentives for drivers purchasing and using the most fuel efficient cars. Manufacturers, in turn, need to deliver the technical progress in conventional and novel powertrains and dictate which vehicles are offered in the marketplace. However, the decision on what size and type of car to buy will continue to rest with individual consumers, and understanding this purchase decision is critical to predicting the rate of decarbonisation and electrification of transport.

A wealth of literature exists on the ways in which consumers make purchase decisions, on products ranging from consumer electronics to energy efficiency measures and different types of vehicles. These studies focus on identifying the relative importance of different product attributes, such as price or performance. For example studies on hybrid cars have repeatedly found that vehicle price is the most important influence on consumer preferences, with fuel cost savings (or reduced CO_2 emissions) playing a much more minor role. Consumer studies also highlight the importance of non-financial attributes, such as vehicle acceleration or the availability of refuelling infrastructure. This shows that any approach to modelling the uptake of new technology should explicitly capture both the financial and non-financial aspects of consumer choices.

Many models of new technologies take a much simpler approach by using „diffusion curves" to estimate how quickly new products will be adopted in the market place. An illustrative diffusion curve is shown in Figure 1. It shows the classic „S-shaped" diffusion, where initially slow uptake is followed by rapid growth through mass-market adoption. The precise shape of the curve is calculated by using proxies from other technologies or markets. While some new technologies show this broad diffusion trend, it is also possible for them to „fail", for example if their price fails to decrease enough to be attractive to mass-market consumers as well as early adopters. This is also shown in Figure 1. Simple "top-down" diffusion models lack the power to explain whether or why a technology will succeed or fail. By contrast, a model that considers individual attributes of new technologies (such as price or performance) and how consumers respond to them can provide substantially more insights into the factors affecting the rate of adoption. Given that these insights are essential if policymakers and businesses are to plan for the deployment of a disruptive technology such as plug-in vehicles, we reject an approach based on diffusion models in favour of a detailed representation of consumer behaviour.

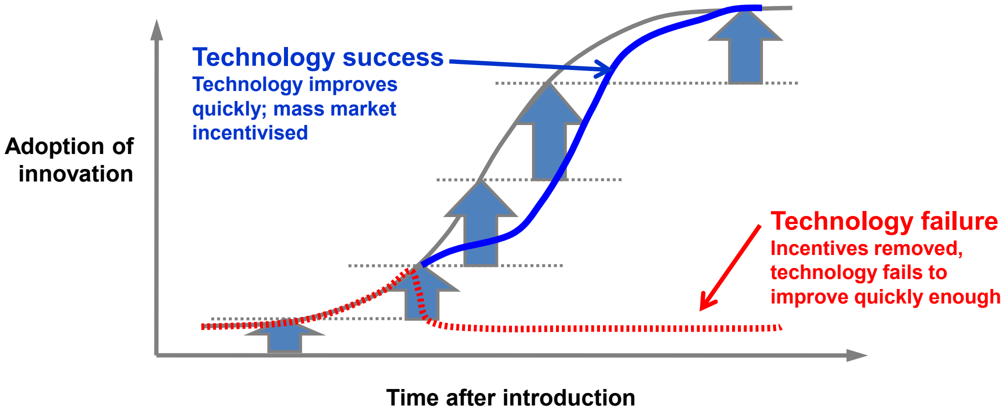
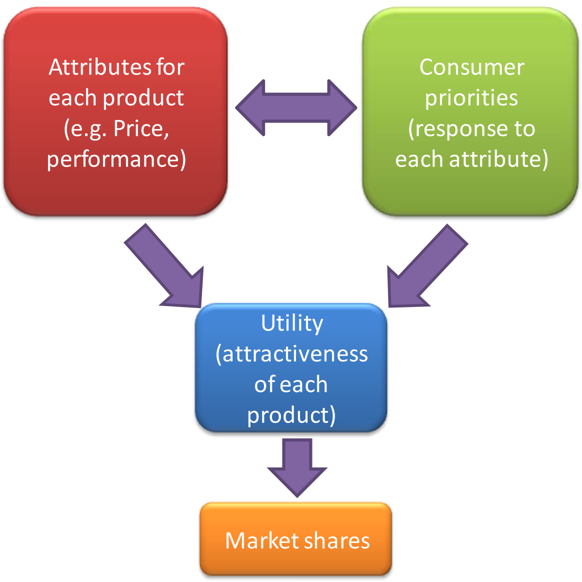


Figure 1 Diffusion of new technologies

2.2.2 Options for quantifying consumer attitudes

To represent consumer behaviour in technology uptake models, it is necessary to quantify the relative importance of different product attributes. In other words, rather than qualitative insights such as that capital cost is „very important" and CO_2 only „slightly important", quantitative techniques allow researchers to determine the willingness to pay (WTP) for different attributes. Quantitative studies are often used by service providers, for example to optimise pricing of new transport systems, or by manufacturers to understand what consumers are willing to pay for product features. The general outline of such a study is shown below. Each product (such as a vehicle) is described by attributes such as price or performance. Consumers are assumed to trade off all of the attributes and „calculate" the overall utility (or attractiveness) for each product. Market shares are then calculated in proportion to the utility of each product. In more complex studies (including this one), the purchasing priorities are allowed vary across different consumer segments, so that early adopters may make very different product choices to the mass market.



Several techniques are available for quantifying responses to product attributes. For example, Hedonic Pricing can be used to evaluate the „value" placed on amenities such as a south facing garden by comparing house prices for similar houses on opposite sides of a street. Other techniques rely on surveys, for example where consumers are asked how much they would be willing to pay (or how far they would be willing to drive) to access a National Park. These tools are most suitable where the focus is on evaluating the importance of single attributes of a product or service. However, where the focus is on understanding competition between different technologies, or the trade-offs between multiple features of a product, researchers turn to more powerful techniques such as Discrete Choice Analysis.

2.2.3 Modelling consumer choice through Discrete Choice Analysis

Discrete Choice Analysis aims to replicate as closely as possible the decision making process followed by consumers in the real world. In other words, consumers are presented with a range of „alternatives‟, each described by certain „attributes‟. For a vehicle purchase, this could involve consumers comparing specifications of several vehicles, each with a different price, fuel consumption, safety level and so on. The prospective customer evaluates each alternative, and chooses the one that provides the highest „utility‟ to them. The aim of the choice experiment is to capture as many as possible of the factors people consider when buying cars, to ensure that the resulting model has the maximum predictive power when calculating likely market shares of new powertrains.

A simple example is shown in Figure 2. Two vehicles with three attributes are offered, and respondents are asked to select which one they would like to buy. The example highlights several interesting features. First, by including at least one attribute expressed in pounds (capital cost), the non-financial attribute (range) can also be converted to pounds. For example, it allows calculation of how much respondents are willing to pay for a vehicle with an extra kilometre of range or conversely, what they would have to be paid to choose a vehicle with a lower range. Secondly, by labelling the vehicles as electric and petrol, it is possible to estimate consumers‟ willingness to pay for an electric vehicle, *all other things being equal*. It also allows the consumer response to attributes such as range to be vehicle-specific, such that consumers place a higher value on extra range in an electric compared to a petrol car.

The example below highlights the power and flexibility of the choice modelling approach. A further benefit is that by analysing the responses from a range of consumer groups, it is possible to quantify differences in attitudes across the population. For example, early adopters may respond favourably to an innovative or „green‟ technology, while mass-market consumers would be expected to place more emphasis on vehicle price. This consumer segmentation is a key part of the approach to the consumer research programme within the PIVEIP.

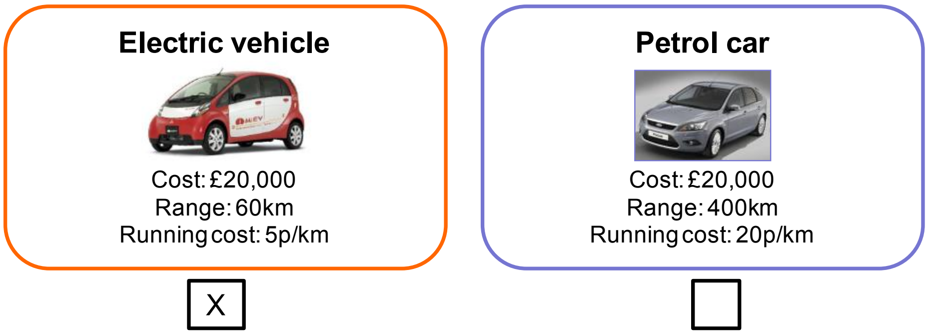


Figure 2 Example of a simple choice experiment

Stated versus revealed preference data

As shown in the example above, Discrete Choice Analysis makes use of data on which products consumers choose given the attributes of those products. It is important to distinguish between two sources for these choice data. For products available to consumers (as opposed to novel products yet to reach the marketplace), researchers can simply gather data on the market shares of products, as well as their attributes such as price, performance brand etc. For example, a study for the Department for Transport analysed the market shares of all new car types available in the market and from this derived the consumer responses to the attributes of the vehicles. For example, it quantified the relative „utility" or attractiveness of a BMW over an Alfa Romeo or the willingness to pay for anti-lock brakes, all other things being equal.

For novel products, such as battery electric vehicles, there are no meaningful sales data on which to generate a consumer choice model. This is because the overall market share for these vehicles is very low, and until recently the vehicles on sale were unrepresentative of the BEVs that will be available over the next decade, for example due to low maximum speeds or very limited range. In this case, we are forced to use „stated preference" (SP) data, where respondents in a survey are presented with hypothetical vehicles and asked to „choose" to purchase one of them (see example below).

At first glance, it seems that „revealed preference" (RP) data are always preferable to SP data, as they are by definition based on real-world rather than hypothetical purchases. This means that they are unaffected by biases inherent in consumer survey work, caused by people being more easily persuaded to spend „hypothetical" money, or wishing to appear to be making the „right" choices, by choosing the most environmentally friendly option. However, use of SP data offers several advantages:

- It allows testing of products that are not yet available in the market place, for example plug-in hybrids and the „new generation" of battery electric vehicles.
- It allows testing of combinations of attributes not found in the market place, for example electric vehicles with a high range or a very high availability of public charging infrastructure.
- It allows detailed analysis of demographic and attitudinal influences on consumer choice, something not possible with revealed preference studies of aggregate market shares[1].

[1] Several studies have addressed this by conducting consumer survey work capturing these demographic variables, but where respondents have been questioned on recent purchases rather than given hypothetical choices.

Our approach, described in detail below, combines the best of both the stated preference and revealed preference methods. It uses SP data on novel powertrains (plug-in hybrids and battery electric vehicles), while making use of real-world data on the uptake of non-plug-in hybrids to calibrate the resulting model.

Use of Discrete Choice Analysis in the transport sector

Discrete Choice Analysis is widely used for understanding product demand in the transport sector. Several studies in the 1980s used the technique to estimate demand for early electric vehicles[2], while in the last decade the focus has turned to alternative fuel vehicles, such as ethanol or LPG cars. For example, a major study by Oak Ridge National Laboratory in 2001[3] used real-world market share data to estimate demand for future diesel cars, taking into account consumer attitudes to capital and running costs, time taken for refuelling, availability of refuelling infrastructure etc. A similar approach was used for the UK market in the studies conducted for DfT referred to above.

With the renewed interest in plug-in vehicles over the last few years, a large number of studies have attempted to capture the consumer attitudes to vehicles with low range and limited „refuelling‟ infrastructure. For example, the US National Renewable Energy Laboratory used a stated choice experiment to capture consumers‟ attitudes towards hydrogen vehicles, using attributes such as the maximum driving radius and the proportion of long distance trips for which refuelling infrastructure was available. Other studies, such as those by Ziegler[4] and Hensher[5] quantified the relative attractiveness of biofuel, hydrogen and electric vehicles using a common set of attributes in a choice experiment.

Very few studies that we are aware of have focused on the consumer response to plug-in hybrid versus pure electric vehicles. Understanding this response is critical to predicting the likely rates of uptake of these technologies, since in the short term they are likely to compete for a similar, and limited, group of innovators for market share. A study by Axsen and Kurani[6] investigated these issues in the US market, by using „design games‟, where participants were asked to „design‟ a plug-in hybrid vehicle by changing attributes such as the overall fuel consumption, all-electric range and performance. Though not a formal choice experiment of the type employed here, the study still provided useful insights into how people respond to plug-in vehicles. One particularly relevant finding was that respondents placed little emphasis on „all-electric range‟, instead focusing on minimising fuel use over all journeys.

In this study, we focus exclusively on plug-in vehicles and consumers‟ attitudes to PHEVs and BEVs, relative to a single „conventional‟ incumbent.

2.3 Summary of consumer research programme

The consumer research programme undertaken during Stage 1 of the PIVEIP had several overarching objectives:

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[2] For example, see Calfee, J. (1985):, The Econometric Estimation of Potential Demand for Electric Automobiles. *Transportation Research Part B* 19(4), pp287-301

[3] Greene, D.L. 2001. TAFV Alternative Fuels and Vehicles Choice Model Documentation, ORNL/TM-2001/134, Oak Ridge National Laboratory, Oak Ridge, Tennessee, July.

[4] Ziegler (2010): Individual Characteristics and Stated Preferences for Alternative Energy Sources and Propulsion Technologies in Vehicles: A Discrete Choice Analysis. Available at http://ideas.repec.org/p/eth/wpswif/10-125.html

[5] Hensher, D.A. and W.G. Greene. (2001). "Choosing between Conventional, Electric and LPG/CNG Vehicles in Single-Vehicle Households" in Hensher, D.A. (eds) The Leading Edge of Travel Behaviour Research, Pergamon, Oxford.

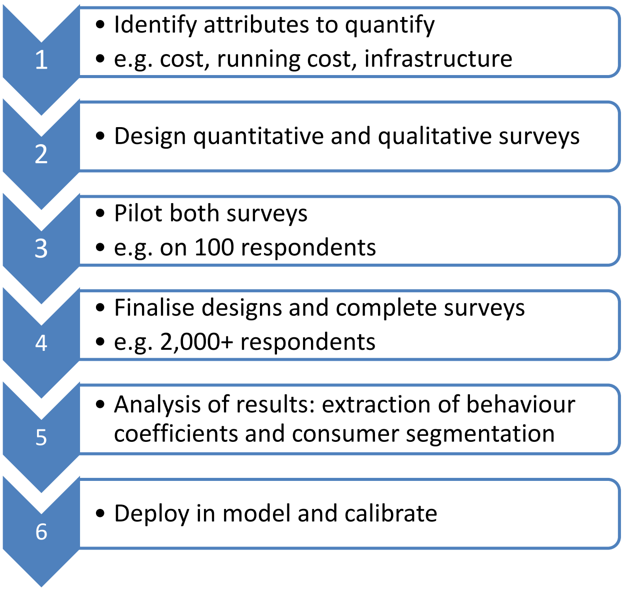
[6] Axsen, Jonn and Kenneth S. Kurani (2008) The Early U.S. Market for PHEVs: Anticipating Consumer Awareness, Recharge Potential, Design Priorities and Energy Impacts. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-08-22

Identify car purchasing criteria – What factors do consumers take into account when purchasing a new vehicle?

Quantify purchasing priorities – How do consumers prioritise these factors? For example, what are buyers willing to pay for a car with an extra 50km of range?

Develop consumer segmentation – How do these priorities vary across the population? For example, do „early adopters" care less about low infrastructure availability than „laggards" do? What demographic and attitudinal factors characterise these distinct parts of the population?

To fulfil these objectives, we used the multi-stage approach detailed below:



The consumer research programme was conducted by the members of the SP1 consortium, including TRL, Shell and the Universities of Aberdeen and Sussex. To avoid duplication, we have not described in detail the approach to the qualitative aspects of the consumer work. We refer readers to the reports delivered as part of Work Package 1.3. Instead, we focus on the development and analysis of the choice experiment itself.

3 Design of the choice experiment

3.1 Selection of attributes for the choice experiment

The first stage in the design of any choice experiment is to decide on the product features that will be provided to respondents in the hypothetical „choice sets". In many projects, focus groups are used to discuss purchasing priorities, such as factors that consumers consider when purchasing a new vehicle. In the PIVIEP, this qualitative work was conducted by providing plug-in vehicles to forty mass-market consumers for a week[7]. Trial participants in this „household study" were interviewed before and after using the vehicles, on a range of issues such as their experience with the car, their understanding of how they worked and how the cars suited their lifestyles. They were also asked to describe which attributes of a car are most important when whether or not to buy it. These interviews resulted in the following short-list of attributes:

- Purchase price
- Running costs
- „Performance"
- Range (for plug-in vehicles)
- Availability of charging infrastructure
- CO_2 emissions
- Recharging time
- Safety
- Practicality
- Appearance
- Reliability

Each attribute must fulfil two key criteria if is to be included in the choice experiment. First, it must be quantifiable and easily understood by respondents. Secondly, it must be possible to predict how the attribute will differ between conventional and plug-in cars, both now and in the future. In parallel with this work, Ricardo developed a database of vehicle cost and performance projections to be used in Element Energy"s Consumers and Vehicles Model; attributes in this dataset had to be matched with attributes in the choice experiment. In the list above, the last four attributes fail to meet both of these criteria. For example, „appearance" is very difficult to quantify in a survey without showing pictures of vehicles, and quantifying the consumer response to each picture is of little use as this cannot be matched to an equivalent appearance attribute in the vehicle dataset, and terms like „best in class styling" or „slightly clunky" are unlikely to produce useful consumer coefficients. Furthermore, as vehicle styling is more a function of manufacturer than powertrain, there is no reason to suggest that styling of plug-in vehicles will be systematically better or worse than the incumbent in the medium to long term.

The remaining attributes can be quantified and related to properties in the vehicle database and so were included in the choice model. A survey of the choice modelling literature, and discussions with Professor Kenneth Train, suggested that using more than ten attributes to describe vehicles in the choice experiment would lead to an excessive cognitive burden on respondents. Given that many of the attributes above are numerical (such as price, running cost and range) rather than qualitative (such as colour), it was agreed that a maximum of eight attributes should be used. This would ensure that respondents completed the exercise by trading off the attributes in each question, rather than choosing at random because the choices were too difficult.

[7] The full results from this „Household Study" have been delivered under Work Package 1.3.

3.2 Attribute metrics and levels

The second stage in the design process is to develop „metrics" for each attribute that will be presented to consumers. For some attributes, such as capital cost, the most obvious metric is pounds, while attributes on infrastructure availability require considerably more thought. Once the metric is decided, we must decide the range of values („levels") to be tested. The attributes can be split into four „generic" parameters that were common across the vehicle types tested, and four attributes that were shown only for the PHEV and BEV:

Generic parameters

- Capital cost
- Annual fuel costs
- Performance
- Emissions

EV-specific parameters

- Availability of home or work charging infrastructure
- Availability of public recharging infrastructure
- Recharging time
- All electric range

Further explanation of these metrics is given below.

Capital cost (£) – Expressing this in pounds allows all other attributes to be related to an equivalent capital cost. Ten levels are used, from £10k to £28k in £2k intervals.

Annual fuel costs (£) – Since running costs are highly dependent on annual mileage, the values shown to respondents were customised based on their stated mileage in an early part of the questionnaire. For someone driving 10,000 miles per year, the values were £300, £600, £900 and £1,200. A respondent covering only 5,000 miles see 50% of each of these values.

Performance (0–60 acceleration relative to a typical vehicle) – This metric was chosen as it is a good proxy for the overall performance of the vehicle at normal driving speeds and is well understood by consumers. Top speed was considered but rejected as for plug-in vehicles it is likely to be artificially restricted to maximise range and so is not a proxy for overall performance as it is in conventional vehicles.

Emissions – This was explained in the pre-read material[8] as the CO_2 emissions produced from driving the vehicles. It is the same as the tailpipe emissions for conventional vehicles. For the plug-in vehicles, it included the emissions due to electricity production. To reduce the complexity of the choice experiment, the values were expressed as a percentage relative to a typical new car with tailpipe emissions of 150g/km, rather than as the actual emissions value[9].

Infrastructure – This was the most challenging aspect of the choice experiment for respondents to understand, as plug-in vehicle infrastructure is fundamentally different from the infrastructure they currently use. There are three main dimensions to infrastructure that could be tested in the choice experiment:

- Availability of home or work charging facilities
- Availability of „public" charging infrastructure
- The time required to recharge the vehicle

[8] The first part of the questionnaire contained background information on plug-in vehicles, developed by the Sub-Project 1 consortium, to ensure that respondents had sufficient knowledge to complete the choice experiment.
[9] The average emissions of a new car sold in 2009 were 149.5g/km, according to the SMMT: http://lib.smmt.co.uk/articles/news/News/SMMT%20New%20Car%20CO2%20Report%202010%20-%20summary.pdf

These dimensions enter the choice experiment as separate attributes, allowing the consumer response to each one to be calculated independently. This approach also allows analyse interactions between them, for example where consumer attitudes to the public charging attribute depend on whether or not home and work charging is available.

The remaining challenge for the infrastructure attribute was the choice of metric. Most studies to date have expressed this as „% of petrol stations where you can refuel/recharge your car". For example, a study by Ziegler[10] used „% of service stations providing the fuel" as a metric in a choice experiment containing both liquid-fuelled vehicles and electric vehicles. While this may be an acceptable compromise for studies of alternative fuels (such as ethanol or LPG) and electric cars, this metric was likely to cause confusion in a study focusing on plug-in vehicles.

Instead, the public infrastructure attribute was expressed as „the % of public car parks or street-side parking spaces at which recharging is available". This is closer to what consumers currently experience when assessing the likelihood of finding a parking space when arriving at a destination. This metric was tested in the pilot study and found to be interpreted correctly by respondents.

Range – To reduce the cognitive load on respondents, we chose not to vary the „liquid fuel" range for conventional vehicles or PHEVs, expressing it simply as „the same as typical vehicle". The rationale for this is that once the vehicle range exceeds 300 or 400 miles, consumers are likely to deem this sufficient and will show only a small response to further increases. However, the „all-electric" range for the PHEV or the battery electric vehicle is included as a standard attribute, with four possible values for each vehicle. For the PHEV, the „all-electric" range was described to respondents as the range the vehicle could travel on electric power alone before the internal combustion engine was required. While this is a simplification[11], we believe the attribute is still a good proxy for the proportion of trips and distance that could be completed under electric power.

The full set of levels for each attribute and vehicle type is shown in the Appendix.

3.3 Generation of choice sets

The attributes described above were combined to create the hypothetical vehicles that form the basis of the choice experiment. In each question, respondents were asked to choose between a conventional car, a PHEV and a BEV. The attributes for each vehicle were varied between choice questions to force respondents to trade off different vehicle and infrastructure properties.

These „choice sets" were generated with the software package Ngene, using a so-called „efficient design". Efficient designs aim to avoid unbalanced choice sets and create only choices where respondents must carefully consider the full range of attributes to make their decisions. An example of an unbalanced choice set would be a one where the conventional car had a lower purchase price and running costs and higher performance than the plug-in alternatives. In this case, the vast majority of respondents would choose the conventional vehicle, but we would gain little information on how they traded off attributes of the plug-in vehicles.

[10] Ziegler (2010): Individual Characteristics and Stated Preferences for Alternative Energy Sources and Propulsion Technologies in Vehicles: A Discrete Choice Analysis. Available at: http://ideas.repec.org/p/eth/wpswif/10-125.html

[11] In reality, the a PHEV may use its internal combustion engine even when the battery has charge remaining if high power is required, for example for overtaking or for motorway driving.

The use of an efficient design means that more information is gained for given number of choice sets (hence the name „efficient design"). Mathematically, this is the same as minimising the standard errors on the coefficients for a given sample size. This is achieved by providing the software with „priors", estimates of what the consumer coefficients are likely to be for each attribute. For example, if we expect that consumers will be strongly averse to BEVs if infrastructure availability is low, we can generate designs that do not contain choice sets where the BEV has simultaneously high costs and low charging infrastructure.

For the pilot experiment, we used estimates of coefficients from previous studies and data from the literature as inputs to create the efficient design in Ngene. The choice data from the pilot experiment were then used as the priors in the main experiment, ensuring that the final coefficients were as statistically robust as possible.

The final experimental design consisted of 100 distinct choice sets, which provided sufficient variation to estimate all the model parameters. Clearly it is not feasible to ask respondents to answer a hundred choice questions, so the choice sets were divided into ten sets of ten questions, with each respondent allocated one version of the experiment at random.

An example of a choice question is shown in Figure 3. This was presented to respondents as an example, with instructions on what questions they could expect from the real experiment. Note that up to three questions are asked for each choice set. The first two asked which of the vehicles respondents would choose if they were to replace their primary or secondary vehicles. Respondents are free to choose from any of the vehicles shown in each case. However, if they choose the conventional vehicle for both the primary and secondary vehicle questions, they were then forced to choose between either the PHEV or the BEV. This „forced choice" was a safeguard in case respondents repeatedly chose the conventional vehicle, so that data were still collected on the differences in consumer responses for the two plug-in vehicles.

	Conventional car	Plug-in hybrid electric car	Pure electric car
Purchase price	**£16,000**	**£20,000**	**£18,000**
Running cost	**£900** per year	**£300** per year	**£600** per year
0-60mph acceleration	The **same** as a typical car	**20% quicker** than a typical car	**40% quicker** than a typical car
Range	The **same** as a typical car	Total range the same as a typical car, **40 mile** range in 'electric mode'	**100** miles
Recharging / refuelling time	5 minutes to fill fuel tank	5 minutes to fill the fuel tank, **4 hours** to charge the battery,	**2 hours** to charge the battery
Home / workplace charging	N/A	Charging available at **home and work**	Charging available at **home**
Public infrastructure	Fuel available at all filling stations	Charging points available at **30%** of public car parks / on-street parking spaces	Charging points available at **50%** of public car parks / on-street parking spaces
CO_2 emissions	The **same** as a typical car	**40% lower** than a typical car	**60% lower** than a typical car

For each set of cars we will ask you the following:

Which one of the above cars would you choose if you were replacing your *main* car?

☐ ☐ ☐

If you have more than one car, which car you would choose if you were replacing your *second car*?

☐ ☐ ☐

If you choose the conventional car for both your first and second car, we will ask you the following:

If you could only buy the plug-in hybrid electric or the pure electric car, which one *of these two* would you choose?

☐ ☐

Figure 3 Example choice question

3.4 Pilot survey

All parts of the questionnaire, including the choice experiment and attitude questions, were piloted with a sample of 100 respondents. The aim of the pilot was to test the questionnaire in the same environment as the main survey with a larger sample than in the cognitive testing, to ensure that all questions were working correctly and that the choice experiment was producing statistically robust results. Specifically, it fulfilled a number of objectives:

- It provided data on the completion times for each part of the questionnaire when tested online, as opposed to a printed questionnaire in the cognitive testing.
- It provided a higher sample (101 respondents) which allows the estimation of robust choice models and provides a high degree of confidence that the choice experiment is working well.
- It gave an estimate of the incidence rate, defined as the number of completed surveys as a proportion of the number of research panel members contacted. If the incidence rate was much lower than expected, this would jeopardise the timescales for collecting the data.
- It allowed formats for data transfer between the market research company (Accent MR) and Element Energy to be tested. This minimised the time required to process the choice data before beginning the analysis.

The choice data from the pilot survey were used to estimate a set of choice coefficients for all the vehicle and infrastructure attributes. All coefficients had the expected signs and magnitudes, suggesting that the experiment was working correctly, and these were used to update the priors in Ngene and generate the final experimental design.

Minor changes to the wording of several attributes were made following the pilot study. This included removing the values given for the performance and emissions attributes (seconds for acceleration from 0–60mph and gCO_2/km respectively), so that respondents saw only the percentage improvement relative to a typical vehicle. These changes were made to reduce the amount of data presented in each question, in order to reduce the cognitive load on respondents.

3.5 Main survey

Following the successful pilot experiment, the final questionnaire was launched in November 2010. The respondents were provided by Research Now, a survey panel company which maintains a database on consumers who have signed up to take part in consumer research. We used two screening criteria to select suitable respondents:

1. Respondents must have purchased/leased a new or nearly new (less than two years old) car in the last five years, OR
2. Respondents must have been planning to buy a new car in the near future.

These criteria were used to exclude people who habitually buy older second hand cars, as these consumers are unlikely to be potential buyers of plug-in vehicles in the short and medium term. A final question in the screening section asked respondents to place themselves on a five-point innovation scale. This question was used to create a quota for the most innovative respondents who “like to buy the latest technology that is right at the cutting edge as soon as it is available”, in the expectation that these consumers are potential early adopters of plug-in vehicles. The quota for this group was set at 200 respondents, in addition to the overall quota of 2,500 responses.

The main survey was conducted using a „two wave" approach, where respondents answered the questionnaire in two parts, with an enforced 48 hour wait between the two parts. Wave one contained demographic and attitude questions as well as the „pre-read" material for the choice experiment; Wave 2 contained the choice experiment itself and further attitude questions. The purpose of the waiting period was to allow respondents time to assimilate the information received in Wave 1 into long term memory, rather than basing their answers to the choice experiment on short term recall. This is discussed in more detail in the final report for WP1.3. The market research team anticipated a drop-out rate of 30% between the two parts of the survey. For this reason, the overall quota of 2,500 (plus 200 „innovators") applied to completed Wave 2 responses.

4 Analysis and consumer segmentation

4.1 Methodology

The quantitative survey resulted in 4,250 respondents for Wave 1, with 2,729 going on to complete Wave 2. The analysis of the data took place in several stages, in collaboration with the University of Aberdeen. Their work on the analysis of the non-choice data is described in the final report of WP1.3. In this report, we focus on the analysis of the choice data and interactions with the consumer segmentation.

The analysis of the choice data took place in several stages:

1. Estimation of „base" model using whole sample.
2. Interaction effects with demographic and attitudinal variables.
3. Testing of initial consumer segmentation and feedback to the University of Aberdeen.
4. Iteration until final segmentation was agreed, providing the best representation of the heterogeneity in the choice data and other parts of the survey.

Data cleaning

To ensure consistency with the analysis of the other parts of the survey, we removed the same 38 respondents from the sample as were excluded by the University of Aberdeen. These included 34 cases where respondents did not actually have a driving licence, two who did not meet the screening criteria and two who failed to answer a large number of the attitudes questions. We also excluded 40 respondents whose stated annual mileage was greater than 50,000 miles a year (including one who reported an annual mileage of 300,000)[12]. These were excluded as the pivoted design for the annual running cost attribute would have produced very large fuel bills, which would have unbalanced the choices and biased the coefficients.

A further check on the remaining sample was carried out to ensure that all respondents had answered the full set of choice questions. No bad observations were found, leaving a sample of 2,670 respondents and 26,700 choice questions.

4.2 Estimation of base model

A base model was estimated using choice data from the whole sample. The purpose of the base model is to confirm that the consumer responses to each of the attributes have the correct sign and magnitude. It also provides a benchmark, against which more complex choice models can be compared. The purpose of the model is to provide the best predictive power on how consumers will choose from a set of competing vehicles. In the base model, the effects of demographics or consumer attitudes (for example towards the environment) are not represented, and are hence captured as „random" variation in the model. By representing these factors explicitly in the model, we increase the explanatory power of the model and reduce the importance of random variation.

All analysis was conducted in Nlogit, a leading statistical software package for estimating models based on choice data[13]. The software produced coefficients for use in the utility equations in a Logit model, which predicts the market shares of different products given

[12] These 40 respondents included 9 who had already been excluded on the previous criteria.
[13] More information on Nlogit is available at www.econometricsoftware.com

their attributes[14]. The coefficients represent the relative weighting attached to each of the attributes that determine the overall utility (or attractiveness) of each vehicle. In other words, the utility of a given vehicle is calculated by multiplying the value of each attribute by its coefficient and summing these products. This is shown mathematically below:

$$U_{conv} = b_0 \times Price + b_1 \times Running\ cost + b_2 \times Acceleration + b_{3(conv)} \times Emissions$$

$$U_{phev} = ASC_{phev} + b_0 \times Price + b_1 \times Running\ cost + b_2 \times Acceleration + b_{3(phev)} \times Emissions + b_{4(phev)} \times Range + b_{5(phev)} \times Private\ inf. + b_{6(phev)} \times Public\ inf. + b_{6(phev)} \times Charging\ time$$

$$U_{bev} = ASC_{bev} + b_0 \times Price + b_1 \times Running\ cost + b_2 \times Acceleration + b_{3(bev)} \times Emissions + b_{4(bev)} \times Range + b_{5(bev)} \times Private\ inf. + b_{6(bev)} \times Public\ inf. + b_{6(bev)} \times Charging\ time$$

where,

U_{conv} = the total utility of the specified vehicle
b_x = the weighting factor for the xth attribute, generic across all vehicle types
$b_{y(phev)}$ = the weighting factor for the yth attribute, calculated for each vehicle type
ASC_{phev}= the alternative specific constant for the specified vehicle type.

These coefficients are used directly in the Consumers and Vehicles Model, but it is more convenient to express them in pounds as willingness to pay (WTP values). These values are calculated by dividing each coefficient by the coefficient for capital cost (also known as the price coefficient). This allows each coefficient to be expressed as the change in capital cost that would have an equivalent effect on the market share of a given vehicle. The table below shows the WTP values for the „base" model.

Table 1 Willingness to pay for vehicle and infrastructure attributes - base model

Attribute	WTP	Unit
Generic Parameters		
Annual running cost	£5	per £ of annual ongoing savings
Performance	£1,376	per 20% improvement relative to typical vehicle
PHEV-specific parameters		
PHEV Constant	-£7,958	constant term (dimensionless)
Emissions	-£15	per g/km
Home Charging	£2,413	binary (1 or 0)
Work Charging	£4,370	binary (1 or 0)
Home + Work Charging	£1,723	binary (1 or 0)
Public infrastructure	£430	per 10% of car parks/parking spaces with charging
Range	£9	per km of electric range
BEV-specific parameters		
BEV Constant	-£24,439	constant term (dimensionless)

[14] A Logit model is used in Element Energy"s Consumers and Vehicles model to predict the uptake of plug-in vehicles over time. The market share calculation is described in detail in our „Model Results and Analysis" report, also delivered under Work Package 1.4.8.

Emissions	£8*	per g/km
Home Charging	£3,325	binary (1 or 0)
Work Charging	£237	binary (1 or 0)
Home + Work Charging	£5,520	binary (1 or 0)
Public infrastructure	£595	per 10% of car parks/parking spaces with charging
Range	£27	per km of electric range
Charging time	-£256	per hour of charging time

* denotes value based on a non-statistically significant coefficient

Generic parameters – running costs and performance

In the base model, the capital cost, running cost and performance attributes are constrained to be equal across the three vehicle types tested in the choice experiment. In other words, £1 of annual running cost saving has the same utility to consumers whether they are driving a conventional or a plug-in vehicle. Table 1 shows that the WTP for each pound of annual running cost saving was £5. In other words, respondents were willing to pay an extra £5 of capital cost for a vehicle which saves £1 in running costs over its lifetime. This is equivalent to demanding a simple payback on a more fuel efficient car of 5 years.

This value is higher than other studies on the willingness to pay for fuel bill savings, both within the transport sector and in the domestic efficiency market, which find simple payback periods of between 3 and 4 years. There are several reasons for the slightly higher value found in this study:

- The low values found in other studies capture numerous factors, such as technology risk (the product not delivering the claimed bill savings), in addition to a simple measurement of the time value of money. The technology risk for plug-in vehicles is explicitly captured in the vehicle-specific constants in this study, effectively removing it from the running cost attribute and raising the value of the stated payback.
- The survey was undertaken in December 2010, during a period of rapidly rising fuel prices (relative to prices during the 2008/2009 recession). If respondents „priced in" higher fuel bill savings than those described in the choice questions, this would raise the implied payback period. This reflects the real-world, where people are more likely to buy energy efficient products during a trend of rapidly rising fuel prices.
- The value shown here relates to the whole sample, which includes a wide range of demographic groups. The results of the segmentation show that for the „laggard" consumers, payback periods are indeed closer to 3 years, and below 2 years for one group (see Section 5).

Vehicle-specific constants

These constants reflect the biases respondents have for or against the PHEV and BEV. They reflect the financial penalty associated with the „label" of these vehicles, which reflects concerns over the new technologies, such as safety or reliability, or the perceived limited utility of the battery electric vehicle. They also capture factors such as how plug-in vehicles fit with respondents" lifestyles and how they would be seen by their peer group. Constants are a widely used in this way when the „label" of a product (in this case, electric vehicle) has a significant influence on consumers" choices even before other attributes are considered. For example, Hidrue *et al.* (2011)[15] conducted a choice experiment to investigate preferences for electric versus gasoline cars, using similar attributes (such as range and recharging time, as in this study. Their results showed very negative constants for a pure electric vehicle, of up to -$22,000 for mass-market respondents. This is in close agreement with our results.

The values shown in Table 1 are very negative for both plug-in vehicles, with the penalty against the BEV three times higher than for the PHEV. However, it must be noted that this highly negative constant is partially offset by the infrastructure attributes and the vehicle range (which have positive coefficients). Therefore it is more useful to think of the „net bias", or the remaining penalty against these vehicles when all other attributes have been taken into account. This is shown in Figure 4. For a mass market consumer, the infrastructure attributes (which have positive utility) do not completely offset the highly negative coefficient, which suggests that these consumers have a residual bias against plug-in vehicles, even if they are offered at the same price as a conventional car. For an early adopter, the constant is much less negative, which means once the infrastructure and range attributes are included these consumers have a net preference for plug-in vehicles. In other words, they are willing to pay more for a PIV than a conventional car, all things being equal. The vehicle-specific constants show very large variation across different groups within the sample. These issues are discussed in detail in Section 5.3.

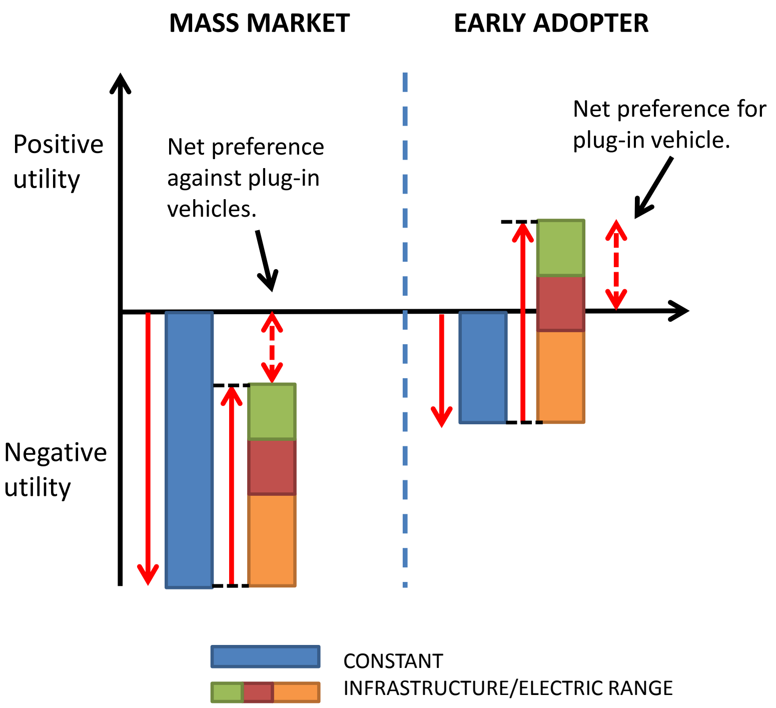


Figure 4 Illustration of 'net' preference for or against plug-in vehicle

Infrastructure attributes

In the base model, separate coefficients (and hence WTP values) were calculated for the home, work and „home + work" charging, as well as a coefficient for public infrastructure availability. The results show significant differences between the PHEV and the BEV.

[15] Hidrue, M.K., et al., Willingness to pay for electric vehicles and their attributes. Resource Energy Econ. (2011), doi:10.1016/j.reseneeco.2011.02.002

For the PHEV, the highest WTP was for work charging rather than home charging. This suggests that respondents understood that the plug-in hybrid offered more flexibility regarding charging infrastructure, and that charging at work (possibly for free) could be more convenient than charging at home.

The coefficients for the BEV suggest a very different consumer response. For these vehicles, workplace only charging has very little value to consumers. In contrast, consumers have a high WTP for home only charging (at £3,325, over 40% more than for the PHEV). This is expected, given that BEV"s lack the fuel flexibility and that the majority of driving trips (over 80%) either begin or end at home.[16] However, the WTP for „home + work" charging of £5,520 suggests that workplace charging does have significant value to potential BEV users if they also have access to home charging.

Public infrastructure

Public infrastructure was expressed in the choice questions as „the % of car parks/public car parking spaces at which charging is available". In the base model, the consumer response is assumed to be linear, so that an additional 10% of car parks/spaces with charging is always worth the same to consumers, whether that change is from 10% to 20% or 40% or 50%. The values in Table 1 suggest that respondents were willing to pay £430 or £595 for an additional 10% of public infrastructure availability for the PHEV and BEV respectively. This implies that unless public infrastructure is *very* widely available, it is significantly less valuable to consumers than home or workplace charging[17].

Electric range

The consumer response to electric range again shows a distinction between attitudes to PHEVs and BEVs. Respondents were willing to pay £9 per km of electric range for a PHEV, compared with £27 per km for the BEV. This large difference suggests that consumers have correctly understood the flexibility afforded by the hybrid vehicles, while recognising that each kilometre of additional range for a BEV has a greater effect on the usefulness of that vehicle than an extra 1km in a PHEV.

It is important to note that the WTP for additional range is significantly less than the cost to car manufacturers of providing it. For example, respondents are willing to pay just £175 for an extra 20km of electric range in a PHEV[18], and £1,340 for an extra 50km of range in a BEV. According to the battery cost trends contained in the Consumers and Vehicles model, the cost of providing this extra range for a C-segment vehicle is £3,500[19]. However, expected battery cost reductions (and vehicle efficiency improvements) mean that this cost decreases to the £1,350 in 2027. These results suggest that until such cost reductions are achieved, manufacturers should prioritise cost reduction over range increases in electric vehicles in order to provide the most attractive offer for consumers.

Emissions

The response to the emissions attribute for the PHEV has the correct sign, and implies a WTP of £15 per g/km. In other words, the perceived benefit of a vehicle saving 50g/km relative to another is £750. Note that this is the direct response to CO_2 emissions rather than the implied fuel savings of a low CO_2 car (since annual fuel cost was captured

[16] Based on National Travel Survey data.
[17] In other words, at plausible future values for public infrastructure (e.g. 20% of car parks/parking spaces with charging available), the willingness to pay is considerably lower than the c. £3,350 WTP for home charging in the BEV.
[18] Note that this ignores the fuel bill saving from the additional driving distance that can be completed in electric mode, though this is likely to be in the order of £50-£100 for most users.
[19] Assuming a battery cost of £510/kWh and an electricity consumption of 14kWh/100km in 2010.

separately). However, it may reflect consumers pricing in other CO_2-dependent motoring costs, such as Vehicle Excise Duty. The introduction to the choice experiment emphasised that all costs/benefits not listed should be assumed to be constant across all of the vehicles in the choice set, but some respondents may have continued to interpret „low CO_2" as receiving favourable tax treatment.

The consumer response to emissions in the BEV was not statistically significant. In other words, the WTP for EV emissions did not differ significantly from zero, and consequently had no influence on whether respondents chose BEVs over any other technology. We propose two explanations for this. The first is that respondents had difficulty understanding the concept of CO_2 emissions from battery vehicles, even after reading the explanation that this was due to emissions from producing the electricity used to charge the batteries. The second is that the label „electric vehicle" is so closely associated with low or zero emissions vehicles that respondents did not pay attention to the emissions attribute when completing the choice experiment, focusing instead on the range and infrastructure attributes.

4.2.1 Comparison with recent studies

It is useful to compare the results in Table 1 with recent stated choice studies in the literature. While the different methodologies used in each study make a direct comparison difficult, it is still possible to compare numbers expressed in terms of willingness to pay. For example, a recent study commissioned by Daimler calculated WTP values for different recharging time, finding a difference of €2,972 between 6 hours and 30 minutes for Germany, and €2,177 for France. This is equivalent to £460/hr and £360/hr, respectively, which are higher but still broadly similar to the value in this study of £260/hr. Such differences may be due to differences in the methodology (such as assumptions on the availability of infrastructure), but are also likely to reflect differences in demographics and driving patterns between the UK and continental Europe.

The study by Hidrue *et al.* (2011), mentioned above, is a particularly relevant point of comparison. The choice experiment used attributes that were similar to those in our study, allowing direct comparison of willingness to pay values. For example, the study found that US consumers capitalised 5 years" worth of annual fuel costs, a figure identical to the 5 year payback shown in our base model. They also found consumers had a willingness to pay for additional electric range of between $35 and $75 per mile, equivalent to £15–£31 per km, again similar to the £27 for BEVs in this study. However, their estimate of the WTP for improvements in performance is significantly higher than in this study, at $7,300 for a 40% improvement in acceleration. This is equivalent to c. £2,400 for a 20% improvement[20], compared to £1,376 from our study.

The Hidrue *et al.* study also shows that the „net" willingness to pay for an electric vehicle can be highly negative for some consumers, even when infrastructure and range are taken into account. The study showed that some consumers would only purchase a battery electric vehicle if it cost $17,000 *less* than a typical car, all other things being equal. In other words, the study showed that consumer biases against electric vehicles can be equivalent to $17,000 of capital cost. Our research is in close agreement with that study. Differences in preferences between consumer groups are discussed further in Section 5.3.

While there is no reason to expect that our results should be identical to other studies in the literature, the fact that our estimates of consumer response are broadly consistent with

[20] Based on an exchange rate of 1.5 USD per £ and dividing the WTP for a 40% improvement by two.

other recent work indicates that the experiment performed well and provided robust coefficients on which to base the Consumers and Vehicles model.

4.3 Extending the base model

Having estimated a base model and identified the overall trends in the consumer response, the next stage of our analysis investigated more complex model specifications that improved the goodness-of-fit relative to the base. Adding complexity to the base model can be achieved in two main ways:

1. Non-linearities in the consumer response – for example diminishing effects of increasing range.
2. Interaction between attributes – e.g. the response to one attribute depends on the value of second attribute.

Non-linearities in the consumer response

In the interest of simplicity, the base model assumes that the consumer response to each attribute is linear. For example, a 50km increase in range always has the same „utility" to consumers, whether it is an increase from 50km to 100km or 150km to 200km. In reality, we would expect non-linearities or threshold effects in the response, such that there is a „sufficient" range for most consumers, after which further increases do not improve the utility of that vehicle. This is shown below.

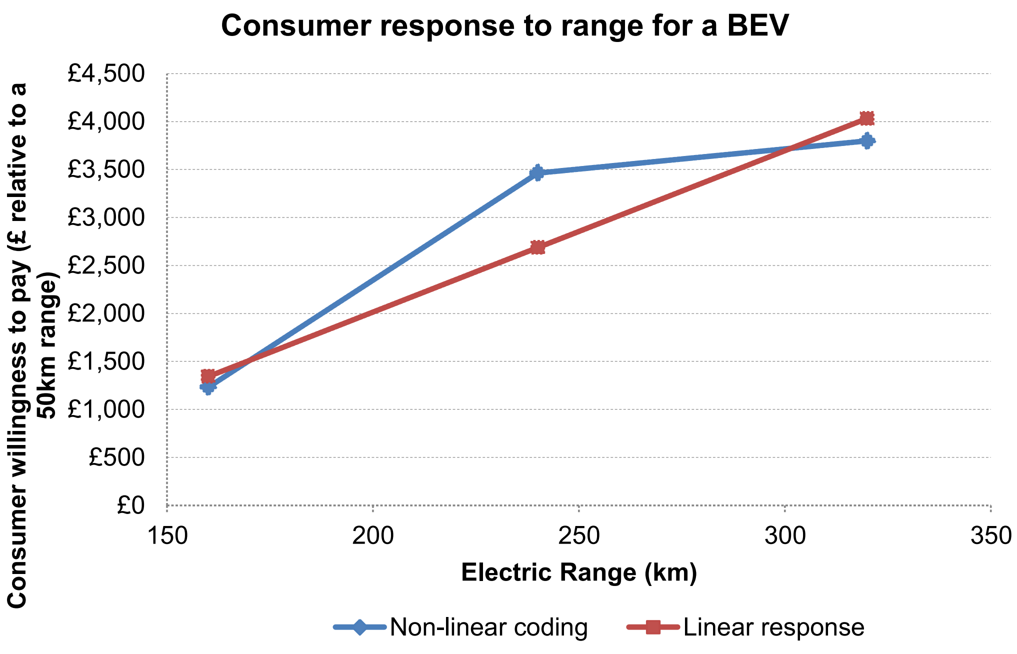


Figure 5 Consumer response to the 'range' attribute for the BEV

Figure 5 shows the effect of specifying a non-linear response to the range attribute for the BEV. To calculate this, the attribute is „dummy" coded, which allows the estimation of a separate coefficient for each value of range tested in the choice experiment. Strictly, coefficients can be estimated for *n-1* levels, so in the figure the willingness to pay values are expressed *relative to a range of 80km*[21].

The data show that there is indeed a non-linear response to the range attribute for BEVs. Respondents were willing to pay £2,300 for an increase in range from 160km to 240km. However, the utility of increasing the range further from 240km to 320km is very low (with a WTP value of just £300). This is an important finding, as it suggests that even consumers with little experience of EVs recognise that 240km (c. 150miles) is a „sufficient" range, and that they are unwilling to pay to increase range beyond this.

The consumer response to the range attribute for PHEVs was much weaker than for BEVs, and did not show the same strong saturation effect. It is important to distinguish between the effect of increasing range in the BEV (which strongly affects the perceived and actual usefulness of the vehicle), and in the PHEV (which reduces running costs by allowing a greater distance to be covered using electric power). In the choice experiment there was no correlation between running cost and electric range (the attributes were independent), and so the results suggest that consumers are relatively unconcerned by electric range *per se* in the PHEV. This reinforces the finding from Axsen and Kurani (see Section 2.2), which showed that consumers care about the *overall* fuel consumption (and hence running cost), rather than explicitly about all-electric range.

Several other attributes were tested in the same way, including the public charging infrastructure and charging time attributes. Electric range in the BEV was the only attribute that showed a clearly non-linear response.

Interactions between attributes

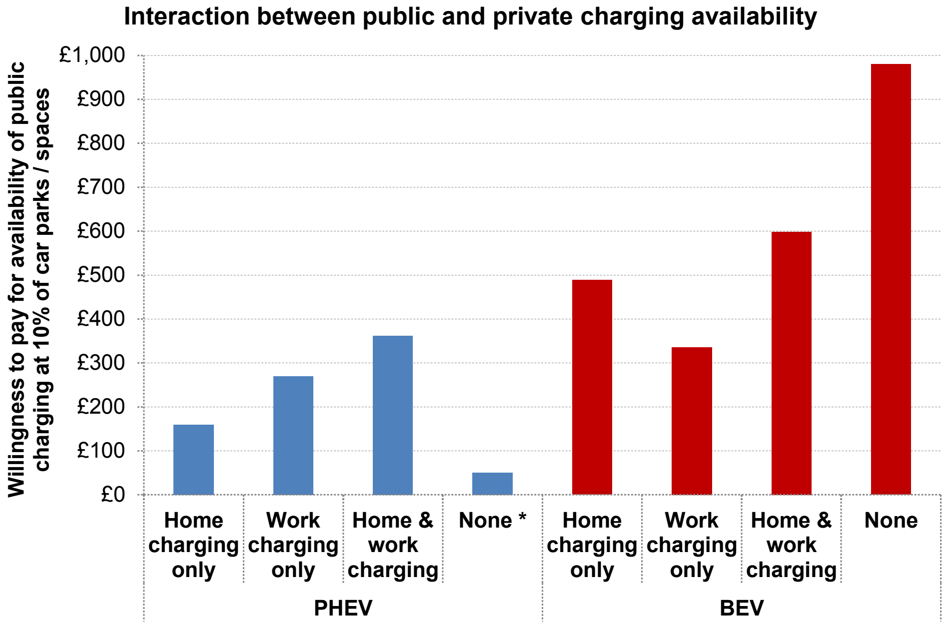
The base model treats the consumer responses to each attribute in the choice experiment as independent to all others. For example, consumers respond to changes in vehicle range and running costs, but the response to range does not depend on the value of running costs. While theoretically it is possible to test interactions between any two attributes in the choice experiment, many of these are unlikely be meaningful in terms of explaining vehicle choice in the real world (for example an interaction between infrastructure availability and acceleration). A more likely interaction is between private and public infrastructure, with the hypothesis that as availability of home and workplace charging increases, consumers perceive less need for public infrastructure and are willing to pay less for it. An alternative but equally plausible hypothesis is that access to private infrastructure makes consumers more willing to pay for public infrastructure, since they might perceive that the latter has no utility to them unless they can *also* charge at home or work.

Figure 6 shows the results of testing the interaction between private and public infrastructure. The willingness to pay for a ten percentage point increase in charging availability at public car parks / parking spaces is calculated for each category of private charging, for PHEVs and BEVs. For the BEV, the data suggest that the WTP for public infrastructure is highest when no other infrastructure is available. However, if home charging is available, the WTP for public charging halves.

A similar trend is seen for work and „home and work" charging – these values do not differ statistically from each other. Again, this suggests that a group of car buyers with little practical experience of plug-in vehicles attaches significantly less importance to public infrastructure if they can charge through other means. For the PHEV, a different trend

[21] The choice experiment tested four levels (50, 100, 150 and 200 miles), which means that three coefficients can be estimated. The values are expressed relative to the lowest value and converted to km.

emerges where respondents placed no value on public charging if they didn‟t also have access to other charging. The reasons for this are unclear, but it may reflect respondents deciding that without work or home charging, they would simply use liquid fuel refuelling infrastructure rather than public charging infrastructure[22].



* indicates not statistically different from zero (at a 5% significance level)

Figure 6 Interaction between public and private charging

The non-linear responses and interaction shown above highlight several interesting trends that warrant further investigation, for example to understand exactly where the „saturation point‟ for electric range occurs in different consumer groups. It is worth noting here that calculating these effects is „costly‟ in a statistical sense, as each non-linear response requires the estimation of three or four parameters compared with just one for a linear response. While this is acceptable for a model calculated for the whole sample (as the base model is), it severely compromises the ability to estimate statistically robust coefficients for a number of consumer groups, as discussed in the next section. In other words, it is possible to estimate only a finite number of parameters from a given quantity of choice data. For this reason, we assume a linear consumer response to range and in the segmentation model implemented in the Consumers and Vehicles model. Given that the electric range for BEVs remains below 240km for most vehicle segments until the 2040s, the effect of this simplifying assumption is small, especially since it allows the model to capture much larger differences in the response to range across consumer segments, described in the next section.

[22] While it is clear that this is not the most efficient use for a PHEV, the design of the experiment would have offered some choice sets where the PHEV was considerably cheaper than a conventional car, leading respondents to choose it even if there was zero or very low availability of infrastructure.

5 Consumer segmentation

In the analysis above, we have ignored the effect of heterogeneity in the consumer response through the sample. Effectively, we have assumed that the whole sample has a single, „average" response to each attribute, and the variation in the data due to differences in consumer attitudes is assumed to be random. In this section, we discuss the results of the consumer segmentation exercise, which aims to explicitly capture differences in the consumer attitudes, and identify the characteristics of key groups, such as early adopters and „laggards".

The consumer segmentation was carried out in parallel with Work Package 1.3, which used factor and cluster analyses on the demographics and attitude questions to create distinct consumer segments. This was an iterative process, and Element Energy tested several interim segmentations by calculating consumer coefficients for each group and providing feedback on whether the segments successfully captured the diversity of car buying preferences. One of the aims of the segmentation was to identify the small „innovator" groups, who have the most „extreme" preferences with regard to new technologies or environmentally friendly products. Element Energy worked with TRL and the University of Aberdeen to develop the consumer segmentation. The workflow is shown in Figure 7.

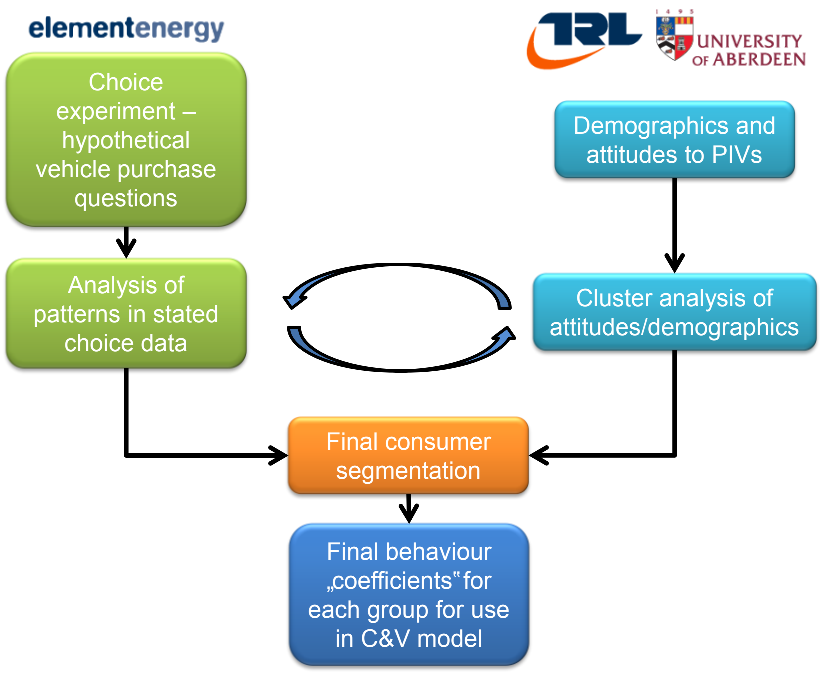


Figure 7 Workflow in the consumer segmentation exercise

The initial segmentation models contained a relatively large early adopter group (over 10% of the sample). Element Energy interacted this group with the choice data and showed that their stated vehicle choices were broadly similar to other groups. In other words, the large size of the group was leading to the „extreme" behaviour of the earliest adopters being diluted by respondents who were closer to mass-market consumers. This analysis led to the development of the final segmentation, described below, where a much smaller „earliest adopter" group (2% of the sample) was identified which had highly favourable attitudes towards plug-in vehicles and whose attitudes were very different from the other segments.

5.1 Final consumer segmentation

The final consumer segmentation consists of eight distinct segments, made up of seven „private consumers" and a further group containing drivers of company cars. These segments cover the spectrum of consumers from the early adopters and early majority through to laggards of the technology, in the terminology of Rogers (1962). A final segment for company car owners was required to represent the unique driving patterns and vehicle purchasing criteria for these drivers.

Figure 8 shows the seven private consumer groups (excluding the company car drivers) plotted on a traditional „innovation curve". The Pioneer group is the smallest „innovator" group, comprising 2% of private car buyers, followed by optimists and pragmatists, who are less enthusiastic but potentially favourable to electric vehicles. At the other end of the range sit the sceptics and rejecters, who are strongly opposed to plug-in vehicles, believing that they do not fit with their driving habits or self-image.

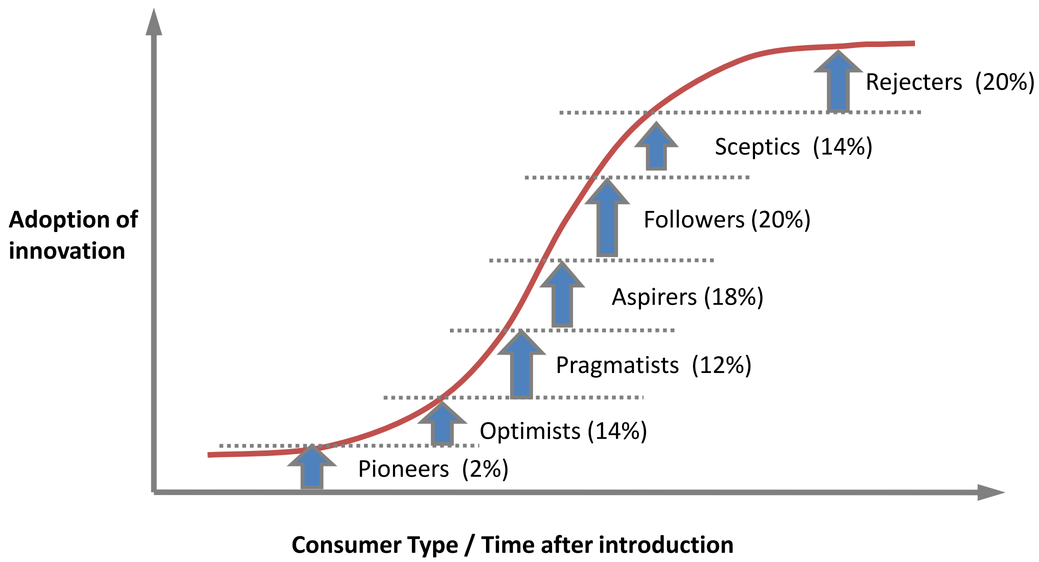


Figure 8 Position of consumer segments on a traditional innovation curve (company car drivers not shown)

In this section, the quantitative consumer responses of each of these groups are described in detail. These results directly inform the dynamics of PIV uptake in the Consumers and Vehicles Model, as they determine whether PIVs will move beyond a niche product sustained by Pioneers to mass-market appeal.

5.2 Response to vehicle and infrastructure attributes

5.2.1 Annual fuel savings

One of the key differentiating characteristics of early adopters and mass-market consumers is the relative importance of upfront versus ongoing costs. This is a critical dimension in understanding consumer behaviour, especially given that PIVs are characterised by high upfront costs and lower running costs. Early adopters are expected to show a higher willingness to pay for lower fuel bills, which is equivalent to having low discount rates or long time horizons. By contrast laggard groups place a much greater emphasis on capital costs.

Figure 9 shows the variation in the emphasis placed on annual fuel savings across the eight consumer segments. Strictly, the values show the amount that consumers are willing to pay upfront for £1 of ongoing fuel savings[23]. The highest implied payback period is seven years in the Optimists group, though the majority of groups show payback periods of 5 years or above. However, this contrasts sharply with the Rejecters and Company Car groups, which have payback requirements of 2 years or less. This confirms that these groups are the least likely to buy plug-in vehicles, as they place little emphasis on the main selling feature of lower running costs. This is before their attitudes to the actual vehicle technologies are taken into account.

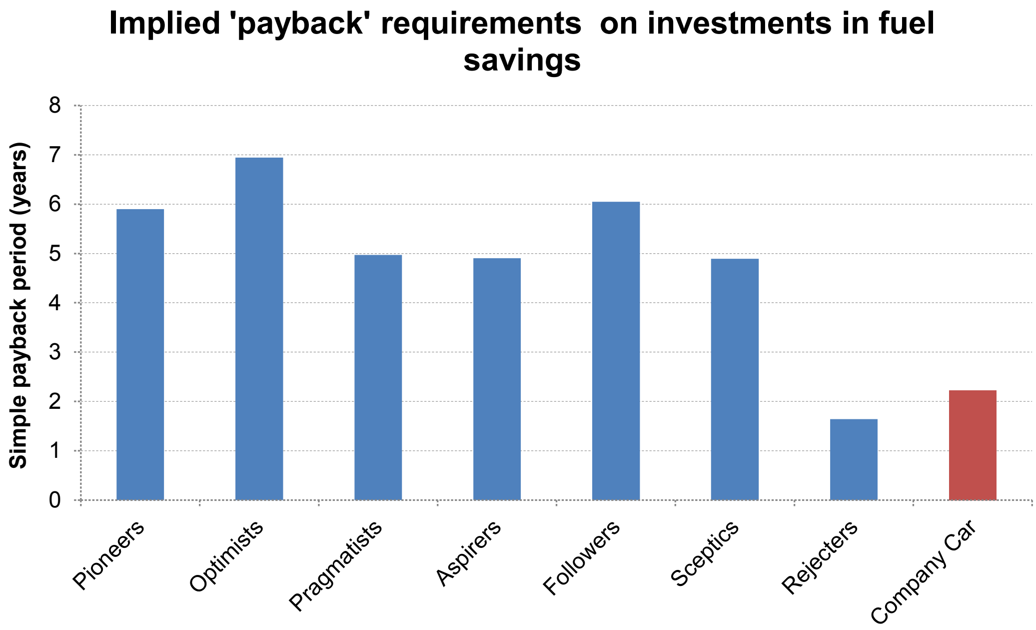


Figure 9 Implied payback periods based on willingness to pay for ongoing fuel savings

5.2.2 Response to acceleration/performance

The willingness to pay for performance improvements shows significant variation across the consumer groups. The values shown in Figure 10 represent the WTP for a 20% improvement in performance, as measured by 0–60mph acceleration time. This is equivalent to decreasing the 0–60mph time by about 2 seconds. The highest values are seen in the Aspirer and Company car groups. The response of company car drivers reflects the fact that they spend more time in their vehicles than average consumers do and so are willing to pay more for a vehicle with enhanced performance (since in most vehicles, 0–60mph acceleration is a good proxy for other performance metrics such as in gear acceleration and motorway driving comfort). Alternatively, it may simply reflect that „user chooser" drivers of company cars are not exposed to the full purchase price of the vehicle, causing them to overstate the importance of performance.

Figure 10 also shows that the Pioneer group places a similar emphasis on vehicle performance as other consumer groups. This is consistent with the responses of this group to other parts of the quantitative survey, which suggest that this group is more concerned with new technology than CO_2 emissions. In other words, they are likely to buy a plug-in

[23] This is calculated by dividing the coefficient for annual running cost by the capital cost (price) coefficient.

vehicle because it is a novel and „exciting" technology, rather than simply because it has lower emissions than the incumbent.

Finally, it is worth noting that though significant differences exist between segments, the overall willingness to pay for performance is relatively low compared with the response to infrastructure or the vehicle type, where the WTP values are several times higher.

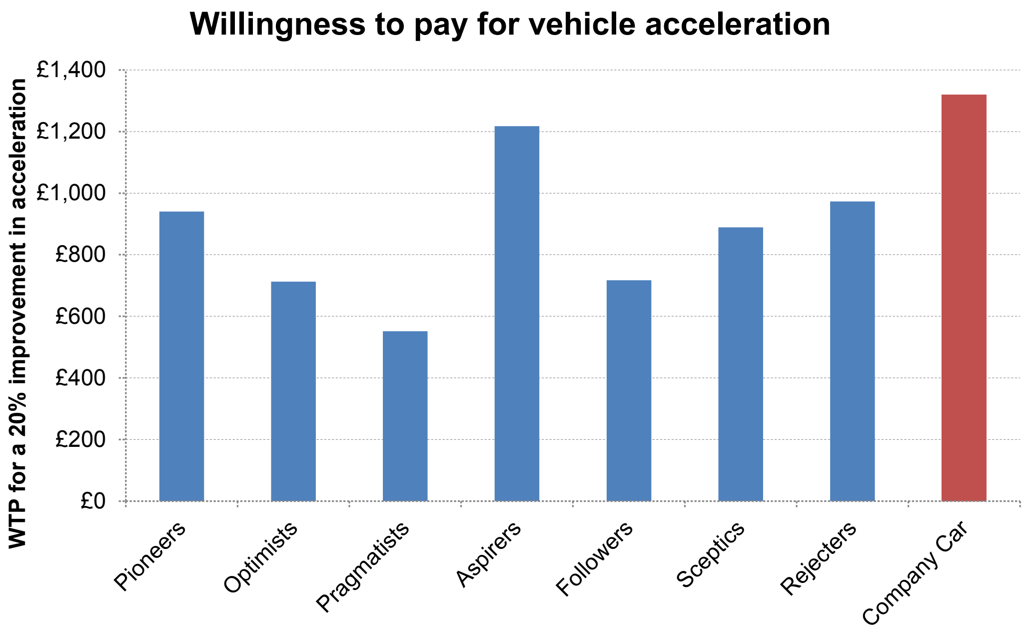


Figure 10: Willingness to pay for a 20% performance improvement (relative to a typical vehicle)

5.2.3 Attitudes to vehicle range

Figure 11 shows the variation in response to electric range in the BEV, in terms of the WTP for a 50km in range. The value for the majority of consumer groups is £2,300 to £3,300, while the highest value of £4,400 is found in the Rejecter group. The Rejecter group is highly sensitive to vehicle range, meaning that an increase in range has a greater effect on the overall attractiveness of the vehicle than in other groups. The converse is also true, so that a decrease in a vehicle"s range has a strong negative effect on its attractiveness for the Rejecter group.

In contrast, the Pioneer group shows an extremely weak response to electric range, and the coefficient was not significantly different from zero. This suggests that these consumers are willing to choose a vehicle with a limited range in order to own a „novel" and low CO_2 car. The Company Car group showed a similarly weak response to electric range. Caution is required when interpreting this finding; the company car drivers rarely chose the battery electric vehicle, which means that their response to different values for electric range is difficult to quantify.

For the PHEV, there was no statistically significant variation in the consumer response to electric range[24]. Therefore we use a single coefficient across all groups, corresponding to a willingness to pay of £9/km (see Section 4).

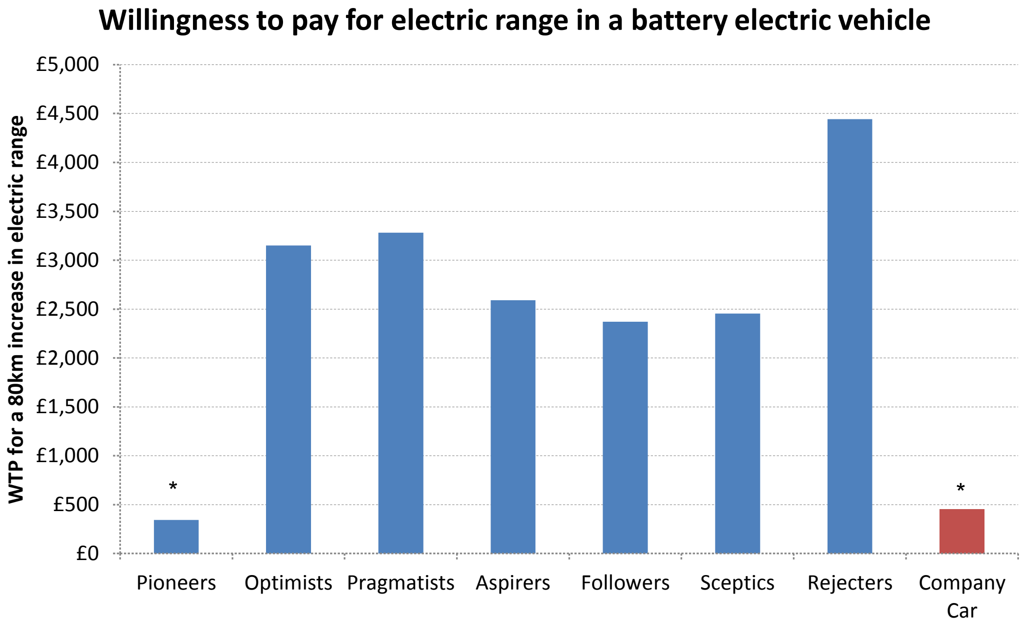


Figure 11 WTP for electric range in a BEV (* indicates coefficient is not statistically significant)

5.2.4 Response to recharging infrastructure

Like the other attributes, we would expect there to be a variation in the importance of infrastructure across the eight consumer groups. For example, the Pioneer group may place a lower emphasis on infrastructure availability, implying they are willing to buy EVs even when widespread infrastructure is not in place. However, as Figure 12 shows, Pioneers exhibit a very strong response to infrastructure availability. The provision of home and workplace charging is worth over £8,000 to them, compared to an average of £5,000 for the other groups. In fact the response of Pioneers to infrastructure is as high as for the Rejecter group.

This result shows that the infrastructure response cannot be viewed in isolation, as there is a critical interaction with the „EV bias", which represents the overall consumer attitude to the technology itself. For example, a positive bias towards EVs in the Pioneer group could lead to these vehicles being relatively attractive even in the absence of infrastructure. If widespread infrastructure becomes available, Pioneers respond strongly to this, and the vehicle becomes even more attractive. Conversely, a rejecter may respond strongly to infrastructure availability, but have such a negative perception of EVs that they still fail to choose them over a conventional vehicle. The interaction of the infrastructure response and the vehicle biases is considered below.

The variation in the infrastructure response (to home/workplace charging) for PHEVs was not statistically significant, and like the electric range for these vehicles, we have

[24] Strictly speaking, we did not have sufficient statistical power to estimate a unique coefficient for each consumer group for PHEV range, since the underlying trend was weak. To mitigate this, we constrain the coefficient to be the same across all consumer groups. Without this constraint, the coefficients for several groups were nonsensical (negative) numbers, which would create implausible results if implemented in the Consumers and Vehicles model.

constrained the model to use a single coefficient for all of these groups, equivalent to the value in the base model for workplace charging[25]. However, the trends in these single coefficients are similar to those described in the base model. For example, workplace only charging has almost no value for the BEV, but is highly valued in the PHEV.

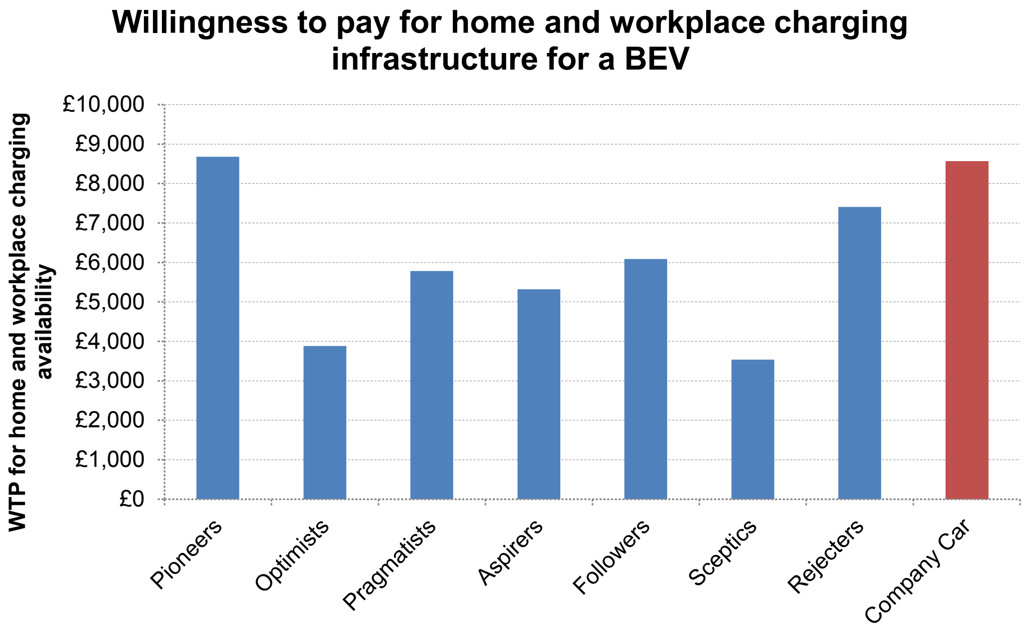


Figure 12 WTP for availability of home and workplace charging for the BEV

Unlike private infrastructure, the variance in consumer response to public infrastructure was statistically significant in the PHEV. In this case, Pioneers *do* show a lower willingness to pay for public charging availability compared to the other consumer groups, as shown in Figure 13. Their willingness to pay for public charging availability in 10% of car parks/spaces is less than £200, compared with over £700 for Aspirers and Company Car drivers. The high WTP in the Company Car group is likely a reflection of the high mileage of these drivers, which at 18,000km per year is 50% higher than in the other groups.

[25] Given the surprising (and hard to believe) result that people were willing to pay more for workplace only charging than „home + work", we have restricted the value of „home + work" so that it can never be less than the value for workplace charging alone. In other words, the additional benefit of home charging may be zero, but we do not allow it to have a negative effect on the attractiveness of PHEVs.

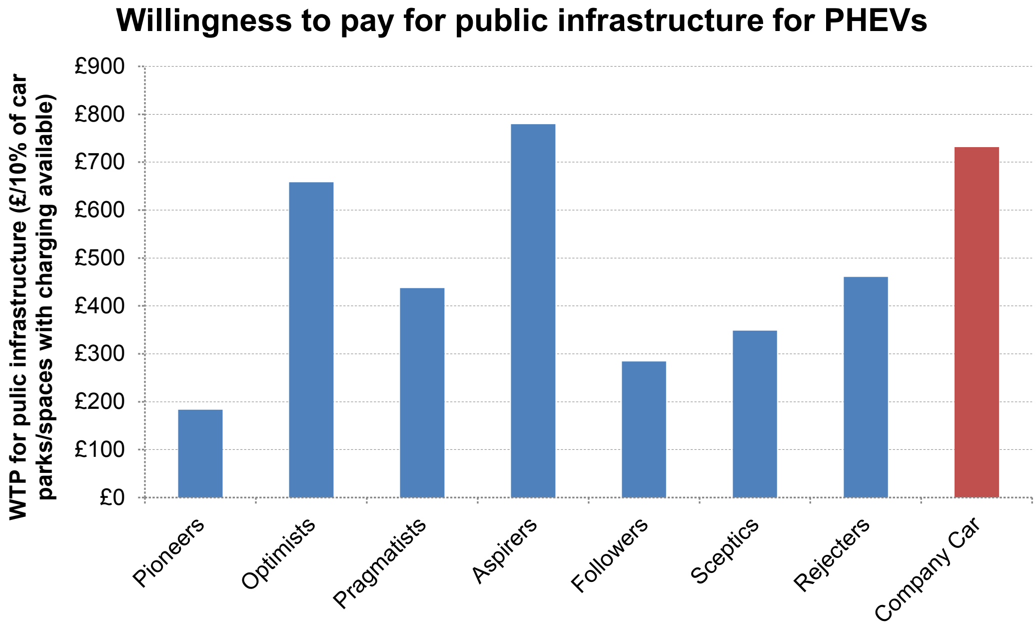


Figure 13 WTP for public infrastructure availability - PHEV

However, it is important to note that there is only a minor difference in the WTP for public infrastructure between the PHEV and BEV. We were unable to calculate unique coefficients for public infrastructure for the BEV, instead constraining the model to calculate a single value for all groups. This „average" WTP is approximately £550[26], which is slightly higher than the average value for the PHEV (£480). This suggests that respondents perceive public infrastructure as similarly important for both vehicle types, despite the added flexibility afforded by the plug-in hybrid. Feedback during the early phases of the consumer research programme suggested that respondents had difficulty understanding the operation of the PHEV, expressing concerns that it would run out of charge and leave them stranded. The results from the choice experiment support that conclusion, though it may also suggest that respondents *did* understand that the fuel bill and CO_2 saving potential of plug-in hybrids depends on them being used in „electric mode" as much as possible.

5.3 Vehicle-specific preferences

The results above show that there is significant variation in the importance of range and infrastructure between consumer groups. However, we must also consider another dimension, which is whether consumers have a strong preference for or against plug-in vehicles, when other factors are taken into account. For example, if consumers were offered conventional and plug-in vehicles with similar prices and running costs, as well as ranges and infrastructure availability, would consumers show a preference for plug-in vehicles, or would they still favour a conventional car? The answer should depend on whether the consumer in question is an early adopter or a more risk-averse mass-market buyer. Mathematically, these preferences for different vehicle types, *all things being equal*, are given by the constants in the model. For example, a constant of £5,000 against the PHEV means that if a consumer faces a choice between a conventional vehicle and PHEV with otherwise identical attributes, the latter would have to cost £5,000 less to have an equal chance of being picked by that consumer. Conversely a positive constant suggests

[26] This value is slightly different from the value shown in the base model in Table 1. This is expected, since more parameters have been introduced in the segmentation model, which changes the estimates of the base coefficients.

that consumers are willing to pay a premium for a vehicle labelled as a PHEV or BEV, all other things being equal. These constants capture many of the aspects of PHEVs and BEVs that are not explicitly represented by the other attributes in the choice experiment. These could include:

- Perceived unreliability, or technology risk, of new powertrains.
- „Novelty factor", which may be positive to an early adopter actively seeking new technology.
- Safety concerns.
- „Inconvenience" related to the need to charge the plug-in vehicles. This is distinct from the value of different types of infrastructure, which are explicitly represented in the choice.
- Factors related to self-image and how consumers perceive that the vehicles „fit" with their image and lifestyle.

In this model, the constants must serve another purpose, which is to account for the fact that attributes such as infrastructure and electric range are included in the utility calculation for PHEVs and BEVs but not the conventional vehicle. In other words, even if consumers have no preference for or against plug-in vehicles, the PHEV and BEV would still need negative constants in their utility equation to offset the positive utility of the electric range and infrastructure availability which do not appear in the utility equation for the conventional car. For this reason, it is more helpful to think of the „net willingness to pay" for plug-in vehicles, including differences in infrastructure and range.

5.3.1 Consumer response to the PHEV

To illustrate the interaction between vehicle-specific biases and infrastructure availability, Figure 14 below shows consumers" willingness to pay for a PHEV, once the effect of range and infrastructure has been taken into account. The values shown represent the willingness to pay for a PHEV with a 40mile range and a 4 hour recharging time. Two values are shown for each consumer group: one where only home charging is available (and there is no public infrastructure) and one where home, work and extensive public infrastructure are available[27].

[27] Extensive public infrastructure is defined as charging being available in all car parks and parking spaces i.e. using the same metric as used in the choice experiment. This does not mean that literally all public car parking spaces have a charging point; instead it represents a situation where charging is available at all destinations a consumer may wish to travel to.

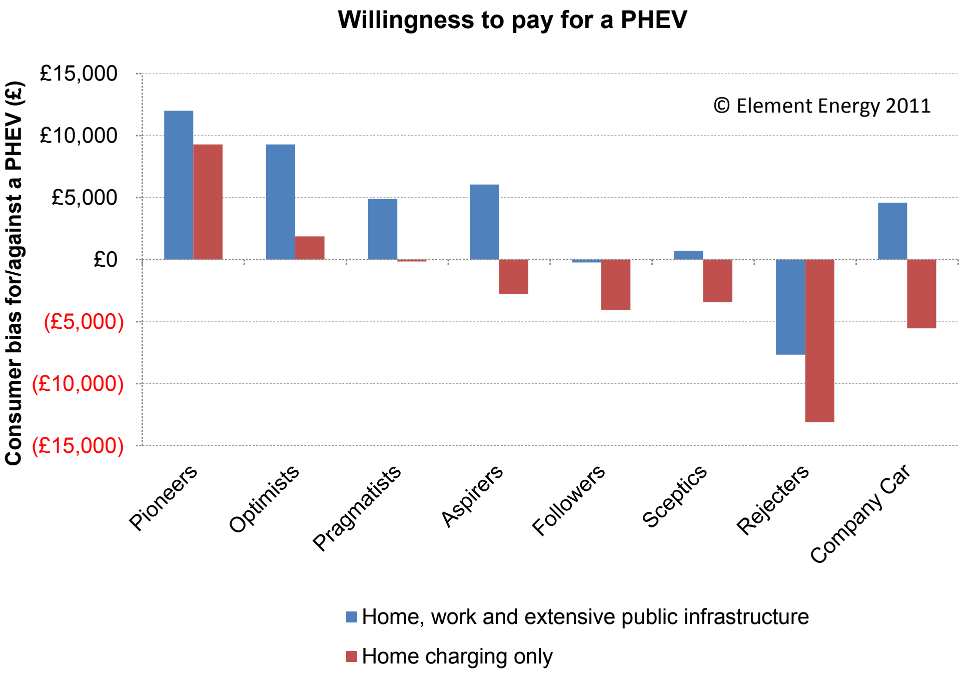


Figure 14 Willingness to pay for a PHEV with a 64km (40mile) electric range and a 4 hour recharge time

The figure shows a very positive response to the PHEV in the Pioneer group. Considering first the case where only home charging is available, the results suggest that the Pioneers are willing to pay £8,000 more for a PHEV than a conventional car, even before the annual running cost is factored in. This is consistent with evidence on early adopters purchasing non-plug-in hybrids (or any new technology), where these consumers are willing to pay a premium for the product, even when a strict assessment of Total Cost of Ownership might favour a conventional diesel car. In fact, the premium of £8,000 is close to the difference in price the Vauxhall Ampera and similar models in its range.[28]

Beyond the Pioneer group, the Optimists still show a positive willingness to pay of c.£2,000, though this is significantly lower than the real-world price premium of PHEVs/E-REVs. The Pragmatists have a WTP of zero, implying that they will only consider these vehicles at a price similar to a conventional car. All other groups have a strong bias *against* the PHEV. In other words, they would not purchase PHEVs unless they were cheaper than a conventional car. This effect is particularly strong in the rejecter group, which has a WTP of -£13,000 for the PHEV.

These results suggest that even if consumers have access to only home charging, two of the consumer groups (comprising 16% of our sample) are willing to pay a premium for a PHEV, with a further 12% willing to consider the vehicles if they reach price parity with conventional vehicles. However, if workplace and extensive public charging facilities are also available (also shown in Figure 14), five of the consumer groups (including the Company Car group) are willing to pay a premium for a PHEV. Only the rejecters remain strongly opposed to these vehicles even with widespread infrastructure provision. This suggests that unless the attitudes of this group change dramatically, they are unlikely to buyers of PHEVs. It is worth noting that this group only makes up 20% of the sample.

[28] A mid-range Astra 5-door hatchback costs c.£18,000, while a mid-range Insignia costs c.£24,000 (www.vauxhall.co.uk). The Ampera will go on sale in January 2012 at a price of £28,990 including the £5,000 OLEV grant.

5.3.2 Consumer response to the BEV

In contrast to the positive results above for the PHEV, respondents showed a much more negative response to the pure electric vehicle.

Figure 15 shows the consumers‟ willingness to pay for a BEV for two infrastructure scenarios. The electric range is set at 160km and the recharging time is set at four hours. The results show that only the Pioneer group has a positive WTP for BEVs in the „home charging only‟ scenario. The value of £2,700 is significantly lower than the £8,000 observed for the PHEV, reflecting the fact that the BEV is potentially more limited in its functionality if only home charging is in place. For all other consumers, the WTP values are highly negative, in the order of £10,000 for most groups, and as high as £27,000 in the Rejecter group. The extremely high penalty implies that the market share for the BEV would be close to zero for this group, even if the BEV were priced similarly to a conventional vehicle[29].

In a scenario with widespread private and public charging infrastructure, the response to BEVs remains consistently more negative than to the PHEV. The exception is the Pioneer group, which is willing to pay a premium of £13,000 for a BEV and £12,000 for the PHEV. The Optimists are willing to pay £2,000, while all other groups have negative WTP values of c.£5,000. Again, the Rejecters remain strongly opposed to the technology even in this „high infrastructure‟ scenario, with a negative bias equivalent to £18,000. The Company Car group shows the greatest response to infrastructure, with bias dropping by £14,000 if workplace and public charging are available. This suggests that these respondents do not have any fundamental opposition to the technology (unlike the Rejecters), but are simply more concerned by a lack of infrastructure due to the nature of their driving patterns.

[29] One of the assumptions in Discrete Choice Analysis is that of „compensatory attributes‟, where a large enough reduction in any attribute (such as price) is sufficient to offset the negative utility of any other. In other words, if a member of the Rejecter group was offered a BEV for £27,000 less than a conventional car, they would be persuaded to buy it. Since this is implausible (as the required discount is greater than the price of the car), the results implies that consumers in this group would not choose a BEV at any price.

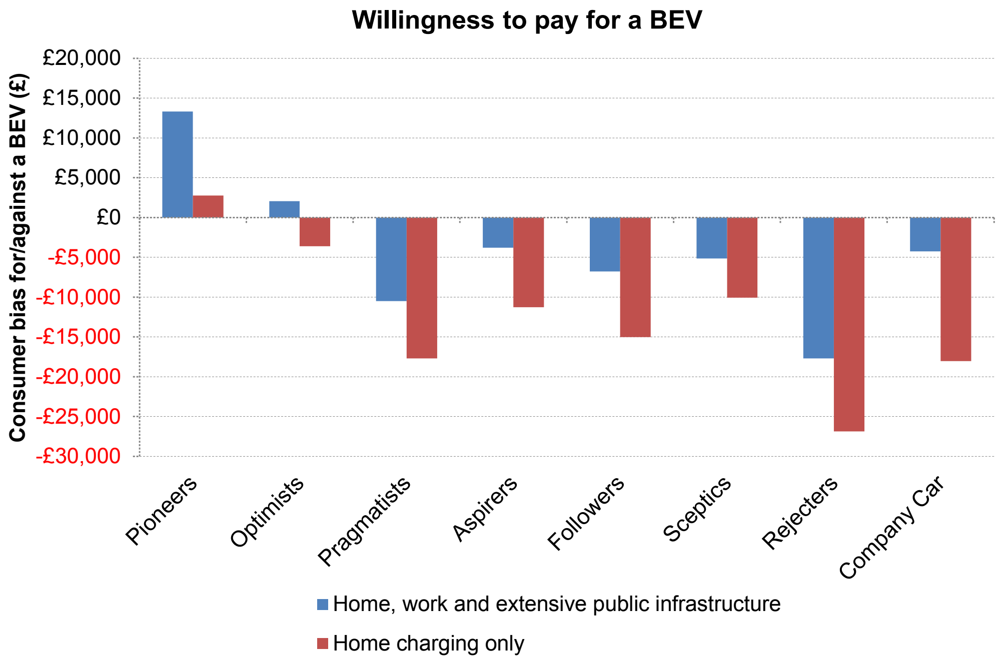


Figure 15 Willingness to pay for a BEV with a 160km (100 mile) range and a 4 hour recharge time

As a sense check to these numbers, it is useful to compare with them to the Hidrue *et al.* study discussed in Section 2.3. In that study, the authors calculate consumers‟ willingness to pay for battery electric vehicles with different configurations such as electric range and charging time. For a BEV with a 100 mile (160km) range and a 5 hour recharging time, the WTP ranged from -\$10,000 to -\$2,000. For a vehicle with a 75 mile (120km) range and a 10 hour recharging time, the WTP was much more negative at between -\$7,000 and -\$18,000. This suggests that for BEVs with limited functionality, the penalty perceived by consumers can indeed exceed £10,000.

Note that the range of WTP values in our study is significantly larger than those in Hidrue *et al.* A direct comparison is difficult here, since that study did not explicitly state the level of infrastructure availability in the choice experiment. The difference may reflect the fact that we have captured a greater diversity of consumer attitudes in our segmentation, from the Pioneers (whose WTP values are c. £5,000–£10,000 higher than in the maximum value in Hidrue *et al.* for an equivalent vehicle) to the Rejecters whose attitudes are substantially more negative.

In summary, the choice model successfully represents a diverse set of consumer attitudes across the eight segments. The results highlight the strong difference between the attitudes to PHEVs and BEVs, as well as the effect of infrastructure availability on the overall willingness to pay for these vehicles. These WTP values are consistent with a comparable study on attitudes to electric vehicles. In the next section, the analysis is extended to investigate how the consumer response differs depending on whether respondents are considering replacing their primary or secondary cars.

5.4 Second car choice

The discussion above has focused on respondents‟ choice of „primary‟ vehicles in the choice experiment. However, it is often suggested that plug-in vehicles (and especially BEVs) are a more natural fit as a second car or in a multi-car household. A multi-car household allows trip substitution for journeys longer than the range of a BEV. It also mitigates some of the technology risk since there is a „back-up" vehicle in the event of a technical problem or a user forgetting to charge their car. Figure 16 shows the proportion of households owning more than one car for each consumer group. There is little variation between the private consumers, with approximately 50% of respondents owning two or more cars. This suggests that the Pioneer group"s positive attitudes towards plug-in vehicles are not simply due to systematically higher second vehicle ownership. Nearly all (88%) company car drivers live in multi-car households.

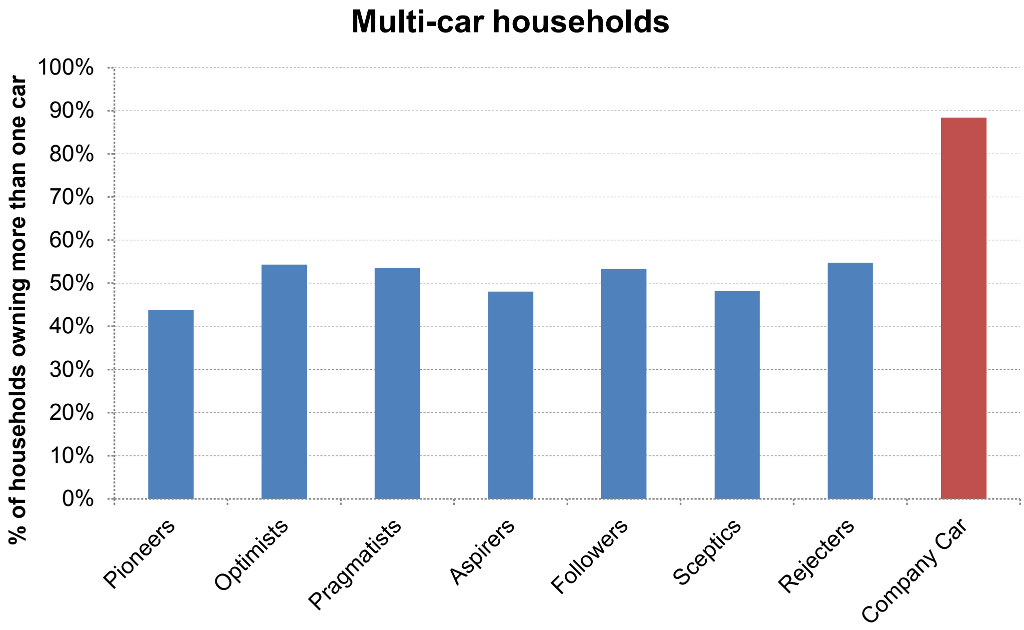


Figure 16: Proportion of households with more than one car

The choice experiment included questions on which vehicles respondents would choose if they were replacing their secondary car. The resulting dataset is identical to the primary car choices (except in the actual choices made), which allows estimation of a distinct model based on second car choices. The consumer response to second car choice is shown in Table 2. For simplicity, coefficients were calculated for the base model described in Section 5.1, in order to highlight the trends in the various attributes.

In the „generic parameters" (those applied to the conventional and plug-in vehicles), the consumer response was less strong for the secondary car choice. For example, the WTP for annual running cost savings was £4 compared with £5 for the primary car, implying that consumers are less concerned by running costs of second cars, or that they require „payback" on fuel efficiency investments in a shorter timeframe. The design of the choice experiment did not customise the fuel cost values according to respondents" stated mileage for their secondary car, using instead the same values as in the primary car choice question. In fact, the average mileage travelled in the secondary car was 25% lower than in the primary car (5,500 versus 7,500 miles per year). Hence, the lower emphasis placed on fuel costs suggests that respondents were discounting the fuel costs in the secondary car choice to reflect their expectation that they would drive fewer miles. Consumers" willingness to pay for improvements in vehicle acceleration was also significantly lower in the secondary car choice, by 30%. This is consistent with the idea of a secondary vehicle as a lower mileage „runabout" where vehicle performance is less important than a primary vehicle used for commuting and longer trips.

The relative importance placed on infrastructure is also weaker in the secondary car choice. In the for the BEV, the willingness to pay for home only charging is 20% higher in the second car choice, while the WTP for public charging is 20% lower. The results for the PHEV show smaller differences between the first and second car choice, though the willingness to pay for workplace charging is significantly lower for second cars.

Table 2 Comparison of consumer response in primary and secondary car choice

Attribute	WTP Choice 1	WTP Choice 2	Unit
Generic Parameters			
Annual running cost	£5	£4	per £ of annual ongoing savings
Performance	£1,376	£955	per 20% improvement relative to typical vehicle
PHEV-specific parameters			
PHEV Constant	-£7,958	-£3,622	constant term (dimensionless)
Emissions	-£15	-£24	per g/km reduced
Home Charging	£2,413	£2,537	binary (1 or 0)
Work Charging	£4,370	£3,309	binary (1 or 0)
Home + Work Charging	£1,723	£984	binary (1 or 0)
Public infrastructure	£430	£394	per 10% of car parks/parking spaces with charging
Range	£9	£12	per km of electric range
BEV-specific parameters			
BEV Constant	-£24,439	-£14,841	constant term (dimensionless)
Emissions	£8*	-£7*	per g/km reduced
Home Charging	£3,325	£4,066	binary (1 or 0)
Work Charging	£237	£225	binary (1 or 0)
Home + Work Charging	£5,520	£4,097	binary (1 or 0)
Public infrastructure	£595	£460	per 10% of car parks/parking spaces with charging
Range	£27	£21	per km of electric range
Charging time	-£256	-£119	per hour of charging time

Indicates value based on a statistically non-significant parameter

These responses to infrastructure and range may appear counterintuitive, as it might be expected these attribute should be less important for a vehicle typically used for fewer trips and lower driving distances, as home charging and relatively limited range should be sufficient for these driving patterns. However, as discussed previously these responses must be considered in the context of the consumer attitudes to the vehicle technologies themselves, as defined by the PHEV and BEV constants. If consumers are fundamentally more attracted to (or less opposed to) plug-in vehicles as second vehicles, then infrastructure and range attributes should be *more* important and determine whether or not the consumer actually chooses this vehicle. In contrast, consumers may pay less attention to the range and infrastructure availability if they are simply not interested in a plug-in vehicle.

The values for the vehicle-specific constants are consistent with this theory. For the PHEV, the value of the constant is -£3,600 for second car, 50% lower than the primary car. A similar pattern exists for the BEV, where the value is -£15,000 compared with nearly -£25,000. Given the fact that the WTP values for the other attributes are broadly similar in both choices, this suggests that the „net" willingness to pay for plug-in vehicles is considerably more positive (or less negative) for the second car choice.

This effect is illustrated in the figures below, which show the net willingness to pay for the PHEV and BEV as a primary and secondary car. As in the primary car choice results in section 5.3, values have been estimated for each of the eight groups in the consumer segmentation model. Assumptions on range and charging time for the secondary car choice are consistent with the primary car choice[30], and the values shown are based on the availability of home charging only.

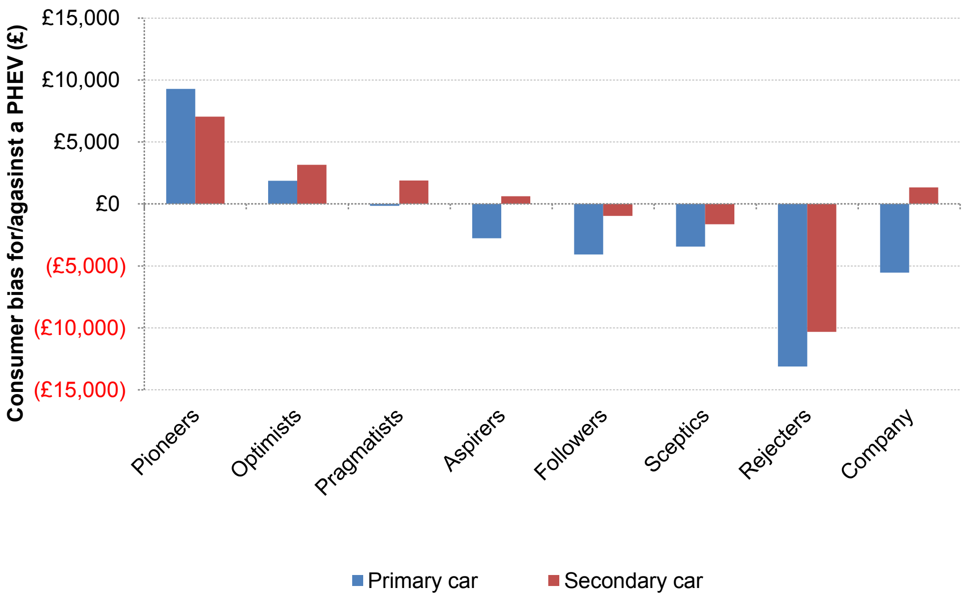


Figure 17 Willingness to pay for PHEV - second car choice

Figure 17 shows that all but one of the consumer groups find PHEVs more attractive as secondary versus primary cars. The exception is in the Pioneer group, where consumers are willing to pay more for a PHEV as a primary car. This suggests that this group views PHEVs so favourably that they would prefer to use one to replace their main vehicle. The other key trend is the relative difference in the values within each consumer group. The largest differences occur in the Pragmatists and Aspirers, where the WTP values are positive for second cars but negative for primary cars. The Company Car group also shows a particularly strong change. However, in the Followers and Sceptics groups, the willingness to pay value remains negative even for the second car choice, and the Rejecters still perceive a „penalty" for the PHEV of over £10,000. This reinforces the conclusion that these three groups are unlikely to be suitable markets for plug-in vehicles unless their attitudes change considerably. Finally it is worth noting that with only home charging available the WTP of groups outside the Pioneers are still less than the current price premium for a PHEV when considering secondary car purchases.

[30] 64km for the PHEV and 160km for the BEV. The charging time is assumed to be 4 hours for both.

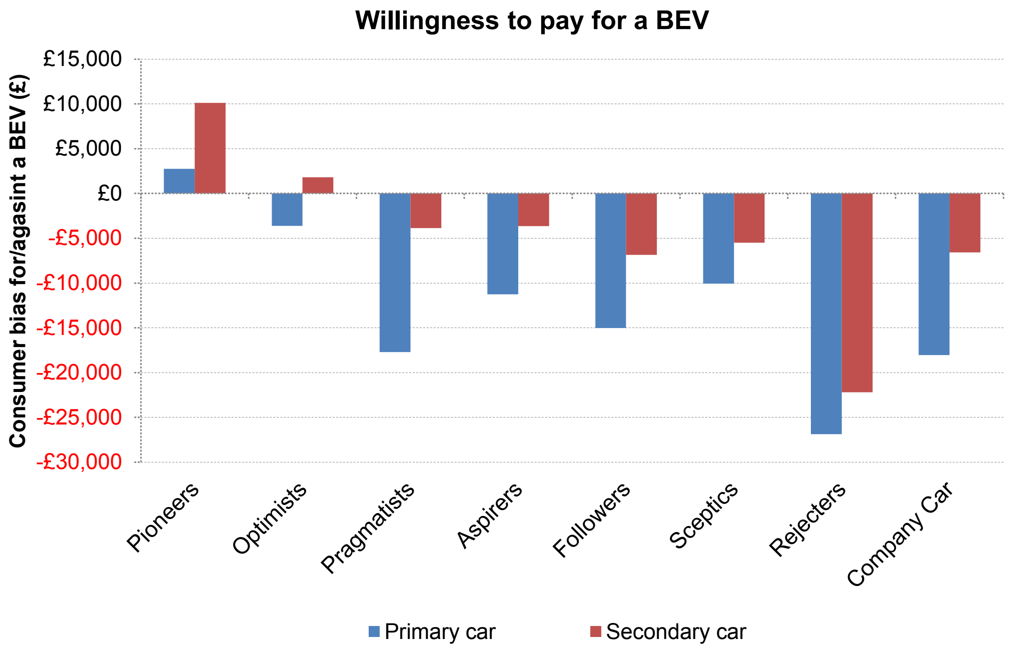


Figure 18 Willingness to pay for a BEV - second car choice

Figure 18 shows the equivalent results for the BEV. Again, the results suggest a systematically more negative attitude towards the BEV than the PHEV. All groups except the Pioneers and Optimists still have negative WTP values for the secondary car. The Pragmatists and Followers show the largest change, while the attitudes of the Rejecters remain highly negative.

These results have important implications for the deployment of BEVs. In the Pioneer group, the WTP for a battery electric vehicle is £10,000 as a second car, *even in the absence of widespread infrastructure*. This is similar to the current price premium of a BEV over an equivalent vehicle (once the OLEV grant is taken into account), suggesting that these consumers are the natural market for the early roll-out of BEVs. However, the results also suggest that with current consumer attitudes and infrastructure availability, only 2% of private car buyers are likely to buy a BEV unless the price premium decreases significantly. If the premium can be reduced to only £2,000 (including capital and ongoing costs), manufacturers could then access the next section of the market in the Optimists group. However, after this, the ownership costs for a BEV would have to be more than £4,000 *below* that of a conventional vehicle before other consumers would consider buying one, based on current consumer attitudes. This emphasises the strength of the bias of mass-market bias against the pure electric vehicle. The potential for this bias to change over time is discussed below.

5.5 Changing consumer attitudes

The analysis above provides detailed insights into consumers‟ attitudes towards plug-in vehicles. However, any consumer survey by definition captures a „snapshot‟ of current attitudes, which reflect the current levels of awareness of the technology, the current macroeconomic trends and so on. While we would expect that real-world behaviour would closely match the survey findings in the short term, it is likely that attitudes themselves will change in the medium term. This change could occur for several reasons. For example, policies such as „eco-labelling‟ for cars in the showroom may provide better information to consumers on the benefits of fuel-efficient vehicles. In the longer term, external factors such as an increasing oil price or more widespread evidence of man-made climate change may cause consumers to place a higher value on fuel use and CO_2 emissions in vehicles. These shifts in attitudes will favour plug-in vehicles as their main benefits over conventional vehicles are in these two metrics.

While encouraging consumers to pay more attention to fuel costs and emissions is certainly beneficial, our results suggest that it is consumers‟ attitudes to the vehicle technologies themselves that have a significant effect on purchasing behaviour. In other words, Pioneers are willing to pay a significant premium for a plug-in vehicle, even before lower running costs are taken into account, while Rejecters show a very strong preference for conventional cars even if widespread infrastructure were to be available for electric vehicles. We would expect vehicle-specific preferences to decrease over time as consumers become more familiar with plug-in vehicles, for example by seeing them on the roads or by knowing people who have purchased them.

However, it remains to be seen whether consumer attitudes will change to the extent that BEVs compete on equal terms with conventional vehicles (or plug-in hybrids). Consumers are willing to pay for convenience, for products that make their lives easier. However, most commentators agree that BEVs will have a range considerably lower than conventional vehicles for the foreseeable future, as well as much longer recharging times than for refuelling a liquid-fuelled car. While analysis of national travel patterns has repeatedly shown that this is not necessarily a barrier for the widespread adoption of BEVs[31], mass-market consumers may remain strongly opposed to paying more for a car with a lower functionality (whether actual or perceived) than a conventional car. A question which applies to all consumers (including the Pioneers) is whether plug-in hybrids will dominate the market for plug-in vehicles by offering large fuel savings from electrifying some trips at a lower price premium and with no loss of range or functionality.

In our companion report on the results from the Consumers and Vehicles model, we investigate these issues in more detail, including quantifying the effects on vehicle uptake of changes in consumer attitudes over time.

[31] See for example Element Energy‟s report to the Committee on Climate Change, available at: http://downloads.theccc.org.uk/Element_Energy_-_EV_infrastructure_report_for_CCC_2009_final.pdf

6 Conclusions

The consumer research programme conducted within the PIVEIP has provided the most detailed insight to date on how attitudes to plug-in vehicles vary across the car-buying population. Though the primary purpose of the choice experiment was to derive consumer coefficients for use in the Consumers and Vehicles model, the choice data can also be analysed in isolation as above, allowing us to draw a range of conclusions on how current consumer attitudes will shape the market for plug-in vehicles.

Our findings suggest that predictions of uptake based solely on the economic „offer" of plug-in vehicles miss the critical role of consumers in the decision making process, and are likely to strongly overestimate the market for PIVs. Our results show that while consumers respond strongly to differences in vehicle prices, running costs and the availability of infrastructure, their overall response to plug-in vehicle technologies plays a key role in consumer choice. This aspect captures consumers" attitudes to risk and new technology, as well as the social factors such as how they perceive these vehicles to fit with their self-image. These factors show a large variation through the car-buying population, and suggest that only a small proportion (c. 2% of private consumers) is willing to pay more for plug-in vehicles than a conventional car. In other words, the majority of the population is currently strongly opposed to buying BEVs (and to a much lesser extent, PHEVs), even if the vehicles reach price parity with conventional cars.

Attitudes to vehicle purchases

- Consumers on average value 5 years of running costs when making their purchase decision. In other words, they require a simple payback of 5 years on any „investment" in a more fuel-efficient vehicle.
- The response to running cost varies significantly across the population. Early adopters value up to 7 years of future costs, while the laggard „Rejecter" group and company car drivers took into account only 2 years of fuel bills.
- Respondents were willing to pay c.£1,400 for a 20% improvement in acceleration in any vehicle type. Recently released electric vehicles have very strong acceleration characteristics, particularly at low speeds due to high torque (and high peak power) from the motors. Marketing of electric vehicles should emphasise these benefits to ensure that they are fully valued by prospective buyers.
- Consumers appear to care very little about CO_2 emissions, suggesting that vehicle marketing should focus on other benefits of plug-in vehicles, such as low running costs, quietness etc.

Range and infrastructure

- Consumers are willing to pay, on average, £27 per km of all-electric range, significantly lower than the current cost of providing it (c.£70 per km). This suggests that while battery costs are high, manufacturers should focus on reducing vehicle prices rather than providing additional electric range, as this has the greater effect consumer choice.
- Our data also show a saturation effect for electric range in the BEV, where consumers were willing to pay very little for additional range beyond 240km.
- There are significant differences between consumer responses to PHEVs and BEVs, suggesting they understand the flexibility afforded by the internal combustion engine in a hybrid vehicle.

- For the BEV, consumers focused overwhelmingly on home recharging; workplace charging on its own had little value, though it was considered important in combination with home charging.
- The willingness to pay for public infrastructure availability was substantially lower home and workplace charging, particularly for the PHEV.
- The WTP for public charging is also very low compared with private infrastructure. This finding contradicts the notion that a lack of *public* infrastructure is the main barrier to deployment of PIVs.

Attitudes to plug-in vehicle technologies

- Many consumers responded favourably to plug-in hybrid vehicles. 16% of private consumers were willing to pay more for a plug-in hybrid with a 64km range than for a typical car, even if only home charging were available.
- If work charging and extensive public infrastructure were available (in addition to home charging), nearly half of private consumers (44%) would be willing to pay more for a PHEV than a conventional vehicle.
- In contrast, the majority of respondents respondent negatively to pure electric vehicles in all but the Pioneer (early adopter) group. Only 2% of consumers in our survey would be willing to pay more for a BEV with a 160km range if only home charging were available.
- This negative attitude persists even if consumers are offered workplace and public charging infrastructure, with only 14% of private consumers willing to pay more than for a BEV over a conventional car.
- Attitudes towards both PHEVs and BEVs are significantly more positive for second car purchases, though all consumers (including the early adopters) continue to prefer a PHEV to a BEV based on current vehicle characteristics.

The strong consumer preference for plug-in hybrids over battery electric vehicles found in this study has important implications for policymakers and infrastructure providers, as well as vehicle manufacturers. It suggests that plug-in hybrid vehicles will see much wider consumer acceptance than pure battery electric vehicles, and that BEVs are unlikely to move beyond a niche technology if current consumer attitudes persist. Our results also show that simply deploying large amounts of infrastructure (whether in workplaces or public places), will not address the current negative attitudes of mass-market consumers against BEVs.

While it is likely that part of the strong consumer opposition to BEVs is down to unfamiliarity, and hence be expected to diminish over time, the availability of plug-in hybrids (and range extended EVs) represent significant competition to pure EVs. Consumers in our survey responded favourably to hybrid vehicles, recognising that they provide the range and flexibility of conventional cars as well as significant running cost savings. Current incentives, such as the OLEV grant and VED exemption, apply equally to plug-in hybrids and battery electric vehicles, and so there are currently few factors that would cause mass-market consumers to favour a pure electric vehicle over a more flexible plug-in hybrid. A key question is whether in the longer term consumers will be willing to sacrifice vehicle functionality in exchange for pure electric (and zero tailpipe emission) driving instead of other low carbon technologies.

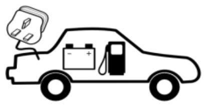
Finally, it should be noted that this survey was conducted just before the launches of the „new generation" of plug-in vehicles being released over the next few years. The release of EVs by major brands may cause a significant change to consumer attitudes, for example changing the „image" of these technologies and perceptions about their benefits and limitations. We recommend that future research is conducted to understand the consumer responses of real-world plug-in vehicle drivers, for example whether there is a gap between perceived range and infrastructure requirements and consumers‟ actual needs once they have experience using the car. Vehicle trials are already beginning to provide valuable insights on these issues, though few current trials contain a representative mix of car buyers. To understand how the early deployment of plug-in vehicles affects *mass market* consumers, we recommend that stated preference work similar to this is repeated at intervals to track changes in consumer attitudes.

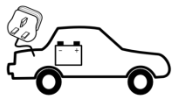
Appendix 1 - Materials used in the main survey

The materials shown below were deployed as part of the main quantitative survey, which was launched by Accent Market Research on November 15th. The respondents view and complete the questionnaire online using specialist survey software. As such, the formats of the materials shown below will not exactly match the online survey.

In this part of the questionnaire, you will be presented with some theoretical new cars and you will be asked to choose which car you would buy if you were replacing your current car. In each question, you will see three different cars:

Introduction to the choice experiment





Conventional car	Plug-in hybrid electric car	Plug-in fully electric car
A normal petrol/diesel car	Uses both a petrol/diesel engine and an electric motor and a small battery	Powered only by battery

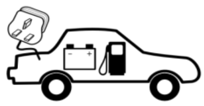
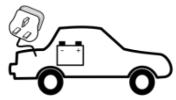
You will be given some pieces of information about each car, for example its performance, where you can charge it if it‟s a plug-in vehicle, and how much it costs. We will ask you to read the information in each question, and choose which vehicle you would like to buy.

You will be given the following information about each vehicle:

Purchase Price	This is the cost to buy the car when new.
Running cost	This is the total cost for fuel that you would pay each year. It includes petrol/diesel as well as electricity for the plug-in hybrid and fully electric vehicle. The costs will be based on **your yearly mileage** that you provided in Part 1 of the questionnaire.
Performance (0-60mph acceleration)	This shows how quickly the car accelerates from a standstill, for example when pulling away from traffic lights. It is expressed as the % improvement or deficit relative to a typical car that you can buy today.
Range	This is the total distance you can drive before you must refuel or recharge the car.
Recharging/refuelling time	This is the time it takes to fully recharge the battery or fill the car up with petrol/diesel. Remember that you can „top up‟ the battery in shorter time, just like you can now with a mobile phone or laptop.
Home/workplace charging	This tells you whether you can charge the car at home or at work, or both.
Public infrastructure	This tells you what percentage (%) of public car parks or street-side parking spaces are available where you can charge your car (i.e. they have a plug socket).
Emissions	This tells you the CO_2 emissions of the car, relative to a typical car that you can buy today. For the electric vehicles, this includes the CO_2 emitted during the production of the electricity. **Note:** Sometimes the electric vehicle will be „zero emissions‟, because it is powered entirely by renewable energy sources.

Please assume that all other aspects of the cars, such as maintenance costs, safety and reliability are always the same as a typical car on sale today.

Choice experiment example

	Conventional car	Plug-in hybrid electric car	Pure electric car
Purchase price	**£16,000**	**£20,000**	**£18,000**
Running cost	**£900** per year	**£300** per year	**£600** per year
0-60mph acceleration	The **same** as a typical car	**20% quicker** than a typical car	**40% quicker** than a typical car
Range	The **same** as a typical car	Total range the same as a typical car, **40 mile** range in „electric mode"	**100** miles
Recharging / refuelling time	5 minutes to fill fuel tank	5 minutes to fill the fuel tank, **4 hours** to charge the battery,	**2 hours** to charge the battery
Home / workplace charging	N/A	Charging available at **home and work**	Charging available at **home**
Public infrastructure	Fuel available at all filling stations	Charging points available at **30%** of public car parks / on-street parking spaces	Charging points available at **50%** of public car parks / on-street parking spaces
CO_2 emissions	The **same** as a typical car	**40% lower** than a typical car	**60% lower** than a typical car

For each set of cars we will ask you the following:

Which one of the above cars would you choose if you were replacing your *main* car?

☐ ☐ ☐

If you have more than one car, which car you would choose if you were replacing your *second car*?

☐ ☐ ☐

If you choose the conventional car for both your first and second car, we will ask you the following:

If you could only buy the plug-in hybrid electric or the pure electric car, which one *of these two* would you choose?

☐ ☐

These choices count as **one** question. That‟s the end of the example. You‟re now going to see the first set of vehicles for real. Once you have made your choice, you will see another set of cars and asked to make another choice, and so on until you have seen 10 sets in total.

The information for each of the cars will change between questions, so remember to read the table fully before you make each choice.

CLICK HERE FOR THE FIRST QUESTION

Appendix 2 - Attributes and levels used in the choice experiment

Conventional car

Attribute	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6-10
Capital cost	**£10,000**	**£12,000**	**£14,000**	**£16,000**	**£18,000**	**£20-£28k**
Running cost	**£300** per year	**£600** per year	**£900** per year	**£1,200** per year		
0-60 mph acceleration	**40% slower** than a typical car	**20% slower** than a typical car	The **same** as a typical car	**20% quicker** than a typical car	**40% quicker** than a typical car	
Home/work recharging	Not available					
Range	Total range same as typical car.					
Recharging time	5 minutes to refuel at a filling station					
Public infrastructure availability	You can refuel at any petrol station					
CO_2 emissions	20% **lower** than a typical car	10% **lower** than a typical car	The **same** as a typical car	20% **higher** than a typical car		

PHEV

Attribute	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6-10
Capital cost	**£10,000**	**£12,000**	**£14,000**	**£16,000**	**£18,000**	**£20-£28k**
Running cost	**£300** per year	**£600** per year	**£900** per year	**£1,200** per year		
0-60mph acceleration	**40% slower** than a typical car	**20% slower** than a typical car	The **same** as a typical car	**20% quicker** than a typical car	**40% quicker** than a typical car	
Home/work recharging	**Home only**	**Workplace only**	**Home and workplace**	**Not available**		
Range	Total range same as a typical car – **10** mile range in „electric mode"	Total range same as a typical car – **20** mile range in „electric mode"	Total range same as a typical car – **40** mile range in „electric mode"	Total range same as a typical car – **60** mile range in „electric mode"		
Recharging time	5 minutes to fill fuel tank, **15** minutes to charge the battery	5 minutes to fill fuel tank, **2 hours** to charge the battery	5 minutes to fill fuel tank, **4 hours** to charge the battery	5 minutes to fill fuel tank**, 8 hours** to charge the battery		
Public infrastructure availability	**No public charging points available**	Charging points available at **10%** of public car parks / on-street parking spaces	Charging points available at **30%** of public car parks / on-street parking spaces	Charging points available at **50%** of public car parks / on-street parking spaces		
CO_2 emissions	**80% lower** than typical car	**60% lower** than typical car	**40% lower** than typical car	**20% lower** than typical car		

Battery electric vehicle

Attribute	Level 1	Level 2	Level 3	Level 4	Level 5	Level

						6-10
Capital cost	**£10,000**	**£12,000**	**£14,000**	**£16,000**	**£18,000**	**£20-£28k**
Running cost	**£300** per year	**£600** per year	**£900** per year	**£1,200** per year		
0-60 mph acceleration	**40% slower** than a typical car	**20% slowe**r than a typical car	The **same** as a typical car	**20% quicker** than a typical car	**40% quicker** than a typical car	
Home/work recharging	**Home only**	**Workplace only**	**Home and workplace**	**Not available**		
Range	**50 mile** range on a single charge	**100 mile** range on a single charge	**150 mile** range on a single charge	**200 mile** range on a single charge		
Recharging time	**15 minutes** to charge the battery	**2 hours** to charge the battery	**4 hours** to charge the battery	**8 hours** to charge the battery		
Public infrastructure availability	**No public charging points available**	Charging points available at **10%** of public car parks / on-street parking spaces	Charging points available at **30%** of public car parks / on-street parking spaces	Charging points available at **50%** of public car parks / on-street parking spaces		
CO_2 emissions	Zero emissions	60% lower than a typical car	40% lower than a typical car	20% lower than a typical car		