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German Car Buyers' Willingness to Pay to Reduce CO_2 Emissions

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Non-technical Summary

Motorized individual transport strongly contributes to global CO_2 emissions, due to its intensive usage of fossil fuels. Current political efforts addressing this issue (i.e. emission performance standards in the EU) are directed towards car manufacturers. Concretely, the whole car industry has to comply with an average of 120 grams of CO_2 per kilometer between 2012 and 2015, with interim targets. The long-term target for 2020 is an average of 95 grams of CO_2 per kilometer (by way of comparison, passenger cars currently emit 160 grams of CO_2 per kilometer on average). Manufacturers who exceed the specified standard will have to pay fines.

From an economic point of view this measure has to be regarded critically. But given the present EU regulation the question arises as to what the optimal strategy for car manufacturers is. Exceeding the emission standard generates costs (through the payment of fines) – but so does complying with the emission standard (through costly abatement measures). Depending on the amount consumers are willing to pay for a specific reduction in CO_2 emissions it could well be optimal for manufacturers to exceed the mandatory standard.

This paper focuses on the demand side. It examines whether CO_2 emissions per kilometer is a relevant attribute in car choices. Based on a discrete choice experiment among potential car buyers from Germany, both a standard and a mixed logit specification are estimated. In addition, distributions of willingness to pay measures for an abatement of CO_2 emissions are obtained. The results suggest that the emissions performance of a car matters substantially, but its consideration varies heavily across the sampled population. In particular, some evidence on gender, age, and education effects on climate concerns is provided.

Das Wichtigste in Kürze

Der motorisierte Individualverkehr stellt eine der bedeutendsten globalen CO_2-Quellen dar. Grund dafür ist vor allem der starke Einsatz fossiler Brennstoffe als Antrieb für Automobile. Um die klimaschädlichen Auswirkungen des motorisierten Individualverkehrs zu reduzieren, setzte die EU kürzlich verbindliche Emissionsstandards für Neuwagen fest. Demnach gilt für die gesamte Automobilindustrie ein durchschnittlicher Emissionsgrenzwert von 120 Gramm CO_2 pro Kilometer. Dieser soll zwischen 2012 und 2015 schrittweise erreicht werden. Das langfristige Ziel bis 2020 ist ein durchschnittlicher Grenzwert von 95 Gramm CO_2 pro Kilometer (zum Vergleich: der derzeitige Durchschnitt liegt bei 160 Gramm). Autohersteller, die diese Grenzwerte verfehlen, müssen Bußgelder zahlen.

Aus ökonomischer Sicht stellen Emissionsstandards kein sinnvolles Politikinstrument zur Bekämpfung des Klimawandels dar. Es stellt sich allerdings die Frage, wie Autohersteller angesichts der bestehenden EU-Regulierung am besten vorgehen sollten. Für die Hersteller verursacht sowohl das Überschreiten der Emissionsgrenzwerte Kosten (durch zu leistende Bußgelder), als auch deren Einhaltung (durch teure technologische Vermeidungsmaßnahmen). Die optimale Strategie wird letztlich auch von der Zahlungsbereitschaft der Konsumenten für vermiedene Emissionen abhängen.

In diesem Papier wird untersucht, inwieweit die CO_2-Menge, die ein Pkw pro Kilometer emittiert, für Autokäufer entscheidungsrelevant ist. Basierend auf Daten eines deutschlandweit durchgeführten *discrete choice experiment* werden dazu verschiedene ökonometrische Modelle geschätzt. Darüber hinaus werden Verteilungen der Zahlungsbereitschaften für CO_2-Vermeidung abgeleitet. Die Ergebnisse zeigen, dass die CO_2-Emissionen eines Pkw tatsächlich einen signifikanten Einfluss auf die Kaufentscheidung haben. Abhängig von soziodemographischen Faktoren ist dieser Einfluss allerdings unterschiedlich stark ausgeprägt.

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Abstract

Motorized individual transport strongly contributes to global CO_2 emissions, due to its intensive usage of fossil fuels. Current political efforts addressing this issue (i.e. emission performance standards in the EU) are directed towards car manufacturers. This paper focuses on the demand side. It examines whether CO_2 emissions per kilometer is a relevant attribute in car choices. Based on a choice experiment among potential car buyers from Germany, a mixed logit specification is estimated. In addition, distributions of willingness-to-pay measures for an abatement of CO_2 emissions are obtained. The results suggest that the emissions performance of a car matters substantially, but its consideration varies heavily across the sampled population. In particular, some evidence on gender, age and education effects on climate concerns is provided.

JEL classification: C25, D12, Q51

Keywords: Choice experiment; CO_2 emissions; Mixed logit; Passenger cars; Willingness to pay

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1 Introduction

Climate change and its anthropogenic character are widely considered as proven within the scientific community. Several studies from the past few years provide overwhelming evidence in this regard (e.g., Stern, 2006; IPCC, 2007). The main driver of global warming is the greenhouse gas (GHG) carbon dioxide (CO_2). It is produced mainly by burning fossil fuels and causes 60% of the anthropogenic greenhouse effect.

Due to its intensive use of fossil fuels the transport sector is one of the main emitters of CO_2. In 2006, transport contributed approximately 23% of total CO_2 emissions (in absolute terms 857,583Gg) within the EU-15[1]. Most of the emissions in this sector are caused by road transport. Passenger cars, in particular, account for approximately 12% of total CO_2 emissions. Moreover, a growing demand for road transport was the main reason for the increase in EU-15 CO_2 emissions between 1990 and 2006 (EEA, 2008).

Consequently, motorized individual transport plays a major role in the political debate on climate change. The European Commission has set the goal of reducing GHG emissions by 20% by 2020, compared to 1990 (EU, 2008). To ensure that the EU will achieve its climate targets, the European Parliament approved the EU's energy and climate package. Part of this package is a regulation which sets emission performance standards for new passenger cars registered in the EU. More concretely, the whole car industry has to comply with an average of 120g of CO_2 per km between 2012 and 2015, with interim targets. The long-term target for 2020 is an average of 95g of CO_2 per km (in 2008, new passenger cars emit 153g of CO_2 per km on average; T&E, 2009). Manufacturers who exceed the specified standard will have to pay penalties. For each gram exceeding the target, €95 times the number of new passenger cars will have to be paid from 2019 onwards. In the transitional period between 2012 and 2018 the penalty for the first three exceeding grams is considerably lower (i.e. €5 for the first gram, €15 for the second gram, and €25 for the third gram).

From an economic point of view this measure has to be regarded critically. Generally, standards are not cost-efficient. Unlike market-based instruments (i.e. taxes

[1]EU-15 comprises the 15 Member States prior to the 2004 enlargement of the European Union: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

and tradable permits), CO_2 emission standards will not equal the marginal abatement costs of different manufacturers (e.g., Kolstad, 2000). Moreover, market-based instruments perform better than standards in providing incentives for firms to adopt advanced abatement technology and to develop such new technology (Requate, 2005). As a consequence the EU environmental targets will be achieved – if at all[2] – at unnecessarily high costs.

But given the present EU regulation the question arises as to what the optimal strategy for car manufacturers is. Exceeding the emission standard generates costs (through the payment of fines) – but so does complying with the emission standard (through costly abatement measures). Depending on the amount consumers are willing to pay for a specific reduction in CO_2 emissions it could well be optimal for manufacturers to exceed the mandatory standard.

This paper focuses on the following questions: Do car buyers care about the environment? Or, more precisely: Do CO_2 emissions have a negative impact on car purchase decisions? And, if yes: How much are car buyers willing to pay for emission reductions? Based on a choice experiment we answer these questions for German car buyers.

In addition, we study the impact of specific demographic characteristics on the respondents' stated choices. Scientific literature discusses whether age, education, gender and income influence consumers' perceptions of environmental issues and their related willingness to pay. The existing results are ambiguous. For example, Hersch and Viscusi (2006) find that older people have a significantly lower willingness to pay higher gasoline prices in order to protect the environment. The authors further provide evidence that the level of support for this environmental policy measure increases with the respondents' education and, to a lesser extent, income levels. Gender is not influential in this study. However, the results of Torgler et al. (2008) indicate that women have stronger preferences towards the environment. On average, for example, women are more likely than men to state a high willingness to pay for environmental protection. In their recent study Daziano

[2]Improving the emission performance (i.e. fuel efficiency) of cars that run on fossil fuels reduces car travel costs. Consumers' likely response to this cost reduction is an increase in car travel demand (implying the so-called "rebound effect"). Frondel and Vance (2009) investigate the determinants of car travel for German households and quantify the effect of fuel prices. Their results suggest that "the logic of introducing fuel efficiency standards to reduce emissions is dubious".

and Bolduc (2011) also analyze stated vehicle choices, using a hybrid choice model. Their findings provide some evidence that women, older people and more educated people are more concerned about environmental issues, while income has no significant effect in the car choice context. By contrast, Hsu et al. (2008) identify income as a strong determinant of the willingness to support gasoline tax increases.[3] They also find some effects of educational level and gender (i.e. women are more likely to support gasoline tax increases), but not of age. To contribute to this discussion we derive the willingness to pay for CO_2 abatement, depending on the respondents' gender, age, and educational level.

For this purpose we estimate a mixed logit model. Mixed (or random parameter) logit is more flexible than standard logit and helps to obviate its limitations (Train, 2003): the coefficients are allowed to vary in the population rather than being fixed, the restrictive *independence of irrelevant alternatives* (IIA) assumption may be dropped, and repeated choices by an respondent may be modeled as correlated. Brownstone and Train (1999) suggest that the "extra difficulty of estimating a mixed logit" is not necessary if "the ratios of coefficients are adequately captured by a standard logit model" and when "the goal is simply estimation of willingness to pay". However, Algers et al. (1998) find significant differences in estimated willingness-to-pay measures, depending on whether model coefficients are allowed to vary or not. We use a mixed logit specification since it fits our data better than standard logit, and through further improvements in computer performance the additional expenditure of time is reasonable.

The paper is organized as follows: The data and the methods used are described in detail in section 2. In section 3 the results of our econometric analysis are presented. The final section summarizes and concludes.

2 Data and methods

2.1 Description of the survey

The data analyzed in this paper comes from a Germany-wide survey among potential car buyers. The survey was designed to study people's preferences regarding

[3]It should be noted that Hsu et al. (2008) coupled the question of gasoline tax increase with income tax reductions.

cars with alternative propulsion technologies and fuel types. It was conducted via computer-assisted personal interviewing (CAPI), from August 2007 to March 2008.[4] The interviews took place in showrooms of car dealers of different brands and in selected offices of the technical inspection authority. The respondents were picked randomly among consumers of all population groups. Only two restrictions were made. Firstly, respondents should be of age and have a valid driving license. And secondly, they should intend to replace an existing car or to buy a new car in the near future, or at least could imagine doing it in principle. The approximately 600 interviews that have been conducted[5], covered people from different regions in Germany (Eastern vs. Western Germany, urban vs. rural areas) and various demographic groups. The sample provides a broad cross-section of the target population, i.e. potential car buyers from Germany. However, while individuals with a higher education entrance qualification are over-represented, women and individuals aged 40 to 49 years are under-represented. Therefore, the paper's results are valid first and foremost (but not only) for the sample used. Table 2 compares the demographic profile of the sample with the population shares.[6]

The core of the questionnaire was a stated preference choice experiment concerning a car purchase decision. Each respondent faced six choice sets. Each choice set consisted of seven hypothetical vehicles, each characterized by the six following attributes: purchase price; fuel costs per 100km; engine power; CO_2 emissions per km; fuel availability (given by the size of the service station network); and fuel type.[7] Respondents were asked to assume that the presented alternatives are

[4]In January 2009, the German government introduced government-financed trade-in incentives in order to stimulate demand for new cars and thereby to modernize the existing car fleet. Drivers who scrap their at least nine years old cars receive €2,500 for a new car (regardless of its fuel efficiency). Since our data was collected roughly one year earlier, it is not biased by this context.

[5]Within the survey both individual (75%) and group (25%) responses were allowed, whereas one individual was always designated to be the decision maker. Hensher et al. (2011) recently investigated in a vehicle choice context whether it makes a difference if one household representative or a group of decision-making household members is interviewed in order to reveal the household's preferences. This might also be an interesting aspect for future research based on this data.

[6]Note that, though there is no official data on the income distribution of the target population, it seems that high-income households are also somewhat over-represented in the sample. However, 18% of survey respondents did not indicate their household's monthly net income.

[7]Purchase price, fuel costs and engine power are standard explanatory variables in vehicle choice models (e.g., Horne et al., 2005; Ewing and Sarigöllü, 2000; Brownstone et al., 2000; McCarthy and Tay, 1998; McCarthy, 1996; Brownstone et al., 1996; Bunch et al., 1993; Manski

otherwise identical.

Table 1 gives the attribute levels used in the choice experiment. A particular focus of the research project of which this survey was a part, was on alternative fuels. Therefore, we basically included each engine technology or fuel type that currently is available and relevant, or might be of importance in the near future: gasoline, diesel, hybrid, LPG/CNG, biofuel, hydrogen, and electric. However, as the total number of alternatives should not get too large, different propulsion or fuel types were pooled into broader categories like hybrid or biofuel. In order to allow for studying alternative-specific effects, it was essential that each fuel type was covered exactly once in each choice set (Hensher et al., 2005). Therefore, the fuel type behaves like a label of the alternatives and the (by design unlabeled) choice experiment is quasi-labeled.

With respect to the attributes "purchase price" and "engine power" we used a pivot design. Each respondent was asked beforehand to characterize the vehicle he or she intends to buy. This characterization referred to the car classification (full-size, compact, mid-size, van, sports car etc.)[8] as well as to upper and lower bounds for purchase price and engine power. The customized values of purchase price and engine power in the choice experiment were equal to 75%, 100% and 125% of the average of indicated bounds. The reason for doing so is the increase of relevancy of attribute levels and choice scenarios (e.g., Hensher, 2010); the approach of pivoting or customization is common and well documented in the transportation literature (e.g., Axsen et al., 2009; Mau et al., 2008; Hensher et al., 2005; Horne et al., 2005; Greene and Hensher, 2003; Ewing and Sarigöllü, 2000, 1998; Bunch et al., 1993).

For fossil fuels there is indeed a constant correlation between fuel consumption and CO_2 emissions. By burning one liter of gasoline, for example, 2.32 kg of CO_2 are emitted.[9] In other words, decreasing the CO_2 emissions of a fossil-fuel-based

and Sherman, 1980). CO_2 emissions and fuel availability are used in only a few surveys (Horne et al., 2005; Brownstone et al., 1996; Bunch et al., 1993).

[8]Based on our data, possible class switching behavior cannot be observed. As noted by a referee, for instance, "some respondents may opt out of larger cars into a smaller vehicle in the presence of overt information about emissions". In their recent study, Axsen et al. (2009) allowed vehicle classes to vary in the choice experiment.

[9]Because of this correlation between fuel consumption and CO_2 emissions, fuel taxes are indeed working like a carbon tax. In Germany, fuel taxes are relatively high. For one liter of gasoline, for example, car drivers have to pay approximately €0.65 fuel tax. Moreover, the value added tax (19%) is added to the sum of the net fuel price and the fuel tax. Hence, the existing incentives for car manufacturers to develop low-emission (i.e. fuel-efficient) cars for the German

vehicle automatically means a decrease in fuel consumption – and therefore in fuel costs. There is no such unambiguous correlation for the other propulsion technologies and fuel types. Power generation by burning coal, for example, is cheaper than power generation by using renewable energies – but emits substantially more CO_2. In trying to capture the pure effect of CO_2 emissions on choice decisions we included both fuel costs and emission performance as independent car attributes in our experimental design.

It should be further noted that the price levels were varied independently over alternatives and choice sets. So, for instance, it was not the case that alternative-fueled cars were always more expensive than conventional-fueled cars, as it might be the case under current market conditions. This is also a common approach used in many previous vehicle choice studies (e.g., Horne et al., 2005; Ewing and Sarigöllü, 2000; Brownstone et al., 1996; Bunch et al., 1993). As the other attributes are treated likewise, all kinds of trade-offs occur within choice scenarios. This approach ensures that each attribute's impact on choices can be isolated.

However, in order to avoid the most unrealistic scenarios, we allowed solely strictly positive emissions for fossil fuels (i.e. gasoline, diesel, CNG/LPG)[10] and excluded the lowest level of service station network (i.e. 20%) for conventional-fueled alternatives. Still, there are some choice scenarios in the resulting design which may be considered as not very realistic, though theoretically possible.[11] But firstly, it should be noted that excluding the most unrealistic attribute levels for certain fuel types (as described above) also ensured that these scenarios appeared less frequently. For example, on average, alternative-fueled cars perform much better than conventional-fueled cars in terms of CO_2 emissions in the choice experiment. And secondly and mainly, according to Moore and Holbrook (1990),

market are high.

[10]Since, in the long term, there is no end-of-pipe technology that may address vehicle CO_2 emissions, this is reasonable. Only for non-fossil fuels (i.e. biofuel, hydrogen, electric) we included the attribute level "no emissions" – 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 emerge in the course of the process of fuel production. Therefore, we also allowed positive CO_2 emissions for non-fossil fuels. Respondents were informed about this context at the beginning of the experiment.

[11]For instance, hybrids might run on biofuels or LPG, so that the network density can be lower than the one for gasoline cars; and depending on how the power is generated, an electric car can – at least theoretically – account for more emissions than an efficient gasoline-fueled car. Note that respondents were asked to treat all hypothetical alternatives so as they would exist.

the realism of attribute-level combinations is of less practical importance as sometimes feared. Moore and Holbrook analyzed the effect of unrealistic stimuli on consumer judgements in terms of perceived realism and predictive power by three experiments in a car choice context. Their results provide evidence that the choice likelihoods are not affected by differences in scenario realism.

The final experimental design was generated by Sawtooth software. As the total number of possible combinations was far too big to let respondents face all of them, a "computer-randomized" fractional factorial design was applied.

At this point, some remarks on the issue of choice complexity are appropriate. There is a growing literature addressing the effect of design dimensions on the consistency of stated choices (e.g., Hensher, 2006; Caussade et al., 2005; DeShazo and Fermo, 2002). Caussade et al. (2005), for instance, identify "number of attributes" and "number of alternatives" as the two most important design dimensions in terms of their impact on choice consistency. Notably, they find an U-shaped relation between the number of alternatives and the error variance (maximizing consistency by a number of four alternatives). This pattern is supported by findings from DeShazo and Fermo (2002) who report a quadratic relation. However, in their study the number of alternatives turns out to be one of the least influential design dimensions. Hensher (2006) investigated attribute consideration by respondents in choice experiments under varying information load. His results suggest that choice complexity is not necessarily increasing with the amount of information respondents are confronted with in choice tasks. According to Hensher, it is not strictly a question of quantity, but rather of relevancy.[12]

The 7×6 choice set design used in this survey is relatively demanding for respondents.[13] However, it is arguable that the number of considered cars and attributes in real-world car choices is even bigger. In order to test whether the experimental design is overly burdensome for respondents, a pretest was conducted. After each pretest interview, the respondent was asked to comment the choice

[12] Hensher (2006): "As we increase the 'number of alternatives' to evaluate, *ceteris paribus*, the importance of considering more attributes increases, as a way of making it easier to differentiate between the alternatives. This is an important finding that runs counter to some views, for example, that individuals will tend to ignore increasing amounts of attribute information as the number of alternatives increases. Our evidence suggests that the processing strategy is dependent on the nature of the attribute information, and not strictly on the quantity."

[13] Brownstone and Train (1999) and Brownstone et al. (1996) used data from a similar large choice matrix in their transportation studies.

Table 1: Attributes and attribute levels for 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 100km	3	€5, €10, €20
CO_2 emissions per km	5	no emissions[b], 90g, 130g, 170g, 250g
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)

experiment and to indicate any possible problems related to this. The feedback was very positive and confirmed the interviewer's impression that the respondents answered the choice tasks very carefully. It was thus concluded that the used design is appropriate for this study's purpose.[14]

2.2 Model specification

To analyze the respondents' car choices econometrically, discrete choice models can be applied. In this paper, relevant explanatory variables are identified with the help of a standard logit model. However, in order to allow also for heterogeneity in unobserved factors, we primarily make use of a mixed logit specification. The more general and flexible mixed logit model can be derived from utility-maximizing behavior (Train, 2003). Meeting the requirements of repeated choices in our survey, the utility U_{njt} that person $n \in \{1, \dots, N\}$ obtains from alternative $j \in \{1, \dots, J\}$ in choice situation $t \in \{1, \dots, T\}$ is modeled as a random variable

$$U_{njt} = \beta_n' x_{njt} + \varepsilon_{njt} \quad (1)$$

with attributes of the alternative and demographics of the person x_{njt}, a related vector of coefficients β_n, and iid extreme value random term ε_{njt}. Unlike in stan-

[14]Note that the survey was conducted through personal interviews, which helped to guarantee the quality of the data. The personal interview situation motivated respondents to finalize the questionnaire (including the choice experiment) thoroughly and enabled respondents to avoid possible misunderstandings.

dard logit, here β_n is allowed to vary over individuals with a specified density f.[15] This specification represents random taste variation in the population.

However, also unlike standard logit, the probability that person n chooses a sequence of alternatives $\mathbf{i} = (i_1, \ldots, i_T)$, given by

$$P_{n\mathbf{i}} = \int \prod_{t=1}^{T} \frac{e^{\beta' x_{ni_t t}}}{\sum_{j=1}^{J} e^{\beta' x_{njt}}} \, f(\beta) \, \mathrm{d}\beta, \tag{2}$$

cannot be solved analytically (Train, 2003). It has to be simulated. We use Halton draws with 1000 replications for the maximum simulated likelihood estimation with Stata's `mixlogit` command (see Hole, 2007).

The independent variables that enter our model (and the way in which they enter) are briefly discussed in the following. We try to keep the model simple, focussing basically on the car attributes that specified the alternatives in the choice sets. The different propulsion technologies and fuel types are included by alternative-specific constants, where diesel serves as baseline alternative. Since different people might prefer different fuels, we assume normal distributions for the related coefficients. Engine power also enters with normally distributed coefficient, while the coefficients of service station availability and CO_2 emissions are assumed to be log-normally distributed. Unlike normal distribution, the log-normal one induces the same coefficient sign for the whole population. It is possible that some people dislike too much horsepower.[16] It is, however, not explainable why people should dislike a denser service station network or fewer emissions. Therefore, we do not allow for both directions of preferences for these variables.[17] Fuel costs per 100km enter our model with log-normally distributed coefficient. Since the negative impact of fuel costs is unambiguous, we thereby restrict the coefficient to

[15] Note that we assume β_n to be constant over time for a given person n and, therefore, allow for correlation over time. This is reasonable since the repeated choices were all made within one interview.

[16] In a recent paper, Beck et al. (2011) analyzed data from a vehicle choice experiment among potential car buyers from the Sydney metropolitan area. Using also a mixed logit model, they found that less engine cylinders are preferred on average.

[17] McFadden and Train (2000), for example, specified service station availability as normally distributed. During the model specification search for this paper, normal distributions for service station availability and CO_2 emissions have also been tried. The resulting share of sampled population with unexpected coefficient sign was between 10 and 15% for both. Hence, it is reasonable to assume that the unlike signs occurred purely by specification.

be non-positive for all individuals.[18] Purchase Price (in thousand €) is the only attribute we consider as fixed parameter. We follow Revelt and Train (1998, 2000) with this specification, since it simplifies the derivation of the distribution of the willingness to pay. As it may be expected that individuals who intend to buy a relatively cheap car are more price-sensitive, we include an additional interaction term between the purchase price and a dummy variable that identifies respondents who indicated an upper price bound (UPB) that is below the sample median of €20,000 (representing 46% of the sample).[19]

In order to capture demographic differences in assessing CO_2 emissions, we include additional fixed-effects interaction terms between dummies covering information about gender, age or educational level, and the CO_2 emissions variable. In respect of age we differentiate between individuals under 45 years[20] and those 45 and older, and in respect of educational level between individuals who possess (at least) a higher education entrance qualification (HEEQ)[21] and those who do not. Thus, men aged 45 years or older without an HEEQ are the reference group (representing 22% of the sample). Our hypotheses are that women, younger, and more educated individuals are more concerned about the environment and, therefore, evaluate the CO_2 emissions of a car more negatively.[22] Table 2 gives the distribution of the sample demographics.

[18]Note that fuel costs and CO_2 emissions each multiplied by minus one actually enter our models. This is due to the fact that a log-normally distributed coefficient has to be positive for all individuals. This conversion is undone after the estimation. See Hole (2007) for more details.

[19]During the model specification search, direct income effects on price sensitivity have also been tested; however, any significant income effect was not found.

[20]This value has been chosen since it is the sample mean and, in addition, almost the sample median.

[21]With HEEQ the general qualification for university entrance is meant. In Germany, the so called "Abitur" certificate can be received after 12 or 13 years at school (compared to other secondary school certificates after 10 or less years at school) and allows holders to attend university.

[22]During the survey interview respondents were asked to indicate the household's monthly net income (possible ranges were: up to €1,000, between €1,000 and €2,000, between €2,000 and €4,000, or more than €4,000). Note that the gender (below $|0.10|$), age (below $|0.15|$), and education (below $|0.20|$) variables are only slightly correlated with the different income ranges – at least for those who did indicate their income level. Hence, there is no evidence that any identified gender, age, or educational effect might be some sort of income effect.

Table 2: Sample demographics and fleet of cars.

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	
Number of cars in the household		
0	2.7	
1	41.1	
2	41.0	
3 and more	15.2	

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 people with a car-driver's license, based on a representative survey on the mobility in Germany (MiD, 2010). To the author's knowledge, there is no data on the income distribution of the target population (i.e. potential car buyers from Germany) available.

3 Empirical results and discussion

3.1 Testing for fatigue, learning, and lexicographic choices

Given the demanding design of choice sets, it is appropriate to control whether, for example, fatigue or learning by respondents could have significantly affected choices and therefore model coefficients. For this purpose, the standard logit specification was estimated three times: using all six, only the first three, and only the last three choice sets, respectively. Applying a likelihood ratio test, the restricted model (i.e. all six choice sets) was compared with the separately estimated models (i.e. only the first three and only the last three choice sets). The null hypothesis of equal coefficients across the first and the last three choices could not be rejected at the 95% significance level ($\chi^2(15) = 22.50$). In view of evidence from Ladenburg and Olsen (2010, 2008) on gender-specific starting point bias, this procedure was repeated for men and women separately. Again, the null hypothesis of equal coefficients across the first and the last three choices could not be rejected at the 95% significance level, neither for men ($\chi^2(14) = 20.60$) nor for women ($\chi^2(14) = 18.82$). It thus seems that the starting point bias (or learning effect) is not of significant importance here. Therefore, using all six choices per respondent for the estimation process seems reasonable.

Furthermore, the choice data was checked for lexicographic choices. It was found that 103 of the 598 respondents (17%) have chosen lexicographically; thereof, 40% used fuel costs, 39% fuel availability, 8% engine power, 7% price, and 6% CO_2 emissions as "sorting attribute". If the fuel type is also considered as possible "sorting attribute", then a total of 175 respondents (29%) were found to have chosen lexicographically; most respondents who have chosen consistently the same fuel type picked gasoline (33%) or diesel (26%). Compared to the total shares of lexicographic choices reported by Sælensminde (2006), the percentage in this sample is rather at the lower bound. It should however be noted that Sælensminde analyzed data from a rather "simple" choice experiment, including only two trip alternatives which were described using three attributes. Therefore, there is no indication that respondents increasingly used lexicographic choices here due to increased choice complexity.[23] It should further be noted that, as in this paper's

[23] According to Sælensminde (2006), lexicographic choices, which do not represent lexicographic preferences, may basically arise for two reasons: (1) simplification, as the choice task

choice experiment there were seven alternatives to choose from, the overall best values of three-level attributes appeared mostly twice or even three times in each choice set. For example, the lowest level of fuel costs (i.e. €5/100km) appeared twice in 67% and three times in the remaining 33% of all choice sets. Likewise, the highest level of network density (i.e. 100%) appeared twice in 62% and three times in 34% of all choice sets. It seems thus likely that many of the lexicographic choices observed in this study represent actual preferences. To sum up, considering choices from all observed respondents for model estimation seems appropriate.

3.2 Parameter estimates for standard and mixed logit

The estimation results are given in Table 3. The second column provides the estimates of the standard logit model which helped to identify relevant variables for the mixed logit model, whose estimates are provided in the last three columns.[24] In the following, we will primarily refer to the latter one, but also consider differences between both specifications.

A likelihood ratio test rejects the standard logit specification ($\chi^2(10) = 1621.56$) relative to our mixed logit specification. That is, allowing for random parameters and correlation over time leads to a significant improvement of model fit in this case. The significant standard deviations also indicate that there are taste variations across the sampled population.

We find that the fuel type of the passenger car is a relevant attribute. On average, diesel is preferred by car buyers.[25] As expected, denser service station

is too difficult, or (2) a study design using widely differing choice alternatives or attribute levels. Depending on the "sorting attribute" used by a respondent and the reason for his/her lexicographic choices, WTP estimates may be lower or higher than the real one.

[24]Note that for log-normally distributed variables (i.e. fuel costs, fuel availability and CO_2 emissions) the presented estimates and standard errors for mean, median and standard deviation are computed after the estimation using Stata's `nlcom` command, as described in Hole (2007). The Stata output after the `mixlogit` command gives the mean (b) and standard deviation (s) of the natural logarithm of log-normally distributed coefficients. The median, mean and standard deviation of the coefficient itself can be computed by $\exp(b)$, $\exp(b + s^2/2)$ and $\exp(b + s^2/2) \times \sqrt{\exp(s^2) - 1}$, respectively (Shimizu and Crow, 1988). For fuel costs and CO_2 emissions, actually, the median and the mean formulas have to be additionally multiplied by minus one. This is due to the sign change introduced in the estimation process (Hole, 2007).

[25]Note that, in Germany, the annual vehicle tax for diesel-driven cars is higher than for gasoline-driven cars, while the tax on diesel fuel is lower than the tax on gasoline. Interestingly, Beck et al. (2011) report diesel to be the least preferred fuel type (behind gasoline and hybrid) in their Australian sample.

Table 3: The estimated standard and mixed logit models.

	Standard logit	Mixed logit		
Variable	Mean	Mean	Median	SD
Purchase price	−0.0322***	−0.0543***		
	(0.00367)	(0.00564)		
Purchase price × Low UPB	−0.0592***	−0.101***		
	(0.0133)	(0.0198)		
Gasoline	−0.0855	−0.803***		2.130***
	(0.0548)	(0.132)		(0.138)
Hybrid	−0.244***	−0.825***		1.676***
	(0.0628)	(0.131)		(0.138)
LPG/CNG	−0.295***	−1.041***		1.833***
	(0.0635)	(0.141)		(0.138)
Biofuels	−0.715***	−1.347***		1.285***
	(0.0700)	(0.129)		(0.136)
Hydrogen	−0.406***	−1.145***		1.773***
	(0.0648)	(0.136)		(0.142)
Electric	−1.005***	−1.809***		1.304***
	(0.0754)	(0.148)		(0.164)
Engine Power	0.00597***	0.00981***		0.0153***
	(0.000652)	(0.00123)		(0.00189)
Fuel availability	0.0123***	0.0259***	0.0127***	0.0460***
	(0.000610)	(0.00238)	(0.00137)	(0.0103)
Fuel costs	−0.0753***	−0.195***	−0.0807***	0.427***
	(0.00325)	(0.0207)	(0.00794)	(0.105)
CO_2	−0.00267***	−0.00585***	−0.00199***	0.0161***
	(0.000425)	(0.000724)	(0.000614)	(0.00441)
CO_2 × Woman	−0.000923*	−0.00145		
	(0.000527)	(0.000943)		
CO_2 × Under 45	−0.00142***	−0.00262***		
	(0.000461)	(0.000770)		
CO_2 × HEEQ	−0.00110**	−0.000848		
	(0.000462)	(0.000772)		
Persons	598	598		
Observed choices	3588	3588		
Log likelihood	−6095.39	−5284.61		
McFadden's Pseudo R2	0.127	0.243		

Note: Standard errors in parentheses. Asterisks denote statistical significance at the *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level.

networks and lower fuel costs per 100km increase choice probabilities. Furthermore, approximately 74% of individuals in our sample prefer more horsepower.[26]

The price coefficient enters both the standard and the mixed logit model significantly with a negative sign. While this is not surprising, the magnitude of the difference between the price coefficients for individuals who indicated an UPB below €20,000 and those who did not is, at least, notable. The resulting coefficient for individuals with a lower UPB, which is given by the sum of the general price and the interaction term coefficients, is almost three times as large in both model specifications. This represents a significantly varying price sensitivity among potential car buyers, depending on the intended price segment for their next car. Considering that we found no direct income effects, this is particularly interesting. It suggests that it is not primarily a matter of income, but rather of the total value of a car that is intended to be bought.[27]

Most notably, we find that the emissions performance of a car influences choice decisions. The CO_2 variable enters our model significantly, negatively signed. This might reasonably be expected. According to a recent study commissioned by the German Federal Ministry for the Environment and the Federal Environment Agency (BMU, 2008), environmental awareness of Germans is high. In this study, 91% of the population rate environmental protection as important. Moreover, 75% blame the car industry for contributing strongly to pollution by not developing environmentally friendly cars. However, this does not automatically mean that people are willing to act on their own account in this regard. Our results suggest that people's environmental and climate concerns indeed motivate them to consider CO_2 emissions as a relevant attribute in car choices.[28] But the influence of this attribute varies in the sampled population, as indicated by the associated standard deviation.

It is important to note that the estimated parameters for the random-effects

[26] If $\beta \sim \mathrm{N}(b, s)$, then $(\beta - b)/s \sim \mathrm{N}(0, 1)$. Thus, $\mathrm{P}(\beta < 0) = \Phi(-b/s)$, where Φ is the cumulative standard normal distribution.

[27] It should be noted, however, that on average the indicated upper price bounds increase with income in the sample.

[28] Since July 2009, the annual vehicle tax is partly based on a vehicle's CO_2 emissions: for each gram exceeding the predefined level of 120g per km, €2 have to be paid each year. However, this holds only for newly registered vehicles. Note that respondents maybe anticipated this tax reform when making their choices. Beck et al. (2011) provide evidence that individuals are more likely to choose fuel-efficient vehicles if (annual or variable) emissions charging is present.

CO_2 variable refer to the reference group (i.e. men aged 45 and older without an HEEQ). The fixed-effects interaction terms between the CO_2 and the demographic variables imply shifts in the mean and median of the population distribution (Andersen et al., 2009). Therefore, in the mixed logit model, the CO_2 coefficient of every other demographic group is also (shifted) log-normally distributed with the same standard deviation. By allowing for heterogeneity in unobserved factors, however, the statistically significant effects of gender and educational level observed in the standard logit model vanish. Though all interaction terms still have the expected sign (based on the underlying hypotheses), only the age variable enters the mixed logit model significantly. Thus, we find strong evidence for an age effect on preferences for low-emission cars, whereas the evidence for gender and education effects is rather weak. In particular, we can confirm the hypothesis that individuals under 45 years of age assess the CO_2 emission variable more negatively than older individuals do.

3.3 Willingness-to-pay estimates

The insights that can be directly drawn from parameters in a nonlinear model are very limited. A useful way to illustrate the influence of CO_2 emissions and the observed differences in price sensitivity is to derive the associated willingness to pay (WTP). That is, the amount an individual is willing to pay in addition to the baseline price p for a marginal decrease of the baseline emissions e, without a change in utility. This is simply the ratio β_e/β_p of the emission (β_e) and the price (β_p) coefficients. As the price coefficient is fixed, this ratio follows the same distribution as the negative emission coefficient. In our case this implies that the WTP is log-normally distributed. Table 4 gives for each demographic group the median and mean of the WTP distribution for a one gram decrease in CO_2 emissions per km separately for the two price segments. The related standard errors are calculated with the help of Stata's `nlcom` command.

In the following discussion we will refer to the median WTP which divides the cumulative distribution function in half.[29] Note that in a (right-skewed) lognormal distribution the standard deviation has a significant positive effect on the mean.

[29] It is important to note that the given WTP measures are point estimates which are measured with uncertainty. We also have to take into account the standard errors.

Table 4: WTP (in €) for an emission reduction of 1g of CO_2 per km.

	Median			Mean	
Demographic groups	Coef.	(SE)		Coef.	(SE)
Higher UPB (i.e. €20,000 or above)					
Reference group	36.65	(11.81)		107.57	(16.85)
Men, 45 and older, with HEEQ	52.26	(15.23)		123.32	(20.31)
Men, younger than 45, without HEEQ	84.85	(15.60)	***	155.77	(22.23)
Men, younger than 45, with HEEQ	100.45	(17.33)	***	171.14	(24.24)
Women, 45 and older, without HEEQ	63.38	(19.27)		134.30	(23.61)
Women, 45 and older, with HEEQ	78.98	(21.23)	*	149.91	(25.94)
Women, younger than 45, without HEEQ	111.57	(21.23)	***	182.49	(27.27)
Women, younger than 45, with HEEQ	127.18	(22.25)	***	198.10	(28.71)
Lower UPB (i.e. below €20,000)					
Reference group	12.79	(4.26)		37.54	(6.53)
Men, 45 and older, with HEEQ	18.24	(5.45)		42.99	(7.67)
Men, younger than 45, without HEEQ	29.61	(5.87)	***	54.36	(8.70)
Men, younger than 45, with HEEQ	35.06	(6.47)	***	59.81	(9.38)
Women, 45 and older, without HEEQ	22.12	(6.89)		46.87	(8.85)
Women, 45 and older, with HEEQ	27.56	(7.57)	*	52.32	(9.65)
Women, younger than 45, without HEEQ	38.94	(7.85)	***	63.69	(10.46)
Women, younger than 45, with HEEQ	44.38	(8.21)	***	69.14	(10.96)

Note: All estimated coefficients are significant at the $p< 0.01$ level; asterisks denote significant differences to median WTP of the reference group at the *** $p< 0.01$, ** $p< 0.05$, and * $p< 0.1$ level.

Since in our model the estimated standard deviations for the WTP measures are relatively high[30] (indicating very heterogeneous preferences and resulting in a high skewness of distributions), the much less outlier-sensitive median seems to be the appropriate measure of central tendency here. Beyond this more technical reason, we assume that the median WTP is more meaningful also from a practical perspective. For example, approximately 77% in the reference group are actually not willing to pay the €108 given by the mean value.[31] But politicians and car manufacturers might be interested in the average person's WTP value. This is rather given by the median WTP.

First of all, it is striking how big the difference in the amount of WTP is, depending on the stated UPB. As the price coefficient is almost three times as large in the low UPB case, the associated WTP is roughly a third of the amount as in the high 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 obviously more likely to consider the purchase price as decisive attribute than individuals who intend to buy a relatively expensive car; therefore, their WTP for improvements in other car attributes is lower. The reference group, for instance, is on average willing to pay about €24 less if we look at the low instead of the high UPB case.

Furthermore, there are differences in the WTP estimates depending on the individual's gender, age, and educational level. In particular, we find younger individuals to have a significantly higher WTP (indicated by the asterisks in Table 4). The fact that a group consists of individuals aged under 45 years more than doubles or triples the median WTP, compared to the reference group. This holds for each price segment. Likewise, it seems that women are willing to pay more than men, and individuals with an HEEQ more than those without. However, the observed differences in WTP depending on gender and educational level are of weak statistical significance or insignificant.

The observed age effect is in line with findings by Hersch and Viscusi (2006) who examined intergenerational differences in support for climate change policies. Their results suggest that "younger age groups may believe that they will person-

[30]The standard deviation with respect to a higher UPB is €296.85 (standard error: 86.11), and with respect to a lower UPB €103.60 (30.80).

[31]If $X \sim \Lambda(b, s)$, then $\mathrm{P}(X < x) = \Phi((\ln(x) - b)/s)$, where $x > 0$ and Φ is the cumulative standard normal distribution (Shimizu and Crow, 1988).

ally benefit more from climate change policies" and are therefore more likely to be willing to pay higher gasoline prices to protect the climate. It is reasonable to assume that people's self interest is determining the age-related differences in this paper as well. Daziano and Bolduc (2011), who recently analyzed stated car choices made by Canadian consumers, provide stronger evidence for the existence of a gender effect. Using Bayesian methods to estimate a hybrid choice model, they find that, on average, women are willing to pay about 2,000 Canadian dollars more than men for a low-emission car. In the literature, differences in gender socialization are discussed as a possible explanation for observed differences between women and men regarding environmental awareness and behavior. For example, it is often argued that the traditional role of women as caregivers and nurturers implies higher environmental concern and stronger willingness to contribute (see Hunter et al., 2004; Zelezny et al., 2000, for overviews). The usual rationale for the effect of education on environmental attitudes and behavior is as follows: well-educated people are better informed about potential environmental risks and damages, and therefore have a stronger willingness to contribute to the protection of the environment (e.g., Torgler and García-Valiñas, 2007).[32] However, Torgler and García-Valiñas (2007) point out that not only formal education (specified by levels, degrees or number of years), but also informal education can be influential. This maybe explains the relatively weak education effect in this paper, as we only distinguished in terms of formal education (by the possession of an HEEQ).

Unfortunately, it is not straightforward to translate the derived WTP into a WTP per tonne of CO_2 (tCO_2), and therefore to compare our results with existing literature.[33] This is due to the fact that different individuals will travel a different total mileage with their cars which results in a different total emission reduction. However, by using the average annual mileage (approximately 14,300km; DIW, 2008) and the average age of a car at the time of its abandonment (approximately

[32]Findings of Viscusi and Zeckhauser (2006) are interesting in this regard. In 2004, they surveyed over 250 Harvard students, thus a group of relatively well-educated individuals. On average, the students estimate the climate-change-induced temperature increase in Boston consistently with the Intergovernmental Panel on Climate Change (IPCC) estimate. In their paper, Viscusi and Zeckhauser provide a rough calculation that converts the students' willingness to pay higher gasoline taxes to curb climate change into an amount of 1,500 dollars per year.

[33]Brouwer et al. (2008) give an overview of the still very limited literature on WTP estimates for climate policy based on stated preference methods. It should be noted that most studies cited therein survey the WTP for the use of a tonne of CO_2 equivalent rather than for its abatement.

ten years[34]; KBA, 2008), we may obtain at least an idea of what the WTP per tCO_2 might be. Over the course of ten years, given an annual mileage of 14,300km, a reduction of 1g of CO_2 per km yields a total reduction of 0.143 tCO_2. Dividing the marginal median WTP by this 0.143t results in an approximation of the average WTP per tCO_2. For the reference group, the median WTPs in the high and low UPB case could be accordingly translated into €256.29 and €89.44 per tCO_2, respectively.

Note that it is possible that this value overestimates the true WTP per tCO_2. During the interview, respondents were asked to indicate the annual mileage they intend to drive with their new car. In our sample the intended annual mileage is 19,500km, on average. Therefore, it is likely that the 14,300km, used in the calculation above, underestimate the total emissions reduction. By comparison, the sample average of 19,500km would result in a total reduction of 0.195 tCO_2, which could be translated analogously into €187.95 and €65.59 per tCO_2, respectively. Nonetheless, all values are extremely high compared to the price that would have to be paid for a CO_2 certificate on the market for emission certificates in Europe (which could be used to offset one's own emissions).

A possible explanation for the high WTP might be the ongoing media presence of global warming and climate change issues and its strong impact on public awareness. Results of Sampei and Aoyagi-Usui (2009) support this assumption. In their recent study, they find evidence for a positive correlation between Japanese newspaper coverage of global warming and public concern for the issue. Though we do not have concrete figures regarding German media, an increase in coverage of climate change was definitely observable in recent years. Hence, people are aware that their demand for motorized mobility accounts for a substantial share of anthropogenic climate change. Our results seem to suggest that Germans are willing to pay for low-emission cars to fulfil their responsibility in this regard, and simultaneously to maintain their mobility.

Besides, the used survey method may also influence the results. Since stated choices by respondents lack the monetary commitment, an overestimation of the true willingness to pay is possible. This phenomenon is referred to as hypothetical bias, which is inherent to any stated preference approach. Murphy et al. (2005),

[34]Note that the reason for abandonment is not identified and that in 2007 some 20% of abandoned cars were licensed again abroad.

for example, assess the magnitude of the hypothetical bias using a meta-analysis. The median ratio of hypothetical to actual value reported by Murphy et al. is 1.35, whereas some evidence is provided that choice-based methods are associated with less hypothetical bias. In a choice experiment, however, the scaling of the price vector may be influential in terms of WTP estimates, though existing evidence is ambiguous (see e.g., Carlsson and Martinsson, 2008; Hanley et al., 2005). Nonetheless, when it comes to the quantification of non-market goods, stated preference methods in general and choice experiments in particular have their indisputable merits (e.g., Louviere et al., 2000).

4 Summary and conclusion

Motorized individual transport strongly contributes to global CO_2 emissions, due to its intensive usage of fossil fuels. Current political efforts addressing this issue (i.e. emission performance standards in the EU) are directed towards car manufacturers. This paper focused on the demand side. We examined whether CO_2 emissions per km is a relevant attribute in car choices. Based on a choice experiment among potential car buyers from Germany, standard and mixed logit specifications were estimated. In addition, distributions of willingness-to-pay measures for a marginal abatement of CO_2 emissions were obtained. Our results suggest that the emissions performance of a car matters substantially, but its consideration varies heavily across the sampled population. In particular, some evidence on gender, age and education effects on climate concerns is provided.

What do we gain from these empirical findings? The gain is twofold. On the one hand, given the emissions performance standards in the EU, the obtained WTP estimates may help car manufacturers to adopt an appropriate strategy. In a very simplified setting, the sum of possible penalties for exceeding the EU standard and WTPs for cars with lower emissions defines the limit for reasonable costs for further abatement measures. On the other hand, knowing people's preferences with respect to public goods (such as climate protection) generally helps to design effective and economically efficient policy instruments. The results seem to suggest that German car buyers are aware of climate change and its anthropogenic character, and that – on average – they are willing to pay substantial amounts of money to fulfil their responsibility in this regard. However, in view of demographic changes in Germany, the observed effect of age indicates that the public's willingness to contribute to climate protection might change again in the future.

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