A Choice Experiment on AFV Preferences of Private Car Owners in The Netherlands

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Abstract

In this paper we aim to get insight into preferences of Dutch private car owners for alternative fuel vehicles (AFVs) and their characteristics. Since AFVs are either not yet available on the market or have only very limited market shares, we have to rely on stated preference research. We perform a state-of-the-art conjoint analysis, based on data obtained through an online choice experiment among Dutch private car owners. Results show that negative preferences for alternative fuel vehicles are large, especially for the electric and fuel cell car. This is mostly related to their limited driving range and considerable refuelling times. AFV preferences increase considerably when improvements in driving range, refuelling time and additional detour time are made. The number of available models and policy measures such as free parking also have added value but only to a limited extent. Negative AFV preferences remain, however, also when substantial improvements to AFV characteristics are made. The fact that most technologies are relatively unknown and their performance and comfort levels are uncertain are likely important factors in this respect. Results from mixed logit models furthermore reveal that consumer preferences for AFVs and AFV characteristics are heterogeneous to a large extent, particularly those on the electric car, on additional detour time, on fuel time for the electric and fuel cell car, on the policy measures free parking and access to bus lanes, and on purchase price and monthly costs. In order to get more insight into the underlying sources of heterogeneity we estimate a model with interactions between the car attributes and respondent background and car (use) characteristics. Several variables, such as using the car for holidays abroad and fuel type, appear to be relevant for car choice. In terms of price and cost sensitivity we find differences in preferences due to new versus second-hand cars, price of the car, weight of the car, 1st and 2nd car in a household, and between men and women. With respect to heterogeneity in preferences for the electric and fuel cell car and their respective driving ranges, by far the most important factor is annual mileage. Preferences for electric and fuel cell cars decrease substantially, while willingness to pay for driving range increases substantially, when annual mileage increases.

JEL-codes: C25; C54; O33; Q54; R41

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1. Introduction

Consumer preferences for, and market potential of, alternative fuel vehicles (AFVs) have received wide attention since the mid-1970s. AFVs such as electric, fuel cell, (plug-in) hybrid and flexifuel cars use non-fossil fuels and have the potential to emit only a fraction of the CO_2 emissions that conventional petrol and diesel cars emit. This became relevant when societal and academic interest was induced by the report to the Club of Rome highlighting the scarcity of fossil fuels. Moreover, concerns over climate change and reducing greenhouse gas emissions, and dependence of economies on foreign energy sources, have become additional reasons for extensive research on the use of alternative fuels in transport in the last ten to fifteen years. The European Union has adopted a long term climate goal to limit global temperature increase to a maximum of 2 degrees Celsius compared to pre-industrial levels. Recently the European Commission announced that a 60% cut in transport CO_2 emissions compared to the year 2000 should be the aim for 2050 in order to reach that goal (European Commission, 2011). AFVs are essential for reaching that goal (PBL, 2009). Since passenger cars make up roughly 50% of Dutch national CO_2 emissions from transport[1] they have a large take in reaching long term climate goals. With this in mind the Dutch government has adopted a national goal to strive for of 1 million electric cars (on a total of approximately 8 million) in the year 2025.

Together with assessing future production and supply of AFVs, assessing the demand is crucial in determining the steps are needed to meet long term climate goals and reduce dependence on non-renewable energy sources. Identifying the barriers that prevent car buyers from buying an AFV reveals whether (and which) policy incentives are necessary to increase market shares of AFVs. Several countries (US, Canada, UK, Norway, Denmark, China) have carried out Stated Preference/Stated Choice research to generate data on consumer preferences for AFVs. Before now such data are not available for the Netherlands. Since car and fuel type characteristics may influence consumer preferences differently in different countries (e.g., because of differences in spatial composition, spatial patterns, income and culture), applying insights from other countries to the Dutch case may lead to under- or overstating the relative importance of certain car and fuel type characteristics. Therefore, there is need for a specific study for The Netherlands.

Since AFVs are either not yet available on the market or have only very limited market shares, we have to rely on stated preference research. Contingent valuation (CVM) has long been the most popular and widely used stated preference method. However, methodical advantages of conjoint analysis, accompanied by the development of specialised software and the use of the internet for obtaining questionnaire data, have made conjoint analysis the preferred method for doing stated preference research. We therefore perform a state-of-the-art conjoint analysis, based on data obtained through an online stated choice experiment among private car owners in The Netherlands. Our main goal is to obtain insight into the preferences of private car owners for AFVs in The Netherlands, to analyse the car characteristics that affect these preferences, and to what extent these characteristics need to change in order to make consumers indifferent between conventional cars and AFVs. We also aim to identify the (socio-demographic) characteristics of car buyers that are currently most susceptible to buy an AFV, thereby hoping to uncover interesting market segments and potential early adopters.

[1] Excluding international shipping and aviation

The remainder of this paper is organised as follows. In the next section we discuss the existing choice experiment literature on AFV preferences and its main findings. In Section 3 we describe the set-up of the choice experiment, the attributes and levels used, the presentation of the online questionnaire to respondents, and the segmentation and sampling criteria used. Estimation results are presented in two separate sections. In Section 5 we present results from a multinomial logit model. We discuss results from a linear specification and a dummy specification in order to analyse potential non-linear attribute effects. In Section 6 we estimate a mixed logit model to test robustness of the MNL results and to explore the heterogeneity in consumer preferences. In this section we also estimate a model with consumer background interactions in order to uncover the main sources of preference heterogeneity, and to identify interesting market segmentations and potential early adopters. Section 7 concludes with a summary and discussion.

2. Overview of the choice experiment literature on AFV preferences

Since the beginning of the 1980s many studies have contributed to our knowledge of the determinants of consumer preferences for, and the relevant factors in the market penetration of, alternative fuel vehicles. In this section we focus on the choice experiments that have been conducted, since these are of special relevance to the current study. Table 1 lists some general characteristics for 17 peer-reviewed studies that were conducted among private car-owners.

Table 1. General characteristics of peer-reviewed choice-experiment studies on consumer preferences for alternative fuel vehicles [a]

	Location	**Response**	**Method**	**Tasks (alternatives)**
Beggs et al. (1981)	USA	193	Ranking	1 (16)
Calfee (1985)	USA	51	Preference	30 (3)
Bunch et al. (1993)	USA	692	Preference	5 (3)
Bunch et al. (1995) [b]	USA	4,747	Preference	2 (3)
Dagsvik et al. (1996) [c]	Norway	642	Ranking	15 (3)
Ewing and Sarigöllü (1998) [d]	Canada	881	Preference	9 (3)
Batley et al. (2004)	UK	179	Preference	?
Horne et al. (2005)	Canada	1,150	Preference	4 (4)
Hess et al. (2006)	USA	500	Preference	15 (3)
Potoglou and Kanaroglou (2007)	Canada	482	Preference	8 (3)
Ahn et al. (2008)	South Korea	280	Preference	4 (3)
Train (2008)	USA	508	Ranking	10 (3)
Mau et al. (2008)	Canada	1,935	Preference	18 (2)
Dagsvik and Liu (2009)	China	100	Ranking	15 (3)
Caulfield et al. (2010)	Ireland	168	Preference	6 (3)
Hidrue et al. (2011)	USA	3,029	Preference	2 (3)
Mabit and Fosgerau (2011)	Denmark	2,146	Preference	12 (2)

[a] Excluded from the table are studies by Hensher (1982) and Chéron and Zins (1997) because their choice experiment included only the electric car.
[b] Reference itself is not peer reviewed but was included because it is the first reference to this study. For peer reviewed articles of this study see Brownstone et al. (1996), Brownstone and Train (1999), and Brownstone et al. (2000).
[c] Reference itself is not peer reviewed but was included because it is the first reference to this study. For a peer reviewed article of this study see Dagsvik et al. (2002).
[d] See also Ewing and Sarigöllü (2000).

Most studies use consumer samples from the USA (seven studies), and within that subgroup most are from California. Also Canada is well represented with four studies, while single studies have been done for China, Denmark, Ireland, Norway, South Korea and the UK. Therefore, if consumer preferences are determined to a large extent by cultural influence, the sample of peer-reviewed studies is very selective with a strong Western orientation. Furthermore, the number of respondents varies widely across studies, as do the number of choice tasks per respondent. Apart from some studies in which respondents were asked to rank various alternatives, the number of options in a choice task was usually equal to three.

An overview of the vehicle and fuel types included in each of the studies is given in Table 2. All studies include a conventional vehicle and the full electric and hybrid electric vehicle were also included regularly. Compressed natural gas (CNG), methanol and/or the hydrogen vehicle were included in four out of the 17 studies. An interesting feature of seven of the selected studies is that they include a general 'alternative fuel vehicle' category, i.e., without specifying which vehicle type is implied. In some studies the underlying reason is to focus on other attributes and to avoid vehicle-specific preferences from dominating the choices made by respondents.

Table 2. Vehicle/fuel types included in peer-reviewed choice experiments on consumer preferences for alternative fuel vehicles

	CV [a]	**AFV** [b]	**CNG**	**Methanol**	**Fuel cell**	**Electric**	**Hybrid**
Beggs et al. (1981)	X					X	
Calfee (1985)	X					X	
Bunch et al. (1993)	X	X				X	
Bunch et al. (1995)	X		X	X		X	
Dagsvik et al. (1996)	X					X	X
Ewing and Sarigöllü (1998)	X	X				X	
Batley et al. (2004)	X	X					
Horne et al. (2005)	X		X		X		X
Hess et al. (2006)	X					X	X
Potoglou and Kanaroglou (2007)	X	X					X
Ahn et al. (2008)	X		X				X
Train (2008)	X	X					
Mau et al. (2008)	X				X		X
Dagsvik and Liu (2009)	X	X					
Caulfield et al. (2010)	X	X					X
Hidrue et al. (2011)	X					X	
Mabit and Fosgerau (2011)	X			X	X	X	X

[a] CV means conventional vehicle.
[b] AFV implies a general category of alternative fuel vehicles was used.

Apart from vehicle and fuel types a wide variety of attributes have been used in choice experiments over the years (see Table 3). With respect to the monetary attributes, purchase price and fuel costs are included in all but two studies, and operation and maintenance costs have been include frequently as well. Most studies include range, but fuel availability and refuelling/recharge time, which have also been recognized as potentially detrimental to AFV adoption, have been included in a relatively limited number of studies (seven and three studies, respectively). In only one study all three attributes have been included (see Bunch et al., 1995). In almost half of the studies emissions or emission reduction have been included as an attribute, which makes sense since from a societal perspective it is one of the most beneficial features of alternative fuel vehicles. Estimation results on the preferences and willingness-to-pay for emission reduction should, however, be interpreted with caution (see the discussion below). A final interesting attribute included in some studies is incentives implemented by government in order to stimulate alternative fuel vehicles. Next to the obvious monetary tax incentives, interesting incentives are free parking, access to express lanes, and access to high-occupancy vehicle lanes.[2]

Table 3. Attributes included in peer-reviewed choice experiments on consumer preferences for alternative fuel vehicles [a]

	Purchase Price	**Fuel cost** [b]	**O&M cost**	**Range**	**Fuel time**	**Fuel availability**	**Emis-sions**	**Incen-tive** [c]
Beggs et al. (1981)	X	X		X				
Calfee (1985)	X		X	X				
Bunch et al. (1993)	X	X		X		X	X	
Bunch et al. (1995)	X	X		X	X	X	X	
Dagsvik et al. (1996)	X	X		X				
Ewing and Sarigöllü (1998)	X		X	X	X		X	
Batley et al. (2004)	X	X	X	X		X	X	
Horne et al. (2005)	X	X				X	X	X
Hess et al. (2006)	X	X	X	X				
Potoglou and Kanaroglou (2007)	X	X	X			X	X	X
Ahn et al. (2008)		X	X					
Train (2008)	X	X		X		X		
Mau et al. (2008)	X	X		X		X		
Dagsvik and Liu (2009)	X	X						
Caulfield et al. (2010)		X					X	X
Hidrue et al. (2011)	X	X		X	X		X	
Mabit and Fosgerau (2011)	X	X	X	X				

[a] Various attributes included in the choice experiments are not included in the table, such as vehicle size, top speed, acceleration, body type, air conditioning.
[b] Includes variations on fuel cost, e.g., fuel consumption, fuel efficiency times fuel price, etc.
[c] This concerns government policies that try to stimulate alternative fuel technologies. Incentives used were reduced taxes, free parking, access to express lanes, and access to high occupancy vehicle lanes.

Early studies already concluded that several characteristics of electric cars were very problematic. Calfee (1985) concludes that the electric car as it existed in 1985 can only have a very small market share, and that the limited driving range is one of the main underlying reasons. Beggs et al. (1981) come to a similar conclusion, and show that potentially lower operating costs of electric cars do not compensate for the limitations in driving range. These two particular studies are from the eighties so one might argue that since then range and recharge time have become less problematic due to substantial improvements in electric car technology. These improvements have been limited however. Calfee (1985) and Beggs et al. (1981) use similar values for driving range and recharge times in their stated choice experiment compared to more recent studies. These recent studies also find these negative effects (e.g., Batley et al., 2004; Mau et al.,

[2] Unique attributes for electric cars are included in Chéron and Zins (1997), who include the cost and delay in case of a dead battery, and Adler et al. (2003), who include gradability, which measures the speed that an electric car can maintain at full power when going up a hill with a certain gradient.

2008; Train, 2008; Hidrue et al., 2011), so limited driving range remains problematic. A related question is then to what extent increases in range would increase electric car preferences. In a meta-analysis on consumer willingness to pay for driving range, Dimitropoulos et al. (2011) show that estimates from the literature vary widely from 3 to 231 US Dollar per mile (2005 prices). Their model estimates furthermore show that the willingness to pay per extra mile decreases when driving range increases, and that regional differences in WTP are large. The latter may reflect some regional differences in taste, but more likely it is due to differences in spatial structure and car use. This observation suggests that it is difficult to compare WTP estimates between countries and regions without controlling for differences in car use, spatial structure and accessibility (of jobs, schools, etc).

Recharge time has not been included very often in choice experiments. An early study by Beggs et al. (1981) shows that long recharge time is an important barrier to consumer acceptance of electric cars, and more recent evidence suggests it still is a problematic issue (Hidrue et al., 2011). Findings on the importance of fuel availability are somewhat mixed. Bunch et al. (1993) find that preferences are less sensitive to fuel availability when range and fuel costs of cars are comparable, although the drop in preferences is larger as fuel availability approaches lower levels. On the other hand, results by Horne et al. (2005) and Potoglou and Kanaroglou (2007) show that limited fuel availability has a strong negative effect on consumer preferences. Other recent studies show similar results. Batley et al. (2004) find a WTP of around 1,100 pound sterling for every 10 percentage point increase in the number of stations with the appropriate fuel. Mau et al. (2008) also measure fuel availability by the proportion of stations with the appropriate fuel and also find a high WTP for this attribute. Train (2008) uses an alternative measure for fuel availability, i.e., extra one-way travel time to get to a station with the appropriate fuel. In the estimated models a dummy was included for an extra one-way travel time of 10 minutes (0 and 3 minutes being the reference category), which was found to have a negative and statistically significant in both the standard MNL and the mixed logit model. In conclusion, limited fuel availability likely has a strong negative effect on consumer preferences, but the evidence suggests that the effects are non-linear. The relevant ranges or cut-off points are difficult to assess.

Results of several studies show that the emission level of an alternative fuel vehicle is an important attribute (see, e.g., Bunch et al., 1993; Ewing and Sarigöllü, 1998). Potoglou and Kanaroglou (2007) even find that the willingness-to-pay for a reduction in emission rates of only 10% compared to the gasoline car is between 2000 and 5000 Dollar. Batley et al. (2004) find a WTP of around 1,000 pound sterling for a 10 percentage point reduction in emission levels, which also is substantial. Hidrue et al. (2011) estimate preferences for a reduction in emission levels of alternative fuel vehicles relative to the current emission levels of a conventional technology, and find substantial although somewhat lower values. With 25% reduction being the reference category, included in the substantial negative WTP for electric vehicles, they report average WTP values of around 1,900 US dollar, 2,600 US dollar and 4,300 US dollar for a further reduction of 50%, 75% and 95%, respectively. Since emission reduction is predominantly a societal good, and does not lead to direct personal gain, these findings are surprising at least.[3] It is of course possible that these results reflect true consumer preferences, but in our opinion it is more likely that these results are due to hypothetical bias, in this case towards giving a socially and morally desirable answer. The high WTP

[3] Fuel costs are included in almost all studies that include emission reduction, so fuel cost reductions that are associated with emission reductions should be controlled for.

for emission reduction found in several studies should therefore at least be interpreted with caution. Some supporting evidence is given in Caulfield et al. (2010), who find that CO_2 emission reductions are relevant but compared to fuel cost savings of relatively limited importance.

Three studies include as an attribute government incentives meant to stimulate adoption of AF vehicles. Potoglou and Kanaroglou (2007) find that free parking is relatively unimportant. Their results also suggest that permission to drive on high occupancy vehicle lanes has only a small positive effect on consumer preferences. Horne et al. (2005) obtain similar findings for access to express lanes. Caulfield et al. (2010) use reductions in vehicle registration taxes as incentive, which is an actual Irish government policy to stimulate sales of alternative fuel vehicles. They study suggest that these tax reductions do not have a large impact on sales. In general, the effects of government policies likely differ across countries, or more generally across different spatial structures and socio-economic circumstances. More specifically, free parking will be more effective in regions where parking space is scarce and parking fees are high, while access to HOV and express lanes likely has a substantial effect in regions with extensive traffic congestion. Unfortunately, the studies discussed above do not test for such issues.

Finally, next to preferences for certain car characteristics, consumers may prefer specific cars just because of the car or the fuel type itself. Not every study provides insight into this issue, either because it did not include fuel-specific constants in the model, or because it did not provide fuel-specific information in the choice task. Early results by Dagsvik et al. (1996) suggest that alternative fuel cars are fully competitive to conventional cars, given that a suitable infrastructure is provided for maintenance and refuelling. Consumers even appear to prefer hybrid technology and hydrogen cars over conventional cars (Horne et al., 2005; Hess et al., 2006; Mau et al., 2008; Mabit and Fosgerau, 2011). The evidence on electric vehicles is somewhat mixed. Ewing and Sarigöllü (1998) and Mabit and Fosgerau (2011) find (strong) preferences for electric vehicles over conventional cars, while Hidrue et al. (2011) and Hess et al. (2006) find (strong) preferences for conventional cars over electric cars. Differences between studies on this particular issue can be explained in two ways. First, they may reflect actual differences in consumer preferences, which in turn may be caused by various factors such as differences in culture, environmental awareness, etc. Second, it may be the product of differences in study design. For example, some studies include important fuel attributes, e.g., refuelling/recharge time and fuel availability, in their experiment, while in others these attributes are not included and are therefore implicitly incorporated in fuel type. In general, when important fuel or car type attributes are not taken into account explicitly, the fuel-specific constants will pick up these effects and will suggest that fuel-specific preferences differ, while in actual fact they may be very similar *ceteris paribus*. Likely both explanations are true to some extent.

To sum up we find that purchase price, operating costs, driving range, fuel availability and recharge times may have substantial effects on consumer preferences for AFVs. We therefore include these attributes in our experiment (see next section). We include various AFV types and not one 'general' AFV, because we are interested in preferences for specific AFV types. Furthermore, willingness-to-pay estimates for emission reduction reported in the literature appear to be (substantially) biased, so caution is warranted when including an attribute on emission levels. Finally, substantial regional differences are found in stated preferences for AFVs and AFV characteristics. This shows that stated choice results from different countries are not directly interchangeable, and that a specific experiment for the Dutch situation is both warranted and necessary.

3. Description of the choice experiment

To examine the preferences of Dutch private car owners for AFVs and AFV characteristics we carry out a choice experiment integrated in an online questionnaire. Stated-preference choice experiments have been used extensively in economics and public policy evaluation (see, e.g., Louviere et al., 2000, for a review of methods and applications). In a choice experiment respondents are confronted with choices, often a number of them. Each choice, or choice task, consists of two or more options, and respondents are asked to indicate which of these options they prefer. The options are described by a number of characteristics, or attributes, and for each of these attributes various attribute levels are created so that people must make trade-offs between the attribute values each time they are asked to make a choice. An efficient statistical design is generated such that sufficient variation in these trade-offs is available. Ultimately, assuming that a sufficient number of respondents is available, statistical models can be estimated, the results of which give insight into the relative impact of each attribute on consumer utility. By also including a monetary attribute, usually the price of good or a service, the relative value of each attribute can also be expressed in monetary terms.

Using a choice experiment to elicit stated preferences has a number of advantages over the contingent valuation method. First, the choices made in a choice experiment resemble reality more closely, because trade-offs are made continuously in reality. Second, in a contingent valuation study people are asked directly for the amount of money they would be willing to pay for a certain change in an attribute, an approach that has been criticised because it is prone to bias and highly sensitive to framing and anchoring effects. In a choice experiment the monetary aspect is an integral part of the trade-off, and willingness to pay is measured in a more indirect way, thereby substantially reducing the before mentioned risks. Finally, in a choice experiment much more information can be obtained from a single respondent than in a contingent valuation set-up in the same amount of time.

A first selection of attributes was based on consultations with stakeholders and a review of the literature (see previous section). Important for our experiment is that the car attribute differs markedly between conventional technologies and AFVs, and that there is (strong) empirical evidence that the attribute matters for car choice. For example, the available empirical evidence shows that range, fuel time and fuel availability are important characteristics, but very few studies actually include all three of these attributes. Ultimately we selected a total of eight attributes, i.e., car type, purchase price, monthly costs, range, charging time/refuelling time, additional detour time for refuelling, number of available brands/models and policy measure.

One of the challenges in designing a stated choice experiment is to make the choice options conceivable and understandable for respondents. For this reason the levels of some attributes (car type, purchase price and monthly costs) were made respondent specific. To this end, several questions were asked prior to the choice tasks to reveal information on the current car of respondents (NB all respondents were private car owners; see further section 4.2 for more information on the panel and selection and segmentation). We asked respondents for information on annual mileage, weight of the car, and whether they were exempted from road taxes. Since characteristics of a next car may be very different from those of the current car due to job changes and changes in family or living situations, we also asked respondents to provide information on the presumed fuel type and purchase price of their *next* car.

We did not include an attribute for the emission levels of AFVs in the choice tasks. As was mentioned in Section 2, reported willingness-to-pay estimates for environmental attributes in the literature are rather high, and we felt that including an environmental attribute in the choice task might increase hypothetical bias. We did however included two questions after the choice tasks in which respondents were asked to give a score (1 to 7) for environmental and safety performance of AFVs compared to the conventional technology (see Section 4.2 for details). This allows us to include perceptions on environmental and safety performance in our model estimations to assess whether these factors matter for car choice.

3.1 Attributes and levels

Car type

We distinguish six different car types i.e., the current technology (petrol, diesel or LPG, depending on the preferred fuel type of the next car as indicated by the respondent), the hybrid, the plug-in hybrid, the fuel cell, the electric and the flexifuel car. For the description of these car types presented to the respondent we refer to Appendix A.

Purchase price

In order to reduce the risk of hypothetical bias in a choice experiment, it is essential that the choices we face respondents with resemble choices in reality as close as possible. The purchase prices were therefore made respondent specific. To achieve this prior to the choice tasks respondents were asked what the price range of their next car would presumably be. They could select car prices from a drop-down menu ranging from less than € 3,000 to more than € 100,000. Price categories had ranges of € 3,000 up to € 30,000, ranges of € 5,000 between € 30,000 and € 40,000, and ranges of € 10,000 between € 40,000 and € 100,000, after which a single category was added for prices higher than € 100,000. From the price range category selected by the respondent we used the lower limit as our point of reference. This figure was multiplied by a random number generated from a uniform distribution between 0.9 and 1.1, and rounded to the nearest hundred.[4] The purchase price of an AFV was equal to the price of the petrol/diesel/LPG car plus a design-dependent mark-up, using three different mark-up levels for each AFV. In addition, the mark-up of the electric vehicle was also dependent on the vehicle range since higher range requires a larger battery pack with higher associated costs. More specifically, three mark-ups were selected for a range of 140 km because for this particular range we were able to obtain some reliable price information. Mark-ups for ranges other than 140 km were assumed to be proportional to the selected mark-ups (e.g., the mark-up of an electric car with a range of 280 km is two times the mark-up of an electric car with a range of 140 km). Table 4 gives an overview of the purchase price mark-up levels for each AFV.

[4] The reason for using random variation was to confront respondents with constantly different prices for the six car types, which is useful for estimation purposes but also prevents respondents from getting used to specific prices. The random numbers were equal within a single choice task, i.e., the prices of all three car alternatives were generated using the same random number in order to keep the mark-ups for AFVs identical across choice tasks. Random numbers were varied between choice tasks in order to generate some price variation between choices.

Table 4. Mark-up levels for alternative fuel vehicles used in the design*

New cars	Level 1	Level 2	Level 3
Hybrid	€ 0	€ 2,000	€ 6,000
Plug-in hybrid	€ 0	€ 2,000	€ 7,000
Fuel-cell	€ 1,000	€ 3,000	€ 10,000
Electric	€ 1,000 * (Range/140)	€ 3,000 * (Range/140)	€ 10,000 * (Range/140)
Flexifuel	€ 500	€ 1,200	€ 3,000

* The mark-ups for second-hand cars are exactly 50% of that of new cars

The additional purchase costs given in Table 4 are meant to reflect additional prices for AFVs in the short as well as in the long run. This would allow us to reveal current preferences but also the change of preferences when prices of AFVs come down as a result of technological improvements and economies of scale. After fielding a pilot (see section 3.3) we decided it was not useful to include current prices for electric vehicles and fuel-cell vehicles, because additional prices for both AFVs (depending on the specifications of the car) can be up to € 100,000. Not surprisingly, cars with these additional costs were not selected by respondents in the pilot. Ultimately the range in costs was chosen such that relevant information on the utility curves could be revealed, which means that mark-up prices for AFVs may be unrealistic at the moment, but may become realistic in the future.

Information on current and future costs of the AFVs that were part of the experiment were derived from a range of studies and consultations with experts. An extensive literature review on costs was not carried out since it was our primary goal to establish how *different* prices would affect preferences. Since the preferences for the complete range in prices shown in Table 4 will be known, it is possible to derive market shares for all car purchase prices within this range.

Monthly costs

Monthly costs were comprised of three different cost elements, i.e., fuel costs, maintenance costs and road taxes (if applicable). Fuel costs presented in the choice tasks were respondent specific and calculated based on the vehicle weight, mileage and fuel type, all indicated by the respondent in questions prior to the choice tasks. More precisely, vehicle weight and mileage were based on their current car, and fuel type was based on the next car they were going to buy. We felt it might be difficult for respondents to indicate what the weight and mileage would be of their next car. As stated above we did want to base the respondent-specific level values as much as possible on the next car of respondents since job, family or living situation of the respondent might change which influence car use and choice.

The prices for electricity, hydrogen and biofuels were varied according to the information in Table 5. Fuel prices for petrol, diesel, LPG were not varied in the design of the experiment. Hence the fuel costs of hybrid cars was also not varied since they can only use conventional fuel and cannot directly tap electricity from the net. One might argue that fixed fuel prices for petrol, diesel and LPG is unrealistic since oil prices have fluctuated significantly over the past decades which is not likely to change in the future. We however were primarily interested in the effects of relative price differences between conventional fuels and alternative fuels. Adopting different level values for conventional fuels in the experimental design we felt would not add much to the information we could retrieve from the experiment.

Table 5. Fuel prices for the six car types (price level 2011)

Fuel type	Car type	Level 1	Level 2	Level 3
Petrol	Petrol, hybrid	€ 1.55/liter	--	--
Diesel	Diesel	€ 1.25/liter	--	--
LPG	LPG	€ 0.65/liter	--	--
Petrol + electricity [a)]	Plug-in hybrid	70% of petrol price	90% of petrol price	100% of petrol price
Hydrogen	Fuel-cell	65% of petrol price	100% of petrol price	130% of petrol price
Electricity	Electric	25% of petrol price	40% of petrol price	75% of petrol price
Biofuels	Flexifuel	65% of petrol price	100% of petrol price	130% of petrol price

a) Plug-in hybrids drive a short distance on electricity and the remainder on petrol or diesel. The variation in the level value is based solely on assumed variation in the price of electricity

Maintenance costs were fixed for petrol (€ 50 a month), diesel and LPG (€ 150 a month). Three levels were adopted for electric vehicles and fuel-cell vehicles: € 20, € 30 and € 50 a month. The maintenance costs were fixed for plug-in hybrids, hybrids (both € 150 a month) and flexifuel cars (€ 100 a month).

In the Netherlands, road taxes (MRB) differ for petrol and diesel vehicles and depend on the vehicle weight. In addition some vehicles, depending on the amount of CO_2 they emit per kilometre, are exempt from MRB. Prior to the choice tasks respondents were asked whether they pay MRB or not. If not than the levels for monthly costs were corrected for this. There were no levels adopted for MRB in the experimental design. All AFVs were exempt from MRB in the experimental design.

Range

Range was car type specific. Electric, plug-in and fuel-cell had different level values for range. Since the total range of hybrids, plug-in hybrids and flexifuel cars does not differ from conventional cars these car types had only one level value being 'same as current range'. The current range was not given to the respondent so it represents a value which according to the respondent is the range of conventional cars. See Table 6 for a detailed overview of the car type specific ranges.

Table 6. Ranges for the six car types

Car type	Level 1	Level 2	Level 3	Level 4
Petrol/diesel/LPG	Same as current range	--	--	--
Hybrid	Same as current range	--	--	--
Plug-in hybrid	Same as current range	--	--	--
Fuel-cell	250	350	450	550
Electric	75	150	250	350
Flexifuel	Same as current range	--	--	--

These ranges of the AFVs included in the experiment were derived from a range of studies and consultations with experts. The ranges were tested in the two pilots carried out (see section 3.3). For electric cars the current real-world range amounts to approximately 75 km, which we adopt as the lower bound of the level values for driving range of the electric car. The pilots showed that ranges above 400 km did not have much effect on utilities of respondents. It was therefore decided to top the best case off at 350 km in order to get the best information on the utility curve. Most studies reviewed suggest that the range of fuel-cell vehicles is less of a barrier compared to electric vehicles. Ranges comparable with current petrol and diesel vehicles may be feasible in the long-run. Current ranges of fuel-cell vehicles are claimed to be around 250 km.

Recharging/refuelling time

Different charging time/fuelling time levels were only applied to the car types plug-in hybrid, electric and fuel-cell. The level value for the other car types was set at two minutes as a good proxy for the average refuelling time of conventional cars. See Table 7 for a detailed overview of the car type specific charging/fuelling times.

For electric cars the level of 30 minutes represents 'fast charging'. We assumed that fast charging would not be available at home. For this particular level we therefore also varied the levels of the attribute 'detour time' (see below). For the other charging time levels the detour time level would be 'N.A., you need to charge at home' in all instances.

Table 7. Recharging/refuelling time for the six car types

Car type	Level 1	Level 2	Level 3	Level 4
Petrol/diesel/LPG	2 minutes	--	--	--
Hybrid	2 minutes	--	--	--
Plug-in hybrid	20 minutes	35 minutes	1 hour	3 hours
Fuel-cell	2 minutes	10 minutes	15 minutes	25 minutes
Electric	30 minutes	1 hour	2.5 hours	8 hours
Flexifuel	2 minutes	--	--	--

Additional detour time

To test for differences in the availability of refuelling locations the attribute additional detour time was used. It was felt that additional travel time would be easier for respondents to understand than for example a percentage of the number of petrol/diesel/LPG fuel stations. An almost identical approach was used by Train (2008). Different levels for this attribute were applied for the car types fuel-cell, electric and flexifuel. For the other car types there was only one level: 'No additional detour time'. For electric vehicles an additional level value was adopted since it may be possible to charge an electric vehicle at or close to home so that there is no additional travel time at all to recharge. The different level values for the electric car would only appear in combination with a level value of 30 minutes for recharging/refuelling time. We felt it would be unlikely that people would decide to charge at location away from home when the charging time would exceed 30 minutes. See Table 8 for a detailed overview of the car type specific charging/refuelling times.

Table 8. Additional detour time for the six car types

Car type	Level 1	Level 2	Level 3	Level 4
Petrol/diesel/LPG	No additional detour time	--	--	--
Hybrid	No additional detour time	--	--	--
Plug-in hybrid	No additional detour time	--	--	--
Fuel-cell	No additional detour time	5 minutes	15 minutes	30 minutes
Electric*	N.A., you need to charge at home	5 minutes	15 minutes	30 minutes
Flexifuel	No additional detour time	5 minutes	15 minutes	30 minutes

* Only in combination with a level value of 30 minutes for charging/refuelling time

Number of available brands/models

Preferences of car buyers are substantially heterogeneous (Hoen en Geurs, 2011; Carlsson et al., 2007; Brownstone et al., 2000). This is also illustrated by the fact that many different car brands and models are on offer and seen driving in the streets. If the car supply would be (much) less diversified the chance that people would be driving the same car would become higher with increasing numbers sold. This might interfere with the desire to distinguish oneself with a car. To test this the attribute Number of available brands/models was included. To the best of our knowledge it is the first time that this or a comparable attribute is included in a Stated Choice experiment for AFVs. Four attribute levels (1, 10, 50 and 200) were assigned to the all AFV car types, while number of models for the current technology was always "Same as current amount".

Policy measure
Finally an attribute was added to test for respondents sensitivity for policy intervention. Three policy measures were included as levels for this attribute, complemented with a fourth 'current policy' level. They were chosen in consultation with the ministry of Energy, Agriculture and Innovation (EL&I). The three policy measures were:

- Free parking;
- Access to bus lanes within the built up area;
- Abolishment of the road tax exemption.

Free parking applies to parking permits and parking zones throughout the country, which was clearly explained to the respondent (see also Appendix A). The third level would only appear in combination with car types that currently have a road tax exemption.

3.2 Choice task presentation

The choice tasks were designed with Sawtooth SSI-web. Figure 1 gives an example of a choice task. Note that for the purpose of this paper we translated the originally Dutch wording in English. Respondents were given three options to choose from. We asked them to state their first and second most preferred choice, which basically resulted in a ranking of the three options, the not chosen option being the least preferred. A total of eight choice tasks were given to each respondent. The order of the attributes remained the same throughout all choice tasks. Prior to the eight choice tasks an example was shown to the respondents so that they could familiarize themselves with it. In this example we asked respondents to imagine that the moment had come when their current car (i.e., the car in which they drive most frequently) would have to be replaced. In the example we also pointed out that additional information could be accessed through 'pop-up tooltips' when moving the cursor over the question marks added to each of the attributes, except for purchase price. Simple and short descriptions of how to interpret the attribute were given in these tooltips. To give an impression of the on-screen information given to respondents in each of the eight choice tasks, the descriptive texts presented before the choice tasks and in the tooltips are given in Appendix A.

Respondents were given three options to choose from. We asked them to state their first and second most preferred choice, which basically resulted in a ranking of the three options, the not chosen option being the least preferred. A total of eight choice tasks were given to each respondent. The order of the attributes remained the same throughout all choice tasks. Prior to the eight choice tasks an example was shown to the respondents so that they could familiarize themselves with it. In this example we asked respondents to imagine that the moment had come when their current car (i.e., the car in which they drive most frequently) would have to be replaced. In the example we also pointed out that additional information could be accessed through 'pop-up tooltips' when moving the cursor over the question marks added to each of the attributes, except for purchase price. Simple and short descriptions of how to interpret the attribute were given

in these tooltips. To give an impression of the on-screen information given to respondents in each of the eight choice tasks, the descriptive texts presented before the choice tasks and in the tooltips are given in Appendix A.

Figure 1. Choice task example[a]

Questionnaire car choice: Choice task 1

	OPTION 1	OPTION 2	OPTION 3
Car type (?)	Petrol	Electric	Fuel cell
Purchase price	€ 19,500	€ 24,900	€ 19,500
Monthly costs (?)	€ 260	€ 60	€ 260
Driving range (?)	Same as current range	75 kilometres	Same as current range
Charging/Refueling time (?)	2 minutes	2,5 hours	2 minutes
Additional detour time (?)	No additional detour time	N.a., you need to charge at home	No additional detour time
Number of brands/models (?)	Same as current amount	1	Same as current amount
Policy measure for this car type (?)	Current policy	Free parking	Current policy

Please state below which car would be your first choice, and which would be your second choice.

	OPTION 1	OPTION 2	OPTION 3
1st choice	○	○	○
2nd choice	○	○	○

Previous question | Next question

[a] Respondent values used in this example are:

- Km/year: 15,000-25,000
- Tax exemption: No
- Weight: 1,200 kg
- Next car new: Yes
- Fuel type next car: Petrol
- Purchase price next car: € 21,000 – € 24,000

3.3 Changes in levels due to tests and pilots

Before fielding the questionnaire a number of consultations, tests and pilots were carried out. The purpose of this was two-fold, (1) to make sure questions were not too difficult to interpret and understand, and (2) to test the level values of the attributes in order to zoom in on the most interesting parts of the utility curves. Experts and policy makers from the Ministry of Infrastructure and Environment were invited to comment on the preliminary selection of attributes and attribute levels. This led to some changes in the questionnaire and design of the stated choice questions. A test version was then prepared and sent to approximately 20 experts and colleagues who commented on wording and general quality of the questionnaire. This led to additional improvements.

Finally two consecutive pilots on small samples were fielded to finalize the testing phase; 52 respondents leading to 416 observations for pilot 1, and 51 respondents leading to 408 observations for pilot 2. The main objective of the pilots was to test the attribute level values. Some additional questions were added following the stated choice questions to determine at which level of a certain attribute respondents decided to reject a choice option. Purchase price and cost ranges included in the design were wide because we are interested in preferences under current circumstances as well as under possible future price and cost scenarios. Levels for these attributes were not up for discussion or change. Also car fuel types and policy measures were not up for discussion, because their levels could not be changed at the margin, they could only be deleted, which was not an option. Results for pilot 1 showed expected signs on all attributes and attribute levels and were plausible in terms of magnitude. Still, changes were made on three aspects.

The range levels for electric vehicles included were 75 km, 150 km, 250 km and 450 km. The results indicated that the difference in preference between the first three levels were minimal. We therefore decided to replace 250 km by 350 km. In a second pilot the distinction between 350 km and 450 km turned out to be minimal. In the main study we therefore included 75 km, 150 km, 250 km and 350 km, mainly because 450 km is technologically possible but at the moment not very realistic and because the first pilot indicated that the added value of 450 km compared to 350 km was limited.

The included levels for hydrogen vehicles were 250 km, 300 km, 400 km and 600 km. Results indicated that differences in preferences for the first three levels were minimal, so we changed the levels to 250 km, 350 km, 500 km and 600 km. Results from the second pilot indicated that the differences in preference between 500 km and 600 km was small, so we changed the levels to 250 km, 350 km, 450 km and 550 km in order to get a better grip on possible non-linearities in the 350 to 550 km range.

Detour times included were 2, 8 and 20 minutes. Results indicated that 2 minutes was not considered relevant by respondents, and that 8 minutes had only limited added value. We changed detour times to 5, 15 and 30 minutes in order to test a wider range of detour times and get a better grip on possible non-linearities. Results from the second pilot were again plausible and showed more interesting differences between the various detour times, so we made no further changes to these levels in our main study.

3.4 Software and statistical design

The questionnaire was programmed in Sawtooth SSI-web. This software package is specifically suited for building an online choice experiment from start to finish. It generates efficient statistical designs with various options and it allows for respondent-specific adaptations of the design through HTML and PERL programming, which can also be used to adapt the online presentation of choice tasks and attribute levels to the respondents.

The default method for generating a statistical design in Sawtooth is called Complete Enumeration, which provides the most efficient design (i.e., lowest standard errors) in terms of main effects. A variation on the Complete Enumeration method is the Balanced Overlap method, which allows for more effective and efficient estimation of attribute interactions by allowing for more overlap of attribute levels between options in a single choice set. For our purposes this option is interesting because some attribute levels (i.e., range, refuel/recharge time and detour time) differ per car type, but also other attribute interactions may prove to be interesting (e.g., interaction between refuel/recharge time and detour time). Sawtooth allows for testing both methods in terms of efficiency, assuming a specific number of respondents. These tests reveal that the loss in efficiency by using the Balanced Overlap method is relatively small. Still, even small losses in efficiency may have large consequences in small samples. However, because we could guarantee a relatively large sample size *a priori*, we chose to use the Balanced Overlap method for generating the statistical design.

Some attribute levels are constant for some of the car fuel types, i.e., do not vary by design (see Section 3.1). In generating the design we therefore included the necessary prohibitions and generated an alternative-specific efficient design. Prohibitions between other attributes were kept to a minimum mainly because of efficiency reasons. We made one manual alteration to the resulting design because for the electric car we did not want a combination of a 75 kilometre range with an 8 hour recharge time. Each time this combination occurred, which is 12 times out of 720 choice options (30 survey versions, each with 8 choice sets of 3 options), we reset the recharge time to one of the other levels (i.e., four times 3 hours, four times 1 hour and 4 times 30 minutes). We compared the resulting design with the Sawtooth design and the change in efficiency was minimal.

We also chose to aim for a close to 65% share of choice tasks that had the conventional technology (CT, depending on what the respondent indicated would be the fuel type of his or her next car) as a choice option. In the other 35% of the choice tasks respondents were forced to choose between three AFVs. The reason is that including the CT as a choice option in every choice task could result in respondents always choosing the CT, regardless of the alternatives and their characteristics (status quo bias). In this case, potentially very little information on preferences for AFVs would result, making reliable model estimations difficult. One could argue that status quo bias should not be a problem since we also asked respondents to provide their second preferred choice. When the first choice was the conventional technology this would in almost all cases be a choice between two AFVs. However, by definition the second preferred choice is far more hypothetical than the first preferred choice. In our opinion the information provided by the second choice is therefore far less reliable.

4. Data description

4.1 Panel, segmentation and selection characteristics

Respondents for the choice experiment were selected from a Dutch internet panel owned by TNS-NIPO. More specifically, respondents were selected from a separate automotive panel containing more than 40,000 households with one or more car. The panel is established through random sampling, meaning that each member of society has an equal chance to be added to the panel as long as he or she has conveyed the willingness to cooperate. The automotive panel offered several advantages for our stated choice experiment:

- Possibility for car type and use specific segmentation;
- Regular screenings revealing additional information on current car type and use, making it possible to limit the number of questions;
- Familiarity of the panel members with automotive related questions which improves the reliability of results.

The experiment focused on the market for privately owned cars (company car drivers are excluded from the sample). We added a segmentation for owners of new and second-hand cars since their preferences for AFVs are likely to be different due to different budget constraints and use of the vehicle. We furthermore made a segmentation on fuel type (gasoline, diesel, LPG) because preferences for AFVs may be influenced by the different tax regimes that are adopted for these fuel types in the Netherlands. Purchase tax, road taxes and fuel levies vary substantially between petrol, diesel and LPG cars.

For car owners of both new and second-hand cars we asked TNS to aim for 300 completes for respondents with petrol, diesel and LPG cars. This made a target of 1,800 completes in total. For each segment we instructed TNS to aim for representative sampling on age (between 18 and 75), gender, education, and place of residence.

We added selection questions in the questionnaire to target the respondents who were most likely to make car choice decisions. For example, in a two-person household with one car where person A would be the main user of that car, we wanted to be sure it would be person A filling in the questionnaire and not person B. Person A is more likely to know the specifics of the car and the way in which it is used. Moreover, replacing that car with a new car (which was the subject of the Stated Choice part) would be more likely a decision for person A than person B. Therefore we added the selection question: "Are you the person that drives this car most frequently (measured in the numbers of kilometres driven)?" If the answer to this question was "No", the respondent was eliminated from the remainder of the questionnaire and excluded from the sample.

In households with more than one car we asked: "In which car do you drive most frequently (measured in the numbers of kilometres driven)?" After this question we specifically asked the respondent to answer the following questions for *that* car.

4.2 Background statistics

The final version of the questionnaire was fielded in June 2011. Total response rate, including the respondents who were disqualified, was 84%. After approximately 2 weeks we obtained 1,903 completes, 660 for petrol, 754 for diesel and 489 for LPG. The share of LPG drivers is relatively low in the Netherlands (around 5%), which is why the target of 600 was not attained. Approximately 5% of respondents indicated they made random choices, and we excluded them from our analyses. Ultimately the choices made by 1,802 respondents were used, leading to a total of 14,413 observations (3 observations were missing). In Appendix B we present background characteristics for these 1,802 respondents. There clearly is an overrepresentation of male respondents in the sample, at least in comparison with total population. Since males are likely overrepresented in the population of car buyers as well, this is likely not very problematic. The age distribution is fairly even between the age group 35 to 65. The age group 18 to 35 is somewhat underrepresented compared to the average Dutch population. The average household size (not shown) is 2.8 which is quite high compared to the national average of 2.2. The distribution of respondents living in urban and rural areas is fairly even.

In Appendix C we present descriptive statistics on a number of car use and travel characteristics for the full sample. Around half of the respondents currently owns a new car (due to our sampling structure), and approximately 40% indicate that their next car will be a new car. Most respondents plan to spend no more than 18,000 Euro on their next car, drive between 7,500 and 25,000 kilometres per year, and most cars weigh between 1,000 and 1,500 kg. A fairly high share (42%) of respondents indicate that they never use their car for commuting purposes, and commuting distance for around 60% of the respondents is less than 20 kilometres. Other relevant characteristics not shown in the table are: 25% of respondents do not use their car for holidays abroad, 16% of respondents use their car for towing a caravan, 9% of respondents need a parking permit for parking at (or close to) home, and more than 65% of the respondents indicate they have the possibility to charge an electric vehicle at home.

As was mentioned in the introduction of Section 3, we added two questions following the choice tasks that aimed to reveal respondents' perceptions on environmental and safety performance of AFVs. We asked respondents to score each AFV on environmental and safety performance compared to the conventional technology a 7-point scale (1=Less safe / Worse environmental performance; 4=equally safe / equal environmental performance; 7=Safer / Better environmental performance). Table 9 shows the mean scores and the standard deviations for each AFV. Consumer perceive AFVs to be better for the environment than the conventional technology. Electric and fuel cell cars are regarded most environmentally friendly. The perception on the safety performance of AFVs is not much different from that for the conventional technology, although there does seem to be some concern over the safety performance of fuel cell cars. The standard deviations also show that there is substantial heterogeneity in people's perceptions. In Section 5 we therefore analyse whether individual respondent perceptions on environmental and safety performance of AFVs affect their car choice behaviour.

Table 9. Means and standard deviations of perceived environmental and safety performance of AFVs compared to the conventional technology (full sample)

	Perceived environmental performance		**Perceived safety performance**	
Car type	Mean	Standard deviation	Mean	Standard deviation
Conventional technology	4	--	4	--
Hybrid	5.12	1.19	4.22	0.85
Electric	5.46	1.34	4.16	0.98
Plug-in	5.15	1.18	4.12	0.81
Flexifuel	4.91	1.20	4.15	0.75
Fuel cell	5.55	1.20	3.72	0.97

4.3 Choice characteristics

Table 10 shows which car types respondents chose in the choice tasks. In the statistical design used for our experiment approximately 65% of the choice tasks contained the conventional technology (CT), and approximately 35% of the choice tasks contained only AFVs. The main reason why we did not include the conventional technology in each choice task was that it might be used as an 'opt out' by many respondents, potentially leaving us with a limited set of information leading to difficulties in obtaining reliable estimates.

Table 10. Counts and percentages of car type choices made by respondents

	Full sample		**Sample with CT in choice set**	
Car type	**Count**	**Percentage**	**Count**	**Percentage**
CT	6,747	47%	6,747	73%
Hybrid	974	7%	214	2%
Electric	1,743	12%	629	7%
Plug-in hybrid	946	7%	238	3%
Flexifuel	1,592	11%	460	5%
Fuel cell	2,411	17%	976	11%
Total	14,413	100%	9,264	100%

The conventional technology was chosen 71% of the times when it was among the choice options. This percentage is of course lower in the full sample. The figures shown in Table 10 tell us nothing about AFV preferences, because the frequency of occurrence is different for each AFV because of efficiency reasons. More specifically, car types that have many different levels (electric car, fuel cell car) appear more often in the choice tasks. The most relevant insight from the table is that there appears to be sufficient variation in car choice for reliably estimating choice models.

Before starting our model estimations it is interesting to explore the characteristics of the AFV's that are chosen by respondents. Table 11 presents range, refuelling time and detour time characteristics of the chosen electric and fuel cell cars. Important to note is that chosen electric and fuel cell cars display a wide range of characteristics, both for the full and the CT sample. This is an indication of preference heterogeneity among preferences, but also clearly indicates that maximum range and short refuelling and detour times are not a necessary condition for an electric or fuel cell car to be the preferred car in a choice set. Stated differently, we have a good indication that respondents have made clear trade-offs between choice options and that our data contain sufficient variation to reliably estimate choice models.

Table 11. Range, refuelling time and detour time characteristics of electric and fuel cell cars chosen by respondents

Electric car	**Full sample**	**CT sample**	**Fuel cell car**	**Full sample**	**CT sample**
Range			**Range**		
75 km	20%	19%	250 km	18%	19%
150 km	25%	25%	350 km	19%	16%
250 km	28%	23%	450 km	29%	32%
350 km	27%	32%	550 km	34%	33%
Refuelling time			**Refuelling time**		
30 minutes	29%	27%	2 minutes	26%	33%
1 hour	28%	34%	10 minutes	27%	21%
2.5 hours	30%	26%	15 minutes	24%	20%
8 hours	14%	13%	25 minutes	23%	26%
Detour time			**Detour time**		
0 minutes	76%	79%	0 minutes	29%	29%
5 minutes	6%	5%	5 minutes	27%	28%
15 minutes	8%	8%	15 minutes	28%	26%
30 minutes	10%	7%	30 minutes	16%	17%

5. Estimation results

As was discussed in the introduction of this paper, estimation results are presented in two separate sections. In this section we present results from a multinomial logit (MNL) model. This model still is the starting point for any choice modelling analysis (Louviere et al., 2000). We first discuss results from a linear specification in Section 5.1, and in Section 5.2 use a dummy specification to test for potential non-linear attribute effects. In Section 6 we estimate a mixed logit model to test for robustness of the MNL results and to explore the heterogeneity in consumer preferences. In that section we also estimate a model with consumer background interactions in order to uncover the main sources of preference heterogeneity, and to identify interesting market segmentations and potential early adopters.

For the purpose of all model estimations respondents that indicated to have made random choices (around 5% of all respondents) were excluded from the sample because the information presumably contains only noise. The remaining completes amount to 1,808 conventional fuel drivers (627 petrol, 716 diesel, 465 LPG).

5.1 Main attribute effects and WTP's

In this section we analyse main effects and willingness to pay estimates using a multinomial logit model and simple linear model specifications. Estimation results for three different models are presented in Table 12.[5] Model 1 is based on the full sample. Model 2 is based on the sample where conventional technology was one of the choice options. As was explained in section 3.4 we decided to have a substantial number of choice tasks in which no current technology (CT) was included as a choice alternative. This was done because CT might be used as an 'opt out' by respondents leaving us with a limited number of observations in which an AFV was chosen. That would influence model estimates negatively. As was shown in section 4.3 respondents chose AFVs in 27% of instances in which they could also choose a CT. The third set of estimates (Model 3) is based on the full sample again, but here the perception of environmental performance and safety performance are included in the model estimation as additional attributes.[6]

In all three models the estimation results for the AFV type constants represent a reference situation in which driving ranges of the electric and fuel cell car are 75 kilometres and 250 kilometres, respectively, refuelling/recharge times for the electric, plug-in and fuel cell car are 480, 180 and 25 minutes, respectively, and additional detour time is 30 minutes for electric, flexifuel and fuel cell cars.

For Model 1 all estimates have the expected sign and the model fit is reasonable with an adjusted pseudo R2 of 0.254. In the reference situation (where range, fuel time and detour time of AFVs are as mentioned above) all AFVs are valued negatively. The car type constants for electric and fuel cell cars are substantially more negative than for the other AFVs, which is largely due to the limited range of these car types and less a results of the long fuel and detour times. If we would assume similar AFV performance on range, fuel time and additional detour time, the differences between AFV constants would become much smaller. Still, AFV constants remain negative, indicating that there is an intrinsic negative utility for AFVs compared to the conventional technology. Table 12 also shows that an increase of the number of models that are available to the respondent increases utility only slightly. The same holds for the policy measures free parking and access to bus lanes which have a positive but limited effect on AFV preferences. Abolishment of the MRB-exemption is valued negatively.

Coefficients in Model 2 are comparable in sign and magnitude to those in Model 1, but the fit of Model 2 is substantially better (adjusted pseudo R2 of 0.339). The higher unexplained variance in Model 1 may be an indication that there was less trading (more random choices) in the choice tasks in which the conventional technology was not included in the choice set.

As discussed in the previous section we asked respondents for their perceptions on environmental and safety performance of AFVs compared to the conventional technology.

[5] All estimations in this paper were done in NLogit 4.0.

[6] We also estimated a nested logit model, with conventional technology in a first tree, and all AFV's in a second tree. Estimates and derived elasticities were very similar, both for the full sample and for the CT sample, and the two nesting coefficients were very similar and both close to one. Other nesting structures, e.g., with conventional technology, hybrid and plug-in hybrid in a first nest and all other AFV's in a second nest, gave comparable results. In conclusion, nested models do not appear to add much to our analyses.

Interesting is that these perceptions can be included as attributes in our model, even though they were not included as explicit attributes in our choice experiment. One might argue that including these attributes is not possible, since the scores on environmental and safety performance for a specific AFV are constant for a single respondent, and as such cannot be distinguished from the AFV-specific constant for that respondent. However, note that an AFV-specific constant is equal for *all* respondents, while the scores on environmental and safety performance for that AFV display variation across respondents, which is why the effects of environmental and safety perceptions on stated choice are identified in our model. In Model 3 both aspects are therefore included as additional attributes. The model fit is slightly better than for Model 1 and the coefficients are very similar in sign and magnitude. Not surprisingly, the estimates show that perceptions on safety performance have a clear effect on respondent choices, i.e., that people are willing to pay for safety. More surprising is that perceived environmental performance also has a positive effect on car choice, i.e., that on average people are willing to pay for cleaner technologies, *ceteris paribus*.

Table 12. MNL estimation results for three models using a simple model specification (monthly costs in Euro, purchase price in 1,000 Euro)

	Model 1 (full sample)			**Model 2 (CT sample)**			**Model 3 (full sample)**		
	b	**se**	**p**	**b**	**se**	**p**	**b**	**se**	**p**
Environmental performance	--	--	--	--	--	--	0.2319	0.0163	0.000
Safety performance	--	--	--	--	--	--	0.1947	0.0198	0.000
Hybrid	−1.0238	0.0486	0.000	−1.2411	0.0785	0.000	−1.0435	0.0533	0.000
Electric	−3.5727	0.1113	0.000	−3.4845	0.1791	0.000	−3.6243	0.1157	0.000
Plug−in hybrid	−2.0339	0.0899	0.000	−2.1454	0.1609	0.000	−2.0499	0.0925	0.000
Flexifuel	−1.4849	0.0553	0.000	−1.5855	0.0805	0.000	−1.5162	0.0585	0.000
Fuel cell	−2.4313	0.0770	0.000	−2.1941	0.1069	0.000	−2.4660	0.0828	0.000
Range electric	0.0039	0.0003	0.000	0.0051	0.0005	0.000	0.0039	0.0003	0.000
Range fuel cell	0.0023	0.0002	0.000	0.0024	0.0003	0.000	0.0023	0.0002	0.000
Fuel time electric	−0.0012	0.0002	0.000	−0.0012	0.0003	0.000	−0.0012	0.0002	0.000
Fuel time plug-in	−0.0029	0.0007	0.000	−0.0034	0.0012	0.005	−0.0029	0.0007	0.000
Fuel time fuel cell	−0.0140	0.0030	0.000	−0.0102	0.0041	0.013	−0.0140	0.0031	0.000
Detour time	−0.0166	0.0016	0.000	−0.0137	0.0024	0.000	−0.0168	0.0016	0.000
Models	0.0006	0.0002	0.000	0.0005	0.0003	0.060	0.0006	0.0002	0.000
Free parking	0.1163	0.0386	0.003	0.1003	0.0619	0.105	0.1120	0.0389	0.004
MRB exemption	−0.1315	0.0434	0.002	−0.1125	0.0713	0.115	−0.1384	0.0436	0.002
Access bus lanes	0.0268	0.0380	0.480	−0.0164	0.0636	0.797	0.0210	0.0383	0.583
Monthly cost	−0.0038	0.0002	0.000	−0.0044	0.0003	0.000	−0.0038	0.0002	0.000
Purchase price	−0.1034	0.0050	0.000	−0.1284	0.0085	0.000	−0.1045	0.0050	0.000
NOBS	14,413			9,264			14,413		
Log-L	−11,788			−6,706			−11,612		
Log-L restricted	−15,807			−10,148			−15,807		
Pseudo R2 (adjusted)	0.254			0.339			0.265		

Table 13 gives willingness-to-pay (WTP) estimates using the purchase price coefficient as common denominator. For Model 1 the negative WTP values range from approximately 10,000 Euro for the hybrid to roughly 34,000 Euro for the electric car. Although these figures represent average compensations needed to make people indifferent between AFVs and the conventional technology, they should be interpreted as statistical constructs and indications of barriers to adoption rather than actual compensation figures.

For the electric car an increase in range is valued positively at around 40 Euro per kilometre, implying that on average respondents are willing to pay around 2,800 Euro for a doubling of the current range of electric vehicles of 75 kilometres to 150 kilometres. As discussed in Section 2, it is difficult to directly compare WTP estimates for driving range between countries and regions because of differences in car use and spatial structure. A meta-analysis by Dimitropoulos et al. (2011) shows that WTP estimates for an extra mile of driving range of the electric car vary widely, and that regional differences are large. After conversion of our WTP estimate into the specific measure used in the meta-analysis it is clear that our results fall well within the range of WTP estimates found in the literature. The WTP for an increase in range of the fuel cell car is substantially lower at 23 Euro per kilometre. This is likely due to the fact that range of the fuel cell car is on average higher than that for the electric car, implying we are on a different part of a non-linear range utility curve. We explore this issue further in the next subsection.

Additional recharge time for the electric car is valued negatively at 12 Euro per minute (comparable to WTP estimate in Hidrue et al., 2011), while for plug-in cars the negative WTP is more than twice as high at 28 Euro per minute. This is counterintuitive since the plug-in car has an alternative fuelling option besides electric charging. Due to this greater flexibility of the plug-in hybrid it would seem logical that the WTP for an increase in fuel time would be lower for the plug-in than for the electric car. Also note that WTP for an increase in fuel time for the fuel cell car (135 Euro per minute) is substantially higher than for the plug-in hybrid and electric car. Since fuel cell cars should be fuelled at gas stations away from home this result is plausible, because car owners can use the time for charging an electric vehicle at home for other activities, whereas the time spent to drive to and refuel at a fuel cell station will generally be considered as lost time.

Additional detour time due to limited charging/refuelling locations is valued negatively at 168 Euro per minute. The value of time (VOT) for detour time is in the same order of magnitude as the VOT for fuel time for fuel cell vehicles. It is much higher than the VOT for fuel time of electric and plug-in cars, which is again related to the fact that fuel time (or charging time) for electric and plug-in cars does not require active presence and can be used for other activities. The only study that also uses additional detour time as a measure of fuel availability is Train (2008); the dummy estimate for additional detour time of 10 minutes (compared to no additional detour time) is negative and statistically significant, but since purchase price is included as the percentage difference with the conventional technology purchase price, a WTP calculation is impossible without additional information. In conclusion, both our study and Train (2008) show that additional detour time has a negative effect on preferences, but in terms of WTP estimates the results are difficult to compare.

Increasing the number of models will lead to a relatively small increase in overall WTP with 6 Euro per additional model. Two of the three policy measures that were included in the experiment appear to have an effect on preferences, although the impact is relatively limited. Free parking is valued at 1,150 Euro, and abolishment of the MRB exemption is valued negatively at roughly 1,700 Euro. The WTP value for access to bus and taxi lanes is small and not statistically significant.

WTP estimates from Model 3 are very similar to those from Model 1, but estimates from Model 2 are generally lower in absolute value. Striking are the differences in WTP for fuel time of the fuel cell car, WTP for detour time, and to a lesser extent WTP for fuel time of the electric car. It is plausible that stated WTP for disadvantages of AFV attributes is lower when the conventional technology is among the choice options than when it is not. For example, when a choice set contains three AFVs of which none would be chosen by a certain respondent when the conventional would have been among the choice options, the attributes of the preferred and chosen alternative get valued in the full sample, but not in the CT sample. Since in reality someone always has the option to chose the conventional technology, WTP estimates from the full sample might overestimate actual willingness to pay. Having said that, full sample estimates might therefore also substantially overestimate initial barriers to adoption, especially for the electric, the plug-in hybrid and the fuel cell car.

Table 13. WTP estimates

Attributes	**Model 1**	**Model 2**	**Model 3**
Environmental performance	--	--	€ 2,219
Safety performance	--	--	€ 1,863
Hybrid	–€ 9,901	–€ 9,666	-€ 9,985
Electric	–€ 34,552	–€ 27,138	-€ 34,679
Plug-in hybrid	–€ 19,670	–€ 16,709	-€ 19,614
Flexifuel	–€ 14,361	–€ 12,348	-€ 14,508
Fuel cell	–€ 23,514	–€ 17,088	-€ 23,596
Range electric	€ 38	€ 40	€ 38
Range fuel cell	€ 22	€ 19	€ 22
Fuel time electric	–€ 12	–€ 9	-€ 12
Fuel time plug-in	–€ 28	–€ 26	-€ 27
Fuel time fuel cell	–€ 135	–€ 79	-€ 134
Detour time	–€ 161	–€ 107	-€ 161
Models	€ 6	€ 4	€ 6
Free parking	€ 1,125	€ 781	€ 1,072
MRB exemption	–€ 1,272	–€ 876	-€ 1,325
Access bus lanes	€ 259	–€ 128	€ 201

5.2 Non-linear attribute effects

In this section we show results of a dummy model specification using a multinomial logit model in which vehicle type specific dummy variables were included for the attribute levels, and in which we made a distinction between respondents that indicated their next car would be a new car (New) and those that indicated they are likely going to buy a second-hand car (Used). Table 14 shows the estimation results for the full sample. Differences between these results and results for the CT sample are similar to those described in the previous subsection, i.e., similar WTP estimates for range, lower WTP estimates for fuel time, detour time and number of models in the CT sample, and lower absolute AFV constants in the CT sample. Non-linear effects discussed below are by and large similar for the CT sample.[7] Note that the model fit is slightly better compared to the simple specification and that the signs of the coefficients are as expected. Furthermore, the only relevant difference between new and second hand cars was in the cost and price coefficients.

[7] Full results are available upon request from the author.

Table 14. MNL estimation results for a dummy coded model specification and associated WTP values for the full sample (monthly costs in Euro, purchase price in 1,000 Euro)

Attributes	**b**	**se**	**p**	**WTP new**	**WTP used**
Hybrid	−1.0289	0.0537	0.000	−€ 12,712	−€ 6,841
Electric	−3.1998	0.1181	0.000	−€ 39,533	−€ 21,274
Plug-in hybrid	−2.0385	0.0940	0.000	−€ 25,185	−€ 13,553
Flexifuel	−1.0754	0.0611	0.000	−€ 13,286	−€ 7,150
Fuel cell	−1.8862	0.0921	0.000	−€ 23,304	−€ 12,541
Range electric					
75 → 150 km	0.5464	0.0832	0.000	€ 6,750	€ 3,632
75 → 250 km	0.8721	0.0843	0.000	€ 10,774	€ 5,798
75 → 350 km	1.1661	0.0870	0.000	€ 14,407	€ 7,753
Range fuel cell					
250 → 350 km	0.0528	0.0783	0.501	€ 652	€ 351
250 → 450 km	0.4473	0.0759	0.000	€ 5,527	€ 2,974
250 → 550 km	0.6196	0.0725	0.000	€ 7,655	€ 4,119
Fuel time electric					
8 hours → 2.5 hours	0.3263	0.0939	0.001	€ 4,031	€ 2,169
8 hours → 1 hour	0.4640	0.0940	0.000	€ 5,732	€ 3,085
8 hours → 30 minutes	0.6020	0.0991	0.000	€ 7,438	€ 4,002
Fuel time plug-in					
3 hours → 1 hour	0.3178	0.1151	0.006	€ 3,927	€ 2,113
3 hours → 35 minutes	0.1820	0.1201	0.130	€ 2,249	€ 1,210
3 hours → 20 minutes	0.6123	0.1097	0.000	€ 7,565	€ 4,071
Fuel time fuel cell					
25 minutes → 15 minutes	0.0430	0.0744	0.563	€ 532	€ 286
25 minutes → 10 minutes	0.0882	0.0738	0.232	€ 1,089	€ 586
25 minutes → 2 minutes	0.3265	0.0720	0.000	€ 4,034	€ 2,171
Detour time					
30 minutes → 15 minutes	0.4211	0.0534	0.000	€ 5,203	€ 2,800
30 minutes → 5 minutes	0.5338	0.0534	0.000	€ 6,595	€ 3,549
30 minutes → No detour	0.5277	0.0554	0.000	€ 6,519	€ 3,508
Models					
1 → 10	0.0312	0.0384	0.417	€ 385	€ 207
1 → 50	0.0665	0.0387	0.086	€ 822	€ 442
1 → 200	0.1309	0.0379	0.001	€ 1,617	€ 870
Free parking	0.1406	0.0399	0.000	€ 1,737	€ 935
MRB exemption	−0.1101	0.0442	0.013	−€ 1,360	−€ 732
Access bus lanes	0.0510	0.0390	0.191	€ 630	€ 339
Monthly cost new cars	−0.0027	0.0002	0.000	--	--
Monthly cost used cars	−0.0046	0.0002	0.000	--	--
Purchase price new cars	−0.0809	0.0054	0.000	--	--
Purchase price used cars	−0.1504	0.0086	0.000	--	--
NOBS		14,413			
Log-L		−11,715			
Log-L restricted		−15,807			
Pseudo R2 (adjusted)		0.258			

A benefit of dummy coded model specifications is that they demonstrate non-linearity's in the attribute utility curves. This is best illustrated using the WTP values given in Table 14. We distinguish between new cars and used cars. The AFV constants represent cars with, when applicable, lowest range, highest fuel and detour times, and lowest number of models. The associated WTPs are negative and range from –13,000 to –40,000 Euro for buyers of new cars, and from –7,000 to –21,000 Euro for buyers of used cars, with the electric car being the least preferred alternative. WTP values for buyers of second-hand cars are less negative, which is solely due to the fact that the purchase price coefficient for used cars is approximately twice as high as that for new cars. Stated differently, second hand car buyers are more price sensitive than new car buyers, and preferences for other attribute level are similar.

The results show that on average respondents are willing to pay substantial amounts for increases in range, both for the electric and the fuel cell car. The range utility curves for electric and fuel cell cars are shown in Figure 2. Since we only know relative preferences for range, we have assumed in this figure that the WTP for range of a fuel cell car of 250 kilometres is identical to the WTP for a range of 250 kilometres for the electric car. As the figure shows the shape of the WTP curve for fuel cell cars is comparable to that of electric cars and that the marginal WTP for range is highest at low ranges. Especially the marginal WTP for an increase in range from 75 to 150 kilometre for the electric car is large; the dotted line represents an extrapolation of this large marginal WTP to higher ranges and clearly is steeper than the rest of the range utility curve for electric cars and the curve for fuel cell cars. This in line with the rest of the literature. In a meta-analysis on WTP for range Dimitropoulos et al. (2011) find a strong non-linear relationship between WTP per kilometre and range, i.e., WTP decreases when range increases (see also Hidrue et al., 2011).

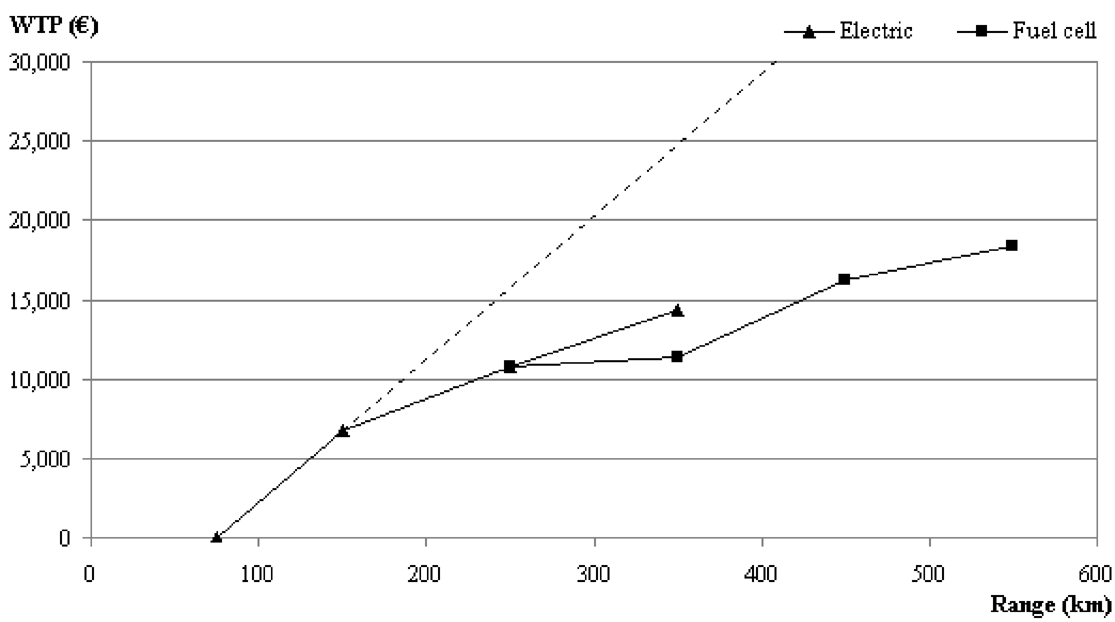

Figure 2. WTP for range for the electric and fuel cell car

WTP for refuelling time of electric cars is shown in Figure 3, while WTP for refuelling time of fuel cell cars is shown in Figure 4. The figures show that for both car types shorter fuel times are valued positively. For electric vehicles the largest absolute impact on WTP is related to a decrease in refuelling time from 8 hours to 2.5 hours, but marginal WTP is highest for a decrease in refuelling time from 1 hour to 30 minutes (around 57 Euro/minute compared to less than 15 Euro/minute for both a decrease from 8 to 2.5 hours and a decrease from 2.5 to 1 hour). This pattern is very similar to the pattern of WTP estimates reported in Hidrue et al. (2011). Marginal WTP for decreases in refuelling time of the fuel cell car are even higher. A decreases from 25 to 15 minutes is valued at around 55 Euro/minute and a decrease from 15 to 10 minutes at around 110 Euro/minute, but from a statistical viewpoint both effects are insignificant. A decrease from 10 to 2 minutes at around 430 Euro/minute. The pattern in marginal WTP for refuelling time of the plug-in hybrid is roughly comparable to that of the fuel cell car.

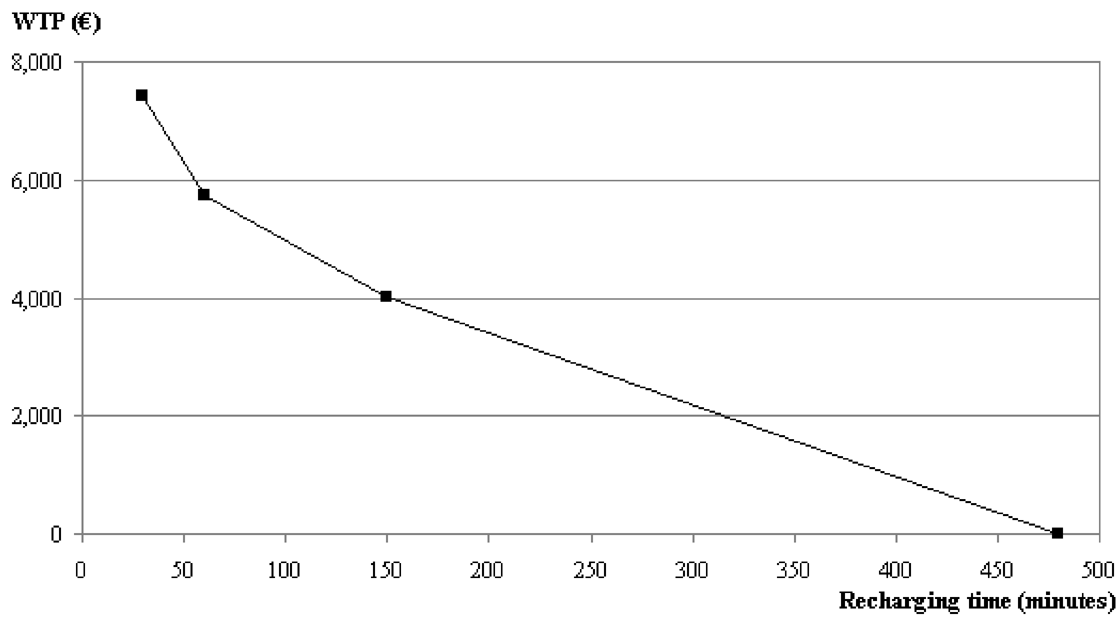

Figure 3. WTP for recharging time of the electric car

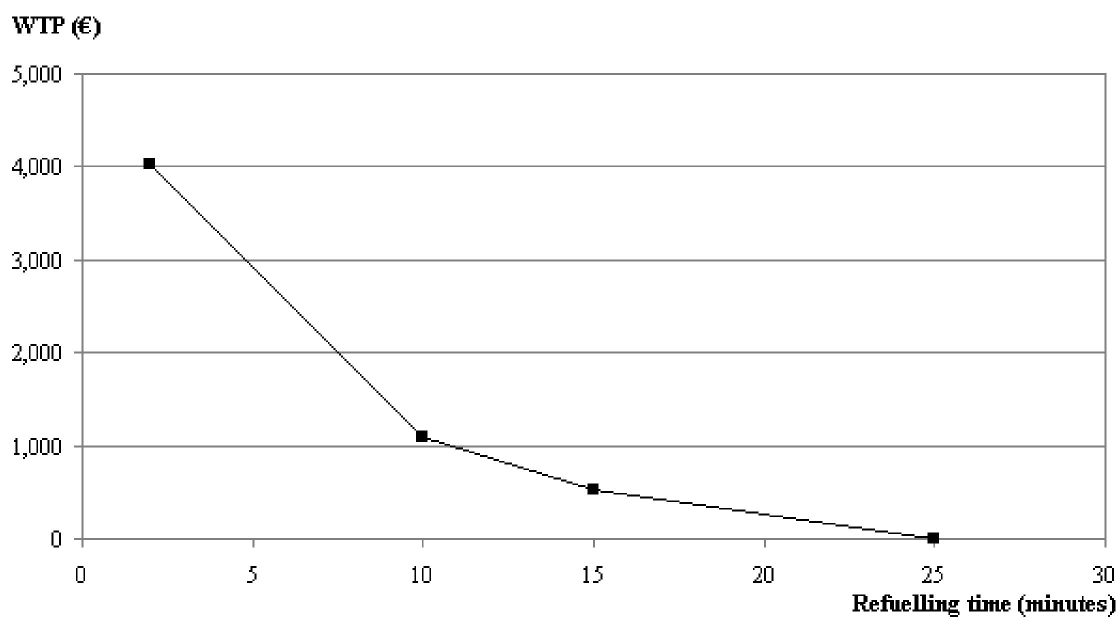

Figure 4. WTP for refuelling time of the fuel cell car

Figure 5 shows the WTP for detour time for the electric, fuel cell and flexifuel car. Note that in the experiment we did not adopt different attribute levels for different car types. The figure shows that the WTP for a reduction in additional detour time from 30 to 15 minutes is large at around 3,000 Euro (around 350 Euro/minute). The WTP for further reductions in detour time to 5 or 0 minutes are small or zero (and statistically insignificant). This suggests that increasing the density of a refuelling network beyond the point in which average detour time is 15 minutes has little additional value.

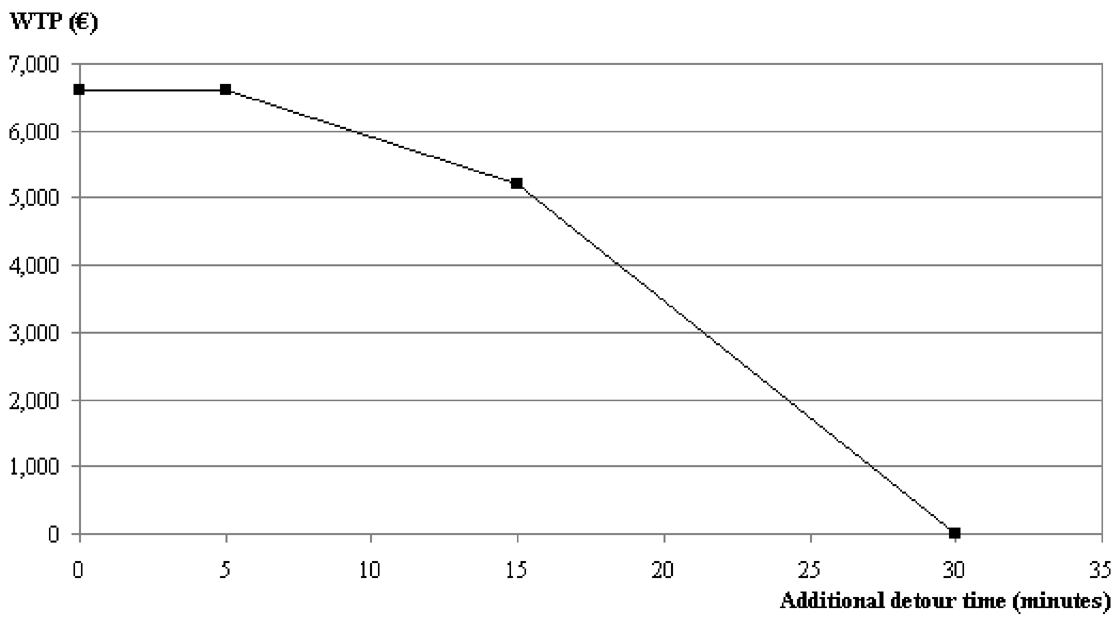

Figure 5. WTP for additional detour time for the electric, fuel cell and flexifuel car

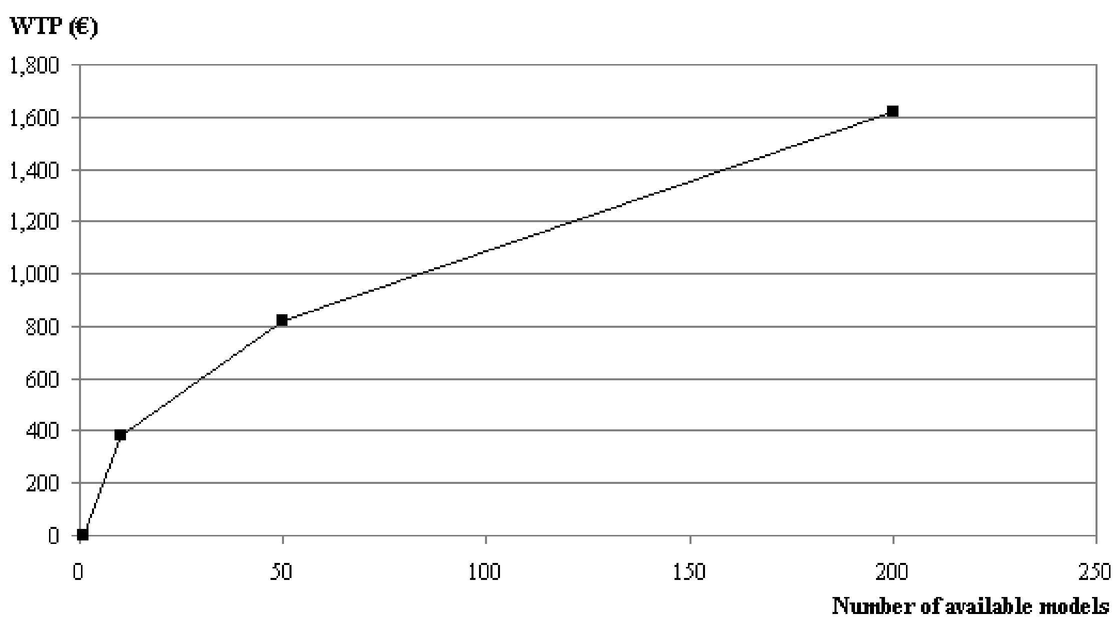

Figure 6. WTP for the number of available car models for all AFVs

Finally we examine WTP for number of available car models (see Figure 6). Clearly the marginal WTP decreases with increasing model availability (WTP per model is highest when availability is low), and the overall effect is modest. On average the WTP for AFVs increases with approximately 1,600 Euro per car when the number of available car models is high.

6. Robustness and preference heterogeneity

In this section we assess the robustness of our results and explore heterogeneity in preferences for car types and car attributes. In the first subsection we discuss mixed logit model estimations in order to check robustness of results presented in the previous section (see Hensher and Greene, 2003, for an extensive discussion of the mixed logit model). An advantage of the mixed logit model is that it also gives insight into the magnitude of preference heterogeneity for the various attributes. However, since the model does not reveal the underlying sources of heterogeneity, we estimate a MNL model including background and car use interactions in the second subsection. From this we aim at identifying relevant market segments and potential early adopters of alternative fuel vehicles within the private car buyer market.

6.1 Insights from mixed logit models

As discussed earlier in this paper car preferences are very heterogeneous. In order to explore the magnitude of the heterogeneity in preferences in our sample we estimate a mixed logit model with random parameter distributions for all attributes. For the simulations we use a maximum of 100 iterations and 2,000 Halton draws from a triangular distribution to obtain sufficient reliability. Results for both the full sample and the sample with only those choice sets that contain the conventional technology (CT sample) are presented in Table 15.

Table 15. Mixed logit model estimation results (monthly costs in Euro, purchase price in 1,000 Euro)

	Full sample			CT sample		
	b	**se**	**p**	**b**	**se**	**p**
Means of parameter distributions						
Perceived environmental performance	0.2370	0.0377	0.000	0.2949	0.0249	0.000
Perceived safety performance	0.2970	0.0457	0.000	0.2001	0.0319	0.000
Hybrid	−1.6309	0.0911	0.000	−1.6020	0.0889	0.000
Electric	−6.3970	0.2217	0.000	−4.4060	0.2104	0.000
Plug-in hybrid	−3.0869	0.1506	0.000	−2.6195	0.1759	0.000
Flexifuel	−2.2907	0.0955	0.000	−1.9453	0.0904	0.000
Fuel cell	−3.8234	0.1365	0.000	−2.6978	0.1234	0.000
Range electric	0.0071	0.0005	0.000	0.0058	0.0005	0.000
Range fuel cell	0.0028	0.0003	0.000	0.0025	0.0004	0.000
Fuel time electric	−0.0017	0.0003	0.000	−0.0015	0.0004	0.000
Fuel time plug-in hybrid	−0.0040	0.0009	0.000	−0.0038	0.0013	0.003
Fuel time fuel cell	−0.0201	0.0049	0.000	−0.0113	0.0045	0.013
Detour time	−0.0238	0.0024	0.000	−0.0133	0.0026	0.000
Models	0.0011	0.0003	0.000	0.0005	0.0003	0.161
Free parking	0.0845	0.0581	0.146	0.1033	0.0668	0.122
MRB exemption	−0.1845	0.0688	0.007	−0.1277	0.0770	0.097

Table 15. *Continued*

	Full sample			CT sample		
	b	**se**	**p**	**b**	**se**	**p**
Access to bus and taxi lanes	−0.0889	0.0585	0.129	−0.0326	0.0700	0.642
Monthly costs	−0.0080	0.0005	0.000	−0.0052	0.0003	0.000
Purchase price	−0.2344	0.0126	0.000	−0.1723	0.0123	0.000
Standard deviations of parameter distributions						
Perceived environmental performance	1.7742	0.0967	0.000	0.6060	0.0624	0.000
Perceived safety performance	1.1260	0.1923	0.000	0.7727	0.1063	0.000
Hybrid	1.8048	0.4305	0.000	0.1149	0.3384	0.734
Electric	4.2179	0.3318	0.000	1.0651	0.2725	0.000
Plug-in hybrid	2.4921	0.3230	0.000	0.7852	0.4109	0.056
Flexifuel	2.0041	0.2876	0.000	0.2982	0.2668	0.264
Fuel cell	2.1233	0.3035	0.000	0.2369	0.2105	0.260
Range electric	0.0033	0.0049	0.502	0.0015	0.0020	0.454
Range fuel cell	0.0050	0.0021	0.018	0.0004	0.0009	0.665
Fuel time electric	0.0047	0.0017	0.006	0.0013	0.0007	0.075
Fuel time plug-in hybrid	0.0025	0.0063	0.688	0.0006	0.0034	0.859
Fuel time fuel cell	0.0846	0.0269	0.002	0.0276	0.0141	0.050
Detour time	0.0638	0.0082	0.000	0.0440	0.0055	0.000
Models	0.0083	0.0013	0.000	0.0046	0.0013	0.000
Free parking	1.1253	0.3155	0.000	0.3492	0.2024	0.084
MRB exemption	0.9832	0.5218	0.060	0.2328	0.2720	0.392
Access to bus and taxi lanes	1.1504	0.3089	0.000	0.5568	0.2719	0.041
Monthly costs	0.0209	0.0011	0.000	0.0050	0.0009	0.000
Purchase price	0.3992	0.0321	0.000	0.1876	0.0285	0.000
NOBS		14,413			9,264	
Iterations completed		69			53	
Log-L		−10,484			−6,374	
Restricted Log-L		−15,834			−10,178	
Pseudo R2 (adjusted)		0.337			0.372	

Comparing the ML coefficients with the MNL coefficients reveals that signs are identical. We furthermore calculate average willingness-to-pay estimates from the 'means of parameter distributions' and compare these with the MNL WTP estimates; results are reported in Table 16. On the whole mixed logit WTP estimates are substantially lower than their MNL counterparts. Ultimately, using the insight from both models as upper and lower bounds seems to be a sensible strategy in dealing with the uncertainty on which parameters to use for addressing policy related questions and model simulations.

Table 16. Comparison of WTP estimates from multinomial and mixed logit models for the full and the CT sample

	Full sample		CT sample	
Attributes	**MNL**	**ME**	**MNL**	**ME**
Environmental performance	€ 2,219	€ 1,011	€ 2,191	€ 1,712
Safety performance	€ 1,863	€ 1,267	€ 1,618	€ 1,161
Hybrid	−€ 12,880	−€ 6,958	−€ 12,538	−€ 9,298
Electric	−€ 38,216	−€ 27,291	−€ 30,839	−€ 25,572
Plug-in hybrid	−€ 22,389	−€ 13,169	−€ 19,503	−€ 15,203

Table 16. *Continued*

Attributes	Full sample		CT sample	
	MNL	ME	MNL	ME
Flexifuel	–€ 16,806	–€ 9,773	–€ 14,749	–€ 11,290
Fuel cell	–€ 26,513	–€ 16,311	–€ 20,052	–€ 15,658
Range electric	€ 38	€ 30	€ 40	€ 34
Range fuel cell	€ 22	€ 12	€ 18	€ 15
Fuel time electric	–€ 12	–€ 7	–€ 9	–€ 9
Fuel time plug-in	–€ 27	–€ 17	–€ 26	–€ 22
Fuel time fuel cell	–€ 134	–€ 86	–€ 83	–€ 66
Detour time	–€ 161	–€ 102	–€ 105	–€ 77
Models	€ 6	€ 5	€ 4	€ 3
Free parking	€ 1,072	€ 360	€ 737	€ 600
MRB exemption	–€ 1,325	–€ 787	–€ 936	–€ 741
Access bus lanes	€ 201	–€ 379	–€ 183	–€ 189

Something that the MNL model does not provide, but the mixed logit model does, is insight into preference heterogeneity, represented in Table 15 by the 'standard deviations of parameter distributions'. With respect to the full sample, results show that heterogeneity in preferences for most attributes is very large and statistically significant at the usual critical significance levels. Two exceptions are rather surprising, i.e., the standard deviation for range of both the electric and the fuel cell car. Although the estimates of heterogeneity are both large, they are statistically insignificant at a 10% critical level. Also heterogeneity on preferences for fuel time of the plug-in hybrid car and for abolishment of tax exemptions are insignificant in a statistical sense. The estimated standard deviations on especially the electric car suggest that preferences for small ranges are heterogeneous to a large extent. Also note that the estimated means of the parameters distributions are much larger than their MNL counterparts, but since the price coefficient of the mixed logit model is larger as well, the WTP estimates are not systematically higher or lower for the mixed logit model.

When looking at the results for the CT sample the picture changes. With the exception of perceived environmental performance the estimated standard deviations of the parameter distributions are much smaller than for the full sample and many of them are now statistically insignificant. Interesting is that the heterogeneity for the electric car, with a range of 75 km and an 8 hour recharge time, remains large and statistically significant. Furthermore robust are the estimated heterogeneity for environmental and safety performance, for fuel time of the electric and fuel cell car, for detour time and for the number of available models, for free parking and access to bus lanes, and for purchase price and monthly costs.[8]

[8] The common assumption in a mixed logit model is that the random parameters are normally or triangularly distributed, which generally forces the resulting parameter distribution to include positive/negative values even when such values are theoretically unlikely. For example, the estimated mean and standard deviation of the parameter distribution on fuel time of the electric car suggests that a substantial part of respondents puts a positive value on fuel time, i.e., is willing to pay money for an increase in fuel time. This is of course not the case, and solely the result of the before mentioned distributional assumption. The estimates from the mixed logit model must therefore be treated with caution and be interpreted purely as indications of the magnitude of preference heterogeneity, and not as credible or accurate indicators of the actual preference distribution. A possible improvement in this respect could be the use of a restricted triangular distribution, with which we can restrict the lower or upper bound to zero. Also the estimation of a latent class mixed logit model would be a possible solution, because it is more flexible in its assumptions by allowing for bi- or multi-modal preference distributions. Although this would be an interesting extension of our estimations, it is beyond the scope of this paper.

It is difficult to assess the underlying reasons for the differences between the two samples, the results may suggest that the choices that respondents make in choice sets that do not contain the conventional technology are made randomly more often and therefore contain a lot of noise. Model results presented in the previous section would confirm such a conclusion given the substantially higher R-squared of the CT sample model. A different explanation, however, could be that respondents often choose the conventional technology when it is included in a choice set without looking at and weighing the attributes of the other options. This would certainly make their preferences in this sample much more homogeneous. Although this may reflect their true preferences at the moment, it may also be a result of status quo bias and as such underestimate true heterogeneity in preferences. The results favour neither of these explanations, and in the end it is not unlikely that the full sample overestimates and the CT sample underestimates preferences and preference heterogeneity.

In any case, the CT sample results show that for some attributes the heterogeneity in preferences remains, although in all cases the estimates are substantially lower than for the full sample. More specifically, preference heterogeneity for electric and plug-in hybrid cars, for fuel time of the fuel cell car, for the number of available models, detour time and access to bus lanes, and for purchase price and monthly costs, remains large and statistically significant. For these attributes or attribute levels we can be fairly sure that preferences are indeed heterogeneous to a large extent. As discussed earlier, the mixed logit model is well suited to assess the magnitude of possible heterogeneity in consumer preferences, but it does not reveal its sources. In the next section we look more deeply into this particular issue.

6.2 Market segmentations and early adopters

Through our survey and from TNS-NIPO we obtained respondent background characteristics, car and car use characteristics. In order to explore different market segments and potential early adopters it is crucial to assess whether and to what extent these characteristics matter for car choice. We therefore estimate a MNL model with interaction effects, i.e., interactions between background characteristics and the choice experiment attributes. The estimation strategy is as follows. For the full sample we estimate a model with an interaction effect for every background characteristic separately. Those interactions that appeared to matter, or are interesting because they do not appear to matter, were included in a model with multiple interaction effects. From this model we subsequently excluded some of the interaction effects that turned out not to matter, while some of these were still included in the final model because their irrelevance is interesting in itself, or because they matter for one attribute but not for the other. This strategy prevents that not only those characteristics are selected that we expect to be relevant a priori, but at the same time ensures that we still end up with a fairly parsimonious model. For robustness we also estimate the final model for the sample with only choice sets that contain the conventional technology (CT sample). Generally the results are robust, but in the few cases where the two samples give different insights we will discuss this explicitly. The results are presented in Table 17.

Table 17. MNL estimation results for a model with interaction effects (monthly costs in Euro, purchase price in 1,000 Euro)

	Full sample			CT sample		
	b	**se**	**p**	**b**	**se**	**p**
Main effects (reference for interaction effects)						
Environmental performance	0.2404	0.0168	0.000	0.2881	0.0219	0.000
Safety performance	0.1396	0.0264	0.000	0.1565	0.0350	0.000
Hybrid	−1.1114	0.0922	0.000	−1.2321	0.1464	0.000
Electric	−2.6849	0.2509	0.000	−2.9063	0.3772	0.000
Plug–in hybrid	−1.5040	0.0986	0.000	−1.5184	0.1599	0.000
Flexifuel	−1.0799	0.0779	0.000	−1.3440	0.1115	0.000
Fuel cell	−2.2487	0.3295	0.000	−2.0404	0.4567	0.000
Range electric	0.0014	0.0010	0.184	0.0021	0.0016	0.201
Range fuel cell	0.0024	0.0007	0.001	0.0020	0.0010	0.042
Fuel time electric	−0.0012	0.0002	0.000	−0.0013	0.0003	0.000
Fuel time plug–in	−0.0028	0.0007	0.000	−0.0034	0.0012	0.006
Fuel time fuel cell	−0.0145	0.0031	0.000	−0.0126	0.0042	0.003
Detour time	−0.0170	0.0016	0.000	−0.0145	0.0024	0.000
Models	0.0006	0.0002	0.000	0.0006	0.0003	0.040
Free parking	0.1111	0.0413	0.007	0.1070	0.0657	0.103
MRB exemption	−0.0569	0.0454	0.211	−0.0598	0.0738	0.417
Access to bus lanes	0.0200	0.0409	0.625	−0.0646	0.0683	0.345
Monthly costs new car	−0.0058	0.0014	0.000	−0.0059	0.0019	0.002
Monthly costs used car	−0.0051	0.0011	0.000	−0.0047	0.0014	0.001
Purchase price new car	−0.1262	0.0308	0.000	−0.0948	0.0422	0.025
Purchase price used car	−0.0410	0.0313	0.190	−0.0714	0.0497	0.151
Interactions annual mileage and commuting						
Hybrid × Commute >= 5 times per week	−0.2538	0.1019	0.013	−0.3555	0.1725	0.039
Electric × Commute >= 5 times per week	−0.0997	0.0816	0.222	−0.1129	0.1122	0.314
Plug–in hybrid × Commute >= 5 times per week	−0.2044	0.0939	0.029	−0.2751	0.1555	0.077
Flexifuel × Commute >= 5 times per week	−0.2109	0.0827	0.011	−0.1081	0.1161	0.352
Fuel cell × Commute >= 5 times per week	−0.1167	0.0739	0.114	−0.1640	0.0930	0.078
Electric × (7,500 < Yearly km < 15,000)	−0.4102	0.2006	0.041	−0.3558	0.2861	0.214
Electric × (15,000 < Yearly km < 25,000)	−0.7231	0.2101	0.001	−0.6749	0.3053	0.027
Electric × (25,000 < Yearly km < 35,000)	−0.8310	0.2453	0.001	−0.9286	0.3704	0.012
Electric × (Yearly km > 35,000)	−1.3669	0.2806	0.000	−1.6315	0.4401	0.000
Fuel cell × (7,500 < Yearly km < 15,000)	−0.2105	0.1914	0.271	−0.2797	0.2606	0.283
Fuel cell × (15,000 < Yearly km < 25,000)	−0.0386	0.1922	0.841	−0.3328	0.2680	0.214
Fuel cell × (25,000 < Yearly km < 35,000)	−0.5358	0.2221	0.016	−0.2199	0.3061	0.473
Fuel cell × (Yearly km > 35,000)	−0.7220	0.2450	0.003	−0.6238	0.3509	0.075
Range electric × (7,500 < Yearly km < 15,000)	0.0024	0.0011	0.025	0.0028	0.0017	0.091
Range electric × (15,000 < Yearly km < 25,000)	0.0030	0.0011	0.005	0.0030	0.0017	0.087
Range electric × (25,000 < Yearly km < 35,000)	0.0025	0.0012	0.040	0.0037	0.0020	0.058
Range electric × (Yearly km > 35,000)	0.0043	0.0013	0.002	0.0060	0.0022	0.006
Range fuel cell × (7,500 < Yearly km < 15,000)	0.0001	0.0008	0.931	0.0004	0.0011	0.738
Range fuel cell × (15,000 < Yearly km < 25,000)	−0.0009	0.0008	0.261	0.0002	0.0012	0.876
Range fuel cell × (25,000 < Yearly km < 35,000)	0.0000	0.0010	0.999	−0.0005	0.0014	0.689
Range fuel cell × (Yearly km > 35,000)	0.0008	0.0011	0.441	0.0011	0.0015	0.468

Table 17. *Continued*

	Full sample			CT sample		
	b	**se**	**p**	**b**	**se**	**p**
Interactions fuel type current car						
Hybrid × Current fuel diesel	0.2158	0.1073	0.044	0.1123	0.1729	0.516
Electric × Current fuel diesel	−0.2253	0.0833	0.007	−0.1723	0.1115	0.122
Plug–in hybrid × Current fuel diesel	−0.1452	0.1000	0.147	−0.1979	0.1587	0.213
Flexifuel × Current fuel diesel	−0.0985	0.0880	0.263	−0.0878	0.1229	0.475
Fuel cell × Current fuel diesel	−0.1105	0.0750	0.141	−0.1446	0.0926	0.119
Hybrid × Current fuel lpg	−0.3179	0.1271	0.012	−0.6281	0.2323	0.007
Electric × Current fuel lpg	−0.0398	0.0920	0.665	0.0158	0.1255	0.900
Plug–in hybrid × Current fuel lpg	−0.3729	0.1159	0.001	−0.4635	0.1997	0.020
Flexifuel × Current fuel lpg	−0.2157	0.1001	0.031	−0.3135	0.1479	0.034
Fuel cell × Current fuel lpg	−0.0200	0.0831	0.810	0.0849	0.1012	0.401
Interactions holidays						
Hybrid × Caravan	−0.4207	0.1295	0.001	−0.6291	0.2279	0.006
Electric × Caravan	−0.2373	0.0984	0.016	−0.3125	0.1346	0.020
Plug–in hybrid × Caravan	−0.3613	0.1204	0.003	−0.3922	0.2025	0.053
Flexifuel × Caravan	−0.0968	0.1021	0.343	0.0648	0.1361	0.634
Fuel cell × Caravan	−0.2877	0.0888	0.001	−0.2995	0.1107	0.007
Electric × Car is not used for holidays	0.2880	0.0726	0.000	0.2779	0.1130	0.014
Interactions on recharging potential and policy measures						
Free parking × Very urbanised area	0.0875	0.0870	0.314	−0.0947	0.1340	0.479
Access to bus lanes × Very urbanised area	0.0836	0.0876	0.340	0.2796	0.1291	0.030
Electric × recharging potential at home	0.2125	0.1041	0.041	0.2998	0.1698	0.077
Range electric × recharging potential at home	0.0006	0.0006	0.361	0.0010	0.0010	0.302
Interactions on perceived safety performance						
Safety performance × Very urbanised area	0.1435	0.0439	0.001	0.1797	0.0566	0.002
Safety performance × Car commute 5 days a week	0.1893	0.0566	0.001	0.1835	0.0724	0.011
Safety performance × Weight car < 1,000 kg	−0.1217	0.0551	0.027	−0.1765	0.0704	0.012
Interactions on monthly costs						
Monthly costs new × Price next car < 6,000 Euro	0.0036	0.0013	0.006	0.0002	0.0028	0.948
Monthly costs new × Weight car < 1,000 kg	−0.0039	0.0008	0.000	−0.0054	0.0015	0.000
Monthly costs new × 2nd car in household	−0.0018	0.0011	0.091	−0.0021	0.0017	0.218
Monthly costs new × respondent is female	−0.0020	0.0006	0.001	−0.0020	0.0011	0.060
Monthly costs new × (7,500 < Yearly km < 15,000)	0.0014	0.0015	0.353	0.0014	0.0020	0.499
Monthly costs new × (15,000 < Yearly km < 25,000)	0.0023	0.0015	0.121	0.0017	0.0020	0.393
Monthly costs new × (25,000 < Yearly km < 35,000)	0.0024	0.0015	0.113	0.0030	0.0020	0.143
Monthly costs new × (Yearly km > 35,000)	0.0031	0.0015	0.040	0.0022	0.0020	0.269
Monthly costs used × Price next car < 6,000 Euro	−0.0015	0.0004	0.000	−0.0023	0.0007	0.001
Monthly costs used × Weight car < 1,000 kg	−0.0030	0.0007	0.000	−0.0033	0.0011	0.003
Monthly costs used × 2nd car in household	−0.0006	0.0007	0.399	−0.0005	0.0010	0.631
Monthly costs used × respondent is female	−0.0020	0.0005	0.000	−0.0026	0.0008	0.001
Monthly costs used × (7,500 < Yearly km < 15,000)	0.0004	0.0012	0.760	0.0002	0.0015	0.909
Monthly costs used × (15,000 < Yearly km < 25,000)	0.0009	0.0012	0.459	−0.0003	0.0015	0.830
Monthly costs used × (25,000 < Yearly km < 35,000)	0.0004	0.0012	0.748	−0.0011	0.0016	0.485
Monthly costs used × (Yearly km > 35,000)	−0.0002	0.0012	0.846	−0.0020	0.0017	0.250

Table 17. *Continued*

	Full sample			CT sample		
	b	se	p	b	se	p
Interactions on purchase price						
Purchase price new × Price next car < 6,000 Euro	−0.0670	0.0395	0.090	−0.3152	0.1181	0.008
Purchase price new × Weight car < 1,000 kg	−0.0511	0.0181	0.005	−0.0614	0.0269	0.023
Purchase price new × 2nd car in household	−0.0207	0.0249	0.405	−0.0672	0.0415	0.105
Purchase price new × respondent is female	−0.0220	0.0158	0.163	−0.0392	0.0247	0.113
Purchase price new × (7,500 < Yearly km < 15,000)	0.0650	0.0313	0.038	0.0362	0.0432	0.403
Purchase price new × (15,000 < Yearly km < 25,000)	0.0495	0.0319	0.120	−0.0059	0.0448	0.896
Purchase price new × (25,000 < Yearly km < 35,000)	0.0623	0.0332	0.060	0.0114	0.0471	0.809
Purchase price new × (Yearly km > 35,000)	0.0603	0.0334	0.071	0.0128	0.0476	0.788
Purchase price used × Price next car < 6,000 Euro	−0.0871	0.0188	0.000	−0.0688	0.0285	0.016
Purchase price used × Weight car < 1,000 kg	−0.0424	0.0248	0.087	−0.0269	0.0367	0.463
Purchase price used × 2nd car in household	−0.0346	0.0266	0.194	−0.0195	0.0393	0.620
Purchase price used × respondent is female	−0.0611	0.0223	0.006	−0.1154	0.0360	0.001
Purchase price used × (7,500 < Yearly km < 15,000)	−0.0556	0.0311	0.074	−0.0598	0.0497	0.229
Purchase price used × (15,000 < Yearly km < 25,000)	−0.0819	0.0331	0.013	−0.0921	0.0534	0.085
Purchase price used × (25,000 < Yearly km < 35,000)	−0.0682	0.0378	0.071	−0.1489	0.0634	0.019
Purchase price used × (Yearly km > 35,000)	−0.1126	0.0464	0.015	−0.2180	0.0854	0.011
NOBS	14,413			9,264		
Log−L	−11,303			−6,369		
Restricted Log−L	−15,807			−10,148		
Pseudo R2 (adjusted)	0.283			0.369		

The main effects in the table primarily serve as reference categories for the interaction effects. These main effects estimates represent preferences for specific groups within our sample. For example, when we estimate preferences for range of respondents with an annual mileage higher than 7,500 kilometres, the main effect on range represents the preferences of respondents with an annual mileage lower than 7,500 kilometres. In terms of magnitude the main effects presented in Table 17 therefore differ somewhat from the average estimates for the entire sample presented in Section 5.

A first set of relevant interactions deal with differences between respondents in annual mileage and car commuting behaviour. With respect to the latter the results show that those who commute to and from work by car often (5 times or more per week) tend to have stronger negative preferences for AFVs in general, although the effects are relatively small. A more relevant factor that greatly affects preferences for electric and fuel cell cars is annual mileage. The results show that the more people drive the more negative are their preferences for the electric car, and that these effects are substantial. A similar pattern can be observed for the fuel cell car, although the effects of annual mileage are smaller (but still substantial) due to the fact that we are on a flatter part of the range utility curve (see Section 5.2). The effects of the electric range attribute also differ between the five distinguished annual mileage groups. More specifically, the more people drive the larger the effect of increases in range, implying that preferences for the electric car for different groups of annual mileage converge when the range of the electric car increases. We do not find this pattern for the fuel cell car. Interactions of annual mileage on fuel time and detour time did not show any relevant patterns, implying that differences in annual mileage only affect range preferences. Put differently, people who drive less find a limited car range substantially less problematic than people who drive more.

A second set of interesting interactions deals with differences in fuel type of the respondent's current car. Relevant car use characteristics, such as annual mileage and commuting behaviour, are included in our model, and their influence on consumer preferences are therefore not incorporated in the effects of the fuel type interactions. However, the effects of fuel type on preferences obviously reflect car use and background characteristics that affect consumer preferences, but for which we do not have data. In any case, the results show that diesel drivers have slightly stronger negative preferences for electric cars and slightly stronger preferences for hybrid cars than petrol drivers, while LPG drivers have stronger negative preferences than petrol drivers for hybrid, plug-in hybrid and flexifuel cars. In all cases the differences in preferences between petrol, diesel and LPG drivers are relatively small for the full sample. In the CT sample differences between LPG and petrol drivers are clearly more substantial.

A third set of interactions deals with respondents that use the car for going on holidays abroad and for towing a caravan. The results show that negative preferences for the electric car are somewhat lower when the car is not used for going on holidays abroad, which is plausible since distances covered in going abroad are generally large, implying frequent recharging and waiting times for low ranges. Respondents that use the car for towing a caravan clearly have more negative preferences for AFVs in general than respondents who don't. Given that this effect shows up for all AFVs the underlying reason for this result is likely that at least a part of the respondents assume that motor power of AFVs is lower than that of the conventional technology. Either that or uncertainty regarding AFV motor power is large among respondents, making them more hesitant to choose an AFV.

Fourth, some interactions on recharging potential and policy measures were estimated. Respondents were asked whether they have a permanent parking space at which it would be possible to charge an electric vehicle. Approximately 60% indicated that they did, which is very high and begs the question whether respondents answered the question correctly. In any case, the interaction effect of this variable with preferences for the electric car shows that the electric car is valued more by those who can charge at home, although the effect is limited in magnitude. Interaction of recharging potential at home and range of the electric appears not to matter. We also analysed the preferences for the policy measures free parking and access to bus lanes of respondents that live in very urbanised areas. In these areas free parking would have relatively large benefits and busy traffic could make access to bus lanes attractive. The interaction effect on free parking appears not to matter for both samples. Access to bus lanes in very urbanised areas is also irrelevant in the full sample, but in the CT sample is has a positive effect on choice, suggesting that in these areas this policy measure may have some effect on AFV adoption in cities, *ceteris paribus*.

Fifth, we tested several interactions on the role of perceived environmental and safety performance of AFVs. With respect to the former we found that none of the background or car use characteristics had any effect. For perceived safety performance, however, we find that the effect is larger for respondents that live in highly urbanised areas and respondents that commute by car 5 times or more per week. Both groups have higher exposure to transport and accident risk, which would explain that they put a higher value on safety. Respondents with relatively light cars (< 1,000 kg) are influenced less by their perceptions on safety, suggesting they care less about safety. This may be partly due to a selection effect, since lighter cars are simply less safe than heavier cars and people who drive lighter cars likely care slightly less about safety. It could, however, also be the result of the way in which lighter cars are used, e.g., for shorter and more local trips, with less exposure to risk, making safety less of an issue.

Finally we tested several interactions on monthly costs and purchase price in order to assess whether some groups are more price sensitive than others. The difference between those who are going to buy a new car and those who are going to buy a used car is again relevant, both in terms of monthly costs and purchase price. People or rather households also appear to be more price sensitive with respect to their second car than with respect to their first car, especially when the second car is a new instead of a second-hand car. Also women are substantially more sensitive to purchase price and monthly costs than men. Not surprisingly, respondents who indicate they are going to buy a relatively cheap car are somewhat more sensitive to monthly costs than others, but their sensitivity to purchase price is especially striking, indicating strict budget constraints. Also people who own a relatively small car are more price sensitive than others in terms of purchase price but especially monthly costs. Considering that fuel cost advantages of especially the electric car can be large when annual mileage is relatively high, people with small cars that drive a lot may benefit substantially from switching to an electric vehicle. Unfortunately, people that drive a lot will also more often run into problems associated with range, making it difficult to assess whether this group is actually more likely to adopt electric an fuel cell cars in the future. Finally, annual mileage also has a substantial effect on cost and price sensitivity.

Because annual mileage matters so much for electric and fuel cell car preferences, it is worthwhile to focus on this factor a little bit more. To get rid of the influence of other mediating factors we estimate an model with only interactions of annual mileage on the electric and fuel cell constants, on driving range dummies of the electric and fuel cell car (we use dummies to allow for potential non-linear effects between mileage groups), and on monthly costs and purchase price. Moreover, we estimate separate models for new and used cars.[9] We subsequently use the estimates from these two models to derive an index of WTP's (or rather an index of compensations needed) for electric and fuel cell cars with different driving ranges for five annual mileage categories. Results for new electric cars are presented in Figure 7.[10]

The figure shows that preference heterogeneity for electric cars with a range of 75 kilometres is very large.[11] The average compensation for the category of respondents with an annual mileage less than 7,500 km is far below the average compensation required for the next three mileage categories, while the compensation required for the highest mileage category is even around two times higher. Willingness to pay for driving range for the lowest mileage category appears to be zero, and increases for those who drive more. As a result, preference heterogeneity for the electric car is substantially reduced when considering a driving range of 150 kilometres, and is reduced even further for driving ranges of 250 and 350 kilometres. Ultimately, the differences in electric car preferences between the lowest mileage category and the other categories are reduced by more than 50% (on average) due to an increase in driving range from 75 to 350 kilometres. In this situation the heterogeneity is still substantial, however.

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[9] Model estimates are available upon request from the authors.

[10] The range coefficient for the annual mileage category 'km<7.5 k' is negative and statistically insignificant, so we set this coefficient equal to zero, which explains the straight line in Figure 7 for this particular category.

[11] The contributions to total observed heterogeneity of heterogeneity in electric car preferences and of heterogeneity in purchase price sensitivity are both approximately 50%.

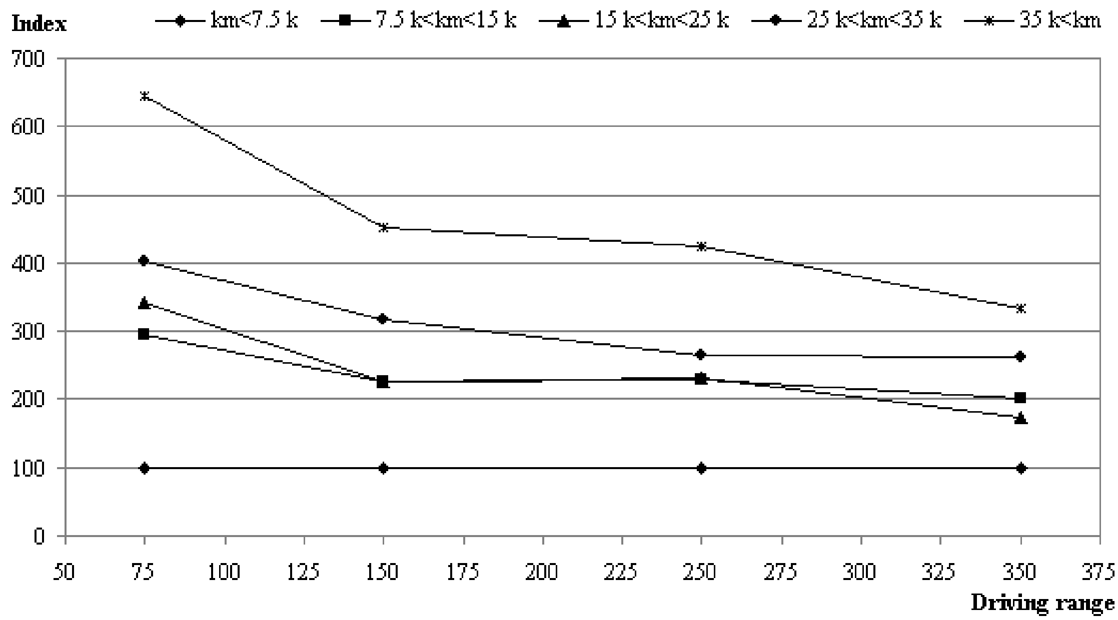

Figure 7. Index of compensation needed for new electric cars with different driving ranges for five annual mileage categories

The pattern for used electric cars is comparable to the pattern for new electric cars, although the initial heterogeneity is much lower to begin with (see Figure 8). This is largely due to the fact that for used cars no differences in price sensitivity between mileage categories were found, so for the used cars model we estimated and subsequently used a single price coefficient. After controlling for differences in price sensitivity the preference heterogeneity for new electric cars with a range of 75 kilometres is still larger than that for used cars, but to a lesser extent. For electric cars with a range of 350 kilometres the differences in heterogeneity between new and used cars is even smaller.

For the fuel cell car we derived similar figures and the results are comparable. A difference is that the amount of preference heterogeneity for new fuel cell cars is substantially smaller than for new electric cars. This is due to the fact that driving ranges for electric and fuel cell cars are different. When comparing preference heterogeneity for new electric cars with those for new fuel cell cars at 250 km and 350 km, the results are almost identical.

It is interesting to briefly asses those interactions that we expected to be relevant but turn out not to be. For example, few relevant interactions on policy measures are found, and also the fact that there appear to be no differences between the first and the second car in a household, e.g., in terms of range preferences, is somewhat surprising. Most likely the potential differences between first and second cars in terms of preferences are largely related to annual mileage, which is already controlled for in the model. We furthermore find no effect of the number of cars in the household on AFV preferences. This is interesting since households with more than one car have substitution possibilities with respect to their transport behaviour. Stated differently, they can mitigate potential negative characteristics of AFVs by making problematic trips by another car, e.g., make longer trips by conventional car and shorter trips by electric car. Finally, no relevant interactions on the number of available models were found, but especially the general lack of relevant interactions on fuel time and detour time is striking. However, this does not necessarily mean that these attributes are not more/less important for different groups. Having a car with a relatively short range also means that the *frequency* of recharging/refuelling and of having to make a detour are relatively high, *ceteris paribus*. This means that recharging/refuelling time and detour time may play an important role in consumer preferences, but that they would do so through range.

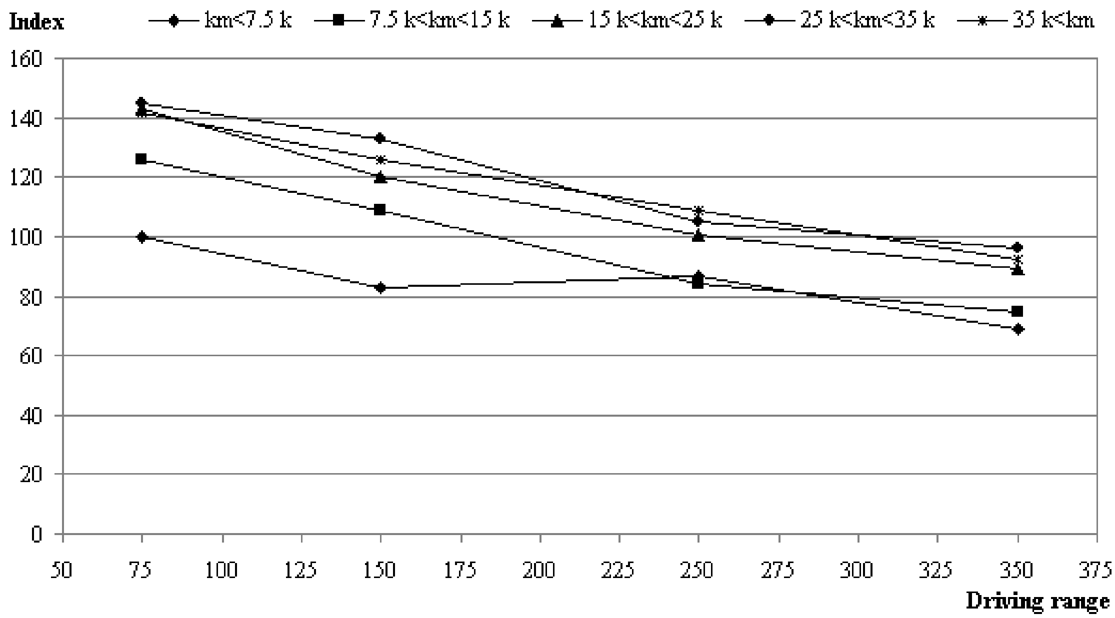

Figure 8. Index of compensation needed for used electric cars with different driving ranges for five annual mileage categories

6.3 Conclusions

We use a mixed logit model to assess whether and if so to what extent preferences on AFVs and their characteristics display heterogeneity. Results for the full sample show substantial heterogeneity on almost all attributes, while results for the CT sample reveal smaller heterogeneity estimates. Robust are the heterogeneity in preferences for environmental and safety performance, the electric car constant, fuel time of the electric and fuel cell car, detour time and the number of available models, free parking and access to bus lanes, and purchase price and monthly costs.

Since mixed logit models do not reveal the underlying sources of the existing heterogeneity in preferences, we also estimate a MNL model including interaction effects of attributes with background and car characteristics. The results show that various factors affect preferences for AFV's and AFV characteristics, such as fuel type and using the car for holidays abroad. We also find differences in sensitivity to monthly costs and purchase price between different groups of respondents, which are highly relevant in explaining the existing heterogeneity in AFV preferences. By far the most important variable with respect to preferences for the electric and fuel cell car is annual mileage. More specifically, people who drive more are substantially more negative about the electric and fuel cell car than people with a relatively low annual mileage, most likely because they run into problems of limited range more frequently. Also people who drive more will on average make longer trips, implying that under current circumstances the electric car, and to a lesser extent the fuel cell car, are simply unsuitable. This conclusion is confirmed by the fact that people who drive more also have a higher WTP for increases in range. We subsequently use this information to show that preference heterogeneity for electric and fuel cell cars is much lower for larger driving ranges.

We analysed the effects of various other background and car characteristics on preferences, but they turned out not to matter. Most striking is that mixed logit models find substantial preference heterogeneity on fuel time and detour time, but that none of the background and car (use) characteristics appear to matter in this respect. Apparently heterogeneity in preferences on fuel and detour time is determined by characteristics for which we have no data. In this respect it is clear that both the mixed logit model and he model with specific background interactions have added value in exploring preference heterogeneity.

7. Summary and discussion

In this paper we aim to obtain insight into the preferences of private car owners for AFVs and AFV characteristics, to uncover the background and car use characteristics that affect these preferences, and to identify possible early adopters. Since most AFVs are not yet offered on the market, or only to a limited extent, we have to rely on stated preference research. More specifically, we conduct a choice experiment among Dutch private car owners using the automotive panel from TNS-NIPO. Although choice experiments represent the state-of-the-art in stated preference research, caution is required in using the results for, e.g., modelling future AFV demand. First, choices made by respondents in choice experiments are hypothetical, and may for various reasons be different in reality. Second, preferences may change substantially over time because of, for example, technological developments and reductions in uncertainty on AFV performance and costs. Repeating this experiment in due time is therefore essential.

In the experiment we presented each respondent with eight choice tasks, of which each consists of three car choice options. Next to the conventional technology we distinguished five different alternative technologies, i.e., hybrid, plug-in hybrid, flexifuel, electric and fuel cell cars. All car types had seven attributes. Two of these, purchase price and monthly costs, were made respondent specific by using information on weight and annual mileage of the current car and the presumed purchase price and fuel type of the next car, as indicated by respondents in the beginning of the online survey. Other attributes were driving range, refuelling time, additional detour time to reach a fuel station, number of available models, and a policy measure. Not all attributes vary for each car type, so we generated an alternative-specific design, and attribute levels for purchase price, monthly costs, driving range, refuelling time and additional detour time were car type specific. Ultimately we obtained 1,802 complete and useable surveys and a total of 14,413 observations.

Results from multinomial logit models show that, on average and assuming current AFV characteristics, preferences for AFVs are substantially lower than those for the conventional technology. Limited driving range, long refuelling times and limited availability of refuelling opportunities are to a large extent responsible for these findings. These barriers are most substantial for the electric car, and to a lesser extent for the fuel cell car, and it is therefore not surprising that, ignoring differences in purchase price and monthly costs, negative preferences for these two car types are largest. Average preferences for AFVs increase considerably when improvements in driving range, refuelling time and additional detour time are made. An increase in the number of available models from which a consumer can chose and measures such as free parking have a positive effect as well, but to a far lesser extent. However, the results clearly show that, also when substantial improvements on these issues occur, average negative preferences remain, and remain substantial. The fact that most technologies are relatively unknown and their performance and comfort levels are uncertain are likely contributing factors in this respect.

Using a dummy model specification we furthermore find some interesting non-linear attribute effects. Consumer willingness to pay for an extra kilometre of driving range is largest for an increase from 75 to 150 kilometres for the electric car and for an increase from 250 to 350 kilometres for the fuel cell car. Further increases still have added value but to a lesser extent. Stated differently, marginal willingness to pay per extra kilometre for both car types is always positive but lower when driving range is larger. The possibility for fast charging an electric car in 30 minutes has substantial added value, more than other recharge time reductions tested in our experiment, but only as long as additional detour time to reach a fast charging point is not much longer than 15 minutes. More specifically, charging an electric vehicle at home in one hour has more added value on average than fast charging in 30 minutes with an additional detour time of 30 minutes. Reductions in refuelling time for the fuel cell car also have a positive impact on consumer preferences. When measuring willingness to pay in Euro per minute the WTP is much higher for fuel cell cars than for electric cars. Also striking is that a reduction of 10 minutes to 2 minutes has more added value (in Euro per minute) than reductions from 25 to 15 minutes and from 15 to 10 minutes. Reductions in additional detour time have a large impact on fuel cell and flexifuel car preferences, although reductions beyond 15 minutes have a limited impact, with obvious consequences for optimal refuelling network densities. Finally, increasing the number of models has relatively limited added value, but marginal WTP per model is highest when the number of models is low.

Although average estimates for the entire sample reveal important patterns, there generally is considerable heterogeneity in consumer car preferences. We therefore estimate mixed logit models in which each of the attribute parameters is assumed to be normally distributed. These models confirm that there is substantial heterogeneity in consumer preferences for AFVs and AFV characteristics. Heterogeneity is particularly large on electric cars, on additional detour time and on purchase price and monthly costs. In order to get more insight into the underlying sources of heterogeneity we estimate a model with interactions between the car attributes and respondent background and car (use) characteristics. Several variables, such as using the car for holidays abroad and fuel type, appear to be relevant for car choice. In terms of price and cost sensitivity we find that respondents who plan to buy a second-hand car and a relatively inexpensive car, and those that currently have a light car, are more sensitive to price and/or cost differences. Also for purchases of a second car in a household, price and cost differences are more important than for a first car, especially when the second car is a new instead of a second-hand car. Finally, women are substantially more sensitive to purchase price and monthly costs than men. With respect to heterogeneity in preferences for the electric and fuel cell car by far the most important factor is annual mileage, i.e., preferences of those with low annual mileage are far less negative than preferences of those with high annual mileage. The main explanation for this pattern is that those who drive more run into problems of limited driving range more often. Because kilometres driven during a single day will also often exceed the maximum electric driving range for this group, recharging would have to take place not only at night but also somewhere in between trips. Recharging potential and recharge time are limiting factors in that respect as well. Furthermore interesting is that annual mileage has a large impact on willingness to pay for driving range as well, implying that the heterogeneity in preferences for electric and fuel cell cars decreases substantially when driving range increases.

Finally, several interesting lines of further research follow from our results. First, we find that annual mileage has a large effect in preferences for range, indicating that the way in which someone uses his or her car may greatly affect the attractiveness of AFVs, and the electric and fuel cell car in particular. In this respect a potentially useful additional piece of information would be average daily kilometres, or more generally a metric that takes into account to what extent a person can make his or her daily trips given a certain range. An interesting extension of our study would be to analyse whether preferences for the electric car, but also the fuel cell car, are affected by such differences in car use and car use patterns. A second interesting extension of our research is related to fact that mixed logit models clearly indicate the existence of heterogeneity in preferences for fuel time and detour time, but that no relevant interactions for these attributes were found. More research into the underlying sources of heterogeneity is therefore necessary. Also, having a car with a relatively short range means that the *frequency* of recharging/refuelling and of having to make a detour are relatively high, *ceteris paribus*. This means that recharging/refuelling time and detour time may play an important role in consumer preferences, but that they would do so through range. Further research could provide more insight in to this issue.

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Appendix A: Descriptive texts on attributes as presented to respondents

Car type

Full electric car: a car that is set in motion by an electric motor. Batteries provide the electric motor with energy. The car must be charged to be able to drive it and electricity from a socket is suitable.

Fuel-cell car: also called hydrogen car. A car that requires to be fuelled with hydrogen in order to be able to drive it. In the car the hydrogen is converted into electricity with fuel cells. An electric motor sets the car in motion.

Plug-in hybrid: a car with both a petrol or diesel engine and batteries. The batteries can be charged with a plug and the car drives several tens of kilometres solely on electricity. When the batteries are empty the car will switch to using petrol/diesel. It is thus also possible to drive solely on petrol/diesel.

Flexifuel car: a car that, besides petrol or diesel, can drive completely on biofuels (fuels manufactured from biological materials). It could be biodiesel, bioethanol (comparable to petrol) or biogas (comparable to natural gas).

Hybrid: a car with batteries but without a plug. The engine in the car charges the batteries during driving and braking energy is recovered as well to charge the batteries. A hybrid can drive several kilometres solely on electricity.

Monthly costs

A combination of fuel costs (tailored to your mileage), maintenance costs and, if applicable, road taxes.

Range

The number of kilometres you can drive at most on a full tank or fully charged batteries (in case of an electric car).

Charging/refuelling time

The time it takes to fully charge the car (electric or plug-in hybrid) or to fill your tank. NB. the time shown at the plug-in hybrid applies to charging time of the batteries.

Additional detour time

In the case that not every fuelling station offers the fuel your car drives on it may be that you have to drive further to be able to refuel. As the availability of the fuel for the concerning car gets lower, the additional detour time is greater.

Number of available brands/models

The larger the number of models, the more alternatives there are for this car type. This concerns different brands and models, and different versions regarding engine size, acceleration and size of the car.

Policy measure

Concerns policies with which the government aims to influence the sales of this car type. We distinguish (1) current policy, (2) free parking, which applies to both parking permits and parking zones, (3) abolishment of the road tax exemption (monthly costs are corrected for this), and (4) permission to drive on bus and taxi lanes within the built-up area. The policy only applies to the car type for which it is shown. When for example the electric car option shows 'Free parking', this policy measure only applies to electric cars and not to the other AFVs. When 'Current policy' is shown all government policies are equal to the current situation.

Appendix B: Background characteristics

Table B1. Background characteristics of respondents used for model estimations

Variable	Percentage share
Gender	
Male	80%
Female	20%
Age category	
18 to 25	0.2%
25 to 35	9%
35 to 45	21%
45 to 55	25%
55 to 65	24%
65 to 75	21%
Household size	
1 person	9%
2 persons	44%
3 persons	16%
4 persons or more	31%
Highest finished education	
Primary school	2%
Secondary school (level1)	12%
Secondary school (level 2)	9%
Secondary school (level 3)	26%
Secondary school (level 4)	10%
Bachelor	28%
Master/PhD	11%
Don't know/no response	1%
Degree of urbanization	
Non urbanised (less than 500 inhabitants/km2)	12%
Little urbanised (500 to 1000 inhabitants/km2)	20%
Moderately urbanised (1000 to 1500 inhabitants/km2)	23%
Urbanised (1500 to 2500 inhabitants/km2)	30%
Very urbanised (2500 or more inhabitants/km2)	15%

Appendix C: Car use and travel characteristics

Table C1. Car use and travel characteristics of respondents used for model estimations

	Percentage share
New/used	
Next car new (Current car new)	40% (51%)
Next car used (Current car used)	60% (49%)
Purchase price next car	
less than 6,000 Euro	22%
6,000 to 12,000 Euro	32%
12,000 to 18,000 Euro	20%
18,000 to 24,000 Euro	11%
24,000 to 30,000 Euro	6%
30,000 to 40,000 Euro	6%
more than 40,000 Euro	2%
Annual mileage current car	
< 7500	9%
7500-15000	33%
15000-25000	31%
25000-35000	15%
> 35000	11%
Weight current car	
< 750 kg	1%
750 – 1000 kg	16%
1000 – 1250 kg	33%
1250 – 1500 kg	34%
1500 – 1750 kg	11%
1750 – 2000 kg	3%
> 2000 kg	2%
Frequency of car commute	
Almost never	40%
Once a week	3%
Twice a week	5%
Three times a week	7%
Four times a week	12%
Five or more times a week	33%
Distance to work (kilometres)	
<10 km	44%
10-20 km	16%
21-30 km	11%
31-40 km	8%
41-50 km	6%
51-60 km	3%
61-70 km	3%
>70 km	9%