Discussion Paper No. 08-088

Impact of Service Station Networks on Purchase Decisions of Alternative-fuel Vehicles

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Revised version: March 2012

Executive Summary

Motorized individual transport plays a major role in the political debate on climate change and energy security. About 26% of the entire CO_2 emissions in the European Union result from the use of passenger cars. In addition, current passenger car transport heavily depends on oil. To reduce this oil dependency and CO_2 emissions, the European Commission aims at substituting traditional automotive fuels by greener alternatives. However, such a strategy is based on the assumption that an acceptable level of infrastructure for new fuel types will be provided.

In this paper we study the impact of service station availability on the demand for alternative-fuel vehicles. Our analysis is based on stated preference data from a discrete choice experiment carried out in Germany, and considers a broad range of fuel types. Applying a standard logit model, we show that fuel availability influences choices positively, but its marginal utility diminishes with supply. Furthermore, we derive consumers' marginal willingness to pay for an expanded service station network. The results suggest that a failure to expand the availability of alternative fuel stations represents a significant barrier to the widespread adoption of alternative-fuel vehicles.

Das Wichtigste in Kürze

Der motorisierte Individualverkehr spielt in der klima- und energiepolitischen Diskussion eine zentrale Rolle. Etwa 26% der gesamten CO_2 Emissionen in der Europäischen Union sind auf den Pkw-Verkehr zurückzuführen. Die Europäische Kommission strebt daher eine Förderung alternativer Antriebstechnologien und Kraftstoffe an, um den CO_2 Ausstoß und die Abhängigkeit vom Öl zu reduzieren. Voraussetzung dafür ist die Existenz einer ausgebauten Tankstellen-Infrastruktur.

In diesem Papier untersuchen wir empirisch den Einfluss des Tankstellennetzes auf die Nachfrage nach Fahrzeugen mit alternativen Kraftstoffen. Hierzu nutzen wir Daten aus einem deutschlandweit durchgeführten *discrete choice experiment*. Im Rahmen dieses Experiments mussten sich potentielle Autokäufer wiederholt zwischen hypothetischen Pkw mit ganz unterschiedlichen Kraftstoffen und Antriebstechnologien entscheiden. In unserer ökonometrischen Analyse zeigen wir mithilfe eines Logit-Modells, dass die Wahrscheinlichkeit, mit der ein Pkw ausgewählt wird, mit der Größe des zugrunde liegenden Tankstellennetzes wächst, der Grenznutzen von zusätzlichen Tankstellen allerdings abnehmend ist. Basierend auf dem Schätzmodell leiten wir außerdem marginale Zahlungsbereitschaften für einen Tankstellenausbau ab. Die Ergebnisse deuten darauf hin, dass ohne einen massiven Ausbau des entsprechenden Tankstellennetztes, alternativ-betriebene Fahrzeuge sich kaum am Markt durchsetzen können.

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Abstract

In this paper, we study the impact of fuel availability on demand for alternative-fuel vehicles, using data from a survey of some 600 potential car buyers in Germany. The survey was conducted as a computer-assisted personal interview and included a choice experiment involving cars with various fuel types. Applying a standard logit model, we show that fuel availability influences choices positively, but its marginal utility diminishes with supply. Furthermore, we derive consumers' marginal willingness to pay for an expanded service station network. The results suggest that a failure to expand the availability of alternative fuel stations represents a significant barrier to the widespread adoption of alternative-fuel vehicles.

JEL classification: C25, D12, R41

Keywords: Alternative Fuels; Automobile; Fueling Infrastructure; Stated Preference

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1 Introduction

In the European Union, transport is the largest consumer of oil products and second largest emitter of carbon dioxide (CO_2); within the sector, road transport dominates in both regards (EU, 2010). In order to reduce oil dependency and to make transport more sustainable, the European Commission set out the target to replace 10% of conventional transport fuels with renewable alternatives, such as biofuel, hydrogen, and green electricity, by the year 2020 (EU, 2009). Moreover, in the Commission's recent White Paper on transport, ambitious emission reduction targets are formulated with a time horizon up to 2050 (EU, 2011). These can only be achieved by systematically switching to renewable energy sources to power transport, especially in terms of passenger cars. In response to this, the German government presented a detailed plan to encourage the adoption of electric vehicles. It aims at putting one million electric and plug-in hybrid cars on Germany's roads by the end of this decade (GFG, 2009).

In this paper, we study the impact of fuel availability on demand for alternative-fuel vehicles. The lack of a widespread service station network for alternative fuels may constitute a barrier to the adoption of alternative-fuel vehicles. Furthermore, network externalities associated with the existing fueling infrastructure for gasoline and diesel may deter consumers from switching to new, incompatible technologies (in the literature this problem is referred to as "excess inertia"; see Farrell and Saloner, 1986, 1985). Expanding the availability of alternative fuels, however, requires large investments. The installation of fueling infrastructure for alternative fuels will only be profitable for service station owners if demand, i.e. the number of vehicles using alternative fuels, considerably increases. The complementary relationship between vehicle demand and fueling infrastructure availability is often described as a "chicken-and-egg" problem, a problem that raises important questions concerning the potential need for political intervention. Yet crucial questions remain unanswered: What impact does fuel availability actually have on car purchase decisions? How much are consumers willing to pay for a larger service station network? Would consumers really switch to vehicles running on alternative fuels if a fully developed network of service stations existed? The answers to these questions would help us to decide whether public subsidies for the development of a service station network for alternative fuels are economically justified.

Based on a choice experiment involving cars with various fuel types, we attempt to answer these questions for the German market. Using a standard logit model, we show that fuel availability has a positive influence on vehicle selection, but that greater availability is subject to diminishing marginal utility. We also provide some evidence of an alternative-specific effect of fuel availability, simulate different scenarios, and analyze how choice probabilities change with a modified fueling infrastructure. Moreover, we derive the marginal willingness to pay (WTP) for an expanded service station network. The estimated WTP amounts are substantial, but decrease with the size of the existing network and vary in relation to the upper price bound that respondents indicated for their next car purchase.

The paper is organized as follows. Section 2 describes the survey and the data used. Section 3 introduces the discrete choice model. The empirical results are presented in section 4, with the parameter estimates discussed in subsection 4.1, the simulation results in subsection 4.2, and the willingness-to-pay estimates in subsection 4.3. The last section summarizes and concludes.

2 Survey design

In this paper, we analyze data from a Germany-wide survey of potential car buyers that was administered between August 2007 and March 2008 as a computer-assisted personal interview (CAPI). The survey was designed to garner insights into consumer preferences for alternative-fuel vehicles. A total of approximately 600 interviews were conducted at various car dealerships and branch offices of TÜV, the German authority responsible for certifying vehicle roadworthiness.[1] The respondents were picked randomly, but had to be of legal age and possess a valid driver's license. The sample comprises individuals from different regions in Germany (eastern and western Germany, urban and rural areas) and various demographic and socioeconomic groups (in terms of age, gender, education, income, etc.). It thus provides a broad cross-section of the target population, i.e. potential car buyers in Germany, although it is not entirely representative. Compared with

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[1] Within the survey both individual (75%) and group (25%) responses were allowed, yet one individual was always designated to be the decision maker. Hensher et al. (2011) recently investigated in a vehicle choice study whether interviewing one or several household members has an impact on declared household preferences. This might also be an interesting aspect for future research based on this data.

the official data available from KBA (2009) and MiD (2010), it seems that more educated individuals are over-represented, whereas women and individuals aged 40 to 49 years are under-represented in the sample; see Table 1 for more details.

In the survey, respondents participated in a choice experiment involving vehicles running on alternative fuels.[2] In each choice set, respondents were presented with seven hypothetical vehicles and asked to select the car they preferred most. The alternatives were characterized by the following six attributes: purchase price; fuel costs per 100 km; engine power; CO_2 emissions per km; fuel availability (given by the service station network size); and fuel type. Respondents were asked to assume that the presented hypothetical alternatives only differed with regard to these attributes, but were otherwise identical. Table 2 gives details on the attribute levels.

By using this stated preference approach, it was possible to consider every fuel type that is currently available or might be of importance in the future. To examine potential alternative-specific effects related to fuel type, however, it was necessary to include each fuel once in each choice set (thus "labeling" the choice experiment; see Hensher et al., 2005). We pooled different drive systems and fuel types into broader categories such as "hybrid" or "biofuel", as otherwise the total number of alternatives would have become too large. Nevertheless, the resulting 7×6 choice set design was still relatively demanding for respondents. However, based on the results of a pretest, we concluded that the experimental design was appropriate and not overly challenging. For a more detailed discussion of the issue of choice complexity, see Achtnicht (2011), who uses the same data set.

The attributes "purchase price" and "engine power" were customized. Respondents were asked beforehand to describe the vehicle they intended to buy, indicating upper and lower bounds for price and horsepower, which were then averaged and used as individual reference or pivot. This pivot or customization approach is common in the transportation literature and it increases the relevancy of attribute levels and choice scenarios (e.g., Hensher, 2010; Hensher et al., 2005). A detailed summary of the vehicles intended for purchase by the respondents is presented in Table 3.

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[2] Note that stated preference choice experiments are routinely used in transportation research when considering alternative fuels. Just to mention a few examples: Axsen et al. (2009); Mau et al. (2008); Horne et al. (2005); Greene and Hensher (2003); Brownstone et al. (2000); Ewing and Sarigöllü (1998); Brownstone et al. (1996); Bunch et al. (1993).

In the choice experiment, the attribute levels were varied independently between alternatives and choice sets. This ensured that each attribute's impact on choice selection could be isolated. However, in order to avoid the inclusion of unrealistic scenarios, only positive emissions were allowed for fossil fuels (i.e. gasoline, diesel, CNG/LPG)[3], and the lowest fuel availability level (i.e. 20%) was excluded for conventional-fuel alternatives.[4] The final fractional factorial design of the choice experiment, which was generated using Sawtooth software, required respondents to evaluate six choice sets.

3 Model specification

Consumer decisions are characterized by a discrete outcome. To analyze them, the use of discrete choice models is required. In this paper, we use a standard logit model to estimate vehicle choice parameters. In standard logit models, the utility U_{nj} provided by alternative j to person n is assumed to be

$$U_{nj} = V_{nj}(x_j, z_n) + \varepsilon_{nj}, \tag{1}$$

where $V_{nj}(x_j, z_n)$ is a deterministic (observed) utility component, depending on attributes x_j of alternative j and demographic variables z_n of person n, and ε_{nj} is an IID extreme value type I (unobserved) stochastic component. Under these assumptions, and given utility-maximizing behavior, it can be shown that the probability person n chooses alternative i takes the following closed form (e.g.,

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[3] Since, in the long term, there is no end-of-pipe technology that may address vehicle CO_2 emissions, this is reasonable. We only included the attribute level "no emissions" for non-fossil fuels (i.e. biofuel, hydrogen, electric), since their in-use emissions are effectively zero. Biofuels may be considered CO_2 neutral if they are the product of an entirely natural process of growth. However, emissions occur during fuel production. Therefore, we also allowed positive CO_2 emissions for non-fossil fuels. Respondents were informed about this at the beginning of the experiment.

[4] According to Moore and Holbrook (1990), the degree to which attribute-level combinations are realistic is of less practical importance than sometimes feared. Moore and Holbrook analyzed the effect of unrealistic stimuli on consumer judgements in terms of perceived realism and predictive power with three experiments in a car choice context. Their results provide evidence that the choice likelihoods are not affected by differences in scenario realism.

Train, 2003):

$$P_{ni} = \frac{\exp(V_{ni})}{\sum_{j=1}^{J} \exp(V_{nj})}. \qquad (2)$$

In a previous working paper of this study, we used a nested logit model in order to relax the *independence from irrelevant alternatives* (IIA) assumption that is inherent to standard logit. In any reasonable nesting structure that we tested, however, the introduced dissimilarity parameters were rather close to 1 and the associated null hypothesis of homoscedasticity could not be rejected by a likelihood ratio test. Therefore, we finally decided on using a standard logit specification.

The explanatory (or independent) variables entering the model and the underlying hypotheses are briefly discussed in the following; Table 4 gives further details. The deterministic component of utility V_{nj} is, as usual, specified linearly in parameters. First and foremost, we include the attributes used in the choice experiment. While the correlation of purchase price, fuel costs, and CO_2 emissions with the probability of being chosen is expected to be negative, it should be positive for engine power and fuel availability. The different fuel types are included as alternative-specific constants (ASC), with diesel serving as the base alternative.

In order to control for nonlinear effects of fuel availability, we also include the squared density of the service station network. Furthermore, it is conceivable that the impact of fuel availability varies based on the type of fuel. Indeed, alternative fuels may be at a disadvantage because of public skepticism regarding their viability. We thus include interaction variables between fuel availability and the ASC to control for possible alternative-specific effects.

We also expect a higher price sensitivity among individuals who intend to buy a relatively cheap car. Therefore, we include an additional interaction variable between purchase price and a dummy variable that identifies respondents who indicated an upper price bound (hereafter abbreviated UPB) that is below the sample median of €20,000 (representing 46% of the sample).[5]

Furthermore, we assume that consumers with a higher awareness for environmental issues are more concerned about vehicle CO_2 emission levels and prefer

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[5] During the model specification search, direct income effects on price sensitivity were also tested. In some specifications, we found some effects for the lowest income group (i.e. respondents with a monthly household net income of less than €1,000). These effects, however, were not robust.

alternative rather than conventional fuels. In order to determine a respondent's environmental attitude we asked four questions: Respondents were asked whether they (1) usually buy environmentally friendly products; (2) were willing to pay higher electricity prices for electricity generated exclusively from renewables; (3) ride a bicycle when traveling short distances; and (4) would consider foregoing a car altogether if public transportation services were improved. Based on the respondents' answers we constructed a simple attitude scale by assigning points to the different response options[6] and summing them up. Respondents who scored more on this attitude scale than the sample mean (7.96) were defined as the more environmentally aware group (60%), the others as the less environmentally aware group (40%). In the model, a dummy variable identifying these groups is interacted with the CO_2 variable and the ASC.[7]

We also try to capture the influence of the respondents' age on their stated choices. Our assumption is that older consumers may show a certain reluctance to purchase unknown or innovative products. Finally, we control for whether preferences for fuel types differ in relation to the intensity of private car use. For this reason, we include both the expected annual mileage and desired vehicle range in the model as interaction variables with the ASC.

4 Empirical results and discussion

4.1 Parameter estimates

Table 5 shows the estimation results. Note that interaction terms regarding different fuel types have to be interpreted with reference to diesel, which is the base fuel type. The coefficient of purchase price has, as expected, a negative sign and is statistically highly significant. We further find that individuals who indicated an UPB below €20,000 are much more price-sensitive.[8] Their price coefficient, which

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[6] The response options were "true" (3 points), "partly true" (2 points), and "not true" (1 point).

[7] This is a rather simple method for considering environmental attitudes. A new generation of discrete choice models, called hybrid choice models (HCM), provide a more sophisticated method for including attitudes and perceptions in the estimation. Bolduc et al. (2008), for example, apply HCM in the context of vehicle choices.

[8] Although we did not find any robust direct income effects, it should be noted that the indicated upper price bound and income are positively correlated in the sample.

is given by the sum of the coefficients for "Purchase price" and "Purchase price × Low UPB," is almost three times as large. This implies a much lower WTP for improvements in other passenger car attributes; we will consider this in our discussion about WTP for an enlarged fueling infrastructure below. Fuel costs and engine power are also highly significant in the model, and both have the expected signs.

Low vehicle emissions also seem to play an important role in car purchase decisions, although their importance strongly depends on individual environmental awareness. The results suggest that the utility value of a vehicle for environmentally aware consumers is affected more negatively by higher CO_2 emissions than it is for other consumers. It would therefore appear that the extensive public discussion surrounding CO_2 emissions and climate change has had an impact on the preferences of German consumers. German consumers are aware of the drawbacks of high CO_2 emissions, and this awareness factors into vehicle purchase decisions (see Achtnicht, 2011, for more on this topic). Likewise, it seems that environmental awareness influences individual preferences for fuel types, irrespective of their CO_2 emissions. Compared to diesel, alternative fuels are particularly preferred by environmentally aware individuals.

Other factors that appear to influence individual choices are age, desired vehicle range, and expected annual mileage. In particular, the estimation results suggest that the preference for alternative fuels decreases with age. It is possible that older consumers have some prejudices against future technologies, and are therefore less likely to choose them. Furthermore, we find that diesel-powered cars are more likely to be chosen in the case of a higher desired vehicle range and expected annual mileage. Although respondents were asked to assume that all alternatives presented in a choice set were identical with regard to non-addressed attributes, it would appear that the specific economic advantages of diesel-powered cars are responsible for this phenomenon.[9] The fact that there is no significant annual mileage effect associated with electric cars should not be interpreted to mean that diesel and electric cars are equally preferred by high-mileage drivers. Given the relatively low ASC for electric cars, which indicates general disfavor, the data

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[9] Note that in Germany, the fuel tax on diesel is lower than it is on gasoline, but the annual vehicle tax is higher on diesel cars than gasoline ones. Generally speaking, diesel vehicles are more economical for the consumer when the annual mileage driven is high, and gasoline vehicles are more economical when the annual mileage driven is low.

suggests instead that we cannot observe an additional significant negative effect for high-mileage drivers.

The impact of fuel availability on car purchase decisions is, as expected, positive and statistically highly significant. A large service station network guarantees low search costs and increases convenience for car drivers. However, the marginal utility of fuel availability is diminishing, as indicated by the negative coefficient of the squared term. This is in line with findings from Bunch et al. (1993), who surveyed approximately 700 households in the California South Coast Air Basin in 1991. In addition, excluding electric cars, we find no evidence that the effect of fuel availability varies between the different fuel types in relation to diesel. Only with respect to electric cars is there some indication of an alternative-specific effect. It seems that the service station network size matters more for electric cars than for diesel cars, implying an additional barrier to market adoption. This finding makes sense, given the rather short ranges that today's electric car models achieve.

4.2 Simulations

In order to illustrate what impact fuel availability has on car purchase decisions, we simulate three different scenarios. Based on the estimated model, we analyze how the average choice probabilities for alternative-fuel vehicles change under different fueling infrastructure scenarios. For this purpose we use standard cars that are identical in all respects except for fuel type and fuel availability. For all other attributes, we use approximate mean values from the sample data. This leads us to define a standard car with a purchase price of €20,700, fuel costs of €11.67 per 100 km, engine power of 127 hp, and CO_2 emissions of 128 g per km. The choice probabilities are first predicted separately for each individual in the sample, and after that the predicted probabilities are averaged. Any difference in choice probabilities that may be observed can then be attributed to the used fuel type and the size of the associated service station network. The scenarios and simulation results are presented in detail in Table 6.

In scenario 1 we look at a stylized and simplified version of the status quo in Germany.[10] For gasoline-fueled, diesel-fueled, and hybrid cars almost every service

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[10] In Germany there are approximately 15,000 service stations (including freeway service stations). Based on an online search, we find the following current figures with respect to alternative fuels: LPG/CNG can be refueled on 6,280/892 service stations; biofuel (here E85, consisting of

station is convenient; the density of the service station network is thus set at 100% in each instance. For LPG/CNG we assign a density of 50%. Finally, for the future or embryonic technologies of biofuel, hydrogen, and electric cars we set a density of 10% to guarantee at least a minimum level of availability. The resulting choice probabilities illustrate the strong impact of fuel availability: the higher the level of fuel availability, the higher the demand for each respective vehicle type. Gasoline, diesel, and hybrid cars each capture approximately 25% of demand, with (slight) advantages for the conventional technologies. LPG/CNG cars, with their 50% density of service stations, also have a fair chance of being chosen (13.4%). However, biofuel, hydrogen, and electric cars only capture a small sliver of demand in this scenario.

In scenario 2 we consider a situation in which biofuel, hydrogen, and electric cars can be refueled or recharged at every third service station. This more than tripling of fuel availability only leads to a roughly 50% jump in demand for each respective future technology. Given the huge financial investments that would be necessary to expand the fueling infrastructure accordingly, particularly for hydrogen, this finding makes clear how difficult the task will be to significantly increase demand for alternative-fuel vehicles, which is an avowed goal of energy and climate policy.

Finally, in scenario 3 we let each service station provide each fuel type. Although this scenario is the most unrealistic one, as a drawn out period in which new fuel types are gradually adopted by fuel stations would be nearly unavoidable, it nevertheless demonstrates how demand for alternative-fuel vehicles would change if differences in fuel availability were eliminated. The results in scenario 3 suggest that gasoline (17.3%) and diesel cars (19.6%) would still capture the largest share of demand, but their lead would dwindle considerably. In addition to hybrid (15.9%) and LPG/CNG cars (14.2%), hydrogen cars (14.1%) would also become a serious alternative to conventional-fueled cars. According to present preferences, biofuel (10.0%) and electric cars (8.9%) would capture the lowest market share. In Germany, the public's perception of biofuel has worsened recently in light of media coverage on the competition between biofuel and food production. It is possible that the sample reflects this changed public perception. Regarding elec-

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85% ethanol and 15% gasoline) on 345; hydrogen on 8; and for electric cars there are 512 charging stations.

tric cars, it is conceivable that existing practical drawbacks, such as long charging times or short ranges, are known to the respondents, thus making such vehicles less attractive.

The foregoing discussion provides empirical evidence regarding one aspect of the "chicken-and-egg" problem. The choice probability – and ultimately the demand – for passenger cars that run on alternative fuels strongly depends on infrastructure considerations. This means that a failure to significantly expand the network of stations for alternative fuels would significantly hamper the adoption of alternative-fuel vehicles. However, such an expansion would require high investments. It is likely that car users will have to pay for such investments, one way or another, given that the European Commission is proposing to apply user- and polluter-pays principles (EU, 2011). In the next section, we therefore address the extent to which consumers would be willing to pay for greater fuel availability.

4.3 Willingness to Pay

From the estimated model, we can derive the marginal WTP for an expanded service station network, i.e. the amount that a person is willing to pay additional to the baseline price p for a marginal increase of one percentage point in the baseline level of fuel availability $a < 100$, without a change in utility. Since the squared fuel availability a^2 also enters the model, the WTP does not fit with the ratio of the corresponding coefficients of the linear terms. Due to the fixed utility level, equation (3) has to hold:

$$\beta_p p + \beta_a a + \beta_{a^2} a^2 + c \overset{!}{=} \beta_p (p + \mathrm{WTP}) + \beta_a (a+1) + \beta_{a^2} (a+1)^2 + c, \tag{3}$$

where β_p, β_a, and β_{a^2} denote the estimated coefficients of the price and fuel availability variables, respectively, and c is the value that the remaining explanatory variables of the model contribute to the deterministic component of utility V_{nj}. Simple algebraic transformations of equation (3) result in the following WTP equation:

$$\mathrm{WTP} = -\frac{\beta_a + \beta_{a^2}(2a+1)}{\beta_p}. \tag{4}$$

Note that equation (4) in particular provides the WTP for a marginal increase of a given level of fuel availability a with respect to diesel-fueled cars and individuals who intend to buy a car that costs €20,000 or more. For other fuel types the respective alternative-specific fuel-availability coefficient simply has to be added to the numerator, whereas the coefficient of the interacted price variable has to be added to the denominator in order to derive the marginal WTP of individuals with a low UPB.

In our calculations, we let the baseline level of fuel availability a vary from 10% to 90% (at intervals of 10) and derive the marginal WTP with respect to diesel and electric cars, for both individuals with a high UPB and those with a low UPB. Since all alternative-specific fuel-availability coefficients aside from the electric one do not differ significantly from zero, the WTP with respect to diesel can also be interpreted as an approximation of the WTP with respect to gasoline, hybrid, LPG/CNG, biofuel, and hydrogen cars. Table 7 shows the results in detail.

Overall, the WTP amounts are substantially high, indicating the importance that is attached to fuel availability by respondents. However, we find that with an expanding fueling infrastructure, the marginal WTP for further expansion decreases. This holds true for each fuel type irrespective of the intended price range. Initial expansion of a rather underdeveloped network is valued highest by consumers. For example, with respect to diesel cars, the marginal WTP of individuals with a high UPB varies from approximately €630 to slightly more than €200, depending on whether diesel would be available at 10% or 90% of all service stations. This suggests that consumers want fueling infrastructure as convenient as possible, but not at any price. This is due to the diminishing marginal utility of fuel availability identified above.

Two further points should be noted. First, due to the positive alternative-specific effect of fuel availability for electric cars, the marginal WTP for the expansion of charging stations is consistently higher. And second, depending on the envisaged price range, the WTP varies considerably. In the high UPB case, the WTP amounts are roughly three times as large as in the low UPB case. This finding makes sense: individuals who contemplate a rather narrow price range for their next car (be it due to income constraints or any other reason), are more likely to consider the purchase price to be the decisive attribute than individuals who intend to buy a relatively expensive car; therefore, their WTP for improvements in other car attributes is lower.

5 Conclusions

Examining choice data from a survey of potential car buyers in Germany, we have shown in this paper that demand for alternative-fuel vehicles strongly depends on the availability of fueling infrastructure. Consequently, a failure to significantly expand the network of stations for alternative fuels would significantly hamper the adoption of alternative-fuel vehicles in coming years. Considering in addition that hydrogen and electric cars are likely to remain more costly than their conventional counterparts due to expensive fuel cells and batteries, the barriers to widespread adoption are considerable.

However, fuel availability and price are not the only factors that govern demand for alternative-fuel vehicles. Other factors also play a role, including consumer age, environmental awareness, desired vehicle range, and expected annual mileage driven. Our simulations demonstrate that consumers distinguish between different types of fuel, even when all other vehicle attributes are identical. In particular, our results show that biofuel and electric cars are currently unpopular among German car buyers, and that even with the significant expansion of fueling station infrastructure, which would certainly serve to support wider adoption, such cars would still capture small market shares. Given the current efforts to promote alternative fuels, this finding is critical. A key task for future research will thus be to examine whether, to what extent, and under what circumstances consumer preferences for different fuel types may change over time.

Acknowledgements

This study was conducted under ECO-CARS research project, which was funded by the German Federal Ministry of Education and Research (FKZ: 07WIN16A). We would like to thank our partners in this project for their valuable input and discussions. Furthermore, we would like to thank participants of the 2009 EAERE FEEM VIU European Summer School in Resources and Environmental Economics and the 2009 EAERE Conference, particularly David Brownstone, Matthew Turner, and Hendrik Wolff, as well as the anonymous referees for their valuable comments. Of course, the views expressed here and any errors remain the sole responsibility of the authors.

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Table 1: Summary of sample statistics

Survey question	Sample (N=598)	Population
Gender		
Male	74.6	69.0
Female	25.4	31.0
Age		
Until 29	20.7	17.7
30–39	21.1	19.9
40–49	20.2	28.2
50–59	17.7	19.4
60 and more	20.2	14.8
Education		
Secondary modern school degree	17.1	24.0
High school degree	31.1	33.2
University of applied sciences entrance qualification	8.0	9.5
Higher education entrance qualification, university or college degree	43.5	31.3
(Yet) without school degree or others	0.3	2.0
Household's monthly net income		
Until €1,000	3.3	
€1,000–2,000	18.4	
€2,000–4,000	37.1	
€4,000 and more	22.6	
Not stated	18.6	

Source: KBA (2009); MiD (2010); own calculations

Note: The population shares for gender and age are based on car owner data including all registrations of new and used cars in Germany in 2008 (KBA, 2009). The population shares for education represent the distribution among individuals with a driver's license, based on a representative survey on the mobility in Germany (MiD, 2010). To the authors' knowledge, there is no data on the income distribution of the target population (i.e. potential car buyers from Germany) available.

Table 2: Attributes and attribute levels in the choice experiment

Attribute	Number of levels	Levels
Fuel type	7	Gasoline, diesel, hybrid, LPG/CNG, biofuel, hydrogen, electric
Purchase price	3	75%, 100%, 125% of reference[a] (in €)
Engine power	3	75%, 100%, 125% of reference[a] (in hp)
Fuel costs per 100 km	3	€5, €10, €20
CO_2 emissions per km	5	No emissions[b], 90 g, 130 g, 170 g, 250 g
Fuel availability	3	20%[c], 60%, 100% of service station network

[a] average of the lower and upper bounds for the next car indicated by the respondent

[b] only applied to non-fossil fuel types (i.e. biofuel, hydrogen, and electric)

[c] not applied to conventional fuel types (i.e. gasoline and diesel)

Table 3: Summary of the vehicles intended for purchase

Survey question	Obs.	Mean	Std.Dev	Min	Max
Vehicle class					
Small/subcompact cars	598	0.145	0.353	0	1
Compact cars	598	0.283	0.450	0	1
Mid/Full-size cars	598	0.336	0.472	0	1
Mid/Full-size luxury cars	598	0.119	0.323	0	1
(Compact) Minivan	598	0.052	0.222	0	1
SUV	598	0.028	0.166	0	1
Sports car, roadster etc.	598	0.037	0.188	0	1
Age of the car					
new car	598	0.328	0.469	0	1
(up to) 1 year old/demonstration car	598	0.304	0.460	0	1
1–3 years old used car	598	0.204	0.403	0	1
4–7 years old used car	598	0.127	0.333	0	1
more than 7 years old used car	598	0.037	0.188	0	1
Purchase price					
Maximum (in thousands of €)	598	23.0	16.3	1	150
Minimum (in thousands of €)	598	18.5	14.3	0	100
Engine power					
Maximum (in hp)	598	141.8	63.3	50	555
Minimum (in hp)	598	112.5	52.4	0	500
Expected annual mileage (in thousands of km)	598	19.5	15.0	2	170
Desired vehicle range (in km)	598	632.7	170.2	100	1100

Table 4: Variable definitions

Variable name	Definition
Purchase price	Purchase price in thousands of €
Purchase price × Low UPB	Purchase price in thousands of € if respondent indicates an upper price bound that is below the sample median of €20,000
Fuel costs	Fuel costs in € per 100 km
Engine power	Engine power in hp
CO_2 emissions	CO_2 emissions in g per km
CO_2 emissions × Less environmentally aware	CO_2 emissions in g per km if respondent is less environmentally aware than the sample average
Fuel availability	Percentage of service stations where the respective fuel type is available
Fuel availability^2	Square of the percentage of service stations where the respective fuel type is available
Gasoline	1 if fuel type is gasoline; zero otherwise
Hybrid	1 if fuel type is hybrid; zero otherwise
LPG/CNG	1 if fuel type is LPG or CNG; zero otherwise
Biofuel	1 if fuel type is biofuel; zero otherwise
Hydrogen	1 if fuel type is hydrogen; zero otherwise
Electric	1 if fuel type is electric; zero otherwise
Fuel type × Fuel availability	Percentage of service stations where the respective fuel type is available (if fuel type is *fuel type*); zero otherwise
Fuel type × Range	Desired vehicle range in km (if fuel type is *fuel type*); zero otherwise
Fuel type × Mileage	Expected annual mileage in thousands of km (if fuel type is *fuel type*); zero otherwise
Fuel type × Less environmentally aware	1 if respondent is less environmentally aware than the sample average (and fuel type is *fuel type*); zero otherwise
Fuel type × Age	Age of the respondent in years (if fuel type is *fuel type*); zero otherwise

Table 5: The estimated standard logit model

Variable		Coefficient	Std.Err	t-value
Purchase price		−0.0337***	0.00372	−9.07
Purchase price ×	Low UPB	−0.0598***	0.0134	−4.46
Fuel costs		−0.0768***	0.00330	−23.31
Engine power		0.00630***	0.000659	9.57
CO2 emissions		−0.00510***	0.000364	−13.99
CO2 emissions ×	Less environmentally aware	0.00212***	0.000572	3.70
Fuel availability		0.0231***	0.00586	3.95
Fuel availability^2		−0.0000901***	0.0000328	−2.75
Gasoline		1.838***	0.386	4.76
Gasoline ×	Fuel availability	−0.00215	0.00312	−0.69
	Range	−0.00303***	0.000355	−8.53
	Mileage	−0.0245***	0.00458	−5.34
	Less environmentally aware	0.119	0.112	1.06
	Age	0.0123***	0.00362	3.39
Hybrid		1.422***	0.397	3.59
Hybrid ×	Fuel availability	0.000470	0.00310	0.15
	Range	−0.00177***	0.000382	−4.64
	Mileage	−0.0133***	0.00444	−2.99
	Less environmentally aware	−0.452***	0.127	−3.55
	Age	−0.00161	0.00413	−0.39
LPG/CNG		2.199***	0.395	5.57
LPG/CNG ×	Fuel availability	−0.000914	0.00312	−0.29
	Range	−0.00247***	0.000388	−6.37
	Mileage	−0.00658	0.00411	−1.60
	Less environmentally aware	−0.343***	0.128	−2.67
	Age	−0.0126***	0.00425	−2.96
Biofuel		0.943**	0.410	2.30
Biofuel ×	Fuel availability	0.00108	0.00314	0.34
	Range	−0.00175***	0.000396	−4.42
	Mileage	−0.00479	0.00424	−1.13
	Less environmentally aware	−0.422***	0.145	−2.92
	Age	−0.00679	0.00440	−1.54
Hydrogen		1.050***	0.389	2.70
Hydrogen ×	Fuel availability	0.00223	0.00305	0.73
	Range	−0.00122***	0.000361	−3.39
	Mileage	−0.00827**	0.00402	−2.05
	Less environmentally aware	−0.505***	0.134	−3.77
	Age	−0.00942**	0.00404	−2.33
Electric		0.342	0.431	0.79
Electric ×	Fuel availability	0.00658**	0.00324	2.03
	Range	−0.000911**	0.000426	−2.14
	Mileage	−0.00467	0.00451	−1.03
	Less environmentally aware	−0.525***	0.158	−3.31
	Age	−0.0200***	0.00495	−4.05
Persons		598		
Observed choices		3588		
Log likelihood		−5924.23		
McFadden's Pseudo R^2		0.151		

Asterisks denote statistical significance at the *** p< 0.01, ** p< 0.05, * p< 0.1 level.

Table 6: Simulation scenarios and results

	Scenario 1			Scenario 2			Scenario 3		
	Netw.	Prob.	SD	Netw.	Prob.	SD	Netw.	Prob.	SD
Gasoline	100	24.3	9.4	100	22.8	9.1	100	17.3	7.8
Diesel	100	28.1	9.9	100	26.2	9.2	100	19.6	7.0
Hybrid	100	22.9	3.6	100	21.3	3.2	100	15.9	2.2
LPG/CNG	50	13.4	3.6	50	12.4	3.2	100	14.2	3.1
Biofuel	10	4.0	0.7	33	5.9	0.9	100	10.0	1.1
Hydrogen	10	5.1	1.1	33	7.8	1.5	100	14.1	2.1
Electric	10	2.2	0.8	33	3.7	1.2	100	8.9	2.5

Note: For the simulation, standard cars were used that are identical in all respects except for fuel type and fuel availability. The used values for purchase price (€20,700), engine power (127 hp), fuel costs (€11.67), and CO_2 emissions (128 g) are approximate mean values from the sample data.

Table 7: The marginal WTP (in thousands of €) for greater fuel availability

	High upper price bound				Low upper price bound			
	Diesel cars		Electric cars		Diesel cars		Electric cars	
Netw.	WTP	Std.Err	WTP	Std.Err	WTP	Std.Err	WTP	Std.Err
10	0.629***	0.171	0.824***	0.147	0.227***	0.064	0.297***	0.058
20	0.576***	0.152	0.771***	0.130	0.208***	0.057	0.278***	0.052
30	0.522***	0.134	0.717***	0.114	0.188***	0.051	0.259***	0.046
40	0.469***	0.117	0.664***	0.101	0.169***	0.045	0.239***	0.041
50	0.416***	0.102	0.611***	0.090	0.150***	0.039	0.220***	0.037
60	0.362***	0.088	0.557***	0.083	0.131***	0.034	0.201***	0.034
70	0.309***	0.077	0.504***	0.080	0.111***	0.029	0.182***	0.033
80	0.255***	0.071	0.450***	0.083	0.092***	0.027	0.162***	0.033
90	0.202***	0.070	0.397***	0.090	0.073***	0.026	0.143***	0.035

Asterisks denote statistical significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level.