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Private Households' Preferences for Alternative Fuel Vehicles in Germany – An Empirically Founded Analysis of Adoption Decisions, Willingness-to-Pay, and Policy Scenarios

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Von der Fakultät für Wirtschaftswissenschaften der
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André Hackbarth

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Contents

1.1 Background and Motivation

Climate change and local air pollution require immediate action and significant reductions in greenhouse gas (GHG) emissions and pollutants, particularly from activities based on the combustion of fossil fuels, as the social costs of global warming and air pollution can be devastatingly high (see e.g. Ciscar et al., 2018, 2019; Stern, 2007). Thus, end of 2019 the European Commission announced the 'European Green Deal'. It reinforces existing emission targets and outlines a long list of initiatives aiming at transforming Europe to become climate-neutral by 2050. In particular, this means to significantly reduce resource consumption in all sectors of the economy and converting them towards being almost entirely based on renewable energy sources (EC, 2019). Above all, actions are especially needed in the transportation sector, as it is the only sector in which emissions remained constant or even increased compared to 1990 levels, especially over the last years (EEA, 2019a). Furthermore, road transportation is responsible for a considerable and increasing share of GHG and air pollutant emissions (e.g. nitrogen oxides or particulate matter). Thus, the transportation sector plays a central role in fighting the major environmental and human health challenges and in achieving the goal to stabilize global warming below 2 °C by the end of the century, as envisaged in the Paris Agreement.

However, since transportation is also crucial for economic activity and social participation and since the automotive industry has a tremendous importance in many economies around the globe and especially in Germany, where the political interest in the prosperity of the large automotive industry is particularly pronounced, scientists and policymakers disagree over the optimal means and timeframe for achieving the emission mitigation targets (Lah and Lah, 2019; Kleinert, 2017; Dimitropoulos, 2016). Hence, it is not very surprising that the strategy for reducing GHG emissions and air pollutants in the transportation sector has long relied on voluntary or easily achievable commitments of vehicle manufacturers to introduce more fuel-efficient and clean cars[1] (Metzler et al., 2019; Gössling and Metzler, 2017). As a result, the automotive industry has mainly focused on marginal improvements of combustion engines and the optimization of vehicles' test cycle performance, without reducing the sales of (large) fossil-fueled vehicles (e.g. sport utility vehicles, SUVs) and has largely neglected the development and shift to new drivetrain technologies or smaller vehicles. This is particularly true for the German premium vehicle manufacturers (Metzler et al., 2019; Kleinert, 2017). However, in the light of tightening regulations at the European level due to the lack of emission reductions in

[1] In this thesis the terms 'vehicle' and 'car' are used as synonyms.

past years, several vehicle manufacturers are now facing severe penalties from impending non-compliance with the European efficiency standards, and are therefore trying to increase their AFV[2] sales – supported by various monetary and non-monetary governmental incentives or regulations (quotas, infrastructure) at the national or regional level.

Despite these concerted efforts, the uptake of AFVs still falls far short of policy targets. Thus, research is needed to better understand the heterogeneous preferences and purchase decisions of private vehicle buyers in order to surpass potential barriers and increase the adoption and diffusion of AFVs or smaller vehicles, for instance, through the development of better fitting marketing and communications strategies and supporting policy measures.

Against this background, the main objective of this doctoral thesis, which comprises three related articles, is to investigate the private households' preferences for vehicle attributes in vehicle purchase decisions – i.e. the choice of a specific fuel type or propulsion technology (e.g. gasoline, diesel, hybrid) and a specific body type (e.g. SUV), with the main focus being on the former. For this purpose, a survey was conducted among recent or potential buyers of new cars. Furthermore, based on these empirical results, willingness-to-pay (WTP) values were calculated and scenario analyses were conducted to assess the impact and economic feasibility of certain policy measures or improvements in vehicle attributes implemented by car manufacturers. This thesis focuses on the case of Germany, as it stands out from the European average in several ways: it is the largest emitter of CO_2 emissions (Eurostat, 2020), has the largest vehicle fleet and number of new vehicle registrations per year (ACEA, 2020a), one of the largest average emission rates of new cars (Mock, 2019), and the largest automobile sector in Europe (ACEA, 2020a). Hence, Germany is particularly important for a success of emission mitigation measures in the transportation sector on the European level.

The remainder of this introductory chapter is organized as follows. Section 1.1 gives some background information on the transportation sector's societal costs. Section 1.2 presents the main research questions and the scope of the doctoral thesis. Section 1.3 introduces the different vehicle technologies, the current developments in the automotive industry and on vehicle markets, as well as the current GHG emissions and transportation policy framework conditions in Europe and Germany. Section 1.4 introduces the methodological approaches applied in the vehicle purchase research literature in general and in this thesis in particular. Section 1.5 presents the structure of the thesis, a brief description of the three articles, and highlights the

[2] AFVs are vehicles that run on liquid or gaseous fuels other than gasoline and diesel, or at least partly on electricity. These include biofuel vehicles (BVs), natural gas vehicles (NGVs), hydrogen (fuel cell electric) vehicles (FCEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fully battery electric vehicles (BEVs).

overall scientific contribution of this dissertation. Section 1.6 outlines potential shortcomings and limitations of the chosen methodological approaches. Finally, Section 1.7 presents starting points for future research.

1.1.1 Transportation Sector's Impact on Society

Almost the entire global transportation system is currently based on the combustion of oil-based fuels. With a share of approximately 71%, particularly road transportation is the main driver of European oil consumption (EEA, 2020c). One consequence of the burning of fossil fuels is the increase in GHG concentrations in the atmosphere and an increase in global average temperatures (IPCC, 2014), a trend that accelerated since the mid-20th century and particularly gained in momentum over the last two decades. Accordingly, extreme changes in global temperature which are accompanied by significant sea-level rise, will cause a wide range of environmental, societal, and economic effects, including coastal floods, ocean acidification, spreading of infectious diseases, and the extinction of species, as well as the increasing frequency and intensity of extreme weather phenomena, such as extreme heat, droughts, wildfires, heavy precipitation, river floods, and storms (IPCC, 2014, 2018). These effects would have severe impacts on ecosystems, economic sectors (especially food production), water resources, settlements, infrastructure, and human lives (human health and well-being), albeit with regionally varying patterns[3] (EEA, 2020b; IPCC, 2014, 2018). Finally, they could lead to increased climate-induced poverty, human migration (climate refugees), and increased geopolitical and security risks in the most affected areas or their neighboring countries and regions (EEA, 2019b; Carr, 2018).

The transportation sector is contributing 27% of all European GHG emissions and accounts for about 31% of total final energy consumption (EEA, 2019a, 2020b), which is slightly above the global average (IEA, 2020a). This currently makes the European transportation sector the second-largest emitter of CO_2 emissions after energy generation (EEA, 2020b). Especially in industrial countries, the transportation sector often is the only main sector with increasing emissions. For instance, from 1990 to 2017, road transportation CO_2 emissions, which are responsible for 73% of the sector's total emissions in the EU-28 and of which passenger cars are responsible for about 44%, increased by 23% (EEA, 2020a). The IPCC, the most important

[3] These vary with the levels of warming, development and vulnerability, as well as geographic location and the type of applied adaptation and mitigation measures (IPCC, 2018). Furthermore, climate change effects do not have to be negative, i.e. some world regions (mostly those being below average global temperature today) could benefit from global warming, especially in agriculture or energy demand (heating). Generally, a geographical North-South divide in the Northern hemisphere will be observable (Ciscar et al., 2019; Tol, 2018).

international organization for scientifically assessing climate change, projects the GHG emissions from the transportation sector to double by 2050 if no countermeasures are taken (IPCC, 2014).[4] Hence, transportation would even more strongly contribute to global warming and its adverse effects in the future than today.

Besides its impact on global warming, another consequence of the burning of fossil fuels is the emission of a wide range of harmful substances, e.g. nitrogen oxides (NO_x), particulate matter (PM), and ground-level ozone. They have substantial negative impacts on air quality and human health (mainly cardiovascular and respiratory diseases). For instance, ambient air pollution is estimated to cause around 4.1 million premature deaths worldwide every year, of which more than 400,000 are allotted to Europe, mainly due to PM emissions (EEA, 2019c; WHO, 2018). Road transportation is a major source of such air pollution, especially in cities. It is responsible for about 22% of PM emissions and around 40% of NO_x emissions in the EU (at roadside locations even more than 60-80%), with most of the latter coming from diesel-fueled vehicles (Niestadt and Bjørnåvold, 2019; EEA, 2019c; Schmidt, 2016; Karagulian et al., 2015). This effect is reinforced by the fact that diesel vehicle emissions are greatly exceeding their certification limits[5] which causes about 5000 premature deaths per year in Europe (850 in Germany[6]), of which almost 40% could be avoided if current emission standards would be enforced (EEA, 2019c; Chossière et al., 2018; Anenberg et al., 2017).

Transportation also is a substantial source of noise pollution which can have negative impacts on hearing, sleep, mental health, and the cardiovascular system. For instance, in the EU almost 130 million people are exposed to traffic noise levels exceeding European thresholds, with road traffic being its leading cause (Niestadt and Bjørnåvold, 2019; EEA, 2016). Finally, the transportation sector leads to the following additional fuel-unrelated external effects and social costs: infrastructure costs, accidents (traffic safety), habitat damage (landscape and nature consumption), and congestion (Jochem et al., 2016; Petruccelli, 2015).

Such external costs in transportation occur if individuals are faced with incorrect incentives because they do not have to fully bear the negative effects their travel decisions might impose

[4] CO_2 emissions from fossil-fueled vehicles are directly related to their fuel consumption, as the combustion of one liter of petrol or diesel produces 2.34 kg CO_2 and 2.68 kg CO_2, respectively (EIA, 2016).
[5] For instance, real-world emissions of new diesel-fueled passenger cars exceed their European type-approval values measured in test stands up to 16 times, with increasing divergence between both average values over time, from 8% in 2001 to about 40% in 2016 (Chossière et al., 2018; Tietge et al., 2017a,b; Fontaras et al., 2017; Schmidt, 2016; Ntziachristos et al., 2014). A reason for this development is the possibility for tampering with the official laboratory tests of the European vehicle testing scheme (Transport & Environment, 2019; Tietge et al., 2017a,b).
[6] In total, approximately 6000 (1.8%) cardiovascular deaths in Germany are caused by long-term exposure to NO_x emissions (Schneider et al., 2018).

on uninvolved third parties, and thus do not take them into account entirely.[7] Without policy intervention this situation leads to welfare losses (Korzhenevych et al., 2014).

The total external costs of transportation in the EU-28 (including congestion costs of €271 billion) sum up to €987 billon, which translates to 6.6% of the gross domestic product (GDP) in 2016. Road transportation, especially passenger cars, is the principal cause of these external costs, accounting for 83% of the total costs (€820 billion). In general, the most important cost categories are accident costs (29% of total costs; in some studies up to 50%, see van Essen et al., 2019a; Schreyer et al., 2007) and congestion costs (27%). Both are fuel-type unspecific and, thus, cannot be reduced by an increased diffusion of AFVs. Environmental costs (e.g. climate change 14%, air pollution 14%, or noise 7%) account for the remaining 44% of the overall damages (Schroten et al., 2019; van Essen et al., 2019a). However, climate costs[8] can become the second-largest impact factor in scenarios with more pronounced global warming (up to 37% of overall costs; Becker et al., 2012). This result indicates that policymakers should also prioritize action to address the other elements of transport externalities in addition to the costs of global warming (COACCH, 2018; Link et al., 2016).

External costs induced by the transportation sector in Germany sum up to about €172 billion (van Essen, 2019a), with a bandwidth ranging from €40-375 billion (depending on assumptions, the year of estimation (i.e. earlier estimations resulted in lower cost estimates), or the inclusion of congestion costs[9], see Puls, 2013; Schreyer et al., 2007), with road transportation being responsible for the largest share (96%; passenger cars 66% of total costs), which translates to 5.8% of the current GDP (van Essen et al., 2019a). Regarding the importance of cost categories and their ranking, the German findings are comparable to the European results mentioned above (Puls, 2013; Schreyer et al., 2007).

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[7] Only about 45% of the external and infrastructure costs of road transportation are currently compensated by transportation taxes and fees (with 81% of these revenues stemming from passenger cars). The highest average external cost coverage ratio (about 50%) in Europe and Germany is found for passenger cars (van Essen et al., 2019b; Tscharaktschiew, 2014). However, under-taxation seems to be an issue for diesel vehicles in particular (Santos, 2017).

[8] The estimated cost of damage caused by climate change depends highly on the future developments of GHG emissions, the considered impact categories (e.g. floods, droughts, heat-related mortality, labor productivity), sectors, and economic model assumptions (e.g. discount rate, see also the discussion on social costs of carbon in Wang et al., 2019a; Pezzey, 2018; Rose et al., 2017; Nordhaus, 2017; Foley et al., 2013; Tol, 2008). The annual economic welfare loss due to climate change in Europe is estimated to range from €90-200 billion in 2050 and €250-2500 billion per year in 2080, respectively. Even the lower boundary of €250 billion corresponds to about 2% of EU GDP (Ciscar et al., 2018; COACCH, 2018; Farid et al., 2016; Hasse, 2012). For Germany, estimations suggest that climate change would cost about €27 billion per year by 2050, adding up to cumulative direct costs of €800 billion (including adaptation costs), which corresponds to 0.3-0.5% loss in GDP growth (Klepper et al., 2017; Lühr et al., 2014; Aaheim et al., 2012; Kemfert, 2007).

[9] For instance, congestion on German highways amounted to a length of 1.45 million km and a delay of 457,000 hours in 2017 (VDA, 2018).

1.1.2 Environmental Benefits of AFVs and Smaller Vehicles

AFVs in general and electric vehicles in particular offer the potential to reduce some of the external costs of road transportation, i.e. GHG emissions and local air pollutants, as they theoretically enable the utilization of renewable energy sources during operation and allow for locally emission-free driving (especially electric vehicles). These potential advantages of AFVs usually compensate for the up to 50% higher emissions of some AFVs during production (especially fuel cell electric vehicles (FCEVs) and battery electric vehicles (BEVs), due to the higher energy and raw material demand, e.g., for batteries), even if the electricity generation is still dominated by conventional power plants (for detailed life-cycle analyses see e.g. IEA, 2020b; Rosenfeld et al., 2019; Niestadt and Bjørnåvold, 2019; Regett et al., 2018; Pero et al., 2018; Woo et al.; 2017; Bauer et al., 2015).

For most use cases – i.e. average range requirements and average carbon intensity of the grid – a BEV is preferred over a FCEV, especially for (sub-)compact cars, while both perform significantly better concerning environmental parameters compared to conventionally fueled vehicles (Woo et al., 2017; Bhatia and Riddell, 2016). That is, after a mileage of 150,000 km an average European BEV emitted about 50% less life-cycle GHG emissions, although the results vary remarkably from 0% to 97% depending on study assumptions[10]. Accordingly, the mileage to offset the electric car's higher manufacturing-phase emissions ranges from 30,000-170,000 km (Kamiya et al., 2019; BMU, 2019; Agora Verkehrswende, 2019a; Wietschel et al., 2019; Rosenfeld et al., 2019; Hall and Lutsey, 2018; Moro and Lonza, 2018; Regett et al., 2018; van Mierlo et al., 2017; Woo et al., 2017; Fritz et al., 2016; Wolfram and Lutsey, 2016; Helms et al., 2011, 2016; Frieske et al., 2015).

Specific requirements (long distances) or conditions (electricity mix) could make FCEVs or plug-in hybrid electric vehicles (PHEVs) more advantageous than BEVs (and conventionally fueled vehicles), especially if the vehicles are larger, such as SUVs (Sternberg et al., 2019; Woo et al., 2017; Bhatia and Riddell, 2016). Particularly for SUVs changing the fuel type or

[10] It is important to mention that the climate balance of a BEV and FCEV depends on a number of influencing factors and thus can vary greatly. The most important are: the emissions from electricity and hydrogen generation, the emissions from vehicle production, which are largely determined by the energy mix (carbon-intensity) and, in the case of electric vehicles, the size of the battery, the total mileage of the vehicle and lifetime of the battery, the energy consumption of the vehicle, which is determined by the weight of the vehicle and its load (small or large car), the individual driving style, driving conditions (inner-city or highway driving), the base vehicle which it is compared to (fuel efficiency; diesel or gasoline), and the climatic conditions of the region (IEA, 2020b; Wietschel et al., 2019; Requia et al., 2019; Agora Verkehrswende, 2019a; Jungmeier et al., 2019; Wu et al., 2018; van Mierlo et al., 2017; Garcia and Freire, 2017; Faria et al., 2013; Hawkins et al., 2012), as well as charging patterns (Luca de Tena and Pregger, 2018; van Mierlo et al., 2017;) and availability of charging infrastructure (Plötz et al., 2018). Furthermore, battery recycling (4-10%) and second-life usage (42%) reduce the GHG emissions of (electric) vehicles which are assignable to the battery (Hall and Lutsey, 2018).

drivetrain technology is paramount, as the increase in SUV registrations resulted in making them the second-largest driver of the CO_2 emissions increase in the past decade after the power sector (IEA, 2019).[11] This is also due to the fact that average SUVs emit about 16 gCO_2/km more than equivalent medium-sized cars, so that a general 'downsizing' of vehicles could be beneficial in terms of decreasing the societal costs of transportation (Transport & Environment, 2018), especially if combined with an alternative fuel in general and electricity in particular – provided the acceptance of vehicle buyers.

1.2 Research Questions and Scope of the Thesis

Against this background, research is urgently needed to inform policy-makers and decision-makers in the automotive industry about the most promising actions for motivating new vehicle buyers to adopt an AFV or smaller vehicle. This is particularly important for disruptive innovations such as BEVs, as compared to conventional fuel vehicles (CFVs) or other AFVs individuals need to significantly change their usage behavior and habits (due to limited driving ranges and potentially long charging times) and, thus, might have unique preferences or characteristics (Li et al., 2017).

1.2.1 Objectives and Scope

The main objective of this thesis is to empirically analyze and evaluate preferences and (hypothetical) vehicle purchases of German private households in order to provide a profound view on car buyers' decision-making processes.

To reach this goal, the main objective is divided into four smaller tasks. The first task is to summarize the characteristics and results of the empirical literature on the adoption of passenger cars in general and AFVs in particular, in order to gain an overview of the *status quo* of international research on this issue (see also Appendix A.1) and to identify research gaps. Based on these insights, the second task aims at gathering data on (potential) purchase decisions of car buyers in Germany. For this purpose an online survey that includes a discrete choice experiment (DCE) is conducted among participants of a commercial market research panel. Based on the survey data, the third task is to empirically explore car buyers' preferences and

[11] That is, PHEVs on average emit between 15-55% less CO_2 in real-world operation compared to their ICEV counterparts. However, it was found that the real-world fuel consumption and corresponding CO_2 emissions of PHEVs exceed the values determined in official test cycles by a factor of 2-4 on average, which is mainly caused by the discrepancy between assumed shares of electric driving in PHEV type approvals and its actual share in the real-world usage of these PHEVs (Plötz et al., 2020).

vehicle choices with a specific focus on the heterogeneity of consumer segments, applying different model specifications. Building upon these results, the fourth task is to provide recommendations for vehicle manufacturers and policy-makers by calculating monetary valuations (WTP, compensating variation (CV)) and investigating market impacts of different policy measures and potential improvements of vehicle attributes in a scenario analysis.

The scope of this thesis is on private owners of new vehicles and households planning to buy one within a year. Hence, decisions of institutional, non-private vehicle buyers, i.e. fleet managers of companies or local governments, have not been considered in this dissertation.

To ensure the greatest technological openness possible, a comprehensive set of seven different fuel types and propulsion technologies has been considered – conventional fuel vehicles (CFVs), hybrid electric vehicles (HEVs), natural gas vehicles (NGVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and biofuel vehicles (BVs) – embracing all options that are currently available on the market. A reason for this decision is that the technology which will dominate the future vehicle market cannot be predicted with certainty today. It is rather more probable that the many different transportation needs and purposes (e.g. long distance travel, heavy duty transportation) cannot be covered by a single disruptive technology, and that the current alternatives will be at least needed as bridging technologies (Robinius et al., 2018). The AFVs considered in this thesis are introduced in Section 1.3.1 below.

Furthermore, the main focus of this dissertation is on passenger cars, as they account for almost 86% of all European vehicle registrations (ACEA, 2020a) and more than ¾ of all passenger kilometers in Germany (Follmer and Gruschwitz, 2019). Hence these are an essential means of mobility, especially for households in remote areas or those with special needs due to age or health status (Priessner et al., 2018). That is, non-passenger cars, especially lightweight freight and heavy duty vehicles have not been included in this thesis. The vehicle segments considered in this theses are also introduced in Section 1.3.1.

Moreover, this thesis focuses on Germany as the main area of study since it is the largest vehicle market and vehicle producer in the EU (ACEA, 2020a), so that political interest in the industry's performance is high. Moreover, Germany was and still is a forerunner regarding ambitious energy and climate policy (sustainable energy transition (*Energiewende*), electric mobility goals) and the implementation of governmental support mechanisms (see e.g. Section 1.3.4.2). However, at the same time, the German government is also very hesitant with regard to tightening vehicle emission standards on the European level in order to protect German vehicle manufacturers (e.g. Mercedes, Audi, Porsche, BMW), which are particularly known for large, heavy, premium, high-performance, and comparably fuel-inefficient vehicles, from their international competitors with, on average, portfolios of smaller and lower-performance vehicles and from the threat of penalties in the case of non-compliance with these strict emission standards (Gössling and Metzler, 2017; Kleinert, 2017). Finally, Germany has the second-most polluting new vehicle fleet in Europe (Mock, 2019) and is the largest emitter of GHG emissions and the largest consumer of energy in the EU (BP, 2020), which makes changes in the vehicle market towards low-emission vehicles and unbiased scientific research to increase their adoption even more important.

Finally, the scope of the thesis is the classic individual vehicle purchase. That is, alternative business models, such as vehicle leasing, car sharing, or multimodal packages including public transportation (mobility as a service), have not been included in the analysis. Specialized diffusion models for projecting the potential market shares of the respective AFVs, such as agent-based models, have not been applied neither, as they are not the main objective of this research.

1.2.2 Research Questions

Following from the objectives of this dissertation, four interrelated research questions guide the empirical investigation of private vehicle buyers' preferences and attitudes towards a broad number of (alternative) fuel and vehicle types as well as important vehicle attributes:

- **Q1:** How do the most important vehicle attributes (e.g. fuel type, vehicle type, purchase price, fuel cost, driving range, fuel availability, refueling/recharging time, CO_2 emissions) influence individuals' vehicle purchase decision or car buyers' choice process? Do they have to meet some minimum requirements?

- **Q2:** Does the acceptance of specific fuel types or propulsion technologies, the preference for specific body types and vehicle segments, and the importance of specific vehicle characteristics vary for distinct consumer groups? How can these different car buyer segments best be described (e.g. socio-demographic and household characteristics, attitudes, behavior)?

- **Q3:** How much are German vehicle buyers willing to pay for an improvement of the main vehicle characteristics?

- **Q4:** How do such beneficial changes, for instance induced by governmental policy measures, affect the potential market shares of the different propulsion technologies?

In three unique but related articles, this doctoral thesis strives to answer the four main research questions concerning individuals' vehicle purchase decisions in Germany. Figure 1.1 provides an overview of the linkages of these research questions, the scope, and the structure of the thesis. As indicated in the lowest box, the three articles included in this dissertation use different methodological approaches, which will be introduced in more detail in Section 1.4.3.

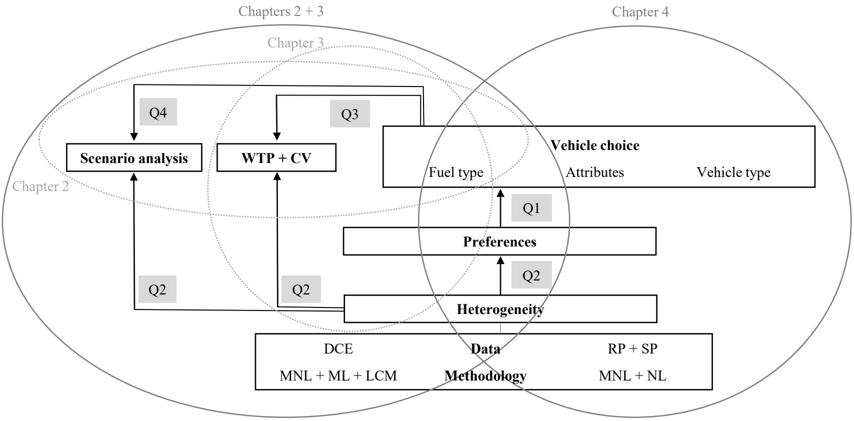

Figure 1.1: Scope and structure of the thesis

Source: Own illustration.

Notes: DCE = discrete choice experiment; RP = revealed preferences; SP = stated preferences; MNL = multinomial logit model; ML = mixed (error components) logit model; LCM = latent class model; NL = nested logit model; WTP = willingness-to-pay; CV = compensating variation; Q1-Q4 = research questions of the doctoral thesis.

1.3 Context of the Thesis

This section provides a brief description of the underlying conditions of the research by introducing the propulsion technologies and vehicle segments covered by the analysis. It further summarizes the developments and the *status quo* regarding the transportation sector in general and the automotive industry in particular, as well as the climate policies and vehicle policies in Europe and Germany, against the background of which the three studies were carried out.

1.3.1 Vehicles Considered

Transportation authorities usually categorize motor vehicles by several criteria, encompassing brand, model, and CO_2 emissions, as well as fuel type and segment. Vehicles are subdivided into segments according to optical (e.g. body type), technical (e.g. engine size, weight or length of cars) and market-oriented criteria to improve statistical comparability. In the EU, 9 segments are defined, while in Germany passenger cars are grouped into 13 segments: mini cars (Europe: car segment A; Germany: *Mini*), small cars (B; *Kleinwagen*), medium-sized cars (C; *Kompaktklasse*), large cars (D; *Mittelklasse*), executive cars (E; *Obere Mittelklasse*), luxury cars (F; *Oberklasse*), sport coupés (S; *Sportwagen*), multi purpose vehicles (M; two segments: *Mini-Van, Großraum-Van*), and sport utility vehicles (J; two segments: *SUV, Geländewagen*) as well as utility vehicles (*Utilities*), mobile homes (*Wohnmobil*) and others (*Sonstige*) for Germany only, with the latter being a category that includes all vehicles that do not fit into one of the previous segments (KBA, 2020a; Gössling and Metzler, 2017; EC, 1999).

If vehicles are categorized by propulsion technologies or fuel types, they usually are subdivided in two ways. Firstly, into conventional vehicles which run on the two fossil fuels gasoline and diesel, respectively, and AFVs, summarizing all vehicles that run (at least partially) on alternative fuels or electricity. Secondly, into internal combustion engine vehicles (ICEVs) which burn conventional fuels, biofuels or natural gas, and electric vehicles, which include both fully (BEVs) and only partially electrified vehicles, such as HEVs and PHEVs (which mainly or additionally rely on an ICE). The technological differences between ICEVs and electric vehicles are illustrated in Figure 1.2.

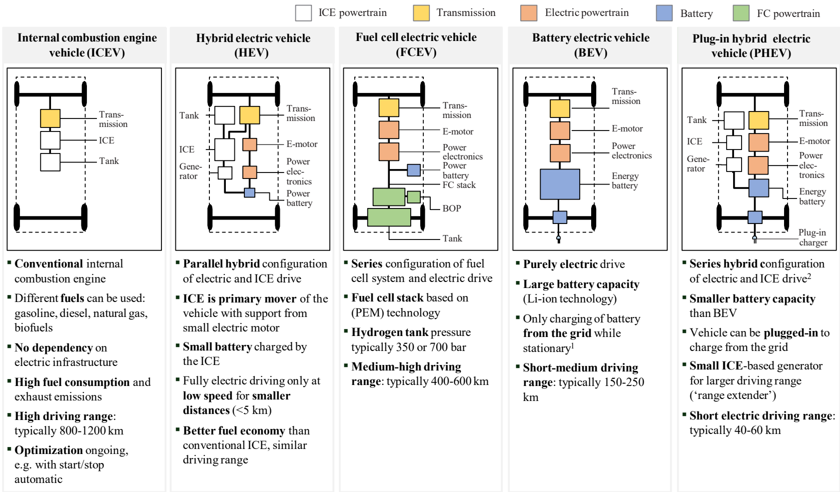

Figure 1.2: Drivetrain technologies

Source: Own illustration, based on Amsterdam Roundtable Foundation/McKinsey & Company (2014), McKinsey & Company (2010).
Notes: 1 = exchange of battery pack is possible; 2 = other configurations are possible; BOP = balance of plant-various required support components (eg. humidifier, pumps, valves, compressor); PEM = proton exchange membrane.

As already mentioned, *internal combustion engine vehicles (ICEVs)* comprise CFVs, using gasoline or diesel, NGVs, burning compressed natural gas (CNG) or a liquid propane-butane mixture (LPG), as well as BVs, using fuels derived from renewable biomass (e.g. soya, rapeseed, sugar cane or beet, residual wood, etc.)[12], to power an (specially adapted) internal combustion engine which produces noise and exhaust emissions. ICEVs are comparably inefficient, as only about 18-25% of the energy is converted into motion. NGVs have a CO_2 advantage of approximately 10-20% over CFVs. Currently, CFVs dominate the vehicle market and its surrounding support infrastructure, e.g. repair and refueling facilities (VDA, 2018; EEA, 2016).

Hybrid electric vehicles (HEVs) combine a conventional engine – usually running on fossil fuels – and a supplementary electric drive, which assists the conventional engine. The electricity for the electric drive is generated during regenerative braking or coasting and stored in a small battery. HEVs cannot be plugged in and recharged from the grid. Vehicle hybridization is a means for increasing fuel efficiency and reducing exhaust emissions of conventional vehicles. There are different forms of HEVs: A micro-hybrid supplies the vehicle's electrical system and

[12] Biofuels are not to be confused with the E10 (super petrol with 10% bioethanol admixture) currently available in Germany, but they consist of 85-100% bioethanol or biodiesel (biodiesel B100, bioethanol E85) and accordingly only a small or no proportion of conventional (fossil) fuel.

enables e.g. the start-stop-function of the combustion engine. A mild hybrid uses regenerative braking to charge the battery and its small electric motor to support the combustion engine when accelerating, or to turn it off to enable coasting. And a full hybrid which allows to electrically drive short stretches. Furthermore, HEVs differ regarding the configuration of the conventional and electric engine: in parallel hybrids, the electric motor and the combustion engine power the vehicle together, while in series hybrids the combustion engine is not directly connected to the wheels but to a generator, which in turn supplies the battery or electric engines with electricity. Combinations of both designs are possible, which allows using only one of the engines (either conventional or electric) or both in any intermediate ratio – although the pure electric mode usually is only available at low speeds and for short distances. The hybridization increases the complexity, mass and costs of vehicles, but enables efficiency gains of up to 20% compared to a CFV (EEA, 2016, 2020a; Frieske et al., 2019).

Plug-in hybrid electric vehicles (PHEVs) are similar to (full) HEVs but with a larger battery that can be charged via the power grid. The larger battery capacity allows using electricity as a primary engine source and, thus, longer distances in electric-only mode of up to about 60 km. However, battery capacity and electric driving range are smaller compared to BEVs. The combustion engine typically serves as a back-up when the battery is depleted and should only be used to cover longer distances to maximize efficiency gains and minimize the environmental impact. Disadvantages of PHEVs are the increased system complexity, costs, and mass compared to CFVs due to the presence of two drivetrains and a comparably large battery. A range-extended electric vehicle (REEV) is a special type of PHEV with some serial hybrid configuration (EEA, 2016, 2020a; Frieske et al., 2019).

Battery-electric vehicles (BEVs) are propelled exclusively by electrical energy stored in a rechargeable on-board battery to power one or more electric motors. The battery must be charged from the grid – either at any household socket or special fast-charging power outlets. The battery capacity also determines the maximum driving range of the vehicle. The tail-pipe emissions of BEVs are considered to be zero and they also produce less noise at low speeds. Although BEVs have the highest battery capacity of all electrified vehicles, they usually have shorter driving ranges compared to CFVs. They generally also suffer from lengthy recharging times and higher costs, thus requiring a significant change in usage behaviors and habits. However, compared to all other drivetrain technologies, BEVs have the highest energy-efficiency (at least 80% of the energy are transformed into propulsion), which is further enhanced by regenerative braking. In comparison to CFVs, the electric drivetrain substantially reduces the complexity of parts (EEA, 2016, 2020a; Frieske et al., 2019; Li et al., 2017).

Finally, *fuel cell electric vehicles (FCEVs)* are also powered exclusively by electricity. However, in FCEVs a fuel cell 'stack' converts hydrogen stored in an on-board pressure tank and atmospheric oxygen into the electrical energy needed to drive the electric motor. Therefore, FCEVs generally have advantages over BEVs that are comparable to those of CFVs, i.e. faster refueling times and longer driving ranges. Furthermore, due to the technological development stage of fuel cells (size, weight, and costs), FCEVs are economically more feasible in larger vehicles and for longer distances. Currently, though, only a very limited number of models and refueling stations are available on the market (EEA, 2016, 2020a; Frieske et al., 2019).

1.3.2 Transportation Sector

The automotive industry is one of the most important industrial sectors in the European economy. In 2018, the automotive sector was directly and indirectly responsible for 6.7% of total EU employment (14.6 million people) and accounted for 7% of EU's total GDP. Moreover, EU manufacturers produced 21% of global passenger car output (ACEA, 2020a,b). Especially in Germany, the origin of several car manufacturers and brands (e.g. Mercedes, Porsche, BMW, Volkswagen, and Audi) and about 5500 direct suppliers, the automotive industry is particularly important. In 2017, about 820,000 employees directly worked in the German automotive industry (VDA, 2018). But also as vehicle market the EU is of global significance, because it is the region with the highest amount of passenger cars, and in 2015 accounted for 27.8% of the world’s stock of passenger cars. However, in terms of new vehicle registrations, with 15.8 million vehicles sold, the EU-28 was only second after China (33%; 21.4 million passenger cars) in 2019 (OICA, 2020; Frieske et al., 2019). The EU market for new passenger cars is dominated by only five countries, which account for 76% of all registrations (ACEA, 2020a). Germany is the largest market with a share of 23%, about 3.4-3.6 million newly registered vehicles per year (Mock, 2019), and a stock of passenger cars of 47.716 million units in 2019 (KBA, 2020b).

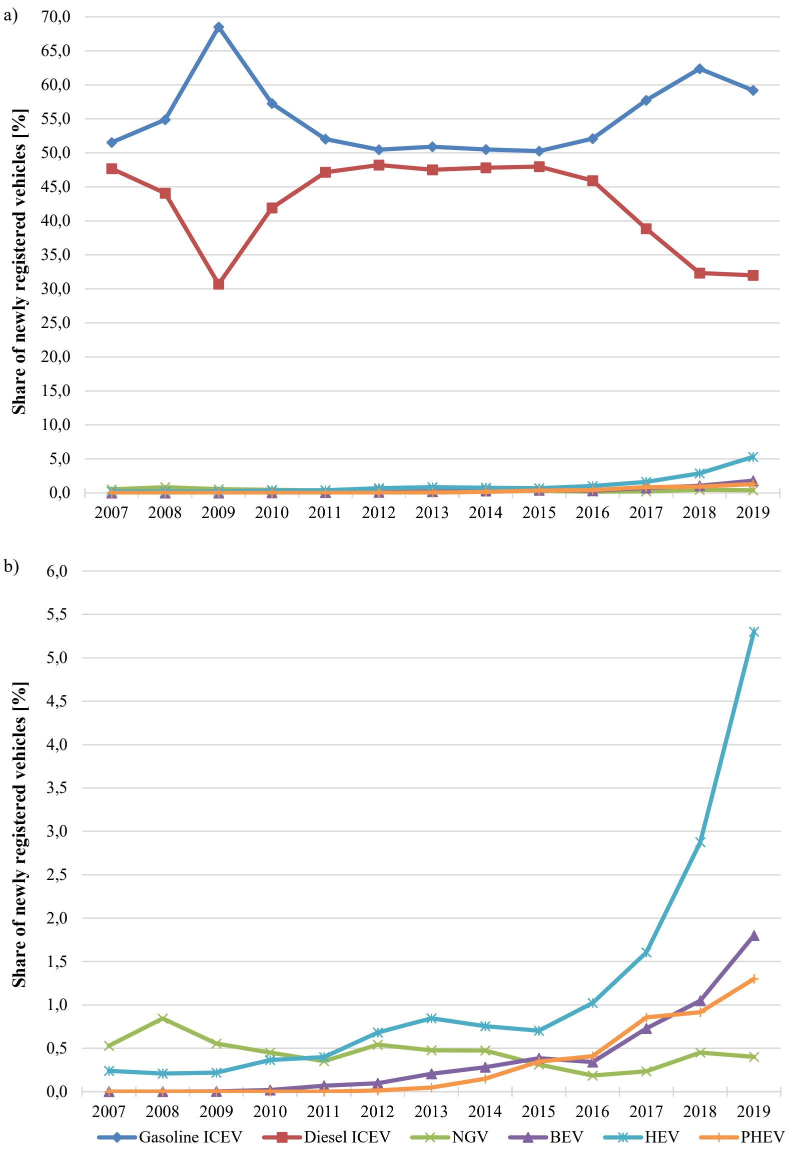

Figure 1.3: a) New vehicle registrations in Germany by fuel type, 2007-2019 (in %), b) New alternative fuel vehicle registrations in Germany, 2007-2019 (in %)

Source: Own illustration, based on KBA (2020c).

Notes: ICEV = internal combustion engine vehicle; NGV = natural gas vehicle, propelled by compressed natural gas (CNG) or liquefied petroleum gas (LPG); BEV = battery electric vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle.

In Europe, the large majority of new vehicles still run on gasoline or diesel. After the so-called 'Dieselgate' scandal, sales of diesel cars dropped significantly to only 36% in 2018 – in Germany even to only 32% in 2019, accelerated by the threat of diesel bans in urban areas – while gasoline accounted for 59.2% (Tietge et al., 2019). AFVs accounted for 3.8% of the total EU vehicle stock, and 10.6% of new passenger car registrations in 2019 (HEVs 5.9%, PHEVs/BEVs/FCEVs 3%[13], NGVs/BVs 1.7%) (ACEA, 2020a,c). Only 2182 FCEVs were registered in Europe in 2019, 679 of which in Germany (Samsun et al., 2020). As on the European level, also in Germany almost all AFVs did show substantial increases in sales, so that in 2019 HEVs accounted for 5.4%, PHEVs for 1.3%, BEVs for 1.8%, and NGVs for 0.4% of new passenger vehicles sales (KBA, 2020c). Thus, Germany has the second-highest rate of new AFV registrations in general and new BEV registrations in particular and the highest share of new PHEV registrations in the EU (EEA, 2020a). The development of the market shares of the different fuel types in Germany is also shown in Figure 1.3. The sharp decrease of diesel vehicle sales during and after the financial crises in 2009 (exacerbated by the German 'environmental bonus', a scrapping subsidy, see Section 1.3.4.2) and in the aftermath of the diesel scandal (September 2015), as well as the strong increase of AFV sales over the same time period are apparent.

In terms of vehicle segment, sales of SUVs recorded the strongest increase in Europe in 2018, leading to an eight times higher share than in 2001. At the same time, small and medium-sized cars lost some market share, e.g. more than 15% from 2015 to 2018 alone (Mock, 2019). A comparable development occurred in the German market, as new vehicles were mainly SUVs (21,1%; 31.3% when including off-road vehicles), medium-sized cars (20.5%), and small cars (13.5%), with SUVs (+21%) and off-road vehicles (+20.3%) showing the highest increase. The development of the market shares of the different segments in Germany over more than the past decade is shown in Figure 1.4. Especially the drastic increase of SUV sales (including off-road vehicles) and the decline in market share of almost all other segments is clearly visible (KBA, 2020d).

[13] Europe was the second-largest electric car market in terms of stock (25%) and sales (27%) after China (47% and 50%, respectively), while Norway had the highest shares in electric vehicle stock and new electric car sales (13% and 56%, respectively) in the world in 2019 (IEA, 2020b).

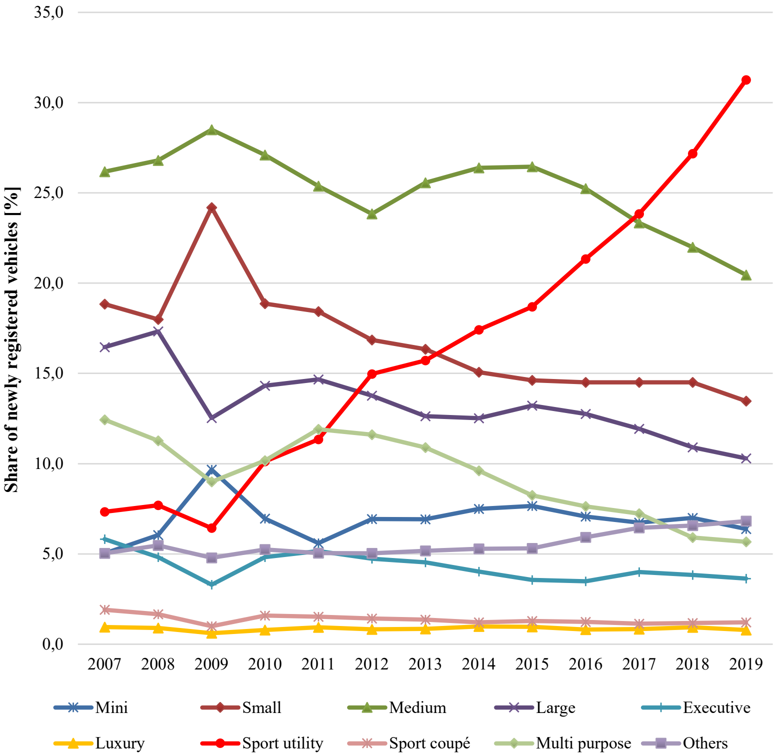

Figure 1.4: New vehicle registrations in Germany by vehicle segment, 2007-2019 (in %)

Source: Own illustration, based on KBA (2020d).

Notes: 'Sport utility' contains sport utility vehicles (SUVs) and off-road vehicles since 2013 and off-road vehicles alone before 2013; 'Multi purpose' contains small and large vans/multi purpose vehicles (MPVs).

This rise in SUV sales in the EU led to an increase in average CO_2 emissions from new passenger cars of 2 g/km to 120.6 gCO_2/km in 2018 compared to the previous year, normalized to the NEDC test cycle – in Germany, as member state with comparably high emission levels, even to 128 gCO_2/km (Tietge et al., 2019).[14] Thus, vehicle manufacturers will have to drastically reduce their fleet emission levels (on average by around 25 gCO_2/km for cars and 11 gCO_2/km for vans), to meet the 2020/21 European emission targets (see Section 1.3.4.1). As a consequence, manufacturers will likely take maximum advantage of flexible compliance mechanisms (e.g. super-credits for low-emission vehicles or eco-innovations that are not

[14] The average mass (1,397 kg in 2018) and engine power (98 kW in 2018) of new cars in the EU increased by about 10% and 25%, respectively, over the past 15 years. Moreover, compared to the EU average new vehicles have much more powerful engines in Germany (113 kW). Hence, lower CO_2 emissions could be achieved if these gains in vehicle weight and engine power would be decreased again (Mock, 2019).

reflected in the test cycle), or pooling with other companies to meet the targets and to forego massive penalties, which are estimated to amount to €32.7 billion per annum, summed over all manufacturers (Mock, 2019; Transport & Environment, 2019; Ellinghorst et al., 2019). Finally, around 132,000 charging points were publicly accessible in Europe in 2017 (ACEA, 2019), around 28,000 of which are located in Germany, with approximately 14% of them having a fast-charging option. On average, about nine BEVs or PHEVs currently share one charging point in Germany (BDEW, 2020; Mock, 2019). Furthermore, 17% of the 470 hydrogen refueling stations worldwide are located in Germany (Samsun et al., 2020).

1.3.3 Emissions and Climate Change Policy Framework

Climate change as a consequence of increasing levels of anthropogenic GHG emissions, and its already observable and forecasted potentially drastic adverse effects, require a swift and fundamental modification of the way energy is produced and consumed. In that respect, one of the most important levers are the increase of energy efficiency and the substitution of fossil fuels with renewable energy. Hence, broad regulatory actions as well as monetary and non-monetary support measures have been introduced in recent years on the global, European, national and local level, aiming at an accelerated usage of renewable energy sources and the uptake of more sustainable technological innovations. A huge milestone in this direction was the so-called 'Paris Agreement'.

1.3.3.1 The Paris Agreement

In December 2015, a total of 196 countries reached the very first legally binding, comprehensive agreement to globally combat climate change at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris (UNFCCC, 2016). The so-called 'Paris Agreement' commits its parties to limiting the rise in global average temperature to less than 2 °C above pre-industrial levels, preferably to 1.5 °C, as this would significantly reduce the societal costs of climate change as well as the adaptation needs (Workman et al., 2019; EEA, 2019b). To achieve these goals, the participating countries aim to reach the maximum level of global GHG emissions as quickly as possible, and to accomplish climate neutrality (net zero emissions) before the end of the century (UNFCCC, 2016). Moreover, they have to report regularly on their 'nationally determined contributions', i.e. their emission objectives and implementation progress, which will be assessed jointly every five years regarding their ability to achieve the global mitigation target and adjusted if necessary.

For limiting global warming to below 2 °C (1.5 °C), global net anthropogenic CO_2 emissions are needed to decrease by about 25% (45%) until 2030 relative to 2010 levels and to reach net zero by around 2070 (2050) (IPCC, 2018). However, even if all current unconditional commitments under the agreement are realized, world average temperature is expected to increase by about 3 °C until the end of the century, probably leading to more destructive impacts (UNEP, 2019). Hence, collective action must increase more than fivefold over the next decade compared to current levels to deliver the mitigation needed to get onto the 1.5 °C pathway (IPCC, 2018).

1.3.3.2 Emissions and Climate Change Policy in Europe

In line with the Paris Agreement, the European Commission presented the 'European Green Deal' in 2019, which outlines a long list of policy initiatives aimed at reaching the overarching goal of a climate-neutral, resource-efficient, modern, and competitive economy while ensuring a socially just transition (EC, 2019). It reinforces the 'Energy Union Strategy' (EC, 2015) and the 'A Clean Planet for All' EU long-term vision (EC, 2018b) and resulted in a proposal for the first 'European Climate Law' in March 2020 to make the stricter GHG emissions reduction targets legally binding (EC, 2020a). That is, instead of the previous target of an 80% reduction by the middle of the 21st century, the EU now aims at mitigating over 90% of GHG emissions and withdrawing the remaining, unavoidable emissions from the atmosphere. It also results in a 55%[15] cut in GHG emissions by 2030 compared to 1990 levels (as proposed in the September 2020 amendment; see EC, 2020b) instead of the previous 40% objective outlined in the 2030 climate and energy framework – alongside the goal to improve energy efficiency by at least 32.5% and to expand the share of renewable energy to at least 32% of final consumption (EC, 2014a).

The EU mitigation efforts mainly rely on the 'EU Emissions Trading System' (EU ETS) and the 'Effort Sharing Regulation' (EU, 2018a; EU, 2009), with the latter setting binding annual GHG emissions reduction targets until 2030 for each member state in sectors that are not covered by the EU ETS, such as transportation.[16] Specific measures for reaching an energy-

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[15] The European Parliament voted to tighten the 2030 emissions target even further to a 60% reduction compared to 1990 levels (European Parliament, 2020).

[16] To meet these reduction targets, the sectors covered by the EU ETS have to cut their GHG emissions by 43% by 2030, while all other sectors (including transportation) have to reduce emissions by 30%, compared to 2005 levels. These values are then transferred into national targets in the Effort Sharing Regulation (ICCT, 2019).

efficient, decarbonized transportation sector were also defined in the 'Strategy for Low-Emission Mobility' (EC, 2016). These mitigation efforts are additionally supplemented by a variety of activities to make Europe more climate-resilient, which are outlined in the 'EU Strategy on Adaptation to Climate Change' (EEA, 2019b; EC, 2013).

1.3.3.3 Emissions and Climate Change Policy in Germany

The energy and climate policy objectives and emission reduction targets of the German government are strongly linked to European climate policy and international agreements, but generally more ambitious. For instance, the mitigation target outlined in the German government's 2010 energy concept is to reduce CO_2 emissions by 40% by 2020[17], 55% by 2030, and 80-95% by 2050, compared to 1990 respectively (BMWi/BMU, 2010). Accordingly, the share of renewable energy in energy production and final energy consumption is expected to rise to 80% and 60%, respectively, by 2050. Simultaneously, primary energy, final energy, and electricity consumption are to be reduced by 50%, 40%, and 25% by 2050 (compared to 2008), respectively. Thus, the sustainable energy transition (*Energiewende*) is a cornerstone of Germany's climate policy (BMWi/BMU, 2010). Additionally, the energy concept already included specific energy efficiency targets for the transportation sector (see Section 1.3.4.2 below). In 2016, in the course of the Paris Agreement, the German government adopted the 'National Climate Protection Plan 2050' which outlines the pathway to GHG neutrality by 2050 (80–95% emission reduction), emphasizing that sector-specific GHG emission mitigation targets are needed in all relevant sectors, e.g. a reduction of 40-42% (compared to 1990) until 2030 in the transportation sector (BMU, 2016; Sharma et al., 2016). These sector-specific mitigation targets and emission allocations were put on a legal basis in the 'Federal Climate Change Act' end of 2019, which also implemented a review mechanism to control the mitigation progresses (German Federal Government, 2019a).

However, more rapid and far-reaching actions are needed in all sectors to achieve the mitigation targets of the Paris Agreement (UBA, 2020; IPCC, 2018). For instance, to limit global warming to 2 °C (1.5 °C), Germany will have to cut its GHG emissions by 68% (73%) by 2030 and by 90% (98%) by 2050 relative to 1990 levels. That is, also the current emission mitigation targets of the transportation sector would have to be increased to 44% (53%) to be in line with the 2 °C (1.5 °C) global warming pathway (Agora Verkehrswende, 2019b).

[17] To reach the 2020 targets, in 2014 the federal government adopted the 'Action Program Climate Protection 2020', which contained additional emission reduction measures to be taken across all sectors (BMU, 2014).

1.3.4 Vehicle Policy Framework

As the transportation sector is recognized as a major contributor to climate change and adverse health effects, various policy measures have been introduced over the past years to tackle the sector's reliance on fossil fuels and ICEVs. These include CO_2 legislation and regulations, quotas, governmental monetary and non-monetary incentives, and the support of R&D activities and of charging and refueling infrastructure for AFVs (Frieske et al., 2019). These political activities on the European and national, German level are described in more detail in the following.

1.3.4.1 Vehicle Policy in Europe

The first uniform emission standards for passenger cars in the EU were introduced in 1970 (EC, 1970). Two decades later, the 'Euro-norm' (EC, 1991) started to set limits for NO_x emissions and to tackle air quality issues (VDA, 2020; Nesbit et al., 2016). In 2009, mandatory CO_2 emission standards for passenger cars were introduced by the EU after the voluntary self-commitment of the automotive industry to cut vehicle emissions was unsuccessful. The regulation set a fleet average target of 130 gCO_2/km to be reached in 2015. In 2014 the limit value was tightened to 95 gCO_2/km, fully effective from 2021. Additionally, so-called 'super credits' were introduced to incentivize the sales of AFVs by increasing the weighting of vehicles with emissions lower than 50 gCO_2/km in the calculation of average fleet emissions (ICCT, 2019; EEA, 2016). In 2018, the average CO_2 emission targets for new cars were strengthened further to reduce the 2021 limit values by 15% until 2025 (translating to 81 gCO_2/km), and by 37.5% (59 gCO_2/km) in 2030, respectively. Furthermore, sales targets for low emission vehicles of 15% (in 2025) and 35% (in 2030) instead of super credits were introduced. Penalties for vehicle manufacturers which fail to comply with their CO_2 emission targets were adopted from the previous legislation and remain at €95 per vehicle for every gCO_2/km of excess emissions (ICCT, 2019).

Already in 2011, the European Commission specified the 2050 goal to reduce 60% of the transportation sector's GHG emissions (and oil dependency, compared to 1990 levels) in its 'White Paper on Transport' (EC, 2011). It also emphasized the phasing-out of conventionally fueled vehicles from cities until this date and the establishment of an EU-wide multimodal 'Trans-European Network for Transport' (TEN-T) by 2030 (Martino et al., 2019; LAIRA Project, 2019). The importance of an adequate availability of dedicated refueling and recharging infrastructure for the diffusion of AFVs was further acknowledged in the 'Directive on the Deployment of Alternative Fuel Infrastructure' (EU, 2014). The so-called AFI directive obliges member states to specify targets for the installation of publicly accessible refueling (natural gas and hydrogen) and recharging possibilities that are in line with their expectations on future demand for this infrastructure (and preferably include a baseline target of one recharging point per 10 electric vehicles), and to guarantee that travel with an AFV is possible at least in suburban and urban areas and throughout the EU (Niestadt and Bjørnåvold, 2019; Cansino et al., 2018; EEA, 2016). Furthermore, the revised 'Energy Performance of Buildings Directive' (EU, 2018b) defines requirements for equipping parking spaces with charging points in residential and non-residential buildings, e.g. shopping malls (Niestadt and Bjørnåvold, 2019).

To guide the disruptive transformations in the transportation sector, the 'Europe on the Move' initiative (EC, 2017a) offered an agenda for a socially fair transition towards clean, competitive and connected mobility, which was underpinned by a set of initiatives and legislature in 2017. Further mobility packages followed in the same (2nd Mobility Package; EC, 2017b) and the following year (3rd Mobility Package; EC, 2018a) on different strategic and specific policy issues, such as the 'AFI Action Plan' (EC, 2017c) that highlights measures to help create an EU backbone infrastructure by 2025, CO_2 emissions standards for cars (see above), vans and heavy duty vehicles, measures on road safety and connected, automated mobility, or the 'Strategic Action Plan on Batteries' (Annex 2 of EC, 2018a), which aims at the installation of sustainable battery production and use in Europe.

The EU also provides financial support for research and development as well as investments in infrastructure concerning AFVs, e.g. through the 'Connecting Europe Facility' and the 'European Structural and Investment Funds', as well as the 'European Framework Programs for Research', currently the 'Horizon Europe' research program (Niestadt and Bjørnåvold. 2019).

Furthermore, the future strategies outlined in the European Green Deal aim at boosting multimodal transportation through the development of smart traffic management systems and mobility as a service solutions, the ending of fossil-fuel subsidies, and effective road pricing in the EU. Moreover, a proposal for stricter limit values for air pollutant emissions of ICEVs ('Euro 7' norm) is scheduled for 2021 (Samaras et al., 2020; EC, 2019). That is, even though the focus on electric mobility has greatly increased in the last years, the EU traditionally follows a technology-neutral approach and promotes all kinds of fuels (Bose Styczynski and Hughes, 2020).[18]

[18] For instance, the 'Renewable Energy Directive' (2009/28/EG) requires member states to increase the share of renewable energy in the transportation sector to 10% by 2020. Other legislation promotes the substitution of gasoline and diesel with alternative fuels (e.g. natural gas, biofuels, or hydrogen) and the operation of electric vehicles with green electricity (Bose Styczynski and Hughes, 2020).

Besides these supranational political measures, several actions are additionally implemented by national, regional or local governments. These include incentives[19] to buyers or users of new electric vehicles or plans for an end of sale of CFVs between 2025 and 2040 (e.g. announced among others by The Netherlands, Spain, Norway, France, the UK, Sweden, and Ireland). Cities across Europe (e.g. London, Paris, Amsterdam and Brussels) are also willing to prohibit CFVs by around 2030-2035, while in some German cities, e.g. Hamburg or Stuttgart, such bans were already introduced for specific diesel cars and road sections (IEA, 2020b; Kovács, 2019; Burch and Gilchrist, 2018). The German vehicle policy is summarized in more detail in the following.

1.3.4.2 Vehicle Policy in Germany

As already mentioned, the German 'National Climate Protection Plan 2050' expects the transportation sector to reduce emissions by 40-42% by 2030 (BMU, 2016), thus tightening previously existing targets (defined in the 'German Federal Energy Concept'; BMWi/BMU, 2010). As on the European level, German policy targets are fully technology-neutral (e.g. 'Mobility and Fuel Strategy'; BMVBS, 2013), although the type and magnitude of support varies across propulsion technologies, with electric mobility currently receiving most attention and funding throughout Europe (Bose Styczynski and Hughes, 2020).

Already in 2009, the German federal government established the 'National Electromobility Development Plan', which envisaged one million registered electric vehicles by 2020 and aimed to make Germany a lead market and provider for electric mobility (German Federal Government, 2009). Furthermore, the 2011 'Government Program Electric Mobility' (German Federal Government, 2011) set a target of six million registered electric vehicles by 2030 (Barton and Schütte, 2017).

The German government began to support research early on, either directly through specific funding programs or through public-private-partnerships, such as the 'National Hydrogen and Fuel Cell Technology Innovation Program' in 2006 (Garche et al., 2009), the 'Clean Energy Partnership' for fuel cell powered vehicle fleets and hydrogen refueling points, the 'Electric Mobility in Pilot Regions' demonstration program (Tenkhoff et al., 2012), or the

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[19] These incentives include one-off purchase subsidies (purchase tax exemptions or grants), reductions of ownership costs (e.g. circulation tax exemptions, fuel/electricity tax adjustments), financial support (funding of charging infrastructure or research and development), local non-monetary incentives (e.g. free parking, allowance to use bus lanes), and education programs (ACEA, 2020d; Niestadt and Bjørnåvold, 2019; EEA, 2016). ACEA (2020d) gives a comprehensive overview of type and design of current global motor vehile taxes. Moreover, detailed discussions on the effects of these different incentives are found in e.g. Santos and Davies (2020), Münzel et al. (2019), Rietmann and Lieven (2019), Wang et al. (2019b), and Cansino et al. (2018).

aforementioned ‘Government Program Electric Mobility’ (German Federal Government, 2011), which was linked to the ‘German High-tech Strategy’ and established so-called lighthouse projects (Bose Styczynski and Hughes, 2020). In 2011, financial incentives were added to support AFVs, such as tax cuts for (privately used) electric company cars and a 10-year suspension of the motor vehicle tax for low emission vehicles (German Federal Government, 2012). Additionally, a purchase premium of €4000 for BEVs and €3000 for PHEVs was implemented in 2016, which was increased by 25-50% (depending on the vehicle’s purchase price) in 2019, and which was financed half by the federal government and half by the vehicle manufacturers. In 2020, the government’s share was doubled, resulting in a maximum achievable purchase premium of €9000 for BEVs with a purchase price of less than €40,000 (BMWi, 2020a,b; Bose Styczynski and Hughes, 2020). In 2015, the government passed the ‘Electric Mobility Law (EmoG)’ to regulate the labeling of PHEVs and BEVs and to enable municipalities to introduce non-monetary incentives for electric vehicles, such as access to bus lanes or roads with drive-through bans, as well as privileged or free parking and/or charging (German Federal Government, 2020; Bose Styczynski and Hughes, 2020). However, municipalities are still reluctant to make use of this policy option. On the other hand, temporary driving bans for diesel vehicles were introduced in some German cities by court order to adhere to NO_x limits (ADAC, 2020).

In 2016, the European AFI Directive was transferred into national law (‘National Strategic Framework on the Development of Infrastructure for Alternative Fuels’; BMVI, 2016; and ‘Charging Station Ordinance’; BMWi, 2017). The German measures focus mainly on electric vehicles and a potentially ambitious market uptake of FCEVs, as the current German CNG network could likely serve more than five times the number of currently registered CNG vehicles in Germany and, thus, does not need further support (EC, 2017d). In addition, the federal government currently funds the expansion of charging infrastructure with €300 million (Fluchs, 2019; BMVI, 2017)

In 2019, the ‘Climate Protection Program 2030’ was adopted by the German government, aiming at 7-10 million registered electric vehicles and one million available charging points by 2030. To achieve these goals, charging points at filling stations, customer parking lots, and residential buildings (comparable to European legislation) are becoming mandatory, and extensions and increases of the purchase premium and tax incentives for electric cars (HEVs, PHEVs, BEVs, and FCEVs), as well as the reform of the motor vehicle tax for passenger cars with a more stringent CO_2 emissions cost factor already have been or will be implemented (German Federal Government, 2019b).

1.4 Methodological Approach

Studies investigating vehicle choices of private households are numerous and diverse in terms of data sources, models and estimation methods. Attempts to analyze car buyers' preferences and their differences in vehicle purchase decisions using disaggregated, individual level data, can be broadly classified into two theoretical approaches: an economic approach and a psychological approach (Rezvani et al., 2015; Anable et al., 2011). The economic approach usually assumes utility-maximizing behavior and rational choice-making processes based on the individual assessment of various vehicle attributes, which can then be translated into monetary terms using WTP calculations (Mohamed et al., 2018). Liao et al. (2017) provide a broad review of the literature applying this theoretical approach. The psychological approach aims at the explanation of interdependencies of psychological and sociological constructs (e.g. beliefs, attitudes, emotions, identity, experience, societal norms, symbols, and lifestyles) and their influence on the purchase intention or actual adoption of specific vehicle and fuel types. It is based on various theoretical approaches, such as cognitive decision models (e.g. theory of reasoned action, theory of planned behavior), normative decision models (norm activation model, new ecological paradigm scale, value-belief-norm theory), symbol, self-identity and lifestyle theories, as well as adoption and diffusion theories (diffusion of innovations theory, technology acceptance model). Li et al. (2017) and Rezvani et al. (2015) comprehensively summarize this stream of research in their review articles.

The economic approach, which is based on preference utilitarianism and the application of choice models (based on surveys and/or DCEs) is dominating the scientific research on vehicle purchase decisions (Mohamed et al., 2018). It is also the theoretical and methodological base for this thesis and, hence, will be described in more detail in the following.

1.4.1 Rational Choice and Random Utility

Vehicle purchase decisions basically are a discrete choice from the given set of finite and mutually exclusive vehicle alternatives. Based on rational choice theory, the main theoretical paradigm in economics and the standard economic theory of consumer behavior[20], decision-makers are assumed to choose the alternative that maximizes their utility subject to their budget and other constraints (Liao et al., 2017; Anable et al., 2011). Following Lancaster's (1966) economic theory of value, the utility of each alternative is assumed to be determined by its

[20] This rationality assumption seems more appropriate in comparably infrequent decisions with great financial or personal impact, such as vehicle purchases, which usually are characterized by being more informed and involving more cognitive effort by decision-makers (Anable et al., 2011).

attributes, so that individuals' choices for a specific alternative are an expression of their innate, stable preferences, i.e. their taste, for these specific attributes (Greene et al., 2018; Amaya-Amaya et al., 2008). However, as utility is not directly observable by researchers, it has to be modeled as a random variable. Following McFadden (1974), the latent utility of an alternative can be decomposed into two additive parts: (1) an observable and explainable component determined by the attributes of the alternatives; and (2) a random and unexplainable component representing unmeasured variation in preferences, caused by e.g. unobserved attributes, taste heterogeneity, measurement errors and/or specific functional specifications. Consequently, only probabilistic statements about choices and the importance of attributes are possible (Amaya-Amaya et al., 2008). Discrete choice models are applied to estimate the weights individuals assign to the vehicle attributes (parameters in the utility functions), using data of real or hypothetical choices. These estimated preferences can then be used to predict the monetary value a car buyer would pay for an additional unit of a vehicle attribute, the WTP. Furthermore, the estimated parameter values can be fed into models that allow for an evaluation of future market potentials, e.g. a scenario analysis of future adoption and diffusion (Amaya-Amaya et al., 2008; Ben-Akiva et al., 1994).

Over the past four decades, a wide variety of different discrete choice models has been developed, mainly focusing on the specification of the distribution and correlations of the error terms in utility functions or the heterogeneity in taste parameters – e.g. via the inclusion of individual-related variables, such as socio-demographic characteristics or psychological constructs (e.g. attitudes or motivations).

1.4.1.1 Discrete Choice Models and Data Types

Basically, two different options to assess individuals' preferences are available: (1) revealed preferences (RP), i.e. real choices made in real markets, using, for instance, the travel cost or the hedonic pricing method; and (2) stated preferences (SP), i.e. hypothetical choices or statements (stated intentions) made in hypothetical, virtual market situations, using direct questioning of individuals, e.g. the contingent valuation method (CVM) or discrete choice experiments (DCEs) (Gerard et al., 2008). DCEs offer several advantages compared to the CVM (see e.g. Boxall et al., 1996) and are therefore used much more often to determine the utility of vehicle alternatives and their attributes. In DCEs respondents are presented one or more hypothetical scenarios (choice sets) which contain at least two competing alternatives that are described by several attributes with levels systematically varied according to statistical design principles (Gerard et al., 2008; Amaya-Amaya et al., 2008).

The fundamental differences in the generation of RP and SP data lead to specific strengths and weaknesses of both options (Fujiwara and Campbell, 2011). For instance, the greatest advantage of RP data is their high reliability and face validity, as they are based on actual decisions with real financial consequences. At the same time, this merit makes RP data relatively inflexible (e.g. insufficient variability and range of attributes or levels, high correlation between attributes, dominance of some few attributes), and often inappropriate (e.g. evaluation of unavailable alternatives or attributes), as the data is limited to the existing alternatives in the current market (Huffman and McCluskey, 2016; Louviere et al., 2000; Ben-Akiva et al., 1994). Furthermore, non-rational choice processes (e.g. large number of alternatives to choose from) or the presence of asymmetric or limited background information are more likely in actual markets, leading to a potential misrepresentation of the real underlying individual preferences and attribute trade-offs of decision-makers (Huffman and McCluskey, 2016; Potoglou and Kanaroglou, 2008; Gerard et al., 2008; Hensher et al., 2005; Ben-Akiva and Lerman, 1985).

On the contrary, SP data has more favorable statistical properties than RP data, as it is able to capture a wider range of attribute levels and choice options (which do not have to be available on the market), leading to more detailed and robust attribute trade-off ratios, especially since SP data is generated by an experimental design so that measurement error is reduced and identification of all effects of interest is enhanced. Moreover, SP data gathered in a DCE allows for repeated measurements per respondent (Huffman and McCluskey, 2016; Potoglou and Kanaroglou, 2008; Louviere et al., 2000). However, although SP data seems to overcome several disadvantages associated with RP data, it also suffers from a major drawback: hypothetical bias, i.e. potentially biased responses due to the hypothetical setting of SP techniques, leading to potential inconsistencies with actual market behavior and problems with the validity and reliability of results (Huffman and McCluskey, 2016; Massiani, 2014; Ben-Akiva et al., 1994). Especially WTP values are found to be exaggerated (compared to real purchase settings). However, even in the presence of hypothetical bias, the output from SP methods can yield valuable insights. Another possibility is the combination of RP and SP data to correct the weaknesses and utilize the advantages of each data type (Potoglou and Kanaroglou, 2008; Gerard et al., 2008; Hensher et al., 2005; Louviere et al., 2000).

1.4.1.2 Scientific Research on Consumer Preferences for Vehicles

The studies in this doctoral thesis build on the rich body of economic, utility-based market research on private households' vehicle choices (see Appendix A.1), which dates back to the late 1970s and early 1980s (e.g., Lave and Train, 1979; Beggs and Cardell, 1980; Beggs et al., 1981; Berkovec and Rust, 1985; Calfee, 1985; Mannering and Winston, 1985). Research began as a reaction to strong increases in the gasoline price caused by the two oil crises in the 1970s and the resulting search for alternatives. It substantially gained in momentum following the implementation of California's zero-emission vehicle mandate in the 1990s (e.g., Bunch et al., 1993; Brownstone et al., 1996, 2000; Tompkins et al., 1998). Research in the past two decades was mainly conducted in North America, followed by Europe (especially Germany, The Netherlands, and Scandinavia), Asia (especially China, Japan, South Korea), and Australia, and broadly can be divided regarding two characteristics. Firstly, the main focus of the studies, which is either on the analysis of private households' choice of vehicles' fuel type or on private households' choice of a particular vehicle type, with the latter being classified by different combinations of size (e.g. small, medium-sized, large cars), body type (e.g. pickup truck, SUV, hatchback, saloon), vintage (e.g. year of manufacture), or make and model, depending on the respective study. Secondly, studies either draw on RP data (i.e. data on actual vehicle ownership from national registers or household surveys) or SP data (i.e. data on hypothetical vehicle purchase decisions or future purchase intentions gathered in DCEs or household surveys), with the latter being used more often.

As can be seen from Table A.1 in Appendix A.1, fuel type choice models are mainly based on SP data, DCEs in particular, while vehicle type choice models usually draw on RP data. However, studies exist that do not regiment into this system. Especially RP data is used more and more often in fuel type choice studies, which is mainly due to increased AFV market diffusion in past years. Other researchers make use of both data sources or analyze vehicle and fuel type choices jointly (either using RP data or SP data, or do both).

The empirical vehicle choice literature can be segmented further on the basis of fundamental model specifications, which can vary substantially between the studies. For instance, the level of aggregation of the dependent variable, i.e. the definition of the choice set and with it the task complexity, ranges from two alternatives – such as passenger cars and trucks or conventional vehicles and BEVs – to several hundred choice options (see Tables A.2-A.4 in Appendix A.1). Usually, a manageable number of common segments or alternatives is used, so that on average three different fuel types and five different vehicle types are assessed per study. Moreover, especially vehicle type choice models can be devided into holdings and purchase models, according to whether the vehicle under consideration is already owned (e.g. the most frequently used vehicle) or recently purchased (or planned to be purchased in the near future; see also Baltas and Saridakis, 2013). Vehicle holding models are additionally used to analyze the composition of the entire household vehicle fleet, i.e. number, type, and age of all vehicles owned by the household, and the according transaction processes (i.e. the addition, replacement, or disposal of a vehicle to or from the current household fleet). Finally, some researchers have extended the vehicle type choice models to incorporate the vehicle usage (i.e. number of kilometers traveled) or the acquisition type into the purchase decisions. As a result of the wide application of DCEs, which often was and still is inevitable in this research field due to a potentially limited availability of vehicles of interest in the market, most fuel type choice models are specified as purchase models. Finally, although also the econometric models utilized in the analysis of households' vehicle type and fuel type choices show a wide bandwidth, the majority of the studies implement multinomial logit models (MNL), nested logit models (NL), or mixed logit models (ML) (see Table A.1 in Appendix A.1 and Section 1.4.3).

A vast amount of factors has been suggested to exert an influence on households' vehicle choice decisions. However, when condensing the model specifications and findings of the vehicle choice studies listed in Tables A.5 and A.6 in Appendix A.1, the most commonly used and significant explanatory variables can be classified into: (1) vehicle attributes; (2) socio-demographic and socio-economic characteristics of the primary driver; (3) attitudes, perceptions, and preferences of the primary driver; (4) behavior of the primary driver; (5) household characteristics; and (6) housing conditions and characteristics of the residential neighborhood (see also Chapter 4). Most vehicle choice studies include more than one category of explanatory variables in their models, although especially various fuel type choice models exist that solely concentrate on vehicle attributes as influencing factors (e.g. Train and Weeks, 2005; Beck et al., 2011; Daziano, 2013), and particularly some vehicle type choice studies solely focus on individual-specific and household characteristics (e.g. Cao et al., 2006; Eluru et al., 2010; Baltas and Saridakis, 2013). Finally, in many vehicle choice studies additional estimations (WTP or marginal effects) and simulations are conducted on the basis of the empirical results (see Table A.14 in Appendix A.1).

The main estimation results of the empirical studies exploring consumer preferences in vehicle purchase decisions, are presented in detail in Tables A.7-A.13 in Appendix A.1.

1.4.2 Survey and Questionnaire

Data on purchase or choice decisions of (potential) buyers of new vehicles was gathered in a Germany-wide web-based survey including a DCE to empirically address the research questions of this dissertation. This approach was determined to be the most appropriate from an administrative point of view (especially regarding the DCE) but also because of its potential to reach more owners of AFVs, given the budget constraint of the research, which was not so easy at that time, as the diffusion of AFVs was much sparser than today. The questionnaire for this online survey was developed based on a comprehensive review of the scientific literature to assess the research gaps and include the influencing factors identified as crucial. A draft version of the questionnaire was then evaluated by experts from different academic backgrounds (economics, psychology and sociology) and recent car buyers to identify possible misunderstandings of questions or potentially missing vital topics. On the basis of this feedback, the questionnaire was improved and subsequently pretested in May 2011 with 128 participants recruited from a probability-based commercial online panel administered by the Dialego AG, Aachen. Based on the results of this pre-test, the final questionnaire was produced. It consisted of five main sections, comprising questions on existing and planned car ownership, vehicle usage behavior and mobility habits, influencing factors before and during vehicle acquisition, importance of vehicle attributes in the purchase decision, environmental attitude and behavior, interest in technology and cars, socio-demographics, and household characteristics. A more thorough presentation of the questionnaire and its implementation is provided in Chapter 3 and in Appendix A.2.

As mentioned earlier, the survey contained a DCE (see also Chapters 2 and 3 for more information) to assess individuals' preferences regarding different AFVs and their attributes. A DCE approach was chosen, since at the time of the survey (in 2011), AFVs were comparably rare, especially BEVs, or even entirely unavailable, such as FCEVs. Furthermore, BEVs available on the market were quite similar in terms of body type and other features, so that the usage of RP market data was neither considered to be favorable nor desirable. Even today, the variability of alternatives and attributes (e.g. body types, battery ranges), as well as the number of variants to choose from, is limited for most AFVs. Finally, incentives for AFVs, which have been identified as important decision factors in other studies, had not yet been adopted in Germany at the time the survey was carried out (see Section 1.3.4.2). The DCE was generated using the Sawtooth software for choice-based conjoint analysis by applying a completely randomized fractional factorial design to experimentally vary the eight attributes of the seven AFVs considered.

The final survey was conducted in July and August 2011. A total of 1500 respondents from Dialego AG's online panel completed the survey. Screening questions ensured that potential respondents were of age, had a driver's license, and had either recently purchased a new car or intended to do so in the upcoming year. Furthermore, soft quotas on body types and purchase prices of the most recent or planned vehicles' were implemented so that the sample largely matched German population statistics regarding these variables. In addition, depending on the status of vehicle adoption, i.e. whether or not respondents had recently purchased a vehicle and whether or not they already owned one, questionnaires slighty differed – mainly regarding the wording or depth of some questions – so that three versions were produced (see Appendix A.2). Finally, also the DCE task was disseminated in two different versions: 711 respondents took part in an experiment with forced choice (i.e. without opt-out option, such as 'none' or 'my current vehicle', as a choice alternative in the experimental choice sets), as well as 789 respondents in an unforced choice setting in which the opt-out option was presented in a follow-up question after the forced choice ('Would you really buy this vehicle if you also had the option not to buy it?') rather than in the initial choice task itself (so-called 'dual response none'). However, the validity and reliability of responses in the latter DCE deteriorated after about half of the choice sets, i.e. participants increasingly chose the opt-out option and decisions were increasingly based on only a few attributes or without preference patterns. This could indicate that the follow-up question was perceived as unnecessary prolongation of the choice task and questionnaire, or that it increased task complexity to an unacceptable level (see e.g. Hensher et al. (2007) or Hensher (2006) for more details). Therefore, the decision was made not to include the responses from the unforced DCE in the analysis, as this would have biased the results (quality, potential systematic impact), so that estimations in Chapters 2 and 3 are only based on the 711 respondents who faced the forced choice task. The entire dataset of 1500 respondents, however, is used in the analysis of individuals' joint vehicle and fuel type choice decisions (Chapter 4), as it is based on respondents' actual or planned vehicle ownership rather than the DCE data.

1.4.3 Analytical Procedure

The dataset of this thesis comprises both revealed – i.e. actual choices of the current, recently purchased vehicle – and stated preferences data – i.e. DCE data or stated purchase intentions – as well as data on the characteristics of respondents (socio-demographics, behavior and attitudes) and their households. To analyze the discrete vehicle choices, four different logistic regression models are used in this thesis. Consequently, as mentioned in Section 1.4.1.1, only probabilistic statements can be made about the choice of a particular vehicle alternative and the influence of the explanatory variables (e.g. characteristics of the vehicle buyers and the vehicles). In addition to the standard multinomial logit (MNL) model, which was included as the baseline in the three studies, several more advanced logistic regression models were applied in the different chapters that extend the MNL by relaxing some of its restrictive assumptions – e.g. allowing correlations between error terms. For instance, a mixed (error components) logit model (ML) was used in Chapter 2, a latent class model (LCM) in Chapter 3, and a nested logit model in Chapter 4. More detailed descriptions of the model specifications and their properties can be found in the respective chapters.

Furthermore, this thesis applied a principal component analysis to the motivational and attitudinal constructs – which aimed to assess environmental awareness and behavior, as well as technophilia and car interest – to reduce potential correlation and examine their dimensionality. The resulting motivational and attitudinal factors were then entered into the choice models as independent variables to assess their influence on the choice between vehicle alternatives. More information on the principal component analysis can be found in Chapter 4. Finally, based on the parameters estimated in the different discrete choice models, monetary values (WTP, CV) were calculated and simulations of future market shares were performed on the basis of various realistic scenarios. Their theoretical and methodological specifications are described in more detail in Chapters 2 and 3.

1.5 Structure and Scientific Contribution

1.5.1 Structure of the Thesis

This doctoral thesis comprises three interrelated articles on German private households' preferences and purchase decisions regarding new passenger cars, with each article contributing to the overall understanding by highlighting different areas of the research problem or by applying different methodological approaches. The first article (Chapter 2) investigates consumer preferences for AFVs and their attributes, calculates WTP values for attribute improvements, and predicts future market shares of AFVs for a broad range of potential technical improvements or policy actions in a scenario analysis. The second article (Chapter 3) builds on these results and specifically expands them in three ways: the consideration of car buyers' preference heterogeneity with respect to specific AFVs and their attributes through segmentation, the improvement of results by allowing for car buyers' preferences to be non-linear for some vehicle attributes, and by calculating the CV to evaluate potential vehicle-specific technical improvements or policy measures instead of less realistic generic WTP values. The third article (Chapter 4) differs from the previous two articles not only in that it does not use DCE data but a combination of RP and SP data, but also in that it focuses on the joint choice of vehicle and fuel type rather than the latter choice alone. In doing so, it assesses the differences between vehicle buyers who prefer conventionally fueled SUVs and individuals who prefer smaller vehicles or AFVs in order to develop recommendations on how to address the problem of increasing sales of fossil-fueled SUVs. The abstracts of the three articles further briefly describe the objectives, methodological approach, and results of each study:

Chapter 2: Consumer preferences for alternative fuel vehicles: A discrete choice analysis

Hackbarth, A., Madlener, R., 2013, *Transportation Research Part D* 25, 5-17

This paper analyzes the potential demand for privately used alternative fuel vehicles using German stated preference discrete choice data. By applying a mixed logit model, we find that the most sensitive group for the adoption of alternative fuel vehicles embraces younger, well-educated, and environmentally aware car buyers, who have the possibility to plug-in their car at home, and undertake numerous urban trips. Moreover, many households are willing to pay considerable amounts for greater fuel economy and emission reduction, improved driving range and charging infrastructure, as well as for enjoying vehicle tax exemptions and free parking or bus lane access. The scenario results suggest that conventional vehicles will maintain their dominance in the market. Finally, an increase in the battery electric vehicles' range to a level comparable with all other vehicles has the same impact as a multiple measures policy intervention package.

Chapter 3: Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany

Hackbarth, A., Madlener, R., 2016, *Transportation Research Part A* 85, 89-111

In the light of European energy efficiency and clean air regulations, as well as an ambitious electric mobility goal of the German government, we examine consumer preferences for alternative fuel vehicles (AFVs) based on a Germany-wide discrete choice experiment among 711 potential car buyers. We estimate consumers' willingness-to-pay (WTP) and compensating variation (CV) for improvements in vehicle attributes, also taking taste differences in the population into account by applying a latent class model with 6 distinct consumer segments. Our results indicate that about 1/3 of the consumers are oriented towards at least one AFV option, with almost half of them being AFV-affine, showing a high probability of choosing AFVs despite their current shortcomings. Our results suggest that German car buyers' WTP for improvements of the various vehicle attributes varies considerably across consumer groups and that the vehicle features have to meet some minimum requirements for considering AFVs. The CV values show that decision-makers in the administration and industry should focus on the most promising consumer group of 'AFV aficionados' and their needs. It also shows that some vehicle attribute improvements could increase the demand for AFVs cost-effectively, and that consumers would accept surcharges for some vehicle attributes at a level which could enable their private provision and economic operation (e.g. fast-charging infrastructure). Improvement of other attributes will need governmental subsidies to compensate for insufficient consumer valuation (e.g. battery capacity).

Chapter 4: Combined vehicle type and fuel type choices of private households: An empirical analysis for Germany

Hackbarth, A., Madlener, R., 2018, FCN Working Paper No. 17/2018, December (revised May 2019)

This paper examines joint consumer purchasing decisions of vehicle type and fuel type based on a dataset from a Germany-wide survey among 1500 potential car buyers. The goal is to study the buyer segments that are considering to purchase the different types of vehicles and to identify the main determinants influencing the joint choice decision: socio-demographic and household characteristics, attitudes and preferences, as well as vehicle-related attributes. Based on a nested logit model, our results suggest that although German car buyers' are very heterogeneous regarding their preferences, several similarities are found between buyers of specific vehicle types (10 vehicle classes) and specific fuel types (gasoline, diesel, alternative fuel), e.g. smaller cars and alternative fuel vehicles (AFVs) have commonalities regarding individuals' environmental awareness/behavior and fuel consumption/costs. Policy-makers, when tailoring their policies, can benefit from making use of the specific insights gained from this particularly comprehensive study, and the comparisons made with the German and international scientific literature on the topic. For instance, the similarities between buyers preferring specific fuel types and specific vehicle types can be used for tailored measures to incentivize individuals' vehicle type shifting (e.g from larger to smaller vehicles), fuel type switching (e.g. from fossil-fueled vehicles to AFVs), or both.

1.5.2 Publications and Contributions to Conferences

The three articles in this doctoral thesis have been published in the Working Paper Series of the Institute for Future Energy Consumer Needs and Behavior (FCN), edited by Prof. Dr. Reinhard Madlener, which is accessable via the institute's website, the *Research Papers in Economics* (RePEc) network, and the *Social Science Research Network* (SSRN). Furthermore, the first two articles have been published in pertinent peer-reviewed scientific journals: *Transportation Research Part D* (Hackbarth and Madlener, 2013; Chapter 2) and *Transportation Research Part A* (Hackbarth and Madlener, 2016; Chapter 3).

Moreover, the research was presented at national and international scientific conferences, workshops, and seminars to enable scientific feedback and to incorporate expert opinions into the research process.

Specifically, the first article (Chapter 2: *Consumer preferences for alternative fuel vehicles: A discrete choice analysis*) was presented at the

- 12th IAEE European Conference "Energy Challenge and Environmental Sustainability", Venice, Italy, September 9-12, 2012.
- 6th International Workshop on Empirical Methods in Energy Economics (EMEE), Ottawa, Canada, July 11-12, 2013.
- Swiss Society of Economics and Statistics (SSES) Annual Congress "The Energy Transition and its Challenges", Neuchâtel, Switzerland, June 20-21, 2013.
- 1st Joint Workshop "Research in Energy Economics" of the Institute of Energy Economics at the University of Cologne (EWI) and the Institute for Future Energy Consumer Needs and Behavior (FCN) at RWTH Aachen University, Cologne, Germany, January 18, 2013.

The second article (Chapter 3: *Willingness-to-pay for alternative fuel vehicle characteristics: A stated choice study for Germany*) was presented at the

- 13th IAEE European Conference "Energy Economics of Phasing out Carbon and Uranium", Düsseldorf, Germany, August 18-21, 2013.
- 14th IAEE European Conference "Sustainable Energy Policy and Strategies for Europe", Rome, Italy, October 28-31, 2014 (presented by co-author).

The third article (Chapter 4: *Combined vehicle type and fuel type choices of private households: An empirical analysis for Germany*) was presented at the

- 2nd Reutlingen Center for Distributed Energy Systems and Energy Efficiency (REZ) Research Colloquium, Reutlingen University, Reutlingen, Germany, May 31, 2017.

1.5.3 Overall Scientific Contribution

The aim of this thesis is to explore the factors shaping individual purchase decisions regarding new passenger cars of private households, particularly taking into account the heterogeneity of vehicle buyers and its impact on the evaluation of vehicle characteristics – especially fuel type – and policy decisions. It further intends to provide recommendations for decision-makers in politics and the automotive industry on the most promising levers to fully exploit the market potential of specific (alternative fuel) vehicles.

Besides these valuable implications for practitioners, the articles comprising this thesis contribute to the academic applied transportation economics literature by expanding previous research and by applying different state-of-the-art econometric approaches. For instance, a distinguishing characteristic of the research contained in this dissertation is the breadth of vehicles considered, as seven different fuel types and ten different segments were included to cover the entire passenger car market. Furthermore, the DCE on which the first two articles are based was the first to consider PHEVs and their unique refueling characteristics as a choice alternative.

Furthermore, this thesis especially expands previous research focusing on the case of Germany. For instance, to the best of our knowledge, three aspects were unprecedented: (1) the application of an LCM approach, enabling a segmentation of car buyers and their detailed description, as well as a specification of the size of these consumer segments; (2) the focus on vehicle buyers' joint vehicle type and fuel type choice decisions using a unique dataset of RP and SP data; and (3) the introduction of additional and previously unconsidered attributes, such as the vehicles' driving range, refueling and/or recharging time, and governmental incentives.

The inclusion of the specific vehicle attributes previously unconsidered in the literature (at least for Germany) and the special attention to the heterogeneity of car buyers are crucial in order to analyze more accurately the preferences of German consumers with respect to AFVs and their attributes – especially for PHEVs and BEVs, as they are the only vehicle alternatives that have to be plugged-in. Moreover, the consideration of diminishing marginal utility – reflected in the nonlinear functional form of individuals' evaluation of recharging time, fuel availability, driving range, and CO_2 emissions – also adds to a more realistic representation of individual preferences and human behavior. Furthermore, the analysis of the specifics of buyers of smaller vehicles and their differences to individuals preferring SUVs improves the understanding of the current market situation of rapidly increasing SUV sales – especially as this analysis is combined with the assessment of buyers' preferences for AFVs.

The assessment of the economic viability of improving specific vehicle attributes or introducing governmental incentives and their impact on adoption decisions is crucial for political and industrial decision-makers to optimally allocate their limited resources. This research therefore extensively analyzes and discusses heterogeneous car buyers' monetary valuation of such actions by applying two different approaches: WTP and CV (Chapters 2 and 3), with the latter being particularly informative for decision-makers since it displays the consequences of non-marginal (and alternative-specific) market changes on consumers' valuation.

This research further assesses the influence of such governmental purchase and tax incentives, or infrastructural and vehicle technology improvements, on the potential demand for AFVs in a scenario-based simulation, in order to get an impression of their effectiveness in terms of market shares instead of monetary values. Finally, the results of each study contained in this dissertation are extensively compared to the findings of the international scientific literature in order to facilitate the commensurability and transferability of the results, recommendations, and conclusions to other countries or applications.

From a methodological perspective, a broad variety of econometric model specifications (MNL, NL, ML, LCM) are used in this thesis, as each model has its strengths and weaknesses. The research makes a methodological contribution to the literature by highlighting the impact of the model specification on the results of the econometric estimations, e.g. by applying two different models in each study – an MNL as the base and starting point and a more sophisticated logistic regression model. The dependence of model results on the specifications made by the researcher is particularly apparent when comparing the first study with the second one (Chapters 2 and 3), i.e. the influence of the functional representation of vehicle attributes on utility (e.g. linear vs. logarithmic), the type of relaxation of the independence of irrelevant alternatives assumption (ML vs. LCM), the type of consideration of individual heterogeneity (interaction terms vs. segmentation), or the method of monetizing attribute and policy changes (WTP vs. CV).

Overall, this thesis shows that a broad array of variables impact actual and hypothetical vehicle choices, i.e. the decision in favor of a specific vehicle type or fuel type is determined by characteristics of the vehicle buyer (attitudes, preferences, socio-demographic and household characteristics), surrounding conditions, and, of course, attributes of the vehicle itself. Thus, by using both RP and SP data, sophisticated research methods, and realistic scenarios, this research contributes to a better understanding of vehicle purchase decisions and to the current search for the best strategy to foster the market diffusion of AFVs in general and electric vehicles in particular, as well as smaller cars instead of gas-guzzling SUVs. The results provide scientifically substantiated policy recommendations for target-group-specific marketing campaigns or tailored offers by vehicle manufacturers, as well as for the development and implementation of the potentially most economically efficient and effective policy instruments and support schemes (e.g. monetary and non-monetary incentives or fast-charging infrastructure).

1.6 Limitations and Shortcomings

Possible general limitations of this thesis, especially with respect to the applied methodology, database, and scope can be noted and are discussed in the following. Additionally, discussions of the specific limitations of each of the three articles comprising this dissertation can be found in the respective chapters.

The main methodological criticism of this research relates to the database, as SP data from DCEs have some shortcomings, as already mentioned in Section 1.4.1.1, that may lead to hypothetical bias and restricted reliability and validity of results, especially when it comes to WTP values. Furthermore, relatively unknown or unfamiliar alternatives (such as FCEVs and BEVs) could lead to the use of heuristics or the consideration of only a limited number of selected attributes in respondents' choice decisions (Anable et al., 2011).

However, since only (potential or new) car buyers were surveyed, respondents most likely had greater awareness about their preferences, greater knowledge about the available vehicle alternatives, and greater familiarity with the choice task compared to individuals without vehicle purchase intention, which enhances the credibility and reliability of their answers. Moreover, no evidence for non-rational behavior was found (e.g. all estimated vehicle attribute parameters had the expected sign). However, the complexity of decisions might have been fully or overly exploited, as indicated by the results of the DCE with unforced choice task.

In summary, given the objective and scope of the thesis, the approach of using SP data was considered to be appropriate due to the unavailability of RP data for some alternatives and attribute levels at that time, but also due to other merits of the approach, such as full information and control over the data and simpler administration, despite its known drawbacks.

Regarding the format and design of the survey, problems might arise from the usage of closed questions that may not cover the full spectrum of response options. Moreover, potential research gaps and the content of the questionnaire and DCE were entirely influenced by the literature or by practical considerations, particularly with respect to the key factors that had been shown to influence vehicle adoption – e.g. vehicle attributes, attitudes, socio-demographics, and vehicle usage habits. Thus, despite a meticulous execution of this review process, there may be other factors that were overlooked by this approach. For instance, additional in-depth qualitative interviews with potential or new car buyers could have identified additional determinants of the choice process. However, measures were applied to consider some of these aspects, such as the pre-test conducted in the development phase of the questionnaire and the usage of well-established measurement scales (e.g. regarding environmental awareness and technophilia).

Several aspects may have affected the representativeness of the sample and the analysis. For instance, respondents were recruited from a commercial online panel of a marketing company and participation was restricted to current or potential buyers of new cars. Thus, strictly speaking, statements can only be derived for this group of German vehicle buyers. Moreover, since the focus of this thesis is on the case of Germany and vehicle purchase decisions of private households, the generalizability of results is further limited and theoretically restricted to this sub-population of the German and especially the European vehicle market. Therefore, these restrictions and the context at the time of the survey (i.e. shortly after the financial crisis, with relatively low availability and diffusion of AFVs, and no governmental incentives for BEVs) should be taken into account when interpreting the results. However, given that Germany is the largest vehicle market in Europe, but still witnesses relatively low AFV adoption rates among German private households, the subject of the study is worth to be analyzed and the chosen conceptual framework of the research is nevertheless a good starting point.

A limitation concerns the theoretical foundation of this dissertation, as the studies included in this thesis all use the economic approach of vehicle choice research, which is based on the rational choice theory and the application of choice models. Thus, the research could have benefitted from the more pronounced inclusion of psychological and sociological constructs and theories. However, the manageability of the questionnaire from the respondents' point of view and the breadth and depth of research topics had to be balanced, so that only selected attitudinal questions were used. Finally, the focus of this research is on one-time vehicle adoption decisions of new cars. However, for disruptive innovations such as PHEVs and BEVs, with their distinctly different vehicle features and potential limitations regarding driving range and charging times, behavioral changes are also necessary, but these were not considered in this research.

1.7 Potential for Future Research

Although the research on car buyers' preferences for AFVs and specific vehicle segments has been broad and ever-increasing since the beginning of this doctoral thesis, attempts to scientifically assess vehicle buyers' preferences still have great methodological and content-related research potential. That is, further research efforts are still needed to better understand vehicle buyers evolving preferences, especially since the diffusion of AFVs is still in its initial phase and, despite substantial efforts (e.g. incentives), still falls short of the expectations of decision-makers in politics and the automotive industry. In addition, car buyers have increasingly switched from smaller vehicles to SUVs. Both developments are undesirable from an environmental and economic perspective.

Thus, the merits and limitations of this doctoral thesis may act as a starting point for future research, such as updating and enhancing the existing models with more recent data and choice models or adding new variables and methodological approaches.

For instance, future research should more closely examine the interdependencies between vehicle type choice and fuel type choice, and focus less on the latter alone, especially since the demand for SUVs is currently the greatest (environmental) concern for political and industrial decision-makers, and not all combinations of alternative propulsion technologies and vehicle segments are economically and environmentally beneficial.

Furthermore, a more pronounced usage of complementary approaches and data to investigate attitudes and preferences, such as RP and SP data, qualitative and quantitative methods, or economic and psychological approaches could provide a deeper understanding of the determinants of vehicle choice and the hierarchy and interaction of these individual influencing factors. Such a coupling of different research directions could result in the following exemplary extensions. Firstly, the inclusion of more psychological variables (e.g. emotions, symbolic value, or personality) and sociological components of vehicle adoption (e.g. peer influence and neighbor effects) in vehicle choice models, although the possibilities are restricted by human processing capacities (number of attributes in a DCE, number of questions in a survey) – one possibility to combine the advantages of choice models and psychological theories is the application of hybrid choice models (see e.g. Ben-Akiva et al., 2002). Secondly, a gradual procedure that alternates between the different methods (e.g. qualitative and quantitative analysis) to mutually enhance the respective models and results (see Kester et al., 2019; Coffman et al., 2017). Finally, a greater inclusion of RP data, i.e. real vehicle purchases, to compensate for the known weaknesses of SP data and, in particular, hypothetical choice tasks. With the projected increasing diffusion of AFVs in the near future, these data should be more readily available.

Moreover, since vehicle purchase in multi-person households usually is a joint rather than an individual decision due to its financial magnitude, these group-dynamic processes and negotiations should be examined in choice models, as they are comparably poorly understood (Anable et al., 2011) and only rarely studied (see e.g. Beck and Rose (2019) or Hensher et al. (2017) for first attempts to capture this issue). Likewise, investigating the development of preferences over time as a consequence of changes in surrounding conditions (e.g. vehicle market, policy, society) and personal characteristics (socio-demographics, stage in life, attitudes, knowledge) would add to a deeper understanding of vehicle purchase as an embedded, dynamic, and very context-specific process (e.g. differences concerning first or second household vehicle), as preferences are not necessarily stable (see Anable et al., 2011). Therefore, studies based on panel data could be an interesting direction for future research.

Additionally, the scope of the research could be broadened, as exploring the new passenger car purchase decisions of private households might be too narrow with regard to market conditions and their anticipated development. That is, about 2/3 of the newly registered vehicles in Germany are registered as commercial vehicles (KBA, 2020b), i.e. investigating the decision criteria of fleet managers or institutional buyers, such as municipalities or local governments (see e.g. Christensen et al., 2017; Koetse and Hoen, 2014; van Rijnsoever et al., 2013), seems to be a promising research topic. Furthermore, freight and heavy duty transportation is responsible for roughly 40% of transportation emissions and expected to expand its share until 2050 (Moultak et al., 2017), indicating that better knowledge on how to increase the adoption of AFVs in this market segment is urgently needed (see e.g. Anderhofstadt and Spinler (2019) or Kluschke et al. (2019) for more information on this specific topic). Likewise, the analysis of second-hand AFVs, especially BEVs, seems to be an interesting subject for future research, as the market for used vehicles will grow in the future. Especially car buyers' preferences regarding additional vehicle features that might gain importance in this market (e.g. battery status and warranty) should be assessed in order to derive scientifically substantiated recommendations. Besides the well-kown vehicle purchase decisions, individuals' preferences for new business models, such as car sharing or mobility as a service, should be assessed. Reasons for this are that an increasing number of these new mobility concepts are available on the market and that younger generations tend to be less interested in vehicle ownership but more open to such sharing economy options and integrated solutions, so that these concepts could be an important factor for a successful diffusion of BEVs (see e.g. Burghard and Dütschke, 2019).

Moreover, the insights of such an empirical analysis of car buyers' preferences could enter more sophisticated, individual-level technology diffusion models, such as agent-based simulation models or spatially disaggregated models, to more realistically assess and predict the diffusion patterns of specific vehicles depending on different framework conditions and interactions of market players. This could enhance the applicability and significance of the derived policy recommendations compared to the results of a scenario analysis based on very broad vehicle categories and average values (see e.g. Gnann et al. (2019) or Al-Alawi and Bradley (2013) for reviews of vehicle market diffusion models).

Finally, extending the research to countries other than Germany or investigating the impact and effectiveness of selected policy measures in more detail could be further interesting subjects for future research.

CHAPTER 2

CONSUMER PREFERENCES FOR ALTERNATIVE FUEL VEHICLES: A DISCRETE CHOICE ANALYSIS

CONTENTS

2.1 Introduction

The transportation sector is responsible for a large share of the European Union's greenhouse gas (GHG) emissions, and consequently is a focal point of the European Commission's sustainability strategies. Beyond that, most individual member countries have decided to implement programs to further accelerate the diffusion of alternative fuel vehicles[1] (AFVs) in general and electric cars in particular, including financial incentives as well as command-and-control measures. However, although there is an increased interest in less environmentally intrusive transportation technologies on the part of European governments, AFVs have not largely penetrated the market yet. Thus, drawing on German stated preferences discrete choice data and applying a mixed logit model, the purpose of this paper is to assess the relative impact of vehicle attributes, such as purchase price, fuel cost, driving range, fuel availability, CO_2 emissions, refueling time, and governmental incentives, on the choice probabilities of AFVs. In particular, we look at the willingness-to-pay (WTP) for such features and simulate how changes of these affect the potential market shares of the different propulsion technologies in a scenario-based analysis.

Our study builds on the rich body of literature on the demand for AFVs, and especially the research of Achtnicht et al. (2012), who also consider the German market, but we expand these studies by additionally taking PHEVs as choice alternative, and driving range, recharging time, and governmental incentives as vehicle attributes into account, to more realistically analyze consumer preferences regarding electric mobility.

2.2 Survey Design and Data

The data were collected in a nationwide, web-based survey conducted in July and August 2011. The sample was drawn from a commercial German online panel, with the restriction that the last vehicle purchase of potential respondents did not date back more than a year, or that the potential respondents intended to purchase a new car within the next year. In total, 711 respondents completed the survey. Although the sample was supposed to represent the German population in terms of socio-economic and socio-demographic factors, a comparison with the population statistics shows certain differences.

[1] AFVs are vehicles that run on liquid or gaseous fuels other than gasoline and diesel, or at least partly on electricity. These include biofuel vehicles (BVs), natural gas vehicles (NGVs), and hydrogen (fuel cell electric) vehicles (FCEVs). There are also hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fully battery electric vehicles (BEVs).

Specifically, the survey under-represents individuals with low incomes, while it over-represents younger and more highly educated people, both being common features of web-based surveys. Moreover, single-person households and households without a car are under-represented. Car buyers who live in urban areas, who are not willing to spend more than €20,000 for their next vehicle, and who drive more than 20,000 km per year are over-represented. The sample, however, almost perfectly reflects the gender ratio, home ownership structure, vehicle segment, and regional distribution of the population among the 16 German federal states

The survey is sectionalized. Section 1 seeks information about the respondents' existing and planned car ownership and driving habits, such as vehicle fuel type and vehicle segment, daily and annual mileage on highways and for city trips. Section 2 focuses on familiarity with AFVs, an introduction to alternative propulsion technologies, and the stated preferences discrete choice experiment. In Section 3, respondents were asked about the importance of a wide range of vehicle attributes, including those used in the choice experiment, in their purchase decision. In Section 4, respondents indicated their level of agreement with a variety of statements regarding their environmental concerns and environmentally friendly behavior, their socio-economic and socio-demographic characteristics, such as age, income, and educational level, and specifics of their place of residence.

The stated preferences discrete choice experiment was at the center of the survey, and embraced seven fuel types (NGVs, HEVs, PHEVs, BEVs, BVs, FCEVs, and conventional (gasoline, and diesel) vehicles (CFVs)) to cover all propulsion technologies, that are already available on the German market, or will be in the near future. The seven vehicle types were described by: purchase price, fuel cost, CO_2 emissions, driving range, fuel availability, refueling time, battery recharging time, and policy incentives. Table 2.1 shows the attribute levels used.

Table 2.1: Attributes and levels of the discrete choice experiment

Variable	Alternative (Fuel type)	No. of levels	Levels
Purchase price	All	3	75%, 100%, 125% of stated reference value (€)
Fuel cost per 100 km	All	3	€5, €15, €25
CO_2 emissions	CFV, NGV, HEV	3	50%, 75%, 100% of average vehicle
	PHEV, BEV, BV, FCEV	3	0%, 50%, 100% of average vehicle
Driving range	CFV, NGV, HEV, PHEV, BV, FCEV	3	400 km, 700 km, 1000 km
	BEV	3	100 km, 400 km, 700 km
Fuel availability	CFV, HEV	2	60%, 100% of all stations
	NGV, PHEV, BEV, BV, FCEV	3	20%, 60%, 100% of all stations
Refueling time	CFV, NGV, HEV, PHEV, BV, FCEV	2	5 min, 10 min
Battery recharging time	PHEV, BEV	3	10 min, 1 h, 6 h
Policy incentives	PHEV, BEV, BV, FCEV	3	None, No vehicle tax, Free parking and bus lane access

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

To reduce the hypothetical bias, respondents were solicited to treat their choices as if it were a real purchase decision, and instructed to treat the vehicles as being identical other than in terms of the attributes described in the experiment. To further increase realism, purchase prices were customized for each respondent based on statements about the price range of their latest or expected next car, and allowed to vary by ±25% for all types of vehicles.[2] Fuel cost was displayed in Euros per 100 km to avoid the unit conversion of other fuel consumption measures (e.g. Euros per liter, kWh or kg), thus making it easily comparable between the different propulsion technologies.

CO_2 emissions were taken as being in proportion to the average vehicle of the respondents' favorite car segment, to establish more realistic choice situations, i.e. as if a fixed, segment-invariant measure (e.g. gram of CO_2 per kilometer) would have been used. Additionally, in contrast to CFVs and NGVs, the CO_2 emissions of the non-fossil fuel vehicles were allowed to be zero.[3] The driving range was defined as the distance that can be traveled on a full tank and/or battery. Because the cruising radius of BEVs is currently limited compared to other propulsion technologies, the levels of their driving range attribute were adjusted downwards in order to increase realism. Fuel availability also varied by fuel type to reflect the current differences in refueling network density.[4] Regarding the length of the battery-charging process, the attribute levels have a great bandwidth to cover current charging options (6 h to fully charge the battery) but also prospective infrastructural means, such as fast-charging or battery-switching stations (1 h, 10 min). The main reason for taking the refueling time into account was to remind respondents of the unfamiliar particularities of PHEVs (two energy sources with probably dissimilar refueling times).

In terms of public policy, we take into account that the German government is considering the introduction of non-monetary incentives (permission for bus lane usage, special parking areas) for AFVs to foster their use (German Federal Government, 2011), and that it has already

[2] This range is unrealistic for some AFVs, especially BEVs. However, it was chosen to circumvent the dominance of purchase price over other vehicle attributes, making AFV choice more likely and parameter estimates more reliable.
[3] This emission value is used because AFVs, especially BEVs, are often promoted as being very environmentally friendly. Besides, FCEVs and BEVs theoretically have the potential to drive nearly emission-free, provided that electricity and hydrogen are generated with renewable energies.
[4] In 2012 there were 14,732 gasoline filling stations in Germany, with almost 7500 selling natural gas, but there were only 2073 publicly accessible battery recharging stations, 337 bioethanol, and about 35 hydrogen filling stations.

introduced a motor vehicle tax exemption for BEVs[5] (BMF, 2012). Moreover, the motor vehicle tax is an important attribute that German car buyers take into account in their purchasing decisions (Dena, 2010). Finally, prior results concerning the influence of non-monetary incentives on AFV choice are mixed (Horne et al., 2005; Potoglou and Kanaroglou, 2007). Thus, an evaluation of the effectiveness of such policy measures in the case of Germany is necessary.

The wide range of seven vehicle alternatives and eight attributes leads to a large number of potential vehicle combinations and choice tasks, which is impossible for a respondent to handle. On this account, a completely randomized fractional factorial design was generated. Each respondent was confronted with 15 choice sets, which in our pretest proved to be a manageable amount without leading to noteworthy fatigue or rejection. To reduce task complexity, each choice set consisted of only four out of the seven vehicle alternatives. The 711 respondents facing 15 choice sets each provided 10,665 observations.

2.3 Methodological Approach and Model Specification

Our analysis of the stated preferences vehicle choice data is based mainly on a mixed (error components) logit model (ML), which is able to account for unobserved correlation between choice alternatives and, thus, relaxes the restrictive independence of irrelevant alternatives (IIA) assumption of the multinomial logit model (MNL). Additionally, it is capable of capturing the panel nature of stated preferences discrete choice experiments, which are usually characterized by repeated choices of respondents.

Assuming utility-maximizing behavior, in every choice set the respondents select the alternative that renders the highest level of utility. Unfortunately, utility is unobservable, so it has to be modeled as a random variable. Thus, drawing directly from Brownstone and Train (1999), the utility U_{nj} that decision-maker *n* receives from alternative *j* from a finite set of *J* alternatives is assumed to be

$$U_{nj} = \beta' x_{nj} + \mu_n' z_{nj} + \varepsilon_{nj}, \tag{4.1}$$

[5] The annual circulation tax in Germany is calculated depending on the fuel type, so that CFVs are burdened on the basis of engine displacement (base tax rates of €2 and €9.5 per 100 ccm for gasoline and diesel engines), and their CO_2 emissions (tax rate of €2 per gCO_2/km for every gram above 110 gCO_2/km), while BEVs are assessed by their weight (€5.63-6.39 per 200 kg, increasing with weight class). The vehicle tax exemption for BEVs is granted for 10 years (BMF, 2012). Thus, compared to an average CFV (1600 ccm and 140 gCO_2/km), the vehicle tax savings over ten years would amount to €920-2120 for PHEV, or compared to a regularly taxed BEV (1500 kg) to €450. Regarding the possibility of free parking, the savings would amount to at least €300, depending on the additional usage of parking lots in other areas. Both incentives, however, would be at the lower end of comparable purchase price subsidies that are granted for electrified vehicles in other European countries.

where $\beta' x_{nj}$ is the deterministic part of utility, with x_{nj} being a vector of observed attributes of the vehicle alternative j and socio-demographic characteristics of the respondent n, and β' being a vector of unknown fixed parameters. The term $\mu_n' z_{nj}$ together with ε_{nj} represents the stochastic portion of utility, with z_{nj} being a vector of observable variables relating to alternative j, μ_n' being a random vector with zero mean, and ε_{nj} being a random term that is independent and identically Gumbel distributed. The correlation between alternatives in unobserved attributes is induced by non-zero random terms in $\mu_n' z_{nj}$[6], which can be interpreted as error components, with the complexity of the correlation structure depending on the specification of z_{nj}.

In our model, we use a correlation structure comparable to the nested logit model, because this fits the data best regarding log likelihood. In this model specification, where the vehicle alternatives are grouped into *K* non-overlapping nests, z_{nj} is defined as a vector of dummy variables d_{jk}, indicating the presence or absence of alternative j in nest k, so that the error components can be specified as $\mu_n' z_{nj} = \sum_{k=1}^{K} \mu_{nk}\, d_{jk}$. As a consequence, μ_{nk} is included in the utility function of each alternative in nest *k*, leading to correlation among these alternatives, while alternatives located in different nests remain uncorrelated. The random term μ_{nk} is specified to be independent and identically normally distributed $\mu_{nk} \sim N(0, \sigma_k)$, with the variance σ_k capturing the size of the correlation between alternatives in the same nest.

A specification of the error components leading to the following three mutually exclusive nests performed best in terms of model fit. The first nest comprises CFVs, HEVs and NGVs, the second, PHEVs and BEVs, and the third, BVs and FCEVs. While we chose this nesting structure on statistical grounds, it is also plausible, because more similar vehicle alternatives are assorted and, thus, correlated in unobserved factors, drawing more demand from each other than from dissimilar vehicle alternatives. For instance, the three vehicle alternatives grouped together in the first nest are the ones exclusively running on fossil fuels, and also the best-known by the potential car buyers because of their current market shares. In the second nest, vehicles are clustered that drive electrically exclusively or at least for the most part, and, thus, have the unfamiliar characteristic of requiring a plug. The remaining two vehicles clustered in the third nest, FCEVs and BVs, are both powered by liquid non-fossil fuels, which are almost non-existent at fuel stations in Germany, resulting in a high unfamiliarity with both fuels.

[6] The IIA property of the MNL and its restrictive substitution patterns arise from defining all terms in z_{nj} as being identically zero, such that no unobserved correlation exists over alternatives.

Further, both fuels had identical attribute levels in the experiment, which possibly made them highly substitutable.

The conditional choice probabilities of the ML are logit as in the standard MNL, given the specified utility functions and values for μ_{nk}. However, since μ_{nk} is a random variable, the unconditional choice probability is obtained by integrating the standard logit choice probability over all values of μ_{nk}, weighted by the density of μ_{nk}. If additionally decision-makers are repeatedly observed in choice situations, this panel effect can be taken into account, e.g. by the inclusion of individual specific error components that are constant over the *T* choice occasions. Hence, the probability that person *n* makes a specific sequence of choices $i = \{i_1, \dots, i_T\}$ is given by

$$P_{ni} = \int_{\mu_{n1}} \cdots \int_{\mu_{nK}} \prod_{t=1}^{T} \frac{\exp(\beta' x_{nit} + \sum_{k=1}^{K} \mu_{nk} d_{jk})}{\sum_{j=1}^{J} \exp(\beta' x_{njt} + \sum_{k=1}^{K} \mu_{nk} d_{jk})} \phi(\mu_{n1} | 0, \sigma_1) \dots \phi(\mu_{nK} | 0, \sigma_K) d\mu_{n1} \dots d\mu_{nK}. \quad (4.2)$$

The choice probabilities cannot be calculated exactly because the integrals do not have a closed form, and, thus, have to be approximated through simulation. To ensure the robustness of results, we used 1000 Halton draws for the maximum simulated likelihood estimation.

Table 2.2: Definition of variables used in the model

Variable	Definition
NGV	1 if fuel type is natural gas, 0 otherwise
HEV	1 if fuel type is hybrid electric, 0 otherwise
PHEV	1 if fuel type is plug-in hybrid electric, 0 otherwise
BEV	1 if fuel type is battery electric, 0 otherwise
BV	1 if fuel type is biofuel, 0 otherwise
FCEV	1 if fuel type is hydrogen (fuel cell), 0 otherwise
Purchase price	Purchase price in € thousands
Fuel cost	Fuel cost in €/100 km
CO_2 emissions	Percentage of CO_2 emissions of an comparable average current vehicle of the respondents' favorite car segment
Driving range	Driving range on a full tank/battery in km
Fuel availability	Percentage of filling/recharging stations with proper fuel
Refueling time	Refueling time in minutes
Battery recharging time	Battery recharging time in minutes
Incentive 1	1 if incentive (no vehicle tax) is granted, 0 otherwise
Incentive 2	1 if incentive (free parking, bus lane usage) is granted, 0 otherwise
Stated purchase price < €20,000	1 if respondent stated to spend €20,000 at most, 0 otherwise
Age < 44 years	1 if respondent is younger than 44 years, 0 otherwise
High environmental awareness	1 if respondent is more environmentally aware than 60% of the sample, 0 otherwise
Parking lot equipped with socket	1 if respondent has access to a parking lot equipped with a socket, 0 otherwise
Share of city trips > 60%	1 if respondents' annual share of trips in cities exceeds 60% of all trips, 0 otherwise
High educational level	1 if respondent has higher education entrance qualification or university (of applied sciences) degree, 0 otherwise
Vehicle segment mini or small	1 if respondent indicated the purchase of a mini or small car, 0 otherwise

The variables entering the deterministic portion of utility are shown in Table 2.2. They can roughly be separated into the attributes used to describe the vehicle alternatives in the discrete choice experiment, and the socio-demographic characteristics of respondents. The fuel types are included as alternative-specific constants (ASCs), with CFV acting as the base alternative.

We do not have any specific expectations about the final order of popularity of the propulsion technologies among respondents, but do anticipate specific impacts on choice probability for vehicle attributes, for instance, that purchase price, fuel cost, CO_2 emissions, refueling time, and battery recharging time all have negative signs, and driving range, fuel availability, and the two government incentives, positive signs.

The vehicle attributes enter the utility functions partly as generic variables, as with purchase price, fuel cost, CO_2 emissions, and fuel availability[7], and partly as alternative-specific/semi-generic variables. The latter is done because these attributes are only linked with particular fuel types (refueling time, government incentives, and battery recharging time), have specific attribute levels for some alternatives (the driving range of BEVs is described by unique levels) or because of content. For example, we assume the duration of the battery-recharging process to be more important for BEVs compared to PHEVs, as the former do not possess a backup propulsion technology.

Additionally, some vehicle attributes interact with socio-demographic and attitudinal variables. For instance, we expect a more pronounced price sensitivity for households with low income (purchase of a reasonably priced car).[8] Moreover, the higher concern about vehicles' CO_2 emissions from above-average environmentally aware car buyers is well documented (e.g. Ewing and Sarigöllü, 2000; Daziano and Bolduc, 2013). On that account, we included an interaction of the CO_2 emission attribute with a dummy variable that identifies the highly environmentally aware consumers.[9]

Further, to trace the consumer groups that are open-minded about the alternative fuels per se, we add interaction terms of the ASCs with characteristics of the respondents. In other words, we expect that younger, well-educated, and environmentally aware car buyers are more impartial towards at least some of the alternative fuels, and that the possibility to plug-in the car at home, a higher share of kilometers driven in urban areas[10], and the preference for a small

[7] Although CO_2 emissions and fuel availability varied alternative-dependently by design, alternative-specific parameter estimates did not differ statistically, so that the inclusion of a corresponding single generic parameter for both vehicle attributes is superior.
[8] Since about a fifth of the respondents did not indicate their income, we follow Achtnicht et al. (2012) and use the respondents' stated purchase price of their current or planned vehicle as a proxy, which can be justified on the ground that both variables are highly correlated. Thus, in the utility functions, the purchase price is additionally interacted with a dummy variable, which indicates individuals who have stated a maximum purchase price of €20,000.
[9] A respondent's environmental awareness was measured with the scale developed by Preisendörfer (1999).
[10] In our sample, 47.7% of the respondents had access to an electric outlet at their parking lot, while only 16.2% used their car predominantly for urban trips.

car, all increase the choice probabilities for electrified vehicles. In contrast to the studies of Mabit and Fosgerau (2011) and Ziegler (2012), we did not find significant effects of, e.g. gender or the number of children and cars in the household on the choice of specific fuel types during the specification of our final model.

2.4 Results

2.4.1 Discrete Choice Models

The results of applying the MNL and the ML are given in Table 2.3. In both cases, all experimentally varied vehicle attributes, except refueling time, impact significantly the choice decision, and the coefficients all have the expected sign. However, there are three differences between the models. First, the fit of the ML specification is significantly better than that of the MNL.[11] Second, although the significance of two parameters is lower in the ML, the opposite is true for a larger number of other variables. Finally, the three error components of the ML are highly significant suggesting correlation between the nested vehicle alternatives.

As expected, both of the main vehicle expense factors – purchase price and fuel cost per 100 km – have a negative, and highly significant impact on the choice decisions. In addition, the results indicate that individuals who have stated a maximum purchase price of €20,000 are more price sensitive. A similar pattern can be observed for the influence that CO_2 emissions exert on respondents' stated choices; high emissions are disfavored by all car buyers, but are rejected even more by environmentally aware consumers.

Driving range enters the model positively; frequent refueling stops being time-consuming and inconvenient. As expected, it also affects the car-purchasing decision concerning BEVs more strongly, compared with the other fuel types. Striking, however, is the almost doubled value of the coefficient, indicating that car buyers assign a high value to an improvement of these limited driving ranges. The density of the filling station network also impacts vehicle choice positively; a widespread refueling infrastructure decreases the risk of being stranded with an empty tank or battery. Refueling time, on the other hand, does not seem to be a crucial factor, at least if it does not exceed our upper bound of 10 min.

The case is different for the battery recharging time, which is highly significant and negatively signed, indicating that a prolongation of the recharging process strongly decreases the utility of the respective vehicle. Confirming our assumption, the magnitude of this effect is

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[11] A likelihood ratio test illustrates that the error components specification is a statistically highly significant improvement over the MNL specification: $-2(LL_{MNL} - LL_{ML}) = 939.62 > \chi^2_{\alpha=0.95}(3) = 7.81$.

dependent on the degree of electrification of the considered vehicles. This implies that the impact of a lacking fast-charging infrastructure on the choice of a BEV is more severe than for a bifueled PHEV. Governmental incentives also play a positive role in vehicle choice, regardless of whether they are monetary or not.

The results further show that new car buyers on average hold a reservation against AFVs, which would of course be a huge barrier to their extensive diffusion.[12] This general and partially very high reluctance, however, is mitigated in some consumer groups, as indicated in Table 2.3 by the significant interaction terms between the socio-demographic variables and the ASCs. For instance, the probability to choose HEVs or BEVs is higher for younger individuals, as revealed by the significant positive coefficients of the two corresponding interaction terms. Apart from having a more pronounced sensitivity for vehicles' CO_2 emissions, environmentally aware car buyers have an increased likelihood to purchase AFVs, regardless of the environmental friendliness of the vehicle, as can be seen by the highly significant and positive interaction parameters.[13] As expected, there is a greater choice probability for PHEVs and BEVs, when consumers' homes have parking lots with a socket.

Further, the demand for NGVs and HEVs is lower for individuals who use their car predominantly for city trips, while they are more likely to buy a BEV. The probability of purchasing a PHEV or a BV, on the other hand, increases with the educational level of car buyers. Finally, car segment is also a relevant attribute in fuel type choice, as the significant interaction coefficients show. While consumers who indicated the purchase of a small vehicle are also more likely to choose a BEV, the opposite is true for HEVs.

[12] We estimated an ML without interactions between the ASCs and socio-demographic and attitudinal variables, to gain an undistorted picture of the general acceptance of the fuel types. Since all fuel type coefficients had a negative sign and were highly significant, AFVs on average are preferred less than CFVs.
[13] This is somewhat surprising, because in Germany NGVs are promoted more in terms of cost-effectiveness than as being 'green', and BVs were at the center of a very controversial discussion.

Table 2.3: Parameter estimates

Variable	Multinomial logit	Mixed logit
NGV	-0.2093*	-0.2749**
HEV	-0.4797***	-0.5740***
PHEV	-0.8170***	-0.9359***
BEV	-1.6639***	-1.8404***
BV	-0.7712***	-0.8096***
FCEV	-0.5973***	-0.6193***
Purchase price	-0.0456***	-0.0499***
Purchase price × Stated purchase price < €20,000	-0.0466***	-0.0510***
Fuel cost	-0.0490***	-0.0532***
CO_2 emissions	-0.0019***	-0.0020***
CO_2 emissions × High environmental awareness	-0.0023***	-0.0025***
Driving range × CFV, NGV, HEV, PHEV, BV, FCEV	0.0008***	0.0008***
Driving range × BEV	0.0015***	0.0016***
Fuel availability	0.0042***	0.0046***
Refueling time	-0.0048	-0.0046
Battery recharging time × PHEV	-0.0004***	-0.0005***
Battery recharging time × BEV	-0.0009***	-0.0009***
Incentive 1 × PHEV, BEV, BV, FCEV	0.2187***	0.2349***
Incentive 2 × PHEV, BEV, BV, FCEV	0.1521***	0.1637***
Age < 44 years × NGV	-0.0522	-0.0507
Age < 44 years × HEV	0.1358	0.1853*
Age < 44 years × PHEV	-0.0654	-0.0468
Age < 44 years × BEV	0.4046***	0.4542***
Age < 44 years × BV	-0.0680	-0.0733
Age < 44 years × FCEV	0.0016	0.0086
High environmental awareness × NGV	0.1683	0.2253**
High environmental awareness × HEV	0.4435***	0.5109***
High environmental awareness × PHEV	0.7152***	0.8658***
High environmental awareness × BEV	0.6445***	0.7814***
High environmental awareness × BV	0.3618***	0.4460***
High environmental awareness × FCEV	0.3049***	0.3792***
Parking lot equipped with socket × NGV	-0.0710	-0.0714
Parking lot equipped with socket × HEV	0.0638	0.0739
Parking lot equipped with socket × PHEV	0.2868***	0.3432***
Parking lot equipped with socket × BEV	0.2341**	0.2919**
Parking lot equipped with socket × BV	0.1236	0.1422
Parking lot equipped with socket × FCEV	0.0339	0.0453
Share of city trips > 60% × NGV	-0.2934**	-0.3815***
Share of city trips > 60% × HEV	-0.2179	-0.2881**
Share of city trips > 60% × PHEV	-0.0464	-0.0533
Share of city trips > 60% × BEV	0.3573***	0.3685**
Share of city trips > 60% × BV	-0.0349	-0.0738
Share of city trips > 60% × FCEV	-0.0983	-0.1545
High educational level × NGV	-0.0161	-0.0009
High educational level × HEV	0.0001	0.0407
High educational level × PHEV	0.2409***	0.2875**
High educational level × BEV	-0.0344	0.0131
High educational level × BV	0.3370***	0.3852***
High educational level × FCEV	0.0921	0.1109
Car segment mini or small × NGV	-0.1932	-0.1878
Car segment mini or small × HEV	-0.2392*	-0.2590**
Car segment mini or small × PHEV	-0.0165	0.0191
Car segment mini or small × BEV	0.4330***	0.4774***
Car segment mini or small × BV	0.0527	0.0596
Car segment mini or small × FCEV	-0.0376	-0.0463
Error components		
σ_1 (CFV, NGV, HEV)		0.7440***
σ_2 (PHEV, BEV)		0.8418***
σ_3 (BV, FCEV)		0.3333***
Persons (Choices)	711 (10,665)	711 (10,665)
Log likelihood	-12,637.94	-12,168.13
$\rho^2(0)$	0.391	0.414
$\rho^2(c)$	0.108	0.141

Notes: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively; ρ^2 = McFadden's pseudo R-squared; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; Incentive 1 = no vehicle tax; Incentive 2 = free parking and bus lane access.

2.4.2 Willingness-to-Pay for Vehicle Attributes

Consumers' marginal WTP for changes in vehicle characteristics is shown in Table 2.4, and is calculated, *ceteris paribus*, as the ratio of the coefficient of a specific vehicle attribute and the purchase price parameter based on Table 2.3.

Table 2.4: Marginal willingness-to-pay for changes in selected vehicle attributes

	Stated purchase price > €20,000	Stated purchase price < €20,000
Fuel cost reduction of €1/100 km	1066.38	527.63
CO_2 emissions abatement of 1% × Low environmental awareness	40.71	20.14
CO_2 emissions abatement of 1% × High environmental awareness	90.24	44.65
Driving range increase of 1 km × CFV, NGV, HEV, PHEV, BV, FCEV	16.82	8.32
Driving range increase of 1 km × BEV	32.76	16.21
Fuel availability increase of 1%	91.59	45.32
Battery recharging time reduction of 1 min × PHEV	9.78	4.84
Battery recharging time reduction of 1 min × BEV	17.58	8.70
Incentive 1 (No vehicle tax)	4704.07	2327.53
Incentive 2 (Free parking and bus lane access)	3278.76	1622.30

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

Individuals with a stated purchase price below €20,000 are willing to pay only half as much for beneficial changes in other vehicle features, compared to respondents who indicated the purchase of a more expensive car. This reflects their markedly stronger price sensitivity and a greater importance of vehicle price in purchasing decisions relative to other vehicle features. Nevertheless, the calculated WTP values for the remaining vehicle attributes are considerable, even for consumers with lower stated purchase prices.

Depending on the targeted price range of their next vehicle, car buyers are willing to expend between approximately €530 and €1070 for fuel cost savings of €1 per 100 km. This result indicates that the average German car driver with an annual mileage of about 15,000 km is willing to accept a payback period of 3.5-7 years for an investment in fuel-saving measures. This is reasonable, as it covers the medium vehicle possession duration of 6-7 years (Deutsche Automobil Treuhand GmbH, 2012). This finding is in line with Batley et al. (2004), who report a WTP of €538 for fuel cost savings of €1/100 km.

The WTP to abate 1% of the CO_2 emissions of a current average car ranges from about €20 to €40 and from €45 to €90, depending on the budget and the environmental awareness of the respondent. We can see that environmentally conscious consumers with lower stated vehicle purchase prices still appraise an emissions reduction higher than less environmentally concerned individuals without this €20,000 budget constraint, and thus are willing to pay more for it. Our results are comparable but slightly different to several other studies; Batley et al. (2004) report a WTP of a 10% reduction in vehicles' CO_2 emissions of about €860 in the UK, while Mabit and Fosgerau (2011) find a WTP in Denmark of €4230-5700 to halve vehicle pollution. Ewing and Sarigöllü (1998) and Potoglou and Kanaroglou (2007) find Canadians willing to spend about €1900 for an emission-free vehicle, or between €1540-3660 for a vehicle emitting only 10% of the current average, and Hidrue et al. (2011) report a WTP of €1470-3310 for pollution reductions of 50% and 95% in the US. Finally, Achtnicht (2012) finds that German car buyers are willing to pay €13-45 and €37-127 per gram CO_2/km emissions reduction, depending on their purchase price range.

For every kilometer of additional driving range, respondents are willing to pay a markup of between €8-17 and €16-33 when purchasing a non-BEV and a BEV, respectively, indicating the sensitivity to the currently short electrically propelled operating radius. Our findings for non-BEVs are more in accordance with Batley et al. (2004), who reveal a WTP of about €2580 for a range extension of 161 km. Regarding WTP for an increase in driving range of BEVs, the result is more in line with Mabit and Fosgerau (2011), who find €3950 for the same cruising radius extension, and Hidrue et al. (2011), who report a WTP of €4290-9710 for a range increase from 121 km to 242 km and 483 km, respectively.

The WTP for a 1% expansion of refueling infrastructure for the corresponding fuel is between €45 and €92; a range considerably lower than the €70-820 found by Achtnicht et al. (2012), and less than the WTP of €1350 for a 10% increase in fuel availability found by Batley et al. (2004), suggesting that vehicle choices are not that strongly influenced by fuel availability. Consumers are willing to pay between about €5 and €18 for every saved minute in battery recharging time, depending on their stated purchase price and the drivetrain technology; PHEV or BEV. What can be seen is that respondents are willing to spend much higher amounts for a decrease in recharging time for BEVs, probably because they do not have a backup propulsion technology and thus depend on short recharging periods. We find that a charging time reduction from 6 h to 10 min would be worth from about €1750-3500 for PHEVs and €3150-6300 for BEVs. The latter WTP values are in line with Hidrue et al. (2011), who find values between €1630-6510 for a decrease in the charging time from 10 h to 5 h and to 10 min. These findings are also partly supported by Ito et al. (2013), who report a WTP for a reduced recharging time from 8 h to 5 min (battery exchange stations) of €6110, but only €660 for a quick recharging at home of 30 min.

Car buyers are willing to pay considerable amounts for the two government incentives considered. For instance, their WTP for a vehicle circulation tax exemption over the entire lifetime of the vehicle ranges between approximately €2330 and €4700. For an assumed life of a vehicle of 10 years, these values appear in line with those of Potoglou and Kanaroglou (2007), who find a WTP of €1600-3790 for tax-free vehicles. Furthermore, the WTP for the possibility of free parking and allowance to use bus lanes amounts to between €1620-3280; comparable to Horne et al. (2005), who find a WTP of €1350 for express lane access alone.

2.4.3 Simulations

To determine realistic market shares of conventional and alternative propulsion technologies with the aid of our model coefficients, we first have to describe the German vehicle market conditions in a representative manner. This *status quo* shown in Table 2.5 is derived by defining an average car for each drivetrain technology or fuel type based on current market data and discounted expected values.

The main focus of the scenario analysis is on the impacts of policy or actions of the automotive industry on the adoption of AFVs in general and all kinds of electrified vehicles in particular. We consider nine scenarios, distinguishable by the level of government intervention and subsidization or by the size of the steps taken by car manufacturers, while holding all other attributes at their base levels.[14] An overview of the scenarios is seen in Table 2.5. The market shares of the fuel types are calculated based on the distribution of socio-economic characteristics in our sample, and the coefficients in Table 2.3. Further, the choice situation underlying the simulations is modeled as unrestricted; for each individual, a single choice set is assumed, in which the seven vehicle alternatives are available, and represented by the attribute levels of the respective scenario. The choice probabilities of the propulsion technologies in the scenarios are first calculated on an individual level and then averaged to obtain sample values, using 1000 draws.

[14] For a similarly detailed analysis covering Flanders see Lebeau et al. (2012), and Daziano and Achtnicht (2012) for the German refueling network.

Table 2.5: Specification of the base and the government intervention scenarios

	Purchase price (€)	Fuel cost (€)	CO_2 emissions (%)	Driving range (km)	Fuel availability (%)	Refueling time (min)	Battery recharging time (min)	Incentive 1	Incentive 2
Scenario 1: Base case									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	50.9	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	30,200	5.5	31	750	43.3	5	240	no	no
BEV	36,800	4.0	0	175	14.1	-	480	no	yes
BV	22,900	9.0	23	750	2.3	5	-	no	no
FCEV	33,800	7.5	0	750	0.2	5	-	no	no
Scenario 2: Incentives (vehicle circulation tax exemption, bus lane access, and free parking) for PHEVs, BEVs, BVs, and FCEVs									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	50.9	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	30,200	5.5	31	750	43.3	5	240	yes	yes
BEV	36,800	4.0	0	175	14.1	-	480	yes	yes
BV	22,900	9.0	23	750	2.3	5	-	yes	yes
FCEV	33,800	7.5	0	750	0.2	5	-	yes	yes
Scenario 3: Purchase premiums of €2500 for PHEVs, and €5000 for BEVs and FCEVs									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	50.9	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	27,700	5.5	31	750	43.3	5	240	no	no
BEV	31,800	4.0	0	175	14.1	-	480	no	yes
BV	22,900	9.0	23	750	2.3	5	-	no	no
FCEV	28,800	7.5	0	750	0.2	5	-	no	no
Scenario 4: Purchase price of €21,800 for all vehicles									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	21,800	6.5	84	1000	50.9	5	-	no	no
HEV	21,800	7.5	77	1000	100.0	5	-	no	no
PHEV	21,800	5.5	31	750	43.3	5	240	no	no
BEV	21,800	4.0	0	175	14.1	-	480	no	yes
BV	21,800	9.0	23	750	2.3	5	-	no	no
FCEV	21,800	7.5	0	750	0.2	5	-	no	no
Scenario 5: Battery leasing contract of €80/month for an annual mileage of 10,000 km (i.e. €5.6/100 km) and purchase price reduction of €10,000 for BEVs									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	50.9	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	30,200	5.5	31	750	43.3	5	240	no	no
BEV	26,800	9.6	0	175	14.1	-	480	no	yes
BV	22,900	9.0	23	750	2.3	5	-	no	no
FCEV	33,800	7.5	0	750	0.2	5	-	no	no
Scenario 6: 750 km driving range for BEVs									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	50.9	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	30,200	5.5	31	750	43.3	5	240	no	no
BEV	36,800	4.0	0	750	14.1	-	480	no	yes
BV	22,900	9.0	23	750	2.3	5	-	no	no
FCEV	33,800	7.5	0	750	0.2	5	-	no	no
Scenario 7: 100% fuel availability for all AFVs									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	100.0	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	30,200	5.5	31	750	100.0	5	240	no	no
BEV	36,800	4.0	0	175	100.0	-	480	no	yes
BV	22,900	9.0	23	750	100.0	5	-	no	no
FCEV	33,800	7.5	0	750	100.0	5	-	no	no
Scenario 8: Battery recharging time of 5 min									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	50.9	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	30,200	5.5	31	750	43.3	5	5	no	no
BEV	36,800	4.0	0	175	14.1	-	5	no	yes
BV	22,900	9.0	23	750	2.3	5	-	no	no
FCEV	33,800	7.5	0	750	0.2	5	-	no	no

(continued on next page)

Table 2.5 *(continued)*

	Purchase price (€)	Fuel cost (€)	CO_2 emissions (%)	Driving range (km)	Fuel availability (%)	Refueling time (min)	Battery recharging time (min)	Incentive 1	Incentive 2
Scenario 9: Combination of Scenarios 2, 3, 7, and 8									
CFV	21,800	9.0	100	1000	100.0	5	-	no	no
NGV	23,900	6.5	84	1000	100.0	5	-	no	no
HEV	26,700	7.5	77	1000	100.0	5	-	no	no
PHEV	27,700	5.5	31	750	100.0	5	5	yes	yes
BEV	31,800	4.0	0	175	100.0	-	5	yes	yes
BV	22,900	9.0	23	750	100.0	5	-	yes	yes
FCEV	28,800	7.5	0	750	100.0	5	-	yes	yes

Sources: ADAC (2012a, 2012b, 2012c, 2012d); BMWi (2012); Clean Energy Partnership (2012); Daziano and Achtnicht (2012); Grüning et al. (2011); McKinsey (2010); and Wietschel and Brüning (2010).

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; Incentive 1 = no vehicle tax; Incentive 2 = free parking and bus lane access; Due to data limitations for FCEVs, and partly for PHEVs and BEVs, we rely on discounted expected future purchase prices and fuel consumption values. The BEVs available are primarily mini or small cars, while the PHEVs are mainly premium vehicles. As our simulations are based on an average German car, the purchase price for PHEVs is adjusted downwards, and for BEVs upwards to reflect expected price differences to current CFVs, NGVs, HEVs, and BVs.

The predicted market shares of fuel types in the base case and the other eight scenarios are seen in Table 2.6 and Figure 2.1a, and the relative changes in market shares of the vehicle technologies induced by the eight policies in Figure 2.1b. Beginning with the base case, the CFVs capture about one third of the market, with the shares of NGVs and HEVs being approximately 20% and 18%. BVs and PHEVs are chosen by 11-12% of potential car buyers, while FCEVs and BEVs are the preferred option for only about 6% and 2%.

Table 2.6: Market shares of the vehicle technologies in the scenarios (in %)

Scenario	CFV	NGV	HEV	PHEV	BEV	BV	FCEV
1: Base case	30.35	17.82	20.08	10.85	2.24	12.47	6.19
2: Incentives for PHEVs, BEVs, BVs, FCEVs	27.01	15.83	17.34	13.83	2.26	15.86	7.87
3: Purchase premiums for PHEVs, BEVs, FCEVs	28.89	16.96	18.79	12.23	3.02	11.68	8.43
4: Purchase price of €21,800 for all vehicles	23.14	16.01	20.60	14.38	4.86	9.82	11.19
5: Battery leasing contract for BEVs of €80/month	30.19	17.74	19.92	10.77	2.83	12.39	6.16
6: 750 km driving range for BEVs	29.58	17.37	19.21	10.34	5.45	12.07	5.98
7: 100% fuel availability for all AFVs	25.74	18.87	16.87	11.73	2.77	16.00	8.02
8: Battery recharging time of 5 min	29.79	17.49	19.45	11.75	3.28	12.19	6.05
9: Combination of Scenarios 2, 3, 7, and 8	21.39	15.64	13.03	18.08	5.47	12.65	13.74

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; AFV = alternative fuel vehicle.

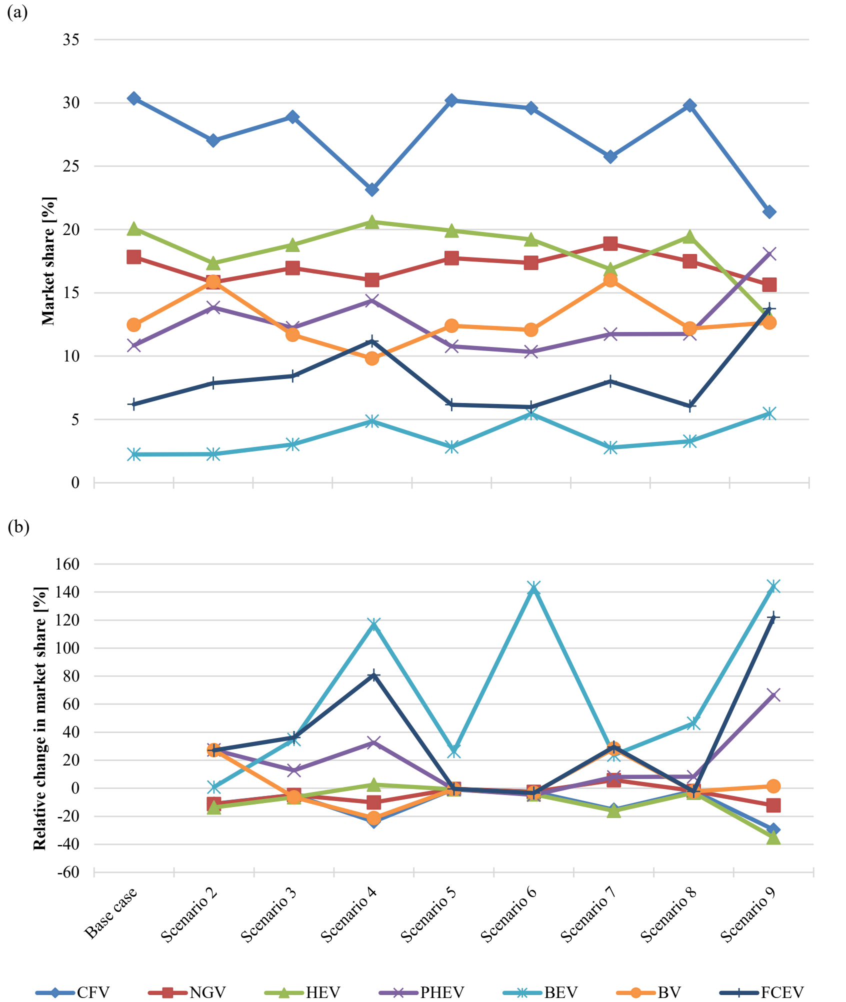

Figure 2.1: (a) Simulated market shares by fuel type subject to the scenarios; (b) Relative change of the simulated market shares compared to the base scenario

Source: Own simulation results.

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

Under Scenario 2, the introduction of monetary and non-monetary incentives for all vehicles that mostly run on non-fossil fuels, i.e. PHEVs, BEVs, BVs, and FCEVs, increases the choice probability for BVs, FCEVs, and PHEVs by approximately 27%, and for BEVs by less than 1%, compared to the base scenario, while the market shares of all other vehicles diminish by 11-13%. Under Scenario 3, the government promotion strategy through purchase price premiums increases the choice probability for BEVs and FCEVs by 35-36%, and for PHEVs by almost 13%, compared to the base case, while all other fuel types lose market shares amounting to 5-6%.

The effect of identical purchase prices of all vehicle alternatives, e.g. due to technical innovation or economies of scale in the vehicle production in general, and battery and fuel cell production in particular, which is analyzed in Scenario 4, increases the choice probability significantly: for BEVs by 117%, FCEVs by almost 81%, PHEVs by approximately 33%, and HEVs by more than 2%, compared to the base case, while the market shares of the remaining vehicle alternatives decrease (for BVs and CFVs by 21-23%, and NGVs by 10%).

The availability of battery leasing contracts, as offered by some car manufacturers to promote BEVs, and considered under Scenario 5, increases the choice probability of BEVs by about 26%, drawing market shares from all vehicle alternatives from 0.5-0.8%. Thus, battery-leasing contracts appear to be unable to significantly push the demand for BEVs. However, this finding should be treated with some caution, as we simply convert the monthly cost of the battery-leasing contract into additional fuel cost, whereas it is reasonable to expect that car buyers will evaluate a fixed monthly battery leasing payment differently from an increase in fuel cost. Furthermore, we do not consider the benefit of battery leasing contracts as a risk mitigation measure, given the unfamiliar technology and unknown battery lifetime, which could lead to an underestimation of their influence on the choice of BEVs.

The improvement of BEVs' driving range to 750 km leads to an increase in their demand of more than 143%, while the market shares of all other fuel types fall by 3-5%, relative to the base case, especially for the two other electrified vehicles. Under Scenario 7, the service station density is assumed to be the same for all vehicles, so that in this respect, all AFVs are competitive with CFVs; this massive investment in refueling infrastructure decreases the choice probabilities of CFVs and HEVs by 15-16%, while the demand for the alternatives increases by between 6% and 30%. The reduction of battery recharging time to 5 min increases the market shares of the two plug-in vehicle types (i.e. more than 46% for BEVs and 8% for PHEVs), while all other vehicle options are chosen less frequently by 2-3%. Under Scenario 9, government monetary and non-monetary incentives, and the provision of a spatially comprehensive refueling and fast-charging infrastructure, reduces the demand for fossil-fueled vehicles by up to 30%, allowing AFVs to reach roughly the same market shares; PHEVs even become the second-most popular vehicle alternative. The only exception is BEVs, with a market share of about 5%, although this is double the base figure.

In terms of comparisons, Lebeau et al. (2012) find that a purchase price premium of €5000 for BEVs and PHEVs increases their market shares by 122% and 82%, an extension of the driving range of BEVs from 100 km to 300 km leads to an increase in market share of 129%, and an enhancement of the recharging infrastructure density from 5% to 10% increases the share of BEVs by 62%, compared to the base scenario. To attain similar impacts on the demand for BEVs and PHEVs our analysis suggests the interventions need to be much more pronounced. One possible explanation for this may be that they omitted fuel type as a vehicle attribute in their analysis, so that AFVs did not suffer from negative ASCs. Daziano and Achtnicht (2012) find a market share of almost 12% for BEVs and 22% for FCEVs in their high fuel availability scenario, comparable to our Scenario 7, while the demand for these vehicle alternatives in our simulation only amounts to some 3% and 8%. One reason for this. difference may be that they do not consider the longer recharging time and the limited driving range of BEVs, which puts them at a disadvantage.

In summary, our simulations show that CFVs can be expected to further dominate the vehicle market, with NGVs and HEVs being the most likely AFVs, although policy initiatives can affect preferences for the various AFVs. In all scenarios except 9, electrically propelled vehicles do not gain substantial market shares (PHEVs mostly take the fifth place in choice probability) and BEVs consistently feature the lowest demand. Further, FCEVs only capture a small market share and are the second most disliked option after BEVs in all scenarios, except for 4 and 9. Car buyers choose BVs even when the density of gasoline stations offering biofuel is low.

When comparing the policy measures in the scenarios with each other, and with the base case, we find that the market share of NGVs and BVs is largest in Scenario 7, for PHEVs and FCEVs it is Scenario 9, and for BEVs it is Scenarios 6 and 9. The influence on HEVs is, except for a strong negative impact under Scenario 9, quite small across all other scenarios, with the highest choice probability found in Scenario 2. CFVs lose market shares in all scenarios, with this influence being lowest under Scenario 5.

Overall, the greatest impact on the vehicle market is found under Scenarios 4, 7, and 9. Further, the choice probabilities of PHEVs, BVs, and FCEVs could be increased quite easily, or at least with a relatively manageable government purchase grant, while limited financial and non-monetary government incentives appear unable to accelerate BEV adoption. Compared to this, battery-leasing contracts have almost no influence on vehicle alternatives, with BEVs showing only small gains in market share. An increase in the driving range to 750 km for BEVs has the same effect as a powerful concerted action by the government and the private sector, although the latter policy intervention has a more pronounced effect on electric mobility as a whole, because it also boosts the demand for PHEVs and FCEVs. A fully developed refueling infrastructure, in contrast, mainly increases the demand for vehicles that run on liquid or gaseous fuels and currently suffer from a limited filling station network, such as FCEVs and BVs. Further, just accelerating the recharging process does not markedly increase the choice probability of plug-in vehicles. Finally, a large market-based intervention, which we assumed to be beneficial at least for all non-fossil-fueled AFVs, produces almost no effect on the market share of BVs.

2.5 Conclusions

We have studied the preferences for AFVs by using discrete choice data from a Germany-wide survey and applying an ML. We find that German car buyers are currently very reluctant toward AFVs, especially BEVs and FCEVs, which could be a great barrier in terms of achieving the very ambitious goal of the German government to get a million electric cars on the road by 2020 (German Federal Government, 2009). However, our results also show that PHEVs are far less likely to be rejected than BEVs and that not all consumers have equally pronounced reservations against AFVs; especially younger, highly educated, and environmentally conscious consumers, and to some extent also urban drivers of small cars with access to a parking lot equipped with a socket, are more prone to buy AFVs in general and plug-in cars in particular. Further, we find that German car buyers are willing to pay considerable amounts for an improvement of vehicle features, although differences in the WTP can be observed, depending on respondents’ characteristics and fuel type. The scenario analysis revealed that CFVs remain dominant in terms of market share, HEVs and NGVs are the AFVs most likely to be chosen, and that choice probabilities of some AFVs, such as PHEVs and BVs, could be increased in a relatively cost-efficient way, while BEVs and FCEVs only gain in demand if multiple policy measures are implemented or the vehicle purchase is subsidized substantially.

CHAPTER 3

WILLINGNESS-TO-PAY FOR ALTERNATIVE FUEL VEHICLE CHARACTERISTICS: A STATED CHOICE STUDY FOR GERMANY

CONTENTS

3.1 Introduction

In the past decades, the transportation sector came increasingly to the fore of policy-makers and energy efficiency and greenhouse gas mitigation legislation in the US, the European Union, and other countries.[1] This can be explained by its strong dependence on carbon-based fuels, and, consequentially both its significant contribution to climate change and local air pollution and its vulnerability to fluctuations in crude oil prices. Hence, general environmental considerations and increased energy security concerns led to attempts of policy-makers to tackle the oil dependency of road transportation and to bring alternative fuel vehicles (AFVs)[2] into the market, e.g. by the introduction or tightening of clean-air legislation and incentive programs. For instance, the European Union has defined legally binding CO_2 emission abatement targets for newly registered vehicles (EC, 2014b). Furthermore, the German government stipulated the very ambitious electric mobility goal of 1 million registered vehicles by the year 2020 (German Federal Government, 2009), which has been accompanied by governmental purchase incentives and funding of technology research.

Despite of these efforts on the part of policy-makers and, as a consequence, also vehicle manufacturers, the reluctance of car buyers towards all kinds of AFVs, especially BEVs, remains very high. Consumer demand thus has to increase drastically in the upcoming years to reach the diffusion targets and to meet the requirements of the European clean-air legislation.[3] Hence, detailed information on the main reasons for such an absence of a widespread adoption of AFVs, especially by buyers of privately used personal cars, and the possibilities to circumvent them, is needed even more urgently. Presumable taste differences of a heterogeneous population concerning the importance of specific vehicle attributes, the thresholds they have to meet, and their different impacts on the potential demand of AFVs are of special interest. Knowledge about such taste differences could be particularly instructive for the German legislature and decision-makers in the automotive industry, in order to accelerate the adoption of AFVs in the future by specifically customizing their products or incentive schemes subject to the differences in preferences between consumer segments.

[1] A comprehensive overview of the evolution of worldwide fuel economy and GHG emissions regulations over the years is given in, e.g., An and Sauer (2004), Onoda (2008), Atabani et al. (2011), or Kodjak et al. (2012).

[2] AFVs encompass vehicles that do not run on conventional fuels (gasoline and diesel) or are propelled electrically at least to some extent, e.g. biofuel vehicles (BVs), natural gas (liquefied petroleum gas, LPG, or compressed natural gas, CNG) vehicles (NGVs), hydrogen (fuel cell electric) vehicles (FCEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fully battery electric vehicles (BEVs).

[3] For instance, today, only a small fraction of the postulated electric mobility goal is accomplished – at the end of 2013 only about 12,000 BEVs were registered in Germany, mainly by commercial users (KBA, 2014) – and also other AFVs exhibit a very modest market penetration.

The aim of this paper is to study the heterogeneity of car buyers' preferences, i.e. to determine the amount that different groups of vehicle buyers are willing to forfeit for improving important vehicle characteristics and how and why the sum differs between the groups. For this reason, two welfare measures are calculated: The willingness-to-pay (WTP) and the compensating variation (CV), which explicitly takes the diverse choice probabilities of the various vehicle alternatives into account. The results are then compared to current market prices for a provision of such attribute improvements to assess the potential of a cost-effective provision or the need for governmental action. Finally, the characteristics of the potential car buyers that are open for all kinds of AFVs are determined.

Our empirical analysis is based on a nation-wide web-based stated preferences discrete choice experiment (DCE), carried out in Germany among 711 potential car buyers in July and August of 2011. To take the preference heterogeneity in the population into account, we apply a latent class model (LCM), which allows for taste differences between consumer groups, in addition to a standard multinomial logit model (MNL).

Our research builds on a comprehensive body of stated preferences DCE literature on the demand for AFVs (see Table B.1 in Appendix B for an overview of selected studies). Especially the works of Abdoolakhan (2010), Hidrue et al. (2011), Beck et al. (2013), and Parsons et al. (2014), which to the best of our knowledge are the only ones so far applying an LCM approach, are closely related to our work. Furthermore, our study is linked to the research of Daziano (2013) who calculated the WTP and CV of Californian car buyers for driving range improvements of BEVs. Finally, the studies by Eggers and Eggers (2011), Achtnicht (2012), Achtnicht et al. (2012), Ziegler (2012), Daziano and Achtnicht (2014), and Hackbarth and Madlener (2013) ought to be mentioned as they also focus on the case of Germany, covering the following topics: (1) the differences in the WTP for CO_2 emission mitigation between groups of potential car buyers (Achtnicht, 2012; Hackbarth and Madlener, 2013); (2) the influence of fuel availability, especially for BEVs and FCEVs, on vehicles' market shares (Achtnicht et al., 2012; Daziano and Achtnicht, 2014; Hackbarth and Madlener, 2013); (3) the impact of car buyers' socio-demographic characteristics on their potential demand for AFVs (Achtnicht et al., 2012; Ziegler, 2012; Hackbarth and Madlener, 2013); and (4) the prediction of the adoption and diffusion of AFVs under various monetary and non-monetary attribute improvement scenarios in a dynamic (Eggers and Eggers, 2011) and static analysis (Hackbarth and Madlener, 2013).

Our research, however, differs to these studies also focusing on Germany at least in three respects: Firstly, we use an LCM to evaluate German car buyers' vehicle choices, which allows for a segmentation of the population into distinct consumer groups, a specification of the size of these consumer groups, and their detailed description by socio-demographic characteristics and attitudes. Secondly, we calculate CV values for a number of vehicle-specific attribute improvement scenarios, which are more informative for decision-makers than unspecific WTP values alone. Finally, as suggested and applied by several authors (see Table B.1 in Appendix B), we consider the effect of decreasing marginal utilities of attribute improvements, which is a more realistic representation of human behavior, and assess this non-linear consumer valuation for driving range, fuel availability, recharging time, and CO_2 emissions.[4]

The remainder of this paper is organized as follows: Section 3.2 describes the survey generation and the data gathered. In Section 3.3, the methodological approach is introduced. Empirical results are reported in Section 3.4 and discussed in Section 3.5. Section 3.6 concludes.

3.2 Survey Design and Data

The examination of new car buyers' potential demand for AFVs is based on data collected in a Germany-wide survey that was conducted in July and August 2011 (see also Hackbarth and Madlener, 2013). Participants were recruited from the probability-based online panel of the Dialego AG, and comprise persons who provided their intention to purchase a new car within the next year or such that made an actual vehicle purchase in the last 12 months. 711 respondents completed the web-based survey.

A comparison of our sample with the German population statistics depicted in Table 3.1 shows many similarities, but also some minor differences.

[4] Eggers and Eggers (2011) and Achtnicht et al. (2012) also accounted for the non-linear impact of driving range and fuel station density, respectively.

Table 3.1: Household and vehicle characteristics of the sample vs. the German population

Variable	Value	Sample (%)	Population (%)
Household characteristics			
Gender	Female	50.4	50.9
	Male	49.6	49.1
Age	18 to 44	57.8	41.1
	45 to 64	38.0	34.3
	65 or above	4.2	24.6
Education	No form of school leaving qualification	0.1	7.7
	Secondary general school leaving qualification	6.6	37.3
	Intermediate school leaving qualification	29.8	29.0
	Higher education entrance qualification or university (of applied sciences) degree	63.5	26.0
Household income per month	Less than €2000	17.9	49.5
	€2000 to €5999	60.4	40.3
	€6000 or more	2.7	2.7
	Not stated and others	19.0	7.5
Number of persons in household	1	15.3	40.2
	2	39.8	34.2
	3	23.5	12.6
	4 or more	21.4	12.9
Type of location	Urban	38.3	28.9
	Suburban	53.7	56.5
	Rural	8.0	14.6
Number of household vehicles	0	5.2	17.7
	1	52.5	53.0
	2	35.6	24.2
	3 or more	6.7	5.0
Vehicle characteristics			
Vehicle purchase	Vehicle purchase in past 12 months	47.3	-
	Vehicle purchase planned within 12 months	52.7	-
Reason for vehicle purchase	Replacement for old vehicle	82.7	81.0
	Additional vehicle	12.1	11.0
	Initial vehicle purchase	5.2	8.0
Purchase price	Less than €20,000	55.3	34.0
	€20,000 to €40,000	35.7	51.0
	€40,000 or more	9.0	15.0
Vehicle segment	Mini and small cars	23.3	26.5
	Medium-sized and large cars	48.6	45.5
	Executive and luxury cars	8.0	6.0
	Multi purpose cars	11.0	8.8
	Sport utility vehicles	4.4	4.8
	Sport coupés and others	4.7	8.4
Annual mileage	Less than 10,000 km	30.8	36.7
	10,000 km to 20,000 km	41.9	41.4
	20,000 km or more	27.3	21.9

Sources: Own calculations; German population shares computed on the basis of Infas/DLR (2010), BBSR (2012), DAT (2012), KBA (2012), Destatis (2012a, 2012b).

For instance, our sample slightly over-represents younger and higher educated individuals with high income, who live in multi-person households, own a car, reside in urban areas, have an above-average annual mileage, and a below-average willingness to spend money for their next vehicle, which needs to be remembered when interpreting the results.[5]

The stated preferences DCE included seven different vehicle types, six AFVs (NGVs, HEVs, PHEVs, BEVs, BVs, and FCEVs) and conventional fuel vehicles (CFVs), to cover all currently or soon commercially available propulsion technologies. They were described by up to eight attributes, which were found to be the most important vehicle features affecting the car purchasing process in Germany (Dena, 2010): (1) purchase price; (2) fuel cost; (3) CO_2 emissions; (4) driving range; (5) fuel availability; (6) refueling time; (7) battery recharging time; and (8) policy incentives (see Table 3.2).

Table 3.2: Vehicle attributes and levels used in the discrete choice experiment

Variable	Vehicle types (Fuel types)	No. of levels	Levels
Purchase price	All	3	75%, 100%, 125% of stated reference value (in €)
Fuel cost per 100 km	All	3	€5, €15, €25
CO_2 emissions	CFV, NGV, HEV	3	50%, 75%, 100% of average vehicle
	PHEV, BEV, BV, FCEV	3	0%, 50%, 100% of average vehicle
Driving range	CFV, NGV, HEV, PHEV, BV, FCEV	3	400 km, 700 km, 1000 km
	BEV	3	100 km, 400 km, 700 km
Fuel availability	CFV, HEV	2	60%, 100% of all stations
	NGV, PHEV, BEV, BV, FCEV	3	20%, 60%, 100% of all stations
Refueling time	CFV, NGV, HEV, PHEV, BV, FCEV	2	5 min, 10 min
Battery recharging time	PHEV, BEV	3	10 min, 1 h, 6 h
Policy incentives	PHEV, BEV, BV, FCEV	3	None, No vehicle tax, Free parking and bus lane access

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

In order to increase the significance of the hypothetical vehicle choices and to reduce task complexity, several actions have been taken in the course of designing the final experiment: (1) the purchase price variable was adjusted to respondents' stated price range of their latest or next vehicle purchase, respectively; (2) a single fuel cost unit (€/100 km) was used for the different vehicle alternatives to increase their commensurability; (3) a fixed car segment-invariant (e.g. gram of CO_2 per kilometer) and alternative-unspecific (e.g. zero emissions for CFVs) measure for CO_2 emissions was avoided; (4) the driving range variable accounted for current limitations in battery technology and was restricted for BEVs compared to all other vehicles; (5) an

[5] In the fuel type choice literature, younger (e.g. Ewing and Sarigöllü, 1998; Potoglou and Kanaroglou, 2007; Hidrue et al., 2011; Achtnicht et al., 2012; Ziegler, 2012; Li et al., 2013; Hackbarth and Madlener, 2013; Shin et al., 2015) and better educated individuals (e.g. Potoglou and Kanaroglou, 2007; Hidrue et al., 2011; Hackbarth and Madlener, 2013; Li et al., 2013) with higher income (e.g. Potoglou and Kanaroglou, 2007; Caulfield et al., 2010; Musti and Kockelman, 2011; Link et al., 2012), living in larger households (e.g. Knockaert, 2010; Musti and Kockelman, 2011), and owning a smaller number of vehicles (e.g. Ewing and Sarigöllü, 1998; Batley et al., 2004; Musti and Kockelman, 2011), are found to be more likely to choose AFVs instead of conventional vehicles. Thus, compared to the entire German population (which is used for comparison since detailed official data on buyers of new vehicles is unavailable) our sample presumably slightly overestimates the share of potential buyers of AFVs.

alternative-specific fuel availability variable was considered to allow for lower densities of the service station network for some AFVs; (6) refueling and recharging time were displayed as separate attributes to meet the requirements of PHEVs; (7) currently available governmental incentives were taken into account, i.e. a motor vehicle tax exemption for BEVs, the permission for bus lane usage, and special parking areas for BEVs and PHEVs (BMF, 2012; German Federal Government, 2014); and (8) respondents had to choose from only four out of the seven different vehicle alternatives in every choice task.[6]

In the final, completely randomized fractional factorial design, which was generated using the Sawtooth software, each respondent had to complete 15 separate choice tasks (Table B.2 in Appendix B gives an example of a choice card), thus resulting in 10,665 observations. A pretest, which was conducted in May 2011 with 128 participants, showed that the cognitive burden of the experiment was well manageable.

3.3 Methodological Approach and Model Specification

Our empirical analysis of the stated preference DCE data is based on two model specifications: A standard MNL and an LCM, the latter of which remedies the known shortcomings of the former, as it is able to account for preference heterogeneity of decision-makers by assuming that the population is composed of a finite number of different segments or classes in the population, to partly overcome the restrictive independence of irrelevant alternatives assumption, and to handle correlations of repeated choices of a single respondent (Swait, 2007). Furthermore, recent studies have concluded that LCMs also seem to be advantageous over mixed logit models (e.g., Greene and Hensher, 2003; Lee et al., 2003; Hynes and Hanley, 2005; Shen, 2009; Hess et al., 2011; Sagebiel, 2011; Keane and Wasi, 2013).

3.3.1 Latent Class Model

Drawing directly from Swait (1994, 2007), Boxall and Adamowicz (2002), Greene and Hensher (2003), Bujosa et al. (2010), and Hess et al. (2011), the main assumption in the LCM framework is the existence of S segments or classes in the population, where the individuals within each group are characterized by homogeneous utility functions, while the preferences

[6] Note that, similarly to the studies summarized in Table B.1 in Appendix B, the goal of our study is to analyze the choice of the newest household vehicle and not to model the choice and composition of the entire household vehicle fleet (i.e. consecutive choices of the first, second, third, etc. household vehicle under consideration of the respective budget constraint). An example for the application of the latter approach can be found in Ahn et al. (2008).

can differ between classes. The utility functions of the respondents are only partially known to the researcher, while their true class membership is even unobservable. Hence, an LCM consists of two separate probabilistic models, which are estimated simultaneously: (1) a choice model which explains individuals' choice among the alternatives available in the different choice occasions, conditional on their membership to a specific class and (2) a class membership model which allocates the decision-makers to the *S* classes, e.g. based on their socio-demographic or attitudinal characteristics.

Beginning with the choice model, and assuming utility-maximizing behavior, individual *n* selects alternative *j* from a finite set of *J* alternatives (e.g. passenger cars) that yields the highest level of utility in choice situation *t*. The utility function U_{njt} is then assumed to be given by

$$U_{njt} = V_{njt} + \varepsilon_{njt}, \quad (3.1)$$

where $V_{njt} = \beta_s' X_{njt}$ is the observable, deterministic part of utility – described by X_{njt}, a vector of the vehicle alternatives' attributes, and β_s', a class-specific vector of parameters – and ε_{njt} is the unobserved, random portion of utility. Assuming, firstly, a distribution of the error terms which leads to the standard MNL, secondly, class membership of each decision-maker as being given, and thirdly, independence of the *t* consecutive choice situations decision-makers are facing,[7] we can express the joint probability of the observed sequence of choices of decision-maker *n* belonging to class *s* as

$$P_{nj|s} = \prod_{t=1}^{T} \frac{\exp(\beta_s' X_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' X_{njt})}. \quad (3.2)$$

Turning to the class membership model, and assuming that it is also specified as a standard MNL, the probability that decision-maker *n* belongs to class *s* is

$$H_{ns} = \frac{\exp(\theta_s' Z_n)}{\sum_{s=1}^{S} \exp(\theta_s' Z_n)}, \quad (3.3)$$

with observable characteristics of the decision-maker Z_n, and the class-specific parameter vector θ_s'.

[7] See Hess et al. (2011, p. 3): ''In the case of multiple choices for each respondent, the assumption is generally made that the tastes vary across respondents but not across choices for the same respondent (cf. Revelt and Train, 1998 and see Hess and Rose, 2009 for a recent discussion of this issue), and the probability of the observed sequence of choices is used in the maximisation of the log-likelihood."

The unconditional probability or likelihood that a randomly chosen decision-maker n selects a sequence of alternatives $j = \{j_1, \dots, j_T\}$ is then obtained by multiplying eqs. (3.2) and (3.3), which yields

$$P_{nj} = \sum_{s=1}^{S} H_{ns} P_{nj|s} = \sum_{s=1}^{S} \frac{\exp(\theta_s' Z_n)}{\sum_{s=1}^{S} \exp(\theta_s' Z_n)} \prod_{t=1}^{T} \frac{\exp(\beta_s' X_{njt})}{\sum_{j=1}^{J} \exp(\beta_s' X_{njt})}. \quad (3.4)$$

The true number of consumer segments is also unknown and has to be specified by the analyst a priori. In doing so, several decision criteria have been recommended to guide the selection of *S*, such as the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC).[8] Our analysis further comprises the calculation of two welfare measures, which monetize car buyers' appreciation for improvements of the different vehicle attributes, enabling us to make profound policy recommendations: the WTP and the CV.

3.3.2 Willingness-to-Pay

The Following Louviere et al. (2000), Train (2003), and Daziano (2013), the WTP indicates the monetary amount that an individual is willing to disburse to acquire benefits or prevent costs from specific (policy) actions leaving the level of utility unchanged. In our linear model specification, the WTP is derived from the ratio of a vehicle attribute's (class-specific) coefficient β_X and the (class-specific) coefficient of an attribute measured in monetary units β_C, such as purchase price or fuel cost, holding everything else constant (weighted by class membership H_{ns}[9]):

$$WTP_n = \sum_{s=1}^{S} H_{ns}\left(-\frac{\beta_X}{\beta_C}\right). \quad (3.5)$$

The WTP of the logarithmically transformed attributes has to consider their non-linear influence on utility, and thus has to take into account the base level *x* of the attribute, from which the action starts out, i.e.

$$WTP_n = \sum_{s=1}^{S} H_{ns}\left(-\frac{\beta_{\ln(X)}}{\beta_C}\frac{1}{x}\right). \quad (3.6)$$

[8] The common procedure in the class selection process is that the final model specification is estimated with varying numbers of classes. The solution, which minimizes the different selection criteria, is the one that should be preferred, although also non-statistical reasons (e.g. behavioral interpretability) should guide the decision.

[9] The probability of individual *n*'s membership in class *s*, H_{ns}, equals unity if the individual is assigned to a specific class with certainty.

However, although the WTP measures the economic welfare and reveals the accepted maximum additional cost for technical progress, it also suffers from drawbacks. WTP values are calculated under the *ceteris paribus* assumption and do not account for the choice probabilities of the different alternatives before and after the improvement. Therefore, more revealing for policy-makers and car manufacturers is the CV, which accounts for this uncertainty and the potentially highly dissimilar selection probabilities of the different vehicle options, e.g. by portraying the current market situation, and the fact that a change in an alternative's attribute does not only have an influence on its own utility level but also on the probability of all other alternatives for being selected.

3.3.3 Compensating Variation

Drawing directly from Small and Rosen (1981), Louviere et al. (2000), Boxall and Adamowicz (2002), Train (2003), Lancsar and Savage (2004), and de Jong et al. (2007), the CV, also known as expected change in consumer surplus, indicates the change in a monetary measure needed to compensate changes in utility after the change in an attribute's level occurred, leaving individuals equally well off. Hence, for an improvement of vehicle attributes the CV is the monetary amount (i.e. purchase price surcharge or increase in fuel costs) car buyers are willing to forfeit to retain the improvement. In a logit model with linear-in-utility and constant monetary attributes, the CV for a representative individual n facing J choice alternatives is calculated as a comparison of the (class-specific) indirect utility functions before (V_{nj}^{0}) and after (V_{nj}^{1}) the attribute change, scaled by the (class-specific) marginal utility of money (β_C), and weighted by class membership probabilities (H_{ns}) if class assignment is uncertain:

$$CV_n = \sum_{s=1}^{S} H_{ns}\left(-\frac{1}{\beta_C}\left[\ln\left(\sum_{j=1}^{J}\exp\left(V_{nj}^{1}\right)\right) - \ln\left(\sum_{j=1}^{J}\exp\left(V_{nj}^{0}\right)\right)\right]\right). \qquad (3.7)$$

3.4 Empirical Results

3.4.1 Discrete Choice Models

The variables that were included in the deterministic part of the utility and the class assignment functions of our final models are given in Table 3.3. Vehicles' CO_2 emissions, driving range, fuel availability, and recharging time were logarithmically transformed to account for their non-linear impact on utility.[10]

Table 3.3: Variables used in the model

Variables	Definition
NGV	1 if fuel type is natural gas, 0 otherwise
HEV	1 if fuel type is hybrid electric, 0 otherwise
PHEV	1 if fuel type is plug-in hybrid electric, 0 otherwise
BEV	1 if fuel type is battery electric, 0 otherwise
BV	1 if fuel type is biofuel, 0 otherwise
FCEV	1 if fuel type is hydrogen (fuel cell), 0 otherwise
Purchase price	Purchase price in thousands of €
Fuel cost	Fuel cost in € per 100 km
CO_2 emissions	Natural logarithm of the fraction of CO_2 emissions of a comparable average current vehicle of the respondents' favorite car segment in percent
Driving range	Natural logarithm of driving range on a full tank/battery in km
Fuel availability	Natural logarithm of the percentage of filling/recharging stations with proper fuel
Refueling time	Refueling time in minutes
Battery recharging time	Natural logarithm of battery recharging time in minutes
Incentive 1	1 if incentive (no vehicle tax) is granted, 0 otherwise
Incentive 2	1 if incentive (free parking, bus lane usage) is granted, 0 otherwise
Vehicle segment	Respondents' favorite vehicle segment ordered by purchase price/size (7 categories)
Technophilia	Respondents' score on a 5-level Likert scale capturing enthusiasm for new technologies
Environmental awareness	Respondents' score on the environmental consciousness scale by Preisendörfer (1999)
Age	Respondents' age in years
Daily mileage	Respondents' daily mileage (5 categories)
Educational level	Respondents' educational level (6 categories)
Additional vehicle	1 if vehicle is an additional one, 0 otherwise

Vehicle segments were primarily ordered by purchase price and secondarily by size, leading to the following ascending order: Mini/small cars, medium-sized cars, large cars, multi purpose cars/SUVs, executive cars, luxury cars, and sports cars. Technophilia was measured with respondents' level of agreement (5-level Likert scale) to the following statement: 'I like to engage myself with the way new technologies function'. Environmental awareness was determined with a scale developed by Preisendörfer (1999), which assesses environmental consciousness by adding up the degree of agreement (5-level Likert scale) to 9 questions. The

[10] Wald tests of non-linear restrictions were performed for all attributes with more than two levels, but were found to be significant only for CO_2 emissions, driving range, fuel availability, and recharging time. A likelihood ratio test illustrated that the stepwise specification (part-worth utilities) of the vehicle attributes is not a statistically significant improvement over their logarithmic specification $(-2(LL_{Pw} - LL_{Log}) = 49.36 < \chi^2_{\alpha=0.95}(36) = 50.99$, whereas the latter is advantageous regarding model parsimony. Moreover, besides the ultimately selected logarithmic transformation, also other functional forms were tested, e.g. quadratic, square root, and inverse functions. However, compared to the logarithmic transformation they did not only perform poorer statistically regarding log likelihood but also visually in reproducing the distribution of the significant part-worths.

average daily distance respondents drive their vehicles was quantified with a scale composed of 5 distinct categories, which ranged from 'up to 50 km' to 'more than 200 km'. The educational level was measured with a 6-level scale, stretching from 'no form of school leaving qualification' to 'university (of applied sciences) degree'. Finally, a dummy variable entered the model that indicates if the new vehicle was/will be an additional one instead of a replacement.

The LCM was estimated over 2-7 classes. As can be seen in Table 3.4, the model with 6 latent classes is best regarding BIC, while all other selection criteria are indicative of the presence of at least 7 distinct classes in the population.

Table 3.4: Class selection criteria

	No. of classes						
	1 (MNL)	**2**	**3**	**4**	**5**	**6**	**7**
LL	-12,874.3	-12,322.9	-11,879.0	-11,579.1	-11,344.1	-11,190.6	-11,121.4
BIC	25,887.8	24,998.2	24,324.4	23,937.4	23,680.6	23,586.8	23,661.9
AIC	25,778.6	24,721.7	23,880.6	23,326.3	22,902.2	22,641.1	22,548.9
$\rho^2(0)$	0.380	0.406	0.428	0.442	0.453	0.461	0.464
$\rho^2(c)$	0.091	0.130	0.162	0.183	0.199	0.210	0.215
No. of parameters	15	38	61	84	107	130	153

Notes: LL = log-likelihood; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; ρ^2 = McFadden's pseudo R-squared.

We nevertheless decided in favor of the LCM with 6 classes as the best model to portray population heterogeneity, since the LCM with 7 classes led to a very small segment with a selection probability of below 1%, and thus did not add to the explanatory power of the model.

The estimation results of the standard MNL and the LCM with 6 distinct classes are shown in Table 3.5. Looking at the results for the MNL first, it can be seen that all parameters (except the alternative-specific constant (ASC) of PHEVs and refueling time) are highly significant and impact vehicle choice in the expected direction. Furthermore, it can be seen that all ASCs are negative, i.e. CFVs are highly preferred to all AFVs *ceteris paribus*.

Turning to the LCM, the picture is slightly more ambiguous, suggesting that considerable taste heterogeneity exists in the population, which was overlooked by the MNL specification.[11] As can be seen in Table 3.5, some of the coefficients vary considerably between the 6 different groups, as do the number and structure of attributes that significantly influence vehicle choice. The only exceptions are purchase price, fuel cost, and driving range, which are the attributes that enter the car buyers' utility functions statistically significantly in all classes.

[11] McFadden's ρ^2 and the LL values reported in Table 3.4 indicate that in general the 6-class LCM greatly and statistically significantly outperforms the MNL specification.

Table 3.5: Estimation results

	MNL	LCM					
		Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Class-specific parameters							
NGV	-0.2648***	-0.3914**	0.0371	-0.6511***	-1.7498***	-0.0508	0.1276
HEV	-0.2949***	-0.0742	0.0199	-1.3858***	0.0782	-0.2390	0.1252
PHEV	-0.0910	0.2003	0.0423	-2.5097***	1.0260***	0.2947	0.5931***
BEV	-0.2155**	0.1535	-0.4887	-2.4808***	-1.2298***	-0.0637	1.0618***
BV	-0.4069***	-0.2273*	-0.0413	-1.7913***	-0.8525***	-0.2626*	0.4066***
FCEV	-0.4227***	-0.1260	-0.2533	-1.5091***	-1.1995***	-0.5335***	0.3467**
Purchase price	-0.0519***	-0.0399***	-0.0786***	-0.0282***	-0.0192**	-0.2665***	-0.0165***
Fuel costs	-0.0480***	-0.0446***	-0.1988***	-0.0224***	-0.0291***	-0.0681***	-0.0142***
CO_2 emissions (logarithmic)	-0.0489***	-0.0608***	-0.0640***	0.0186	-0.0625**	-0.0444**	-0.0855***
Driving range (logarithmic)	0.4939***	1.3803***	0.7395***	0.4240***	0.1871	0.4845***	0.1458**
Fuel availability (logarithmic)	0.2203***	0.7661***	0.1352**	0.0428	0.2485***	0.1872***	0.0820**
Refueling time	-0.0043	-0.0016	-0.0213	-0.0241*	-0.0008	0.0091	-0.0018
Recharging time (logarithmic)	-0.0651***	-0.1493***	-0.0519	-0.0847	-0.0246	-0.1221***	-0.0546**
Incentive 1	0.2104***	0.2692***	0.2494*	0.4884***	0.0020	0.2788***	0.2914***
Incentive 2	0.1458***	0.1768*	0.2214*	0.3992***	0.1360	0.0755	0.2207***
Class assignment parameters							
Constant		-1.6810	-4.5600**	-2.0268	-8.3148***	-3.1742*	0
Vehicle segment		0.6100***	0.3800**	0.6202***	0.5161**	0.4004**	0
Technophilia		-0.5853**	0.6170**	-0.1224	0.6255*	-0.2102	0
Environmental awareness		-0.1334***	-0.0703*	-0.1177***	-0.0061	-0.0783*	0
Age		0.0696***	0.0659***	0.0800***	0.0897***	0.1028***	0
Daily mileage		-0.3003	-0.4943*	-0.7443**	-0.6615	-0.7515**	0
Educational level		0.4987**	0.2257	0.1883	0.2599	0.3479*	0
Additional vehicle		0.3531	0.3411	0.6457	0.3430	1.3071*	0
Class probabilities		0.174	0.196	0.084	0.206	0.190	0.150

Notes: *, ** and *** indicate significance at the 10%, 5% and 1% levels, respectively; MNL = multinomial logit model; LCM = latent class model; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; Incentive 1 = no vehicle tax; Incentive 2 = free parking and bus lane access.

To ensure model identification, the coefficients of one class have to be normalized to zero – in our case class 6 – and the class-assignment parameters of all other consumer segments have to be interpreted in relation to that base group.

The base group consists of car buyers having a strong preference for vehicles with low CO_2 emissions and especially for non-fossil-fueled AFVs, as indicated by the positive and significant ASCs for PHEVs, BEVs, BVs, and FCEVs. In contrast, charging time and both governmental incentives only show a relatively moderate impact, compared to other groups, while purchase price, fuel cost, driving range, and service station density even seem to be quite unimportant factors in the decision process of this consumer group, although they enter the utility function significantly. Thus, individuals in class 6 can be labeled 'AFV aficionados'.

In class 1, in contrast, respondents have a stronger preference than car buyers in any other class for a long driving range, large fuel availability, and a short recharging time. Purchase price, fuel cost, and the two governmental incentives only have a medium influence on vehicle choice, compared to other consumer segments, while refueling time and most ASCs (except NGV, BV) are found to be insignificant. Compared to the base group, individuals in this class are more likely to be older, less environmentally aware, and higher educated buyers of larger/more expensive cars with less technical interest. Their high daily mileage, a feature that is comparable to the base group, seems to mainly drive the vehicle choice decisions and the pronounced valuation of the three mobility attributes, so that this group can be labeled 'car dependents'.

Consumers in class 2 appraise fuel costs as more important than members of any other group. Purchase price and CO_2 emissions, driving range, and the non-monetary governmental incentive exert a great influence on vehicle choice, too. In contrast, refueling and charging time, as well as all ASCs, do not seem to have much impact on the decision process. Compared to the base group, the members of this class are more likely to be older, less environmentally aware, but technically more interested buyers of larger/more expensive cars with lower daily mileage. Thus, although individuals in this group drive less than the base group, their purchase decisions are strongly influenced by mobility attributes, especially fuel costs, so that they could be best described as 'fuel cost savers'. A possible explanation for this finding could be that vehicle purchase decisions of members of this group are subject to budget constraints, which are not captured by our model.

In class 3, decisions are mainly based on the availability of both governmental incentives and the large and negatively signed ASCs, indicating a pronounced reluctance towards the adoption of AFVs. Purchase price, fuel cost, and driving range also influence vehicle choice, but the coefficients are comparably small. Interestingly, consumers in class 3 are the only ones who consider refueling time in their vehicle choice decisions. Since they are more likely to be older and less environmentally aware buyers of larger/more expensive cars who have a smaller daily mileage than members of the base group, the strong reluctance towards all kinds of AFVs in this group is reasonable, and their members can be dubbed 'CFV buyers'.

Car buyers in class 4 show the largest or second-largest negative parameter values for almost all ASCs, except for HEVs and PHEVs. The latter are *ceteris paribus* even more preferred than CFVs by individuals in this group. Vehicle emissions and fuel availability are also quite important, compared to other consumer groups, while driving range, purchase price and fuel costs are relatively unimportant, although they exert a significant influence on vehicle choice. Both governmental incentives and recharging and refueling time do not enter the utility function significantly. Thus, although individuals in this group are comparable to members of the remaining non-base classes in being older and planning to buy a larger/more expensive car, they are the only ones besides car buyers of the base group who at least rate one AFV positively. However, they are also equally environmentally aware and, even more important, more technophile than the reference group, which could be an explanation for being such 'PHEV enthusiasts'.

In class 5, purchase decisions are mainly influenced by the price of the vehicle, its fuel costs and recharging time, and the ASC of BEVs. Driving range, fuel availability, CO_2 emissions and the monetary governmental incentive, as well as the ASCs of BVs and FCEVs, on the other hand, only have an average influence on vehicle choice. Refueling time, the non-monetary governmental incentive, and the remaining ASCs do not impact the vehicle choice process significantly. Individuals in this consumer segment are more likely to be older, less environmentally aware, and higher educated drivers with lower daily mileage than the base group, but, on the other hand, planning to buy an additional and larger/more expensive car for their household, which would explain why mobility cost attributes, such as the vehicles' purchase price, dominate their vehicle choice decision. Thus, this consumer segment could be termed 'purchase price sensitives'.

To summarize, we find that individuals who at a first glance share many socio-demographic characteristics do behave quite differently: (1) attributes that are important in one class are irrelevant in another class, e.g. purchase price and fuel cost are relatively unimportant for those individuals who prefer AFVs (class 6), while two of the groups consist of individuals for whom monetary attributes are the most decisive factors in vehicle choice (classes 2 and 5), and some consumers even leave most attributes aside (class 3); (2) incentives have a large impact on vehicle choice; (3) on average, AFVs are disliked in the population (as can be seen in the MNL), but two market segments exist who favor at least some AFVs (PHEVs, BEVs, BVs, and FCEVs in class 6; PHEVs in class 4), all else equal; and (4) 'AFV aficionados' are more likely to be composed of younger, more environmentally aware, and slightly less educated buyers of smaller/cheaper cars, having a high daily mileage and a moderate technical interest.

3.4.2 Willingness-to-Pay

Based on the estimation results depicted in Table 3.4, consumers' marginal WTP expressed as the increased purchase price individuals are willing to spend for improvements of the most important vehicle characteristics is calculated using Eqs. (5) and (6), and shown in Table 3.6 (the WTP for marginal changes in the attribute levels expressed as additional fuel cost per 100 km is shown in Table B.3 in Appendix B).

As can easily be seen from the LCM results, the WTP values conditional on class membership (columns 3-8) differ significantly across consumer segments and vehicle attributes. This finding is supported, firstly, by the marked variation (standard deviation) around the unconditional mean WTP of the sample, which in turn is gained by weighting the class-specific WTP values by the class membership probabilities for each individual.[12]

Secondly, it is supported by the specific class and respective class membership probability of the decile of individuals with the highest WTP (last column). The latter confirms the particularly pronounced importance of vehicles' fuel costs in class 2, tax incentives, and vehicles' CO_2 emissions in class 6, non-monetary incentives in class 3, and flexibility of vehicle utilization enhancing attributes in class 1. Furthermore, the WTP values calculated with MNL coefficients are lower than the probability-weighted average WTP values of the LCM. For the non-monetary incentive the WTP calculated from the MNL parameters is even lower than the WTP of the group willing to pay least in the LCM (class 2).

[12] In our model, the individual probabilities of belonging to a specific class range from 0 to 1. Each respondent can be allocated to a specific class with a probability of at a minimum 0.45, with 68.8% of the individuals being assigned to a specific class with a probability of at least 0.9, and 44.3% of our sample belonging to a specific class with a probability of at a minimum 0.99.

Table 3.6: Marginal willingness-to-pay for changes in vehicle attributes (in € of purchase price surcharge)

	MNL	LCM								
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.	$Prob_{WTP>0.9}$
Fuel cost reduction of €1/100 km	926.64	1117.30	2528.52	793.97	1516.70	255.71	864.79	1055.74	686.80	0.9938 (Class 2)
Incentive 1	4058.70	6749.78	3171.83	17,309.00	105.63†	1046.17	17,712.21	7175.20	6414.98	0.9972 (Class 6)
Incentive 2	2811.24	4432.38	2815.96	14,147.83	7074.97†	283.44†	13,410.50	5924.88	4963.02	0.8797 (Class 3)
CO_2 emissions abatement by 1%										0.9982 (Class 6)
at 100%	9.43	15.24	8.14	-6.61†	32.51	1.67	51.98	14.32	17.66	
at 50%	18.86	30.49	16.28	-13.22†	65.02	3.33	103.96	28.64	35.31	
at 1%	942.95	1524.39	814.06	-660.93†	3250.84	166.53	5197.90	1432.20	1765.50	
Driving range increase by1 km										0.9757 (Class 1)
at 100 km	95.25	346.13	94.04	150.28	97.39†	18.18	88.59	124.77	98.22	
at 500 km	19.05	69.23	18.81	30.06	19.48†	3.64	17.72	24.95	19.64	
at 1000 km	9.53	34.61	9.40	15.03	9.74†	1.82	8.86	12.48	9.82	
Fuel availability increase by 1%										0.9651 (Class 1)
at 20%	212.48	960.60	85.97	75.79†	646.60	35.12	249.26	296.09	308.81	
at 60%	70.83	320.20	28.66	25.26†	215.53	11.71	83.09	98.70	102.94	
at 99%	42.93	194.06	17.37	15.31†	130.63	7.09	50.36	59.82	62.39	
Battery recharging time reduction by 1 min										0.9615 (Class 1)
at 6 h	3.49	10.40	1.83†	8.34†	3.55†	1.27	9.21	5.39	3.50	
at 1 h	20.93	62.40	11.01†	50.05†	21.30†	7.64	55.26	32.31	21.01	
at 10 min	125.60	374.39	66.06†	300.29†	127.80†	45.81	331.54	193.85	126.04	

Notes: † indicates WTP values based on insignificant attribute coefficients; MNL = multinomial logit model; LCM = latent class model; Incentive 1 = no vehicle tax; Incentive 2 = free parking and bus lane access.

The WTP for driving range, service station density, and battery recharging time not only differs between consumer groups but, due to its logarithmic shape, also depending on the value set as a base for the improvement, reflecting a different valuation of e.g. the last percent of CO_2 mitigations (resulting in a zero emission vehicle) and the first percent of emission reduction measures in the *status quo*. Finally, it can be observed that for the improvement of vehicles' driving range and fuel availability car buyers in class 1 are even willing to spend a larger extra amount for the further improvement of vehicles' long driving ranges and the last percent of fuel availability than respondents in other consumer segments for extensions of short ranges (class 5) and the first percent of additional fuel availability (classes 2 and 5), respectively.

On average, individuals are willing to spend €1056 for a fuel cost reduction of €1/100 km, €7175 and €5925 for a vehicle tax exemption and the permission to use bus lanes and park free of charge, respectively, between €14 and €1432 for the abatement of one percent of vehicles' CO_2 emissions,[13] €12-125 for an additional kilometer of driving range, €60-296 for increasing fuel availability by one percent, and between €5 and €194 for a one minute foreshortening of the battery recharging process.

Although our WTP estimates are apparently at the top end for some vehicle attributes, they are broadly in line with the wide bandwidth of results reported in previous studies, which are selectively summarized in the following. For instance, Jensen et al. (2013), Batley et al. (2004), and Hackbarth and Madlener (2013) report a WTP[14] of €79-200, €538, and €530-1070, respectively, for fuel cost savings of €1/100 km. Hoen and Koetse (2014), Potoglou and Kanaroglou (2007), and Hackbarth and Madlener (2013) reveal a WTP of €1670, €1600-3790, and €2330-4700, respectively, for all kinds of vehicle tax exemptions. Hoen and Koetse (2014), Horne et al. (2005), Daziano and Bolduc (2013), and Hess et al. (2012) find a WTP of €553, €1350, €1436, and €515-2233 for express/bus lane access, while Hoen and Koetse (2014) and Hess et al. (2012) report a WTP of €377 and €394-1415, respectively, for the possibility to park free of charge. Tanaka et al. (2014) and Hackbarth and Madlener (2013) state a WTP of €5-65 and €20-90, respectively, for the abatement of 1% of vehicle CO_2 emissions, while Mabit and Fosgerau (2011) report a WTP of €4230-5700 for halving the vehicle pollution, and Hidrue et al. (2011) find a WTP of €3310 for a pollution reduction of 95%. Concerning a kilometer of

[13] The WTP values for improvements of vehicles' CO_2 emissions have to be treated with caution for at least two reasons. First, emission mitigation is a socially desirable action, so that it is probable that respondents tend to overstate their appreciation and WTP for such an attribute. Second, due to the logarithmic transformation of the attribute, small attribute levels automatically lead to very high WTP values, approaching infinity when moving the attribute levels infinitesimally close towards zero.

[14] Currency conversions are based on the following exchange rates: £1 = €1.23, $1 = €0.76 (for Canadian and US dollars), and ¥1 = €0.009. The conversion factor of miles to kilometers is 1.609344.

additional driving range, Hoen and Koetse (2014), Parsons et al. (2014), Hackbarth and Madlener (2013), and Jensen et al. (2013) state a WTP of €8-33, €16-34, €19-52, and €3-134, respectively, while Hess et al. (2012) and Daziano (2013) find a WTP of €12-43 (at 215 km) and €20 (at 400 km) to €105 (at 80 km), respectively. Regarding a 1% expansion of the refueling infrastructure, Tanaka et al. (2014), Hackbarth and Madlener (2013), Daziano and Bolduc (2013), and Achtnicht et al. (2012) state a WTP of €10-21, €45-92, €126, and €70-820, respectively. Hackbarth and Madlener (2013) and Hoen and Koetse (2014) find a WTP of €5-18 and €24-182, respectively, for every saved minute in battery recharging time of BEVs, while Hidrue et al. (2011) and Ito et al. (2013) report a WTP of €1630 (10 h to 5 h) to €6510 (10 h to 5 min) and €6110 (8 h to 5 min), respectively.

The decreasing marginal utilities of non-linear attribute improvements are additionally illustrated in Figure 3.1 for the statistically significant WTP values expressed as purchase price surcharge (Figure B.1 in Appendix B shows these changes expressed as additional fuel cost per 100 km). As can be seen, consumers do have some minimum requirements, which have to be met so that they are willing to pay money for improvements of vehicle attributes.

For example, the WTP for a reduction of vehicles' CO_2 emissions by 1% starts to accelerate when they are about to drop below 10-15% of a current average car's emissions. Comparably, the WTP for shortening the charging process increases sharply when the charging time undercuts the 30 min mark. The WTP function for driving range and fuel availability does not have such an extreme threshold, although it also shows long tails with a relatively low WTP. The in some cases marked differences in the WTP across consumer groups are also eye-catching, e.g. the high importance of vehicle attributes that enable and simplify long trips (driving range, fuel station density, and recharging time) in class 1, or the high valuation of substantial emission mitigation measures and fast-charging in class 6.

Summarizing the results obtained so far, we find that on average German car buyers are willing to forfeit substantial amounts of money for all kinds of attribute improvements, which in some cases by far exceed the current cost for their production or provision.

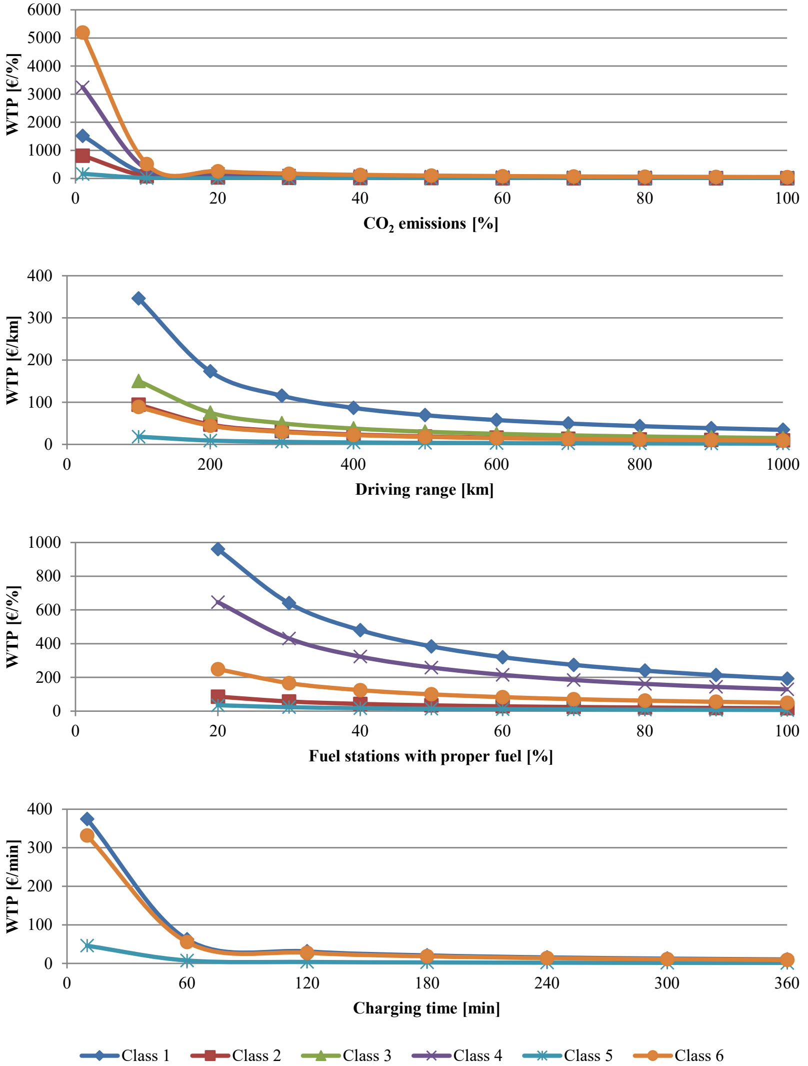

Figure 3.1: Marginal willingness-to-pay for changes in vehicle attributes (in € of purchase price surcharge)
Source: Own simulation results.

However, the interpretation of WTP values is only valid if certainty exists about which particular vehicle option is chosen, which usually is not the case in DCEs, or if, all else being equal, every vehicle alternative undergoes the exactly same attribute improvement, which is very unrealistic in the case of highly heterogeneous vehicle alternatives (Louviere et al., 2000; Train, 2003). For instance, respondents in class 1 would be willing to pay almost €24,000 and €50,400 for an extension of the driving range from 175 km to 350 km and to 750 km, respectively, if they had chosen a car with a limited driving range of 175 km (i.e. a BEV). This, however, would currently almost never happen (choice probability of 0.5%). The second interpretation of the WTP values is problematic, too, as we deal with very dissimilar choice alternatives regarding their current attribute levels, which can also be seen in the German *status quo* figures (Table 3.8). Furthermore, car buyers are usually not willing to pay for an attribute improvement of a vehicle alternative they will not select. For example, a person that intends to purchase a CFV does not care about the density of charging stations, nor is she willing to forfeit money for them.

3.4.3 Compensating Variation

In the following, the expected CV for several non-marginal attribute improvement scenarios is calculated for the specific vehicle alternatives, taking the considerable choice probability differences in the six distinct consumer groups into account. This measure is thus explicitly useful for policy-makers and car manufacturers to assess the economic viability of different potential actions. Individuals' class-specific, i.e. conditional on their assignment to a particular consumer segment, and unconditional, i.e. sample mean and standard deviation, CV is computed for manifold fuel-specific policy scenarios, based on the estimation results in Table 3.4 and the *status quo* on the German vehicle market. The respective policy scenarios comprise non-marginal improvements of the individual vehicle attributes and further include four multi-attribute enhancement programs, such as a governmental incentive package or the availability of area-wide fast-charging. The underlying base scenario depicted in Table 3.7 describes the current to near-term German vehicle market by defining average cars for every fuel type, based on market data and recent research (for further details on the database see Hackbarth and Madlener, 2013).

Table 3.7: Attribute levels of base scenario by vehicle type

	Purchase price (€)	Fuel cost (€)	CO_2 emissions (%)	Driving range (km)	Fuel availability (%)	Refueling time (min)	Battery recharging time (min)	Incentive 1	Incentive 2
CFV	21,800	9.0	100	1000	100	5			
NGV	23,900	6.5	84	1000	50.9	5			
HEV	26,700	7.5	77	1000	100	5			
PHEV	30,200	5.5	31	750	43.3	5	240	0	0
BEV	36,800	4.0	0	175	14.1		480	0	1
BV	22,900	9.0	23	750	2.3	5		0	0
FCEV	33,800	7.5	0	750	0.2	5		0	0

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; Incentive 1 = no vehicle tax; Incentive 2 = free parking and bus lane access.

Table 3.8 shows that the conditional and unconditional choice probabilities of the different vehicle alternatives vary considerably between consumer segments in the base scenario.

Table 3.8: Choice probabilities in the base scenario by vehicle type

	MNL	LCM							
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.
CFV	0.315	0.405	0.211	0.497	0.224	0.463	0.113	0.354	0.100
NGV	0.213	0.170	0.282	0.250	0.034	0.265	0.123	0.173	0.043
HEV	0.198	0.336	0.201	0.111	0.234	0.111	0.123	0.283	0.078
PHEV	0.118	0.069	0.134	0.018	0.426	0.034	0.137	0.092	0.063
BEV	0.043	0.005	0.032	0.013	0.029	0.002	0.258	0.038	0.076
BV	0.080	0.013	0.099	0.059	0.038	0.122	0.133	0.039	0.041
FCEV	0.033	0.002	0.040	0.050	0.015	0.004	0.114	0.020	0.034

Notes: CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

For instance, while the principally fossil-fueled vehicles (CFVs, NGVs, HEVs) have a combined market share of 91.1%, 85.8%, and 83.9% in classes 1, 3, and 5, respectively, they account for only 35.9% of the potential demand in class 6. Moreover, the vehicle technology favored most varies between groups as well. While CFVs are the most likely chosen option on average and in classes 1, 3 and 5, it is NGVs in class 2, PHEVs in class 4, and BEVs in class 6. However, despite this particular appreciation of BEVs in class 6, it can be stated that BEVs, BVs, and especially FCEVs, are the vehicle alternatives disliked most in the population. Interestingly, in class 4 NGVs are as much rejected as these three alternatives, as are PHEVs in classes 1, 3, and 5. However, they can gain a market share of more than 10% in the other three classes, with a maximum of 42.6% in class 4, and on average are the third-most preferred AFV (after HEVs and NGVs).

As already observed for the WTP, the results in Tables 3.9 and 3.10 show that also the conditional and unconditional CV values significantly vary across the consumer segments and attributes, but now are additionally dependent on the vehicle alternative for which the attribute improvement is established (i.e. generally a very large standard deviation of the mean CV for attribute improvements, especially in the case of BEVs, can be observed). Again, the values calculated from MNL coefficients are lower than the probability-weighted average CV values of the LCM, although not consistently. Furthermore, comparable to the WTP results, the class membership of those individuals with the greatest CV varies depending on the respective policy scenario, thus indicating the existing heterogeneity in the population regarding the importance of the different vehicle attributes.

Starting with the CV expressed as a purchase price surcharge car buyers would have to pay extra to secure their gain in utility, it can be seen in Table 3.9 that fuel cost reductions for biofuels and hydrogen, e.g. due to governmental tax reliefs, leading to competitiveness regarding operating costs with currently already fuel tax-advantaged NGVs, are not valued highly (up to €790 for a reduction in fuel costs to €6.5/100 km for BVs, class 2).

In contrast, governmental granting of monetary and non-monetary incentives is much more appreciated by German car buyers, i.e. especially consumers in class 6 are willing to forfeit more than €2750 for a vehicle tax exemption (PHEVs), and more than €3750 for the permission to use bus lanes and to park free of charge (BEVs). The CV for a CO_2 emissions abatement measure that reduces the pollution caused by the different exclusively fossil-fueled vehicle alternatives from their current level to half of an average present-day car is highest for CFVs in class 4, amounting to around €513.

Although not showing the lowest valuation for such improvements, individuals in class 1, which had the highest WTP for driving range extensions, have a much lower CV than individuals in class 6, who value them most (almost €3600 to increase the driving range of BEVs to 750 km).[15]

Car buyers in class 1 have the highest appreciation for an improvement of the fuel availability of all non-electrified AFVs. Concerning BEVs and FCEVs, car buyers in classes 6 and 1 have the highest CV, while individuals in class 4 show the highest valuation of an increased station density for PHEVs (amounting up to €4890 to increase the fuel availability to 100%). The acceleration of the battery recharging process, e.g. through the installation of fast-charging or battery swapping stations, assessed separately for PHEVs and BEVs, is valued higher for the latter vehicle alternative, where the CV is almost €4280 to shorten the battery recharging process to 5 min (class 6).

[15] Note that the CV for an extension of a vehicle's driving range is calculated for BEVs only, since today very short driving ranges (175 km) only occur in BEVs.

Table 3.9: Compensating variation for changes in vehicle attributes (in € of purchase price surcharge)

	MNL	LCM								
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.	$Prob_{CV>0.9}$
Fuel cost reduction scenario										
BV (€9/100 km → €6.5/100 km)	197.03	37.29	787.81	120.08	149.26	83.85	290.95	235.20	237.55	0.9947 (Class 2)
FCEV (€7.5/100 km → €6.5/100 km)	31.22	2.06	112.34	40.51	23.21	1.08	99.25	42.25	41.79	0.9938 (Class 2)
Incentive 1 (No vehicle tax) scenario										
PHEV	524.66	532.38	473.04	402.06	45.01†	40.49	2751.67	674.31	848.05	0.9986 (Class 6)
BV	360.06	97.64	352.61	1291.02	4.02†	144.00	2665.59	710.49	859.86	0.9986 (Class 6)
FCEV	148.13	13.96	144.49	1108.94	1.60†	4.94	2301.12	539.39	780.28	0.9986 (Class 6)
Incentive 2 (Free parking and bus lane access) scenario										
PHEV	353.08	334.56	414.86	313.66	3131.18†	9.92†	2020.11	735.13	890.09	0.6975 (Class 4)
BEV	129.90	21.98	99.53	232.00	219.39†	0.72†	3752.55	656.36	1246.57	0.9986 (Class 6)
BV	241.97	61.16	309.06	1009.92	287.20†	35.65†	1956.54	538.85	634.82	0.9986 (Class 6)
FCEV	99.37	8.74	126.52	867.00	114.21†	1.21†	1687.68	414.23	571.38	0.9986 (Class 6)
CO_2 emissions abatement scenario										
CFV (100% → 50%)	208.38	433.79	121.45	-227.09†	512.84	53.86	416.54	187.34	215.93	0.6858 (Class 4)
NGV (84% → 50%)	105.03	136.04	120.67	-85.52†	58.85	23.06	338.17	96.79	114.99	0.9986 (Class 6)
HEV (77% → 50%)	81.35	223.31	71.47	-31.70†	331.72	8.02	280.55	119.61	117.38	0.6540 (Class 4)
Driving range increase scenario										
BEV (175 km → 350 km)	336.14	181.70	267.11	161.72	208.68†	3.64	1644.37	373.58	515.83	0.9986 (Class 6)
BEV (175 km → 750 km)	854.49	723.54	756.48	402.63	470.45†	9.34	3596.26	912.29	1102.56	0.9986 (Class 6)
Fuel availability increase scenario										
PHEV (43.3% → 50%)	73.00	202.18	33.38	3.96†	800.45	3.45	98.68	121.23	192.35	0.8118 (Class 4)
BEV (14.1% → 50%)	265.38	185.56	75.03	26.38†	555.12	2.44	1691.64	357.92	553.74	0.9982 (Class 6)
BV (2.3% → 50%)	1450.51	2864.34	635.62	292.70†	2224.73	340.01	2271.03	1283.92	945.58	0.9624 (Class 1)
FCEV (0.2% → 50%)	1452.15	2888.04	556.90	473.34†	2261.34	27.72	3846.49	1460.47	1331.73	0.9982 (Class 6)
NGV (50.9% → 100%)	646.76	2730.67	338.72	259.01†	325.59	131.49	424.23	709.71	827.52	0.9772 (Class 1)
PHEV (43.3% → 100%)	454.51	1518.95	202.25	23.40†	4887.15	21.41	588.41	788.66	1195.64	0.7940 (Class 4)
BEV (14.1% → 100%)	443.24	393.36	121.67	41.44†	938.28	4.04	2673.31	588.84	871.72	0.9982 (Class 6)
BV (2.3% → 100%)	1912.98	4876.05	813.26	363.71†	2984.72	441.42	2852.53	1862.42	1512.14	0.9687 (Class 1)
FCEV (0.2% → 100%)	1777.37	4756.35	658.27	540.54†	2815.68	33.66	4442.26	1959.18	1791.92	0.9610 (Class 1)
Battery recharging time reduction scenario										
PHEV (4 h → 1 h)	213.37	397.42	126.40†	79.95†	761.88†	23.28	650.07	270.89	243.73	0.6114 (Class 4)
BEV (8 h → 1 h)	120.09	41.38	45.90†	91.29†	79.04†	2.64	1854.65	324.47	615.30	0.9986 (Class 6)
PHEV (4 h → 5 min)	640.37	1327.25	373.41†	248.41†	2164.66†	75.73	1925.37	825.38	718.72	0.5977 (Class 4)
BEV (8 h → 5 min)	285.41	110.86	107.41†	223.30†	178.77†	6.81	4278.42	753.19	1417.55	0.9986 (Class 6)
Area-wide fast-charging scenario: fuel availability 100%, battery recharging time 5 min										
PHEV	1204.49	3843.82	613.20	280.66	7307.43	109.34	2628.80	1841.52	1947.02	0.7622 (Class 4)
BEV	871.12	879.21	260.15	283.91	1223.68	13.85	7460.98	1505.77	2418.08	0.9986 (Class 6)

(continued on next page)

Table 3.9 *(continued)*

	MNL	LCM								
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.	$Prob_{CV>0.9}$
Governmental incentive scenario: purchase price subsidy €5000 (PHEV, BEV, FCEV), fuel costs €6.5/100 km (BV, FCEV), incentives 1 and 2										
PHEV	1840.56	1531.56	2144.07	1135.75	5538.94	519.66	6404.80	2367.89	2001.19	0.9966 (Class 6)
BEV	410.35	51.89	337.71	338.29	392.79	28.10	5308.38	980.50	1743.19	0.9986 (Class 6)
BV	924.24	235.16	1909.66	3133.80	462.12	302.46	5606.05	1786.61	1772.14	0.9986 (Class 6)
FCEV	588.68	44.86	936.55	3181.49	235.87	72.79	5546.47	1504.93	1864.14	0.9986 (Class 6)
NGV support scenario: purchase price €21,800, CO_2 emissions 50%, fuel availability 100%										
NGV	1296.65	3501.36	1152.43	716.78	483.92	906.23	1065.09	1377.84	877.01	0.9786 (Class 1)
Massive multi-measure support scenario: purchase price €21,800, fuel costs €6.5/100 km (BV, FCEV), driving range 750 km, fuel availability 100%, battery recharging time 5 min, incentives 1 and 2										
PHEV	4826.88	9211.86	4584.80	2136.84	15,695.25	2231.70	11,590.46	6375.55	4130.78	0.6929 (Class 4)
BEV	6737.93	12,498.10	5912.24	2629.47	3858.17	2048.96	24,995.24	8372.09	7347.25	0.9986 (Class 6)
BV	4062.02	8472.71	4051.56	4160.44	4215.03	1359.96	10,338.20	5091.18	2921.49	0.9984 (Class 6)
FCEV	5476.77	11,043.88	4537.90	5836.47	4490.50	1484.79	14,885.15	6629.36	4300.03	0.9984 (Class 6)

Notes: † indicates WTP values based on insignificant attribute coefficients; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

Turning to the multi-attribute scenarios, the CV for the installation of a large-scale fast-charging infrastructure is highest in class 4 for PHEVs and class 6 for BEVs, amounting up to €7460 for the latter. It is worth mentioning that the CV for such a multi-attribute measure is larger than the sum of the CV values for equivalent individual attribute improvements, which arises from the impact that changes in attribute levels exert on the choice probabilities of the respective vehicle alternatives. The governmental incentive scenario, which includes a purchase price subsidy of €5000 for PHEVs, BEVs, and FCEVs (comparable to support programs in other European countries, see e.g. ACEA, 2013), tax reliefs resulting in fuel costs of €6.5/100 km for BVs and FCEVs, as well as a vehicle tax exemption and non-monetary incentives, is most appreciated in class 6 for all vehicle alternatives considered, and sums up to about €6400 for PHEVs.

The CV for increasing the attractiveness of NGVs by reducing their purchase price and increasing the fuel availability to the level of CFVs, as well as cutting their CO_2 emissions to 50% of a current average car is highest in class 1 and amounts up to €3500. Finally, a substantial governmental and corporate multi-measure support program, leading to identical purchase prices of all vehicle alternatives and a huge increase in driving range of BEVs, induced, for example, by subsidies or technical progress and economies of scale in the AFV production, and including further governmental monetary and non-monetary incentives, fuel costs of €6.5/100 km for BVs and FCEVs, and the provision of a large-scale fast-charging infrastructure, is greatly valued in classes 4 (PHEVs) and 6, and the CV runs up to almost €25,000 for BEVs.

Looking at the CV values expressed in additional fuel costs per 100 km that consumers would be willing to disburse in Table 3.10 and beginning with purchase price reductions which lower the up-front expenditure for AFVs, we can observe the highest appreciation of such a measure in classes 5 and 6, and a maximum CV of €4.90/100 km for a purchase price reduction of €15,000 (BEVs, class 6).

Individuals in class 6 also show the highest appreciation for vehicle tax exemptions, free parking and the allowance for bus lane usage for all AFVs considered, which aggregate to €3.18 and €4.34 for the monetary (PHEVs) and the non-monetary (BEVs) governmental incentives, respectively. The base group also exhibits the highest valuation regarding CO_2 emission reductions (maximally about €0.48 for halving CFV's emissions), and extensions of the cruising radius of BEVs (up to €4.16 for the expansion of BEVs' driving range to 750 km).

Table 3.10: Compensating variation for changes in vehicle attributes (in €/100 km of fuel cost increase)

	MNL	LCM								
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.	$Prob_{CV>0.9}$
Purchase price reduction scenario										
BEV (€36,800 → €30,000)	0.376	0.032	0.111	0.126	0.139	0.182	2.114	0.438	0.689	0.9987 (Class 6)
FCEV (€33,800 → €30,000)	0.149	0.007	0.070	0.254	0.039	0.105	0.515	0.160	0.160	0.9987 (Class 6)
NGV (€23,900 → €21,800)	0.503	0.330	0.249	0.677	0.048	2.657	0.303	0.838	0.861	0.9908 (Class 5)
HEV (€26,700 → €21,800)	1.160	1.573	0.454	0.732	0.783	3.824	0.722	1.513	1.131	0.9906 (Class 5)
PHEV (€30,200 → €21,800)	1.296	0.612	0.593	0.216	2.469	3.654	1.412	1.503	1.136	0.9889 (Class 5)
BEV (€36,800 → €21,800)	1.029	0.083	0.347	0.314	0.331	1.795	4.900	1.336	1.568	0.9987 (Class 6)
BV (€22,900 → €21,800)	0.098	0.013	0.045	0.083	0.028	0.596	0.170	0.182	0.198	0.9884 (Class 5)
FCEV (€33,800 → €21,800)	0.583	0.025	0.309	0.899	0.134	1.347	1.728	0.774	0.583	0.9985 (Class 6)
Incentive 1 (No vehicle tax) scenario										
PHEV	0.566	0.476	0.187	0.506	0.030†	0.158	3.182	0.750	1.004	0.9987 (Class 6)
BV	0.389	0.087	0.139	1.626	0.003†	0.563	3.082	0.889	1.011	0.9987 (Class 6)
FCEV	0.160	0.012	0.057	1.397	0.001†	0.019	2.661	0.709	0.832	0.9983 (Class 6)
Incentive 2 (Free parking and bus lane access) scenario										
PHEV	0.381	0.299	0.164	0.395	2.064†	0.039†	2.336	0.709	0.832	0.9983 (Class 6)
BEV	0.140	0.020	0.039	0.292	0.145†	0.003†	4.339	0.764	1.468	0.9987 (Class 6)
BV	0.261	0.055	0.122	1.272	0.189†	0.139†	2.262	0.623	0.763	0.9987 (Class 6)
FCEV	0.107	0.008	0.050	1.092	0.075†	0.005†	1.952	0.485	0.686	0.9987 (Class 6)
CO_2 emissions abatement scenario										
CFV (100% → 50%)	0.225	0.388	0.048	-0.286†	0.338	0.211	0.482	0.198	0.221	0.9986 (Class 6)
NGV (84% → 50%)	0.113	0.122	0.048	-0.108†	0.039	0.090	0.391	0.104	0.133	0.9988 (Class 6)
HEV (77% → 50%)	0.088	0.200	0.028	-0.040†	0.219	0.031	0.324	0.117	0.116	0.9987 (Class 6)
Driving range increase scenario										
BEV (175 km → 350 km)	0.363	0.163	0.106	0.204	0.138†	0.014	1.901	0.402	0.616	0.9987 (Class 6)
BEV (175 km → 750 km)	0.922	0.648	0.299	0.507	0.310†	0.037	4.159	0.961	1.320	0.9987 (Class 6)
Fuel availability increase scenario										
PHEV (43.3% → 50%)	0.079	0.181	0.013	0.005†	0.528	0.014	0.114	0.106	0.134	0.8118 (Class 4)
BEV (14.1% → 50%)	0.286	0.166	0.030	0.033†	0.366	0.010	1.956	0.391	0.649	0.9987 (Class 6)
BV (2.3% → 50%)	1.565	2.564	0.251	0.369†	1.467	1.330	2.626	1.438	0.868	0.9986 (Class 6)
FCEV (0.2% → 50%)	1.567	2.585	0.220	0.596†	1.491	0.108	4.448	1.498	1.450	0.9987 (Class 6)
NGV (50.9% → 100%)	0.698	2.444	0.134	0.326†	0.215	0.514	0.491	0.757	0.739	0.9809 (Class 1)
PHEV (43.3% → 100%)	0.490	1.359	0.080	0.029†	3.222	0.084	0.680	0.692	0.845	0.8102 (Class 4)
BEV (14.1% → 100%)	0.478	0.352	0.048	0.052†	0.619	0.016	3.091	0.640	1.020	0.9987 (Class 6)
BV (2.3% → 100%)	2.064	4.364	0.322	0.458†	1.968	1.726	3.299	2.053	1.344	0.9752 (Class 1)
FCEV (0.2% → 100%)	1.918	4.257	0.260	0.681†	1.856	0.132	5.137	1.991	1.851	0.9986 (Class 6)

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Table 3.10 *(continued)*

	MNL	LCM								
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.	$Prob_{CV>0.9}$
Battery recharging time reduction scenario										
PHEV (4 h → 1 h)	0.230	0.356	0.050†	0.101†	0.502†	0.091	0.752	0.277	0.236	0.9987 (Class 6)
BEV (8 h → 1 h)	0.130	0.037	0.018†	0.115†	0.052†	0.010	2.145	0.379	0.724	0.9987 (Class 6)
PHEV (4 h → 5 min)	0.691	1.188	0.148†	0.313†	1.427†	0.296	2.226	0.850	0.697	0.9987 (Class 6)
BEV (8 h → 5 min)	0.308	0.099	0.042†	0.281†	0.118†	0.027	4.947	0.879	1.668	0.9987 (Class 6)
Area-wide fast-charging scenario: fuel availability 100%, battery recharging time 5 min										
PHEV	1.300	3.440	0.243	0.353	4.818	0.428	3.040	1.766	1.514	0.7653 (Class 4)
BEV	0.940	0.787	0.103	0.358	0.807	0.054	8.627	1.693	2.854	0.9987 (Class 6)
Governmental incentive scenario: purchase price subsidy €5000 (PHEV, BEV, FCEV), fuel costs €6.5/100 km (BV, FCEV), incentives 1 and 2										
PHEV	1.986	1.371	0.848	1.430	3.652	2.032	7.406	2.585	2.103	0.9986 (Class 6)
BEV	0.443	0.046	0.134	0.426	0.259	0.110	6.138	1.129	2.055	0.9987 (Class 6)
BV	0.997	0.210	0.755	3.947	0.305	1.183	6.483	2.067	2.094	0.9987 (Class 6)
FCEV	0.635	0.040	0.370	4.007	0.156	0.285	6.414	1.746	2.245	0.9987 (Class 6)
NGV support scenario: purchase price €21,800, CO_2 emissions 50%, fuel availability 100%										
NGV	1.399	3.134	0.456	0.903	0.319	3.544	1.232	1.821	1.168	0.9878 (Class 5)
Massive multi-measure support scenario: purchase price €21,800, fuel costs €6.5/100 km (BV, FCEV), driving range 750 km, fuel availability 100%, battery recharging time 5 min, incentives 1 and 2										
PHEV	5.209	8.245	1.813	2.691	10.348	8.728	13.403	7.290	3.766	0.9987 (Class 6)
BEV	7.271	11.186	2.338	3.312	2.544	8.013	28.903	9.716	8.373	0.9988 (Class 6)
BV	4.384	7.583	1.602	5.240	2.779	5.318	11.955	5.844	3.085	0.9986 (Class 6)
FCEV	5.910	9.884	1.795	7.351	2.961	5.807	17.212	7.590	4.650	0.9986 (Class 6)

Notes: † indicates WTP values based on insignificant attribute coefficients; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle.

Concerning the valuation of a refueling network extension, for the most part the highest CV values can be found in class 1 for NGVs and BVs, in class 4 for PHEVs, and in class 6 for BEVs and FCEVs, regardless of the size of the fuel network expansion, maximally adding up to about €5.14 for increasing the fuel station density of FCEVs to 100%. The appreciation for reducing the time to fully recharge a battery is highest in class 6 and reaches the total of €4.95 to fast-charge a BEV in 5 min.

The CV for the provision of an area-wide fast-charging network is highest in class 4 for PHEVs and class 6 for BEVs, totaling up to €8.63 for the latter. For all vehicle alternatives considered, individuals in class 6 also have the highest appreciation for the governmental monetary and non-monetary incentive program, which sums up to €7.41 for PHEVs. Regarding the valuation of an NGV support package, the highest CV can now be found in class 5, maximally adding up to €3.54, while a massive AFV support program on the part of the government and the industry is greatest in class 6 and aggregates up to €28.90 for BEVs.

Summing up the results, we find that German car buyers on average are willing to forfeit significant amounts of money for the improvement of vehicle attributes, and that the distinct consumer groups attach different importance to these attributes, leading to partially huge differences in their CV. Car buyers in classes 4 and 6 consistently show the highest appreciation for all attribute improvements (except for fuel cost reductions and the NGV support package), although not necessarily for every single vehicle alternative, while the lowest CV values are almost always found in classes 1, 2, or 5. This finding can be explained by the marked probability to choose (at least some of the) AFVs in classes 4 and 6. Interestingly, this is in sharp contrast to the WTP calculations, where individuals in classes 4 and 6 had the highest WTP for incentives and CO_2 emissions only. A further distinction between the CV and WTP results stems from the differences in their calculation formula, so that the CV values for all attribute improvements are consistently lower than the WTP values for identical non-marginal changes in attribute levels. For instance, the maximum CV for increasing the driving range of BEVs to 750 km is about €3600, while the maximum WTP for such an extension is about €50,400, and thus 14 times larger. This finding shows that a calculation of realistic (and not potentially misleading) monetary measures of consumers' appreciation for vehicle attribute improvements should take the current market situation and the choice probability of the respective vehicle technology into account.

3.5 Discussion

In the following discussion, we focus on the implications of the more informative results of the CV calculations, and assess the potential of the various attribute improvement measures to increase AFV demand, and to be realized cost-effectively.

Fuel tax reductions for BVs and FCEVs are not highly valued on the consumer side, and at most equivalent to a required payback period of slightly more than two years, assuming the annual mileage of an average German car driver of 14,210 km (DAT, 2014). This result suggests that car buyers in our sample undervalue fuel cost savings of individual AFVs and thus seem to act slightly myopically.[16] Hence, fuel price cuts do not seem to be able to significantly increase AFV demand, and the losses in fuel tax revenues would probably exceed the monetized environmental benefits, especially as the biofuel and hydrogen production goes along with undesired (environmental) side effects. However, a reverse approach, i.e. making conventional fuels more expensive, could still be a possible way to accelerate the diffusion of AFVs, although it is questionable whether such a measure would be politically enforceable. Comparably to this, a compensation of purchase price subsidies through higher mobility costs (which are accepted in class 6 up to the point where fuel or electricity costs are about €9/100 km, i.e. comparable to those of CFVs) does not seem to be a revenue-neutral option to increase the demand for AFVs: for instance, in the case of BEVs the €15,000 purchase price reduction would need a lifetime mileage of around 300,000 km to be fully compensated. However, and as seen in Norway for example, such a measure could nevertheless be useful for increasing AFV diffusion.

Vehicle tax exemptions are highly appreciated in class 6 (and to a somewhat lesser extent in class 3), where the willingness-to-pay for such an incentive exceeds the forgone tax revenue over the entire vehicle lifetime, while in other consumer segments they are not. Non-monetary governmental incentives are again only appreciated by individuals in class 6, and to a lesser extent in class 3, but could increase the demand especially for BEVs in these consumer segments in a quite cost-effective way, as the CV amounts by far exceed the losses in parking

[16] However, this myopic behavior cannot be observed when we look at the mean WTP for a fuel-unspecific operating cost reduction of €1/100 km (see Table 3.6), which can be translated into an accepted payback period of 7.5 years. In general, the literature on consumers' valuation of fuel economy measures does not show entirely consistent results, although taken together they point in the same direction. For instance, in a review paper, Greene (2010a) reports a wide bandwidth of consumers' WTP for fuel economy improvements, with a prevalence of an undervaluation of fuel efficiency gains, which is also reflected in consumers' requirement for short payback periods of 1.5-2.5 years for fuel-saving investments (Greene, 2010b). This underestimation of fuel cost differences between vehicles is also found in the majority of the most recent studies on this topic. They report implicit discount rates of around 15%, which can be explained by slight myopic behavior, but also by rational decisions, given the uncertainty about future fuel prices and annual mileage, or commensurate interest rates for credit-financed vehicle purchases (e.g. Helfand and Wolverton, 2011; Allcott and Wozny, 2012; Busse et al., 2013; Allcott, 2013; Gillingham and Palmer, 2014).

fees. Taken together, German car buyers in class 6 value these two governmental incentives with an amount that is comparable to the purchase subsidies other European countries grant for electric cars, while their provision is less costly for the German government.[17]

The CV for a CO_2 emissions mitigation measure of (mainly) fossil-fueled vehicles is quite low. One possible explanation for this finding is that individuals who value emission reduction actions high are unlikely to choose fossil-fueled vehicles, while individuals having a high choice probability for fossil-fueled cars do not care that much about CO_2 emissions, and thus are unwilling to spend money for their improvement. Consequently, it could be more expedient to promote more environmentally friendly fossil-fueled vehicles by emphasizing their fuel efficiency instead of their 'greenness'.

The CV for an extension of the driving range of BEVs lies between maximally €55.3/kWh and €36.8/kWh (class 6), assuming a consumption of 17 kWh/100 km. This is far less than the current battery prices of about €250/kWh. Put differently, even BEV-affine consumers are far away from being willing to spend high extra amounts for a driving range expansion up-front or through higher operating costs (around €0.001-0.004/100 km for an additional kWh of battery capacity).

Regarding a refueling infrastructure expansion and a charging time reduction, the CV displayed in operating costs gives a better insight into the potential of business models, since vehicle manufacturers are usually not the same as the providers of the respective fuel or mobility service. German car buyers are currently willing to forfeit up to €0.35/l and €0.53/l extra for NGVs and BVs (class1), and €0.18/kWh and €5.14/kg for BEVs and FCEVs (class 6) for 100% fuel availability.[18] Concerning FCEVs and BEVs, this is equivalent to an accepted increase in fuel or electricity price by more than 2/3 and 3/4, respectively, compared to the *status quo*. Furthermore, individuals in class 6 would additionally spend about €0.29/kWh for fast-charging stations that enable to fully recharge the battery of BEVs in 5 min. Hence, car buyers would accept an increase in operating costs of 123%, if the recharging process is sped up in turn. These results suggest that the potential for private investors exists to provide, in a cost-effective manner, either an area-wide refueling and recharging infrastructure or selected fast-charging stations.

[17] Hackbarth and Madlener (2013) exemplarily calculated the savings from a vehicle circulation tax exemption and the possibility of free parking over the entire vehicle lifetime of 10 years. They find that, compared to an average CFV, the vehicle tax savings would amount to between €920 and €2120 and, compared to a regularly taxed BEV, to €450, while the savings in parking costs would sum up to at least €300.

[18] The calculation is based on the following assumptions regarding vehicles' energy consumption: 6.9 l/100 km for NGVs, 8.3 l/100 km for BVs, 17 kWh/100 km for BEVs, and 1 kg/100 km for FCEVs.

This impression is reinforced by the monetary values that German car buyers are willing to pay for a spatially fully extended network of fast-charging stations for their PHEVs or BEVs. More specifically, individuals in class 6 would additionally forfeit up to €0.51/kWh for such an infrastructure for BEVs alone, and thus would accept more than a tripling of current operating costs of BEVs and much higher operating costs than comparable CFVs.[19]

Finally, we look at the three scenarios that combine policy actions, which seem to be economically viable, with measures that do not seem to be realized cost-effectively, as our analysis of the CV for the individual attribute improvements has shown, to assess if such multi-attribute improvement schemes become cost-effectively in total, since the willingness to spend money for multi-measure packages is higher than the sum of individual actions.

Our CV results for a governmental incentive scheme, which are at the most €1600 higher than a support package without €5000 purchase support (PHEVs, class 6), suggest that the more is not always the merrier, since car buyers seem to heavily discount such buyer's premia for AFVs. Thus, from a cost-effectiveness viewpoint, the approach of the German government of not implementing purchase subsidies seems to be reasonable. Regarding the NGV support package and the multi-measure attribute improvement program the same marked discounting of up-front monetary purchase premia can be observed for all kinds of AFVs, which reduces the economic viability of these multi-measure support packages in general.

Furthermore, our results suggest that although the CV for combined attribute improvements is higher on average and within classes, compared to the sum of CV values for individual attribute enhancements, it can be lower than the sum of the maximum CV across classes, as the consumer groups who appreciate attribute improvements most can differ by attribute (e.g. in the NGV support scenario the maximum valuation for CO_2 emissions can be found in class 6 and for fuel availability in class 1, while individuals in class 1 have the highest CV for the combination of measures). Moreover, in the multi-measure support scenario, which massively reduces the main disadvantages of all AFVs, but especially those of BEVs, car buyers in classes 4 and 6, who did stand out due to their high AFV choice probability even in the base scenario, show an even stronger appreciation for AFVs, which amounts to a choice probability of almost

[19] The following simple calculation might help to convey a sense of the economic potential of providing a nationwide fast-charging infrastructure for PHEVs and BEVs, for which car buyers in class 6 would be willing to pay €11.32/100 km extra in total. Conservatively assuming (1) total investment costs of €625 million (12,500 fast-charging stations at €50,000 each); (2) a less than average annual mileage of 12,000 km; (3) a usage of the fast-charging infrastructure for 50% of the kWh needed for the annually driven distance, while the other half is recharged at home; (4) a payback period of the investment of 5 years; and (5) interest rates and running costs set to zero, about 184,000 PHEVs or BEVs would suffice for a profitable operation of the comprehensive fast-charging network, i.e. less than 1/5 of the 2020 German electric mobility target.

58% for PHEVs (class 4), 51% for BEVs (class 6), and 36% for FCEVs (class 1). The latter is particularly interesting since it shows that also individuals that are not highly AFV-affine would consider the purchase of at least some AFV options, if the current disadvantages are (massively) reduced, and that they would accept substantial additional purchase price charges for competitive BEVs and FCEVs, as indicated by the relatively pronounced CV values.

Finally, note that the conclusions from such a cost-effectiveness assessment of individual or simultaneous attribute improvements will look totally different if they are based on the average CV values, since the sample mean is often considerably lower than the CV of the consumer segment willing to pay most (which in most cases is class 6, i.e. most if not all AFV support measures would be uneconomical).[20] However, the class-specific CV results show that the costs for providing attribute improvements do not have to decrease first, e.g. through technical progress, to be implemented cost-effectively, since consumer groups exist already today that value such measures sufficiently, while the average CV values indicate the cost targets which should be reached in an AFV mass market.

3.6 Summary and Conclusion

We investigate German car buyers' preferences for AFVs, based on stated preferences discrete choice data and by applying two model specifications, a standard MNL and an LCM. The findings of the LCM show that the population of German car buyers is not as homogeneous as assumed by the MNL, but can be best described by six distinct consumer groups that vary in taste concerning vehicle characteristics and fuel types: 'car dependents' (class 1), 'fuel cost savers' (class 2), 'CFV buyers' (class 3), 'PHEV enthusiasts' (class 4), 'purchase price sensitives' (class 5), and 'AFV aficionados' (class 6). The results reveal that currently two consumer segments exist which, everything else equal, might choose at least some of the AFVs: Especially younger, less educated, and highly environmentally aware consumers with a high daily mileage are more likely to choose new vehicle technologies in general, while particularly PHEVs find enthusiasts also among the elderly and technophile buyers of larger cars. That is, over all other propulsion technologies 20.6% of the respondents prefer PHEVs (class 4) and 15% favor PHEVs, BEVs, BVs, and FCEVs (class 6), although especially the size of the latter segment is likely to be smaller in the entire German population (see footnote 5), so that these results need to be interpreted with some caution.

[20] Please note further that due to the presumable slight overrepresentation of AFV-friendly individuals in our sample (see footnote 5), the average CVs of the overall population are probably even somewhat lower.

Moreover, we find that German car buyers are willing to pay considerable amounts for the improvement of all vehicle attributes and that this appreciation varies depending on the consumer group, and is characterized by diminishing marginal returns of improvements of vehicles' CO_2 emissions, driving range, fuel availability, and recharging time, i.e. minimum requirements exist beyond which attributes rapidly gain in consumer's valuation.

We additionally calculated fuel-specific CV values, which are more useful than the fuel-unspecific WTP values, as they account for the currently low choice probabilities of AFVs in the majority of the consumer segments. Our results suggest that in contrast to the WTP values car buyers in class 6 have the highest willingness to forfeit money for the improvement of most of the vehicle attributes. Regarding the single vehicle attributes, our results show differences in their potential to increase the acceptance of AFVs, and also the possibility to be provided in a cost-effective way. For instance, our findings suggest that governmental purchase price subsidies and fuel cost reductions are not valued high enough on the consumer side to be made available cost-effectively, even though they could be able to strongly push the demand for AFVs. On the other hand, especially vehicle tax exemptions and non-monetary governmental incentives could increase the probability to choose AFVs very cost-effectively, at least in class 6.

The limited driving range of BEVs is one of the major barriers for electric mobility. Consequently, its extension is identified as the silver bullet to increase consumer acceptance. Problematic in this respect is that German car buyers are not willing to pay the necessary amounts of money for the increase in battery capacity, even if they generally seem to like BEVs (class 6). Hence, either battery research is vigorously intensified (e.g. through governmental financial support) to achieve a major technological break-through, enabling battery prices of €50/kWh (corresponding to about 20% of today's costs), or the concerted efforts should be focused on the installation of a comprehensive fast-charging infrastructure and the enhancement of its ease of use (e.g. by offering battery swapping stations or inductive charging), to alleviate the shortcoming of BEVs' limited cruising radius. Such an increase in recharging station density could potentially be accomplished cost-effectively by private investors, since our results suggest that individuals would accept considerable markups on the electricity price for a large-scale fast-charging infrastructure. However, due to the very high up-front costs of such an investment, governmental support could be necessary to that end.

Finally, such a comprehensive fast-charging network, especially when its installation is accompanied by other attribute improvements (e.g. like in the multi-measure scenarios) would in turn help to increase the acceptance of AFVs in general, and especially BEVs, in consumer groups that currently are very reluctant towards the adoption of AFVs, but actually have the highest WTP, e.g. for driving range or fuel availability improvements (class 1). This increase in potential consumers would in turn open up new possibilities for the cost-effective provision of attribute enhancements.

These findings are particularly interesting for vehicle manufacturers, private investors, and policy-makers, and should be taken into account in their financial efforts and strategic decisions. They suggest that: (1) consumers do not accept to be charged for small reductions in recharging time and vehicle emissions, whereas they are willing to forfeit the highest amounts for initial improvements of driving range and fuel availability; (2) improvements of some vehicle attributes could be provided entirely privately and maybe even cost-effectively, while others might need governmental support (e.g. for basic research or in terms of a purchase price subsidy) to take the hurdle beyond which they are valued sufficiently high by German car buyers; (3) specific actions should be accompanied by marketing and information campaigns tailored to those distinct consumer groups which appreciate these improvements most; (4) in order to effectively increase the adoption rates of AFVs, car manufacturers and government policies should aim at consumers in classes 4 and 6, i.e. 'PHEV enthusiasts' and 'AFV aficionados', since they show the highest CV values for all kinds of attribute improvements and for all kinds of vehicle alternatives; and (5) the attainment of the ambitious German electric vehicle goal could not be reached by solely focusing on these two consumer groups[21], which, however, in a first step should nevertheless be done for obtaining a rapid and major adoption, which in turn could lead to the afore-mentioned bandwagon effects and sustained diffusion of AFVs.

Finally, since our study is based on a DCE, the results suffer from the major drawbacks of this methodological approach: The choices are made in a hypothetical setting, and the number of vehicle attributes is limited, so that no statements can be made about omitted variables. Nevertheless, this study and our results establish a good starting point for political decision-makers and car manufacturers alike to review their strategic decisions on how the acceptance of and the demand for AFVs could be raised most cost-effectively, which areas most urgently need governmental subsidies to support actions from car manufacturers, and which ones could be provided by the private sector alone. Accordingly, future research will have to develop and

[21] In the base case scenario the aggregated weighted choice probability for PHEVs and BEVs in classes 4 and 6 is 15.3%. Since, for example, in 2014 private households purchased only 1.1 million new vehicles (KBA, 2015), the German electric mobility target cannot be reached until 2020 by 'PHEV enthusiasts' and 'AFV aficionados' alone.

evaluate business models for a cost-effective deployment of refueling and recharging infrastructure in Germany.

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CHAPTER 4

COMBINED VEHICLE TYPE AND FUEL TYPE CHOICES OF PRIVATE HOUSEHOLDS: AN EMPIRICAL ANALYSIS FOR GERMANY

CONTENTS

4.1 Introduction

Clean air legislation in the EU forces vehicle manufacturers to comply with the legally binding CO_2 emission abatement targets for all newly registered vehicles, which were set at 95 gCO_2/km to be achieved by 2021 (EC, 2014b). The pressure to act is strong on the part of manufacturers, as they are threatened with substantial fines in the event of noncompliance with the targets. Furthermore, the average CO_2 emissions of new cars in the EU rose slightly by 0.34% to 118.5 g/km in 2017. In Germany, the situation is even worse compared to the European average, i.e. the average CO_2 emissions of newly registered vehicles not only lie well above the European average but also show a slightly greater increase of 0.39% to 127.9 g/km. This growth connotates a trend reversal of CO_2 emission reductions of past years and is mainly caused by two changes in consumer purchase decisions: Firstly, the share of newly registered diesel-powered passenger cars, whose specific CO_2 emissions are lower than those of comparable vehicles with gasoline engines, decreased by 13.2% to only 38.8% in 2017 in Germany. The main driver behind this sharp decline continues to be the Volkswagen emissions scandal (so-called 'Dieselgate') and its repercussions. Secondly, and more importantly, sport utility vehicles (SUVs) with relatively high fuel consumption and CO_2 emissions (133.2-159.2 g/km on average) continue to enjoy growing popularity among car buyers. With a share of 15.2%, SUVs represent the second-largest vehicle segment in the German market in 2017 and showed an increase of 22.5% compared to the previous year, while the proportion of small vehicles has been steadily declining for years (EEA, 2018; KBA, 2018a).

Besides CO_2 emissions, the popularity of SUVs has further implications for transportation policy: (1) increase in local air pollution from the tailpipe of vehicles due to higher fuel consumption and, usually, greater mileage of larger vehicles, (2) decrease of roadway capacity, since larger vehicles need more space, resulting in traffic congestion and problems with parking spaces in cities, (3) decrease in traffic safety, especially for non-SUV drivers, due to shifts in accident frequencies and injury severity, potentially leading to an 'arms race', i.e. the spiraling up of still larger and heavier vehicles (e.g. van Essen et al., 2019; De Clerck et al., 2018; Liu, 2017; Schmidt, 2016; Yasmin et al., 2014; Jacobsen, 2013; Li, 2012).

Thus, the goal of this research is to determine the buyer segments that are considering to purchase the different vehicle types and fuel types and the factors that influence their joint choice decisions. It is highly pertinent to gain a deeper understanding on what can be done to make households adjust their vehicle fleet by incentivizing them to purchase smaller vehicle segments and alternative fuel vehicles (AFVs), instead of 'diesel-guzzling' larger vehicles, such as SUVs, with their higher external costs (e.g. De Clerck et al., 2018). This means targeting a heterogeneous group of vehicle buyers who differ in terms of their socio-demographic, attitudinal, and household-related characteristics.

For the purpose of our research, we make use of data from a national web-based survey among 1500 new vehicle buyers in Germany, which was conducted in 2011. The participants were sourced from an online panel and had either purchased a vehicle recently or were planning to do so in the upcoming year. We apply a discrete choice model on this combination of revealed preferences and stated preferences data.

Our study builds on a wide range of research that has dealt with the explanation of individuals' intended or actual choices of vehicle types or fuel types[1] in the past. Liao et al. (2017) provide a comprehensive review of the literature that applies a rational choice theoretical approach to assess private households' vehicle purchase decisions – i.e. probabilistic discrete choice analysis based on the assumption of utility maximization – which is also the main basis for the research undertaken in the present study.[2]

While the majority of the reviewed choice-based studies aims at explaining fuel type choice decisions, with a special focus on the adoption of electric vehicles (e.g. Ferguson et al., 2018; Jansson et al., 2017a,b; Rasouli and Timmermans, 2016; Helveston et al., 2015; Mabit et al., 2015; Hensher et al., 2013, 2017; Beck et al., 2011, 2013), some studies concentrate on the main drivers of the purchase of specific vehicle types or classes (e.g. Biswas et al., 2014; Baltas and Saridakis, 2013; Eluru et al., 2010; Bhat et al, 2009; Chiou et al., 2009; Cao et al., 2006; Choo and Mokhtarian, 2004). However, it is argued that factors influencing fuel type choice are found to vary considerably across vehicle classes (e.g. Mohamed et al., 2018; Higgins et al., 2017). Hence, several studies have jointly considered vehicle type and fuel type choices in their explanatory models in order to account for this heterogeneity in vehicle buyers' preferences (e.g. Habibi et al., 2019; Hahn et al., 2018; Liu and Cirillo, 2018; DeShazo et al., 2017; Higgins et al., 2017; Dumortier et al., 2015; Mabit, 2014; Hess et al., 2012; Potoglou and Kanaroglou, 2007).

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[1] Vehicle type classified by different combinations of size (i.e. small, medium-sized, large cars etc.), body type (i.e. pickup truck, SUV, van etc.), vintage (e.g. year of manufacture), or make and model, depending on the respective study, and fuel type segmented into conventional fuels, such as gasoline and diesel, and alternative fuels, such as natural gas, biofuel, electricity (hybrid, plug-in hybrid, battery electric) or hydrogen.

[2] On the other hand, the review articles of Li et al. (2017) and Rezvani et al. (2015) predominantly focus on psychology-motivated literature – i.e. behavioral theories, such as the theory of planned behavior, normative theories, and lifestyle theories – which aims at the explanation of interdependencies of psychological constructs and their influence on the purchase intention of specific fuel types, as well as the main motivators and barriers in decisions for specific vehicle/fuel types (e.g. Barth et al., 2016; Nayum et al., 2016; Plötz et al., 2014; Noppers et al., 2014; Nayum and Klöckner, 2014; Schuitema et al., 2013; Egbue and Long, 2012; Graham-Rowe et al., 2012; Skippon and Garwood, 2011).

In this empirical literature, a vast amount of factors has been found to significantly influence individuals' vehicle choice decisions and purchase intentions. Most studies include more than one of the following categories of explanatory variables in their models:

(1) Vehicle attributes – such as purchase price or driving range, including policy influences, such as taxes or incentives – or the rank of the vehicle in the household vehicle fleet (Jakobsson et al., 2016; Axsen et al., 2016; Prieto and Cammerer, 2013; Link et al., 2012), either specified in discrete choice experiments or derived from real market data;
(2) Socio-demographic characteristics of the decision-maker (e.g. age, gender, education, income), which are controlled for in almost all studies;
(3) Individual (mobility-related) behavior, such as the purpose of vehicle usage (Baltas and Saridakis, 2013, Noblet et al., 2006), usage of carsharing services (Javid and Nejat, 2017), access to and usage of public transportation (e.g. Rudolph, 2016; Jäggi et al., 2013; Spissu et al., 2009), and annual mileage (e.g. Higgins et al., 2017; Shin et al., 2015; Hoen and Koetse, 2014; Kuwano et al., 2013; Ziegler, 2012; Lave and Train, 1979);
(4) Household characteristics, such as household size or number of children in the household (e.g. He et al., 2014; Potoglou and Kanaroglou, 2007; Bhat and Sen, 2006; Choo and Mokhtarian, 2004; Mohammadian and Miller, 2002) and type or number of household vehicles (e.g. Hahn et al., 2018; DeShazo et al., 2017; Helveston et al., 2015; Qian and Soopramanien, 2011; Potoglou, 2008; Cao et al., 2006);
(5) Housing conditions, location and characteristics of the residential neighborhood (Antolín et al., 2018; Liu, 2014; Jäggi et al., 2013; Li et al., 2013; Musti and Kockelman, 2011; Paleti et al., 2011); and
(6) Psychological factors, encompassing attitudes, perceptions, and preferences of the decision-maker – environmental attitude (e.g. Bahamonde-Birke and Hanappi, 2016; Daziano and Bolduc, 2013; Hackbarth and Madlener, 2013; Jensen et al., 2013; Achtnicht et al., 2012; Ewing and Sarigöllü, 2000), technical interest (Soto et al., 2018; Hackbarth and Madlener, 2016; Kim et al., 2014, Hidrue et al., 2011), personal knowledge about AFVs (Hahn et al., 2018), and attitude towards specific vehicle attributes (e.g. Ferguson et al., 2018; Higgins et al., 2017; Biswas et al., 2014; Baltas and Saridakis, 2013; Jäggi et al., 2013) – pre-purchase information sources (Baltas and Saridakis, 2013; Li et al., 2013), as well as signaling (innovativeness, technology-oriented or forward-thinking personality) and societal influences, such as social norms or peer effects (e.g. Cherchi, 2017; Smith et al., 2017; Jansson et al., 2017a,b; Rasouli and Timmermans, 2016; Helveston et al., 2015; Kim et al., 2014).

Generalized results show that individuals preferring smaller vehicles and AFVs, especially battery electric vehicles (BEVs), seem to be younger, better educated, environmentally more aware, living in suburban or more densely populated areas with better access to public transportation, smaller households without children, and have a lower annual mileage. In contrast to buyers of AFVs, individuals preferring smaller vehicles are more likely to be female or have a higher income and are less likely to use the vehicle for commuting or to be home owners. Additionally, personal or social norms and signaling as well as a positive attitude towards or better knowledge about AFVs is shown to positively affect AFV choice probability. However, for most variables either conflicting or insufficient (in the sense of lack of significance of effects, or a lack of sufficing number of studies) evidence concerning their influence on the purchase probability of a specific vehicle type or fuel type can be found. This is mainly due to the fact that their impact is highly dependent on the particularities of the respective studies, i.e. the available data set or applied methodology (see Appendix A.1).

In that sense, we contribute to the literature in several ways. First, to the best of our knowledge, our work is the first scientific research to study German vehicle buyers' joint vehicle type and fuel type choice decisions by using a unique dataset of revealed preferences and stated preferences (intentions).[3]

Secondly, closely related to the vehicle type choice studies of Baltas and Saridakis (2013), Eluru et al. (2010), and Cao et al. (2006), as well as the fuel type choice studies of Jansson et al. (2017a) and Javid and Nejat (2017), we are mainly focusing on car buyers' characteristics, preferences and attitudes as main explanatory factors and less on vehicle-related attributes to explain specific vehicle type and fuel type purchases. However, our work extends on these international studies, in that it combines many of their most relevant and explanatory factors in a single model for analyzing joint vehicle and fuel type choice decisions. Moreover, we integrate several promising but rarely used explanatory factors, such as the source of funding of the vehicle (Ziegler, 2012), individuals usage of carsharing services (Javid and Nejat, 2017), or the premium-quality of the original equipment manufacturer (OEM). The latter information could be peculiarly interesting for German OEMs.

Thirdly, we especially analyze the specifics of buyers of smaller vehicles and their differences to those individuals preferring SUVs, as grasping a better understanding of this issue seems vital in the current market situation of rapidly increasing SUV sales figures.

[3] That is, until now scientific studies focused on the explanation of fuel type purchase decisions or intentions alone, regardless of the underlying theoretical approach: rational choice studies (e.g. Jacobs et al., 2016; Bauer, 2015; Hackbarth and Madlener, 2013, 2016; Achtnicht et al., 2012; Ziegler, 2012; Eggers and Eggers, 2011), behavioral or psychological studies (e.g. Barth et al., 2016; Plötz et al., 2014; Bühler et al., 2014; Petschnig et al., 2014).

Finally, we compare our results with the international research in great detail in order to facilitate the commensurability and transferability of our results, recommendations, and conclusions to other use cases.

This paper is, thus, motivated both from a transportation policy and a car manufacturer's perspective alike, as the problems shown above have strategic, behavioral, and marketing implications for both. A deeper knowledge of the preferences and determinants that shape vehicle adoption decisions could help to further accelerate the diffusion of smaller and alternatively fueled vehicles[4] by adjusting business models, information, or policies accordingly.

The remainder of this paper is organized as follows. In Section 4.2, we describe the survey generation and the data gathered. In Section 4.3, the methodological approach is introduced. Empirical results are reported and compared to previous research in Section 4.4. In Section 4.5, the recommendations for action are derived. Section 4.6 concludes.

4.2 Data

The data, on which our empirical analysis of consumers' vehicle choice is based, stems from a Germany-wide web-based survey that was conducted by the authors in July and August 2011. In total, 1500 respondents completed the survey and were recruited from a probability-based commercial online panel. Potential respondents had to meet two requirements. Firstly, they had to own a driver's license. Secondly, they had to have either purchased their newest vehicle in the last 12 months or they had to be intending to purchase one within the upcoming year.

The sample, which almost perfectly reflects the regional distribution of the population among the 16 German federal states, shows many similarities regarding socio-economic and socio-demographic factors when compared to the general population in Germany. However, also some minor differences can be found (Table 4.1). For instance, our sample under-represents individuals with low income, while it over-represents younger and highly educated people, which is a common finding in web-based surveys. Moreover, the survey participants are comparatively less often owning a vehicle and living less often in single-person households or rural areas. Finally, our sample slightly over-represents buyers of relatively inexpensive

[4] Electrified vehicles considerably increased their market share among newly registered vehicles in Germany over the past year: 25,056 BEVs (+119.6%), 84,675 HEVs (+76.4%), including 29,436 PHEVs (+114.2%). However, the share of gasoline-powered passenger cars is still increasing (+5.6%), and making up for the biggest part (57.7%) of the 3.44 million newly registered passenger cars in 2017 (KBA, 2018a).

vehicles and AFVs, as well as drivers with high annual mileage. This needs to be taken into account when interpreting the results.

Table 4.1: Household and vehicle characteristics of the sample vs. the population in Germany

Variable	Value	Sample (%)	Population (%)
Household characteristics			
Gender	Female	48.8	50.9
	Male	51.2	49.1
Age	18 to 24	8.9	9.8
	25 to 44	50.0	31.3
	45 to 64	37.1	34.3
	65 or above	4.0	24.6
Education	No form of school leaving qualification	0.4	7.7
	Secondary general school leaving qualification	6.7	37.3
	Intermediate school leaving qualification	29.5	29.0
	Higher education entrance qualification or university (of applied sciences) degree	63.4	26.0
Household income per month	Less than €2000	17.4	49.5
	€2000 to €5999	62.1	40.3
	€6000 or more	2.6	2.7
	Not stated and others	17.9	7.5
Number of persons in household	1	16.3	40.2
	2	39.7	34.2
	3	22.5	12.6
	4	16.0	9.5
	5 or more	5.5	3.4
Type of location	Urban (central city)	39.8	28.9
	Suburban / subrural	51.6	56.5
	Rural	8.6	14.6
Number of vehicles in household	0	4.7	17.7
	1	52.9	53.0
	2	35.7	24.2
	3	5.1	4.0
	4 or more	1.5	1.0
Vehicle characteristics			
Vehicle purchase	Vehicle purchase in past 12 months	48.0	-
	Vehicle purchase planned within 12 months	52.0	-
Reason for vehicle purchase	Replacement of old vehicle	82.8	81.0
	Additional vehicle	12.5	11.0
	Initial vehicle purchase	4.7	8.0
Purchase price	Less than €20,000	49.8	34.0
	€20,000 to €40,000	41.6	51.0
	€40,000 or more	8.6	15.0
Vehicle type	Mini cars	5.5	5.6
	Small cars	18.6	18.4
	Medium-sized cars	28.1	25.4
	Large cars	19.9	14.7
	Executive cars	6.4	5.2
	Luxury cars	0.9	0.9
	Multi purpose cars	9.3	11.9
	Sport utility vehicles	6.4	11.3
	Sport coupés	1.1	1.5
	Others	3.7	5.1
Fuel type	Gasoline	59.3	52.0
	Diesel	29.5	47.1
	Alternative fuel	11.2	0.9
Annual mileage	Less than 10,000 km	29.2	36.7
	10,000 km to 20,000 km	41.3	41.4
	20,000 km or more	29.5	21.9

Sources: Own calculations; Population shares for Germany computed on the basis of BBSR (2012), DAT (2012), KBA (2012, 2014), Destatis (2012a, 2012b), and Infas/DLR (2010).

The pre-tested and revised final survey consisted of five main sections. In the first section, respondents had to provide detailed information about existing (revealed preferences) and planned (stated intentions) car ownership, i.e. the vehicle segment (and make/model if possible) and fuel type of the newest/next vehicle, the (expected) driving habits, and the influencing factors before and during vehicle acquisition. The second section retrieved respondents' familiarity with six types of AFVs, followed by a detailed introduction to these alternative propulsion technologies, and a stated preferences discrete choice experiment.[5] In the third section, participants had to indicate the magnitude of importance of 16 different vehicle attributes in their purchase decision, while their level of agreement with numerous statements touching environmental concern, environmentally compatible behavior, and the interest in technology in general, and cars in particular, was gathered in the fourth section.

Finally, the fifth section comprised several socio-economic and socio-demographic questions, such as gender, age, income, occupation, and educational level, but also questions regarding specifics of the respondents' household, such as its size and residential environment, as well as respondents' habits concerning public transport utilization.

4.3 Methodological Approach and Model Specification

4.3.1 Methodological Approach

Our empirical analysis of the joint vehicle type and fuel type choice data is based on a discrete choice model, since the dependent variable indicates (potential) new car buyers' choices out of a finite set of 30 disjoint vehicle alternatives – all possible combinations of 10 different vehicle types and 3 fuel types (see Section 4.3.2).

Since the Hausman-McFadden tests for all possible reduced choice sets showed violations of the restrictive independence of irrelevant alternatives (IIA) assumption[6], we chose to estimate a less restrictive nested logit model (NL) – in addition to a standard multinomial logit model (MNL) for comparative reasons. The NL allows correlation in unobserved attributes by

[5] The experimental fuel type choice data is described and explored elsewhere (see Hackbarth and Madlener, 2013, 2016).

[6] The IIA assumption states that the ratio of choice probabilities of two alternatives is independent from the availability of any other alternative. It directly originates from the assumption that the error terms ε_{nj} are independently and identically extreme value distributed (Hensher et al. 2005; Louviere et al., 2000).

grouping similar alternatives into nests (e.g. mini and small cars), while keeping alternatives in different nests uncorrelated.[7]

The methodological approach of such an NL with two levels is described briefly in the following, drawing directly from Silberhorn et al. (2008), Cameron and Trivedi (2005), Train (2003), Hensher and Greene (2002), and Louviere et al. (2000), respectively.

It is assumed that the *J* elementary choice alternatives on the lower level, so-called twigs, can be clustered into *K* nests on the upper level, so-called branches, depending on their similarity, depictable in a tree structure.[8] Thus, the overall random utility U_{jk} a decision-maker receives of a specific alternative j now can be decomposed into two parts. First, a marginal utility component $U_k = V_k + \varepsilon_k$ on the branch level, with a deterministic part $V_k = \gamma' Y_k$ – comprising a vector of explanatory variables of the specific branch Y_k and a vector of unknown coefficients γ' – and the stochastic part ε_k. Second, a conditional utility component $U_{j|k} = V_{j|k} + \varepsilon_{j|k}$ on the twig level given that branch *k* was chosen, with a deterministic part $V_{j|k} = \beta' X_{j|k}$ – comprising a vector of characteristics of the specific vehicle alternatives or the vehicle buyers $X_{j|k}$ and a vector of unknown coefficients β' – and the stochastic part $\varepsilon_{j|k}$.

Taking all this into account, the probability P_{jk} that a utility maximizing decision-maker selects alternative *j* within nest *k* results from the product of the marginal choice probability P_k for nest *k* (upper level) and the conditional probability $P_{j|k}$ for choosing alternative *j* within nest *k* (lower level), which are both logit models. Applying RU2 normalization[9], the choice probability is as follows:

$$P_{jk} = P_k \cdot P_{j|k} = \frac{\exp\left(V_k + \frac{1}{\mu_k} IV_k\right)}{\sum_{l=1}^{K} \exp\left(V_l + \frac{1}{\mu_l} IV_l\right)} \cdot \frac{\exp(\mu_k V_{j|k})}{\sum_{m=1}^{J|k} \exp(\mu_k V_{m|k})}, \tag{4.1}$$

with $IV_k = ln \sum_{m=1}^{J|k} \exp(\mu_k V_{m|k})$ being the inclusive value, which represents the expected utility for the choice of alternatives within nest *m* and connects the two decision levels, and

[7] That is, while in an NL the IIA assumption still holds regarding alternatives in the same nest (comparably to an MNL), it is relaxed when it comes to alternatives in different nests. Thus, the variances of the random error components in the utility functions can differ between groups of alternatives. To accommodate these potential variance differences, scale parameters (μ_k and λ_k) have to be introduced into the utility functions (Louviere et al., 2000).

[8] Note that this tree structure has nothing to do with behavioral reasons or decision trees but is defined by the researcher. In other words, NLs do not portray the decision-making process, but only account for differences in variances in the unobservable utility components. Still, congruency between both might occur (Hensher et al. 2005).

[9] We chose the RU2 normalization on the upper level ($\lambda_k = 1$; see also footnote 7) and allow the IV parameters to be free between partitions of a nest because of the unrestricted compatibility of this normalization with the necessary conditions for utility maximization (see Hensher and Greene, 2002).

scale parameter μ_k, which has to be in the unity interval for consistency with utility maximization (with values closer to unity indicating less correlation).

We tested and compared an exhaustive range of models with two- or three-level nesting structures as to vehicle type, fuel type, or a combination of both. We found, however, that the nesting structures compatible with identification requirements under the utility maximization paradigm were predominantly those in which the alternatives were jointly grouped based on vehicle and fuel type, with best results obtained by a two-level structure. From the many NL partition structures evaluated, the tree structure presented in Figure C.1 in Appendix C showed the best statistical model fit and, thus, was chosen for our final empirical analysis. In this final structure, the 30 vehicle alternatives were clustered into six nests: a nest comprising of all mini, small, and medium-sized vehicle options irrespective of their fuel type; a nest containing all comparably spaceous gasoline-fueled vehicles, i.e. large, executive, luxury, and sports cars, as well as SUVs, MPVs, and other vehicles; two nests comprising the first four of these more spaceous vehicles (large, executive, luxury, and sports cars) each, separated regarding the two fuel types diesel and alternative fuel; and, finally, two nests containing the remaining three spaceous vehicles (SUVs, MPVs, and other vehicles) each, again segmented with regard to fuel type (diesel and alternative fuel).

4.3.2 Model Specification

The specification of the utility functions, i.e. the dependent and the explanatory variables that were included in our final vehicle type and fuel type choice model, are explained in more detail in the following.

4.3.2.1 Dependent Variables

The dependent variables of our choice model are the new vehicles that respondents either purchased recently (i.e. the latest household vehicle acquired within the preceding 12 months – revealed preference) or were about to purchase in the upcoming year (stated intention). The possible vehicle alternatives are defined by vehicle type, classified into 10 categories, and three fuel types, leading to 30 distinct choice options. The 10 vehicle categories used in the present study are mainly classified in terms of their size and body type according to the segmentation scheme set by the German Federal Motor Transport Authority (e.g. KBA, 2018a): mini cars, small cars, medium-sized cars, large cars, executive cars, luxury cars, sport coupés, multi-purpose vehicles (MPVs), i.e. minivans and vans, SUVs (including off-road vehicles), and others (summarizing the segments labeled 'utilities', 'camping vans', and 'others'). The three fuel types used to categorize the vehicle alternatives in our study are gasoline, diesel, and alternative fuels, the latter containing all kinds of partially or fully electrified vehicles – i.e. hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs) – and those running on natural gas.

The shares of and preferences for the different vehicle types and fuel types in our sample are presented in Table 4.2.

Table 4.2: Variables used in the model

Variable	Definition	Mean	Std. dev.	Min	Max
Individual and household characteristics					
Demographics					
Age	Age of the respondent in years	41.615	12.678	18	84
Female	1 if respondent is female, 0 otherwise	0.488	0.500	0	1
Attitudes and behavior					
Environmental awareness	Respondent's environmental awareness (average of the seven 5-point Likert scale[1] item scores)	3.468	0.757	1	5
Technophilia	Respondent's technophilia (average of the three 5-point Likert scale[1] item scores)	3.199	0.913	1	5
Environmental behavior 1	Respondent's environmental purchase and donation behavior (average of the three 5-point Likert scale[1] item scores)	2.680	0.930	1	5
Environmental mobility	Respondent's environmental mobility (average of the three 5-point Likert scale[1] item scores)	3.408	0.966	1	5
Knowledge about AFVs	Respondent's knowledge about alternative fuel vehicles (average of the six 5-point Likert scale[2] item scores)	2.809	1.046	1	5
Importance of vehicle attributes					
Fuel consumption and fuel cost	Importance of vehicle's fuel consumption and fuel cost in purchase decision (5-point Likert scale[3])	4.223	0.971	1	5
Motor vehicle tax	Importance of vehicle's annual tax in purchase decision (5-point Likert scale[3])	3.840	0.973	1	5
Size and spaciousness	Importance of vehicle's size and spaciousness in purchase decision (5-point Likert scale[3])	3.755	1.004	1	5
Horsepower	Importance of vehicle's horsepower in purchase decision (5-point Likert scale[3])	3.460	0.993	1	5
Uniqueness and rarity	Importance of vehicle's uniqueness and rarity in purchase decision (5-point Likert scale[3])	2.660	1.174	1	5
Appearance and design	Importance of vehicle's appearance and design in purchase decision (5-point Likert scale[3])	3.561	1.067	1	5
Driving range	Importance of vehicle's driving range on full tank or battery in purchase decision (5-point Likert scale[3])	3.921	0.967	1	5
Fuel type	Importance of vehicle's fuel type in purchase decision (5-point Likert scale[3])	3.524	1.023	1	5
Household characteristics					
Without children	1 if household is without children, 0 otherwise	0.655	0.476	0	1
No. of automobiles	5-point scale of household's number of automobiles, ranging from '0 = without vehicle' to '4 = four or above'	1.457	0.732		
User of carsharing services	1 if respondent uses carsharing services, 0 otherwise	0.041	0.198	0	1
Residential location	4-point scale of household's residential location, ranging from '1 = central city' to '4 = rural area'	1.877	0.914	1	4
Vehicle characteristics					
Utilization					
Main purpose of vehicle use: commute	1 if main purpose of vehicle use is commuting to work, 0 otherwise	0.513	0.492	0	1
Household's main vehicle	1 if vehicle is household's main vehicle, 0 otherwise	0.411	0.492	0	1
Annual mileage	6-point scale of vehicle's annual mileage, ranging from '1 = up to 5000 km' to '6 = 40,000 km and above'	3.079	1.095	1	6

(continued on next page)

Table 4.2 *(continued)*

Variable	Definition	Mean	Std. dev.	Min	Max
Purchase					
Recent vehicle purchase	1 if vehicle was purchased in past year, 0 otherwise	0.480	0.500	0	1
Purchase price	7-point scale of vehicle's purchase price range, ranging from '1 = up to €10,000' to '7 = €70,000 and above'	2.741	1.225	1	7
Company car	1 if vehicle is a company car, 0 otherwise	0.039	0.194	0	1
Premium OEM	1 if vehicle manufacturer is BMW, Mercedes, Lexus, Infinity, Porsche, Aston Martin, Audi, Jaguar, or Ferrari, 0 otherwise	0.221	0.415	0	1
Alternative-specific constants					
Mini gasoline	1 if vehicle type is mini and fuel type is gasoline, 0 otherwise	0.042	0.201	0	1
Mini diesel	1 if vehicle type is mini and fuel type is diesel, 0 otherwise	0.007	0.085	0	1
Mini altern. fuel	1 if vehicle type is mini and fuel type is alternative, 0 otherwise	0.006	0.077	0	1
Small gasoline	1 if vehicle type is small and fuel type is gasoline, 0 otherwise	0.142	0.349	0	1
Small diesel	1 if vehicle type is small and fuel type is diesel, 0 otherwise	0.023	0.151	0	1
Small altern. fuel	1 if vehicle type is small and fuel type is alternative, 0 otherwise	0.021	0.142	0	1
Medium gasoline	1 if vehicle type is medium-sized and fuel type is gasoline, 0 otherwise	0.182	0.386	0	1
Medium diesel	1 if vehicle type is medium-sized and fuel type is diesel, 0 otherwise	0.067	0.249	0	1
Medium altern. fuel	1 if vehicle type is medium-sized and fuel type is alternative, 0 otherwise	0.032	0.176	0	1
Large gasoline	1 if vehicle type is large and fuel type is gasoline, 0 otherwise	0.091	0.287	0	1
Large diesel	1 if vehicle type is large and fuel type is diesel, 0 otherwise	0.085	0.279	0	1
Large altern. fuel	1 if vehicle type is large and fuel type is alternative, 0 otherwise	0.023	0.151	0	1
Executive gasoline	1 if vehicle type is executive and fuel type is gasoline, 0 otherwise	0.030	0.171	0	1
Executive diesel	1 if vehicle type is executive and fuel type is diesel, 0 otherwise	0.029	0.169	0	1
Executive altern. fuel	1 if vehicle type is executive and fuel type is alternative, 0 otherwise	0.005	0.068	0	1
Luxury gasoline	1 if vehicle type is luxury and fuel type is gasoline, 0 otherwise	0.005	0.073	0	1
Luxury diesel	1 if vehicle type is luxury and fuel type is diesel, 0 otherwise	0.002	0.045	0	1
Luxury altern. fuel	1 if vehicle type is luxury and fuel type is alternative, 0 otherwise	0.002	0.045	0	1
Sport coupé gasoline	1 if vehicle type is sports car or roadster and fuel type is gasoline, 0 otherwise	0.008	0.089	0	1
Sport coupé diesel	1 if vehicle type is sports car or roadster and fuel type is diesel, 0 otherwise	0.001	0.036	0	1
Sport coupé altern. fuel	1 if vehicle type is sports car or roadster and fuel type is alternative, 0 otherwise	0.002	0.045	0	1
SUV diesel	1 if vehicle type is sport utility vehicle and fuel type is diesel, 0 otherwise	0.031	0.172	0	1
SUV altern. fuel	1 if vehicle type is sport utility vehicle and fuel type is alternative, 0 otherwise	0.004	0.063	0	1
MPV gasoline	1 if vehicle type is multi purpose vehicle and fuel type is gasoline, 0 otherwise	0.045	0.208	0	1
MPV diesel	1 if vehicle type is multi purpose vehicle and fuel type is diesel, 0 otherwise	0.033	0.180	0	1
MPV altern. fuel	1 if vehicle type is multi purpose vehicle and fuel type is alternative, 0 otherwise	0.014	0.117	0	1
Others gasoline	1 if vehicle type is pickup truck, camper van, light commercial vehicle, leisure activity vehicle, etc. and fuel type is gasoline, 0 otherwise	0.018	0.133	0	1
Others diesel	1 if vehicle type is pickup truck, camper van, light commercial vehicle, leisure activity vehicle, etc. and fuel type is diesel, 0 otherwise	0.016	0.125	0	1
Others altern. fuel	1 if vehicle type is pickup truck, camper van, light commercial vehicle, leisure activity vehicle, etc. and fuel type is alternative, 0 otherwise	0.003	0.058	0	1

Notes: 1 = The 5-point Likert scale ranges from '1 = strongly disagree' to '5 = strongly agree'; 2 = The 5-point Likert scale ranges from '1 = I could not explain it at all' to '5 = I could explain it well '; 3 = The 5-point Likert scale ranges from '1 = not at all important' to '5 = very important'.

Finally, we chose gasoline SUV as base alternative (parameter set to zero) in our model, as, firstly, determinants of SUV purchase and their differences to other segments are one of the main research goals of our study, and, secondly, most vehicles run on gasoline, so that this specific fuel type is a natural candidate as a base category. Thus, the estimated coefficients will have to be interpreted with respect to that category.

4.3.2.2 Explanatory Variables

The variables entering the deterministic part of utility in our vehicle choice model are given in Table 4.2, and can roughly be classified into decision-maker/household characteristics and vehicle characteristics. The former can further be arranged into 4 subgroups, i.e. (1) socio-demographic characteristics, (2) attitudes and behavior, (3) importance of vehicle attributes, and (4) household characteristics, while the latter comprise 3 subgroups: (1) vehicle utilization, (2) vehicle purchase, and (3) alternative-specific constants.

Note that numerous explanatory variables which were found to exert a significant influence on vehicle choice in previous research were tested in the course of model specification. However, not all of them were found to have a statistically significant impact on the choice decision of at least one alternative in our sample, and, thus, were discarded in our final model.[10] The remaining 26 key explanatory variables that entered the vehicle choice model are:

- *Socio-demographic characteristics:* The demographic variables that significantly influence vehicle purchase decisions include the age and gender of the primary driver.
- *Attitudes and behavior:* Our survey contained 22 statements adopted from the literature and adapted where needed (e.g. Karrer et al., 2009; Kuckartz, 2000; Preisendörfer, 1999), measuring the underlying subject of environmental concern, environmental behavior and interest in cars or new technologies. In order to extract the slightly correlated fundamental attitudes and behaviors and, thus, to reduce the dimensions of variation, we applied a principal component analysis using Promax rotation as the extraction method on these 22 items. As can be seen in Tables C.1 and C.2 in Appendix C, six[11] underlying components

[10] We derived our final model comprising solely significant explanatory variables from exhaustive tests applying backward elimination. The deleted variables include: pre-purchase information sources, utilization of other means of transportation, availability of public transportation, current job, education, income, and the importance of some vehicle attributes (e.g. safety, reliability, driving range, emissions, service, fuel availability).

[11] A principal component analysis is suitable for our data, as indicated by the Kaiser-Meyer-Olkin statistic (0.887) and the highly significant Bartlett test of sphericity ($p < 0.0001$). Furthermore, the number of items (≥3) and the reliability (Cronbach's alpha ≥ 0.66) for each of the six extracted factors is sufficient, i.e. exceeding the proposed critical threshold values of 0.60-0.70 (Peterson, 1994). All of the items had factor loadings greater than (or close to) 0.6, and generally loaded strongly on a single factor in the six-factor solution. Finally, a content-related label could easily be assigned to each of the six components, due to their great intra-component item homogeneity.

with eigenvalues greater than unity were identified, accounting for 64.05% of the overall variance. Of the six extracted components only four – environmental awareness, environmental mobility, environmental (purchase and donation) behavior, and technophilia – had an impact on vehicle choice and, hence, were used in our final model by averaging the item scores into sum scales for each factor. Furthermore, respondents were asked to rate their familiarity with different alternative propulsion technologies. The scores for the single AFVs were then added up and averaged for each respondent in order to obtain a unidimensional scale as an indicator for their general knowledge about alternatively fueled vehicles. As shown in Table 4.2, on average respondents evaluate themselves as being rather inexperienced with regard to AFVs.

- *Importance of vehicle attributes:* The importance that vehicle buyers' ascribe to 16 different vehicle attributes was measured in the questionnaire, of which only 8 were found to significantly influence the vehicle purchase decision: fuel consumption and fuel cost, motor vehicle tax, size and spaciousness, horsepower, uniqueness and rarity, appearance and design, driving range, and fuel type.[12]
- *Household characteristics:* Four household-related variables were significant in our final model: number of automobiles, residential location (categorizing the German districts with regard to population density, see BBSR, 2012), and two variables indicating the absence of children and the usage of car-sharing services, respectively. As shown in Table 4.2, the latter household characteristic is comparatively rare.
- *Vehicle utilization:* The survey contained several questions related to vehicle usage, which resulted in only three statistically significant variables: indicators for commuting as main intended vehicle use[13], main vehicle (as can be seen in Table 4.2, around 41% of the (intended) vehicle purchases are concerning the principal vehicle of the household), and annual mileage.
- *Vehicle purchase:* The significant variables entering our final model indicated whether the vehicle was funded by the employer (company car)[14], built by one of the nine premium manufacturers (BMW, Mercedes, Lexus, Infinity, Porsche, Aston Martin, Audi, Jaguar, or Ferrari) defined by Rosengarten and Stürmer (2005), or already and actually purchased in

[12] Multi-collinearity between the 8 remaining items measuring the importance of vehicle attributes was tested for. Since in our final model the slightly correlated vehicle attributes never enter the utility functions of the same vehicle alternative, multi-collinearity is not an issue.
[13] In our sample, the indicated main purposes of vehicle usage were commute to work (51%), private affairs (35%), business-related (9%), recreation and vacation (4%), and others (1%).
[14] The means of vehicle financing of survey participants were cash payment (52%), personal credit (21%), leasing (12%), funded by employer (4%), and others (11%).

the year prior to the survey participation, respectively. Respondents further had to indicate their budget constraint, i.e. the stated price range of their last/next vehicle purchase.

4.4 Empirical Results

The impact of driver, household, and vehicle characteristics on the choice probability of the 30 distinct vehicle alternatives, described by vehicle and fuel type, was assessed by estimating an MNL and NL. Although the estimation results of the MNL and NL (see Table 4.3) are comparably similar, small differences can be found particularly regarding the size of coefficients and the statistical significance of some variables.

For instance, while one parameter is insignificant in the NL but not in the MNL (luxury gasoline vehicle constant), a greater number of variables are insignificant in the MNL compared to the NL (medium-sized alternative fuel vehicle constant, user of carsharing services*medium-sized vehicle, and premium OEM*luxury vehicle). Differences in the sign of parameters between the two models are only observed for three insignificant alternative specific constants (large diesel vehicle, MPV diesel, and other diesel) and, thus, negligible.

However, as indicated by the goodness-of-fit test statistics (log likelihood values, McFadden's ρ^2), the final NL shows significant statistical improvement compared to the MNL specification, i.e. the final NL more precisely explains individuals' vehicle choice behavior.[15] This result is accentuated by the six inclusive value parameters which are found to be significantly different from zero and one, respectively (see p-values and Wald test statistic in Table 4.3), implying that the utility maximization requirement is met, alternatives belonging to the specific nests actually are sharing unobserved attributes, and the nesting structure does not necessarily have to be changed.[16] Further, the $\rho^2(c)$ value of 0.21 of the final NL compared to the model containing constant terms alone falls within the range of other models found in the literature. Therefore, in the following detailed discussion of the estimation results, we focus on the NL parameters only.

[15] The result of the likelihood ratio test between MNL and NL illustrates the statistically highly significant superiority of the NL: $55.06 > \chi^2_{\alpha=0.99}(6) = 16.81$.

[16] That is, although the difference between some of the parameters (e.g. the IV parameters of the two nests containing larger alternatively fueled vehicles) is quite small, collapsing these two nests into one single branch results in a deterioration of the model's goodness-of-fit indicators.

Table 4.3: Estimation results

	MNL		NL	
	Coefficient	**Std. error**	**Coefficient**	**Std. error**
Alternative-specific constants				
Mini gasoline	7.37233***	1.12238	6.25585***	0.75301
Mini diesel	4.96998***	1.24543	4.86024***	0.86004
Mini altern. fuel	3.06719**	1.36743	3.42986***	0.94627
Small gasoline	7.43790***	0.78667	6.28745***	0.60101
Small diesel	4.76997***	0.93020	4.71374***	0.69891
Small altern. fuel	3.10097***	1.05439	3.43020***	0.76884
Medium gasoline	5.18599***	0.59918	5.01613***	0.55909
Medium diesel	2.93983***	0.76376	3.58716***	0.68028
Medium altern. fuel	0.89271	0.92295	2.13517***	0.82702
Large gasoline	2.08411***	0.57446	0.96929**	0.43958
Large diesel	0.38203	0.74322	-0.50810	0.59023
Large altern. fuel	-1.96125**	0.94152	-2.57674***	0.73200
Executive gasoline	-3.91154***	0.77882	-2.32076***	0.68534
Executive diesel	-6.19701***	0.96222	-3.96737***	0.83899
Executive altern. fuel	-8.75466***	1.18099	-5.92831***	0.97445
Luxury gasoline	-3.77145**	1.63603	-2.28834	1.40515
Luxury diesel	-7.39398***	1.90543	-4.34484***	1.64018
Luxury altern. fuel	-8.47697***	1.94421	-5.43298***	1.44638
Sport coupé gasoline	-9.33926***	2.40899	-6.16261***	2.11365
Sport coupé diesel	-13.9271***	2.64646	-9.09170***	2.34563
Sport coupé altern. fuel	-14.1556***	2.63389	-9.65693***	2.15538
SUV diesel	-1.70121***	0.51192	-1.43767***	0.40630
SUV altern. fuel	-5.00972***	0.85687	-3.92143***	0.67318
MPV gasoline	2.09056***	0.73901	1.29730***	0.45258
MPV diesel	0.09773	0.87345	-0.24676	0.62657
MPV altern. fuel	-2.22747**	1.04437	-2.39309***	0.74961
Others gasoline	2.08964**	0.92716	1.02428**	0.52230
Others diesel	0.55721	1.04654	-0.14378	0.70961
Others altern. fuel	-2.47280**	1.25639	-2.61471***	0.78136
Mini				
Female	0.56598**	0.27884	0.33945**	0.15397
Environmental awareness	0.59905***	0.19940	0.47541***	0.13808
Importance of fuel consumption and cost	0.42043***	0.15958	0.18377**	0.08597
Importance of size and spaciousness	-0.89750***	0.15532	-0.68244***	0.10834
Household without children	0.96374***	0.32952	0.90813***	0.21745
User of carsharing services	2.09869***	0.60766	1.43205***	0.43990
Household's main vehicle	-1.58027***	0.32260	-1.04446***	0.23557
Annual mileage	-0.78128***	0.14921	-0.39986***	0.09025
Purchase price	-2.85028***	0.23955	-2.17794***	0.16264
Small				
Age	-0.01279**	0.00592	-0.00703**	0.00330
Female	0.50451***	0.16305	0.30084***	0.09767
Environmental awareness	0.39528***	0.13029	0.37195***	0.10319
Importance of fuel consumption and cost	0.26855***	0.09569	0.10522*	0.05388
Importance of size and spaciousness	-0.62789***	0.11116	-0.54397***	0.08888
Household without children	0.81958***	0.20950	0.81865***	0.16994
User of carsharing services	1.09656**	0.48126	0.92434**	0.39321
Household's main vehicle	-1.04842***	0.21455	-0.75865***	0.17849
Annual mileage	-0.30254***	0.08490	-0.15385***	0.04761
Purchase price	-2.21317***	0.16063	-1.83228***	0.11560
Medium				
Environmental awareness	0.33911***	0.09841	0.33382***	0.09403
Importance of size and spaciousness	-0.34511***	0.08613	-0.40544***	0.07816
Importance of uniqueness and rarity	-0.14270**	0.06019	-0.06697*	0.03598
Household without children	0.58285***	0.15990	0.68395***	0.15251
User of carsharing services	0.61994	0.38931	0.64215*	0.35776
Household's main vehicle	-0.67693***	0.17426	-0.55076***	0.15903
Purchase price	-1.17741***	0.11049	-1.28560***	0.09827
Premium OEM	0.90119***	0.23368	0.65072***	0.17642
Large				
Technophilia	0.16008*	0.08507	0.11321*	0.06243
Importance of uniqueness and rarity	-0.21204***	0.06895	-0.13631***	0.04981
Importance of driving range	0.17389**	0.08213	0.12642**	0.05780
No. of automobiles	-0.26700**	0.10600	-0.14605*	0.07726
Household's main vehicle	-0.65139***	0.17317	-0.37401***	0.12482
Purchase price	-0.32829***	0.09560	-0.18549**	0.07815
Premium OEM	1.18722***	0.23537	0.92113***	0.19338

(continued on next page)

Table 4.3 *(continued)*

	MNL		NL	
	Coefficient	**Std. error**	**Coefficient**	**Std. error**
Executive				
Environmental awareness	0.32024**	0.16049	0.18908*	0.10554
Purchase price	0.57883***	0.12592	0.32594***	0.10751
Premium OEM	1.78611***	0.32000	1.23650***	0.25222
Luxury				
No. of automobiles	-1.82321***	0.59225	-0.83184**	0.37244
Purchase price	1.41243***	0.26442	0.72236***	0.24661
Premium OEM	1.10593	0.70691	0.80507**	0.35899
Sport coupé				
Technophilia	0.91198**	0.38175	0.65055**	0.27899
Importance of size and spaciousness	-1.25687***	0.25412	-0.76655***	0.22505
Importance of appearance and design	0.99116***	0.33297	0.61301**	0.25891
Purchase price	1.29479***	0.24561	0.81473***	0.20454
MPV				
Importance of size and spaciousness	0.34653***	0.12937	0.20623***	0.07260
Importance of horsepower	-0.45397***	0.11493	-0.28112***	0.08104
Importance of uniqueness and rarity	-0.24127**	0.09888	-0.13545**	0.05825
Household without children	-0.62590***	0.20854	-0.30441***	0.11578
No. of automobiles	-0.36171**	0.15270	-0.22021**	0.09516
Residential location	0.24397**	0.09955	0.10465*	0.05542
Premium OEM	-0.82813**	0.37449	-0.46456**	0.20066
Others				
Importance of size and spaciousness	0.52642***	0.18244	0.31498***	0.10618
Importance of horsepower	-0.30206*	0.16863	-0.27053***	0.09711
Importance of appearance and design	-0.46072***	0.14517	-0.21864**	0.09685
Main purpose of use: commuting	-0.76175**	0.31062	-0.31238**	0.15484
Household's main vehicle	-0.79281**	0.32015	-0.27259*	0.16119
Annual mileage	-0.45989***	0.14551	-0.20486***	0.07905
Premium OEM	-1.70001**	0.75333	-0.73722**	0.36186
Diesel				
Environmental mobility	-0.14326**	0.06603	-0.08817*	0.04702
Importance of motor vehicle tax	-0.12890*	0.07157	-0.08919*	0.05338
Importance of uniqueness and rarity	-0.14636**	0.05698	-0.12220***	0.04157
Importance of fuel type	0.20331***	0.07179	0.15103***	0.05537
Household without children	-0.37608***	0.13234	-0.29829***	0.09676
Household's main vehicle	0.39696***	0.13327	0.28290***	0.09819
Annual mileage	0.58979***	0.08010	0.42776***	0.06799
Purchase price	0.40219***	0.07205	0.27717***	0.05579
Company car	1.71979***	0.35403	1.21556***	0.27214
Alternative fuel				
Environmental behavior: purchase/donation	0.22402**	0.10234	0.14054**	0.07035
Knowledge about AFVs	0.20469**	0.09078	0.15295**	0.06952
Importance of fuel consumption and cost	0.27928**	0.11350	0.17994**	0.07645
Importance of horsepower	-0.45886***	0.09613	-0.33640***	0.07762
Importance of fuel type	0.24572**	0.10413	0.20030***	0.07087
Residential location	-0.24348**	0.10527	-0.13437*	0.07735
Annual mileage	0.52960***	0.11827	0.36114***	0.08345
Recent vehicle purchase	-2.05931***	0.23405	-1.43778***	0.21006
Purchase price	0.53409***	0.11191	0.40954***	0.09050
Premium OEM	-1.24493***	0.29383	-0.96411***	0.23744
Inclusive value (IV) parameters[1]				
Mini/small/medium			0.50784***	0.06412
Large/Executive/Luxury/Sport–Diesel			0.47347***	0.13468
Large/Executive/Luxury/Sport–Altern. fuel			0.32826*	0.17341
SUV/MPV/Other–Diesel			0.30472***	0.08318
SUV/MPV/Other–Altern. fuel			0.31801*	0.18072
Spacious vehicles–Gasoline			0.57299***	0.11008
Estimation statistics				
No. of observations	1500		1500	
Log likelihood at zero LL(0)	-5101.41		-5101.41	
Log likelihood at constants LL(c)	-4216.18		-4216.18	
Log likelihood at convergence	-3356.54		-3329.01	
$\rho^2(0)$	0.342		0.347	
$\rho^2(c)$	0.204		0.210	

Notes: ***, **, * indicate significance at the 1%, 5%, 10% level; 1 = Wald statistics against unity are (top-down) -7.68, -3.91, -3.87, -8.36, -3.77, and -3.88, respectively (i.e. all being greater than the critical value of ±1.96 at α=0.05); ρ^2 = McFadden's pseudo R-squared; Base alternative: Gasoline SUV; MNL = multinomial logit model; NL = nested logit model; SUV = sport utility vehicle; MPV = multi purpose vehicle; AFV = alternative fuel vehicle; OEM = original equipment manufacturer; Altern. = alternative.

4.4.1 Results Ordered by Vehicle Alternatives

First, we analyze the statistically significant key influencing factors by vehicle type to gain better knowledge about the characteristics of typical buyers of each vehicle segment and fuel type. Most of the 29 alternative-specific constants are significant, except for gasoline-fueled luxury cars, and three diesel-fueled vehicles (large cars, MPVs, ‘others’). Mini (all fuel types), small (all fuel types), medium-sized (gasoline and diesel), and large gasoline cars as well as gasoline MPVs have a positive sign compared to gasoline-fueled SUVs, the base category, suggesting that the average effect of all unmeasured factors seems to increase the probability of selecting these vehicle alternatives. In contrast, the alternative-specific constants of executive (all fuel types) and luxury (diesel and alternative fuel) cars, sport coupés (all fuel types), SUVs (diesel and alternative fuel) as well as alternatively fueled large cars, MPVs, and ‘others’ are negative compared to gasoline SUVs, suggesting that the average impact of all unmeasured factors seems to decrease the choice probability of these vehicles. Furthermore, the comparably large alternative-specific constants for sport coupés as well as the alternatively fueled vehicles in general suggest that the variables included in the model explain have the lowest explanatory power regarding the choice probability of these vehicle types.

Mini: Buyers of mini cars are more likely to be female and more environmentally aware and tend to place more emphasis on the vehicles’ fuel consumption and fuel costs in the purchase decision. On the other hand, individuals perceiving vehicle size and spaciousness as being an important vehicle attribute are less likely to purchase mini cars. Smaller households without children and users of carsharing services are overrepresented among buyers of mini cars. Finally, mini vehicles are less likely to be household’s main vehicle and less likely to be chosen by car buyers willing to spend greater amounts for their new vehicle and individuals with high annual mileage.

Small: Likewise, the probability of purchasing a small car is higher for younger, female vehicle buyers, and individuals with stronger environmental attitude or living in childless households. It is less likely for drivers with high annual mileage and car buyers deciding about the household’s main vehicle to buy a small car. Interested consumers tend to have a smaller budget for the purchase and place less emphasis on vehicle size and spaciousness, while placing stronger emphasis on fuel consumption and fuel costs.

Medium: The propensity to prefer a vehicle from the medium class is higher for individuals who are more environmentally aware, user of carsharing services, or those who live in households without children. Medium-sized vehicles are less likely to be the household’s main car but more likely to be manufactured by a premium OEM. Individuals placing weaker emphasis on vehicles' size and spaciousness or uniqueness and rarity in their purchase decision and spending smaller amounts on their vehicle have a higher than average probability of purchasing a medium-sized vehicle.

Large: Being technically interested increases the likelihood of choosing a large vehicle, while the purchase probability decreases with the number of automobiles already available in the household and the purchase price of the vehicle. If the vehicle is intended to be the household's main vehicle, car buyers are also less likely to purchase a large vehicle. However, large vehicles are more likely to be from a premium brand. Finally, individuals placing less emphasis on the importance of a vehicle's uniqueness and rarity but more importance on its driving range tend to purchase large vehicles more often.

Executive: Executive vehicle buyers tend to be more environmentally aware, pay greater amounts for their vehicle, and are more likely to purchase a vehicle from a premium manufacturer.

Luxury: Similarly to the executive vehicle segment, luxury vehicles are more likely to be manufactured by a premium OEM and, on average, tend to have a greater purchase price. The number of automobiles in the buyer's household, however, decreases the purchase probability of luxury vehicles.

MPV: Compared to buyers of SUVs, individuals interested in MPVs are less likely to place higher importance on horsepower or uniqueness and rarity, but greater emphasis on vehicles' size and spaciousness. They tend to live in more rural areas, in households with children, or households with a smaller number of available vehicles. Finally, MPVs are less likely purchased from a premium manufacturer.

Sport coupé: The likelihood of purchasing a sport coupé is higher for individuals who have stronger technical interest or rate vehicles' appearance and design as being more important during the purchase decision. Vehicle size and spaciousness, on the other hand, tend to be comparably unimportant for individuals being more likely to purchase a sport coupé. Compared to SUVs the purchase price is likely to be higher.

Others: Conversely, car buyers placing more emphasis on vehicle size and spaciousness and less emphasis on horsepower or appearance and design purchase vehicles from the 'others' segment more often. It is, however, less likely to be chosen if it is the main vehicle in a household or from a premium manufacturer. A high annual mileage and work-related usage as the main vehicle purpose also has a negative effect on the likelihood of purchasing an 'other' vehicle.

Diesel: Diesel is more likely to be chosen as the household's main vehicle, if it is a company vehicle (i.e. entirely or co-financed by the employer) and if the acquisition budget is higher. Furthermore, individuals with a weaker environmental mobility attitude and a greater annual mileage are also more likely to purchase diesel vehicles, whereas living in a household without children decreases the purchase probability. Car buyers placing more emphasis on motor vehicle taxes and vehicles' uniqueness and rarity are less likely to purchase a diesel-fueled vehicle, while its likelihood of being chosen increases with the importance of fuel type in the decision process.

AFV: Individuals with greater annual mileage, living in more urban areas, with greater environmental behavior, or knowledge about AFVs in general tend to be more open towards alternative fuels, while those having purchased a vehicle recently are less likely to have chosen an AFV. AFVs are also found to have higher purchase prices but are less likely to be from a premium manufacturer. Vehicle buyers placing more emphasis on fuel consumption and fuel cost and fuel type tend to prefer AFVs, while alternative fuel is less likely to be chosen if horsepower is valued as more important.

4.4.2 Results Ordered by Explanatory Variables

Second, we describe the results according to the type of explanatory variable, i.e. individual and household characteristics as well as attributes of the vehicle options, assess their impact on the choice probability of the different vehicle alternatives, and compare our results to findings from previous research.

4.4.2.1 Individual and Household Characteristics

Demographics: Our results indicate that socio-demographics only have a comparably small impact on vehicle choice, as only age and gender show a significant influence. Age has a negative impact on the choice probability of small cars, i.e. older car buyers are less likely to choose this car type compared to (gasoline) SUVs, while, all else equal, women are more likely to choose mini and small cars. This finding is, on the one hand, in contrast to previous studies, often showing an impact of various further socio-demographic variables, such as education, income, marital status, or employment, on vehicle choice decisions and especially the choice probability of AFVs (e.g. Cirillo et al., 2017; Higgins et al., 2017; Rasouli and Timmermans, 2016; Nayum et al., 2016, Mabit et al., 2015; Peters and Dütschke, 2014; Plötz et al., 2014). On the other hand, our results corroborate previous research stating that the effects of socio-demographic characteristics greatly decrease when other explanatory variables, especially psychological factors, are accounted for (e.g. Mohamed et al., 2018; Axsen et al., 2016; Nordlund et al., 2016; Rezvani et al., 2015; Nayum and Klöckner, 2014).

Moreover, the results that younger and female vehicle buyers are buying smaller vehicles is broadly in line with the literature and the reported negative impact of age (Adjemian et al., 2010; Bhat et al., 2009; Choo and Mokhtarian, 2004) or being male (e.g. Jäggi et al., 2013; Prieto and Cammerer, 2013; Chiou et al., 2009; Spissu et al., 2009; Bhat and Sen, 2006; Cao et al., 2006; Choo and Mokhtarian, 2004) on the probability of purchasing mini, small, or medium-sized vehicles in relation to larger or more massive vehicles (e.g. pickup trucks).

Attitudes and behavior: Environmental awareness has a positive impact on the choice probability of mini, small, and medium-sized cars. Hence, buyers of larger (such as SUVs) or more sportive vehicles generally are less environmentally aware than buyers of smaller vehicle types, which was expected – as they, on average, are heavier, more powerful, less fuel-efficient and, thus, less environmentally friendly – and corroborates previous findings (Mohamed et al., 2018; Kahn, 2007; Choo and Mokhtarian, 2004). Interesting, however, is that environmental awareness also exerts a positive influence on the purchase probability of executive vehicles, which is only comparable to the results of Higgins et al. (2017), who find that prospective luxury car buyers seem to make greener decisions.

Consumers donating to environmental organizations or paying attention to environmental attributes in their purchase decisions are more likely to choose AFVs.[17] This result corroborates the general findings from other studies regarding the impact of environmental concern on fuel type choice, especially regarding electrified vehicles (e.g. Nordlund et al., 2016; Krause et al., 2016; Helveston et al., 2015; Krupa et al., 2014; Noppers et al., 2014; Petschnig et al., 2014; Hackbarth and Madlener, 2013; Daziano and Bolduc, 2013; Axsen et al.; 2013; Carley et al., 2013; Schuitema et al., 2013; Daziano and Chiew, 2012; Hidrue et al., 2011). Finally, respondents putting much emphasis on environmentally-friendly mobility are less likely to buy diesel-fueled cars – a finding which opposes the result of Soto et al. (2018) for Columbian data.

Car buyers who are interested in (new) technologies are more likely to buy large cars and sport coupés (compared to SUVs), which especially regarding the latter makes sense. Our finding is broadly in line with the studies of Baltas and Saridakis (2013) concerning sport coupés as well as Higgins et al. (2017) for the case of (electrified) large vehicles. However, unlike previous studies (e.g. Soto et al., 2018; Axsen et al., 2016; Hackbarth and Madlener,

[17] Regarding fuel type choice, factors measuring environmental behavior and attitudes towards environmental mobility were more informative than the environmental awareness scale.

2016; Egbue and Long, 2012; Hidrue et al., 2011), we did not find a significant positive impact of technical interest on fuel type choice, especially concerning electrified vehicles. This, however, may be caused by the fact that we explicitly tested for individuals' specific knowledge about all kinds of AFVs, which in our model is found to increase a car buyer's likelihood of choosing such an alternatively propelled vehicle. This result also supports the studies reporting that personal knowledge and experience increase BEV acceptance (e.g. Hahn et al., 2018; Schmalfuß et al., 2017; Barth et al., 2016; Krause et al., 2013; Egbue and Long, 2012; Graham-Rowe et al., 2012).

Importance of vehicle attributes: Fuel consumption and the according fuel costs have a positive impact on the choice of mini and small cars, i.e. car buyers who rate fuel costs as being important are more likely to choose mini and small cars. Furthermore, respondents for whom fuel costs are important also tend to more likely choose alternatively fueled cars. Both results, especially the latter, are in line with previous findings (e.g. Higgins et al., 2017; Jäggi et al., 2013; Link et al., 2012) and were expected, since smaller vehicles tend to be more fuel-efficient and alternative fuels generally are less expensive (mainly due to lower tax rates).

We further find that respondents who place more emphasis on the motor vehicle tax during new car purchase decisions are less likely to buy vehicles that run on diesel, which is in line with Habibi et al. (2019). Our result makes sense, as in Germany this tax for diesel vehicles is higher, compared to gasoline vehicles and AFVs.[18]

Car buyers who place more emphasis on vehicle size and spaciousness are, as expected, less likely to choose mini, small, and medium-sized cars, as well as sport coupés and are more likely to buy MPVs and 'other' vehicles, compared to SUVs, which is also broadly in line with the literature (Mohammadian and Miller, 2002; Beggs and Cardell, 1980).

However, if a vehicle's horsepower is considered to be an important vehicle feature, MPVs and 'other' vehicles as well as AFVs in general are less likely to be chosen. The latter result is in line with the finding of Biresselioglu et al. (2018), who describe the lack of trust in BEVs' performance as a major barrier for their adoption, while our former result is broadly in line with the finding of Baltas and Saridakis (2013), who report a positive impact of horsepower on the purchase probability of large vehicles, sport coupés and station wagons, also compared to SUVs.

[18] The annual circulation tax in Germany is calculated depending on the fuel type (BMF, 2018), so that conventionally fueled vehicles are burdened on the basis of the engine displacement (base tax rates of €2/100 ccm for gasoline and €9.5/100 ccm for diesel engines) and, additionally, the CO_2 emissions (tax rate of €2 per gCO_2/km for every gram above 95 gCO_2/km) of the newly registered vehicle since 2014. Electric vehicles are exempted from the tax for 10 years. After the expiration of that term, they are assessed by their total weight (€5.63-6.39/200 kg, increasing with weight class).

Car buyers who place more emphasis on vehicle uniqueness and rarity are less likely to choose medium-sized and large cars, as well as MPVs. Regarding the choice of fuel type, diesel cars are chosen less often by consumers who value uniqueness and rarity as being more important. Sport coupés are more likely to be chosen by car buyers who put more emphasis on vehicles' appearance and design, while those consumers are less likely to choose 'other' vehicles, which is absolutely reasonable given the highly different and unique characteristics and application areas of both vehicle types. The results of Baltas and Saridakis (2013) are pointing in the same direction concerning sport coupés, while they additionally report that individuals putting more importance on vehicles' image in their purchase decision are more likely to purchase mini or luxury vehicles compared to SUVs.

In contrast to the literature, we did not find a positive effect of these more image-related vehicle features on the choice probability of AFVs (e.g. Schuitema et al., 2013; Graham-Rowe et al., 2012; Skippon and Garwood, 2011).

Consumers who are more interested in driving range are more likely to choose large cars, suggesting that they are used more frequently for longer trips than SUVs, as the annual mileage does not seem to be significantly different between both vehicle types. Our finding generally supports the results of Hahn et al. (2018), who report medium-sized and executive vehicles to be preferred by individuals valuing driving range as being more important.

Finally, car buyers who place more importance on the fuel type of the new vehicle are more likely to choose diesel and alternatively fueled cars compared to gasoline cars. The implication is that buyers of non-gasoline vehicles (diesel and AFVs) are making this decision very intentionally and, thus, potentially are also better informed.

Household characteristics: Households without children are more likely to choose mini, small and medium-sized cars, and are less likely to purchase MPVs. Also diesel-fueled vehicles are less likely to be purchased by childless households. This is in line with the literature, which reports a positive impact of household size on the purchase probability of diesel vehicles (e.g. Knockaert, 2010), MPVs (e.g. Xu et al., 2015; Eluru et al., 2010; Spissu et al., 2009; Potoglou and Kanaroglou, 2007; Bhat and Sen, 2006), or SUVs compared to smaller vehicles (Musti and Kockelman, 2011; Bhat et al. 2009; Mannering et al., 2002), as well as a negative impact on medium-sized vehicles (Xu et al., 2015; Adjemian et al., 2010; Eluru et al., 2010). Additionally, the presence of children in a household in particular is found to exert a positive influence on the choice of MPVs (He et al., 2014; Mabit, 2014; Potoglou, 2008; Spissu et al., 2009; Choo and Mokhtarian, 2004; Mohammadian and Miller, 2002) and SUVs (Paleti et al., 2011; Spissu et al., 2009; Bhat and Sen, 2006; Cao et al., 2006), while a negative impact is reported for small (Antolín et al., 2018) and medium-sized cars (Paleti et al., 2011).

The number of automobiles has a negative impact on large and luxury cars, as well as MPVs. Put differently, multi-vehicle households are less likely to choose these vehicle types, suggesting that they are also more likely to be the households' main vehicle. Other studies find a generally negative impact on large vehicles (Adjemian et al., 2010), MPVs and passenger cars (Liu et al., 2014), and a positive impact on luxury vehicles (Antolín et al., 2018), sport coupés (DeShazo et al., 2017; Liu et al., 2014; Adjemian et al., 2010; Lave and Train, 1979) and pickup trucks (Liu et al., 2014; Adjemian et al., 2010; Potoglou, 2008; Cao et al., 2006) when compared to smaller vehicles, which is partially contrary to our results.[19]

Individuals using car-sharing services are more likely to buy mini, small, and medium-sized vehicles. This finding makes sense, as larger cars, which might be needed only occasionally (e.g. for transporting bulky goods), could then be rented easily from the car-sharing company.

Individuals that do not live in the city center but in suburbs or in rural areas are more likely to choose MPVs and are less likely to choose AFVs. This finding is contrary to the result of Baltas and Saridakis (2013) that MPVs are more likely to be chosen by more urban households, compared to SUVs. The findings from previous research concerning the impact of household location on preferences for all kinds of AFVs is also rather mixed, i.e. both a positive impact (Antolín et al., 2018; Liu, 2014; Egbue and Long, 2012; Musti and Kockelman, 2011; Skippon and Garwood, 2011) as well as a negative impact (Antolín et al., 2018; Plötz et al., 2014; Paleti et al., 2011) of urban location on AFV choice probability is described.

4.4.2.2 Vehicle Characteristics

Utilization: Those who mainly use a vehicle for commuting are significantly less likely to purchase vehicles from the 'others' segment. Thus, we do not find a specifically positive effect of commuting as the main vehicle use on the likelihood of purchasing larger passenger cars or SUVs, in contrast to other literature (Baltas and Saridakis, 2013, Noblet et al., 2006).

Mini, small, medium-sized, and large cars as well as 'others' tend to be chosen less often, when looking for the main household vehicle compared to more massive SUVs. On the other hand, vehicles running on diesel are more likely to be the main vehicle of the household. These

[19] In contrast to our study, in the literature significant impacts are found concerning the different fuel types, e.g. negative effects for NGVs, HEVs, and PHEVs (Antolín et al., 2018; Higgins et al., 2017; Musti and Kockelman, 2011) as well as positive effects for BEVs (Higgins et al., 2017; Helveston et al., 2015; Jensen et al., 2013; Qian and Soopramanien, 2011).

findings are in line with our expectations, as the main household vehicle is driven more frequently and used for a broader number of purposes. Our results are expanding the findings from previous studies which report a greater probability of larger vehicles having a higher rank in the vehicle fleet (Prieto and Cammerer, 2013) and HEVs or gasoline vehicles being the main household vehicles as well as BEVs being the second or an additional car (Jakobsson et al., 2016; Axsen et al., 2016; Link et al., 2012).

The annual mileage has a negative influence on the choice probability of mini and small cars as well as 'others'. This result is in line with the positive effect found in the literature on the choice probability of larger vehicles (Shin et al., 2015; Kuwano et al., 2013; Lave and Train, 1979). On the other hand, annual mileage positively influences the purchase probability of diesel and alternative fuel vehicles in our sample. While the former result corroborates previous findings (Shin et al., 2015; Ziegler, 2012), the latter result is in contrast to the predominant finding in the literature of a negative impact of annual mileage on the choice probability of AFVs (e.g. Higgins et al., 2017; Hoen and Koetse, 2014; Li et al., 2013; Achtnicht et al., 2012).

Purchase: The amount of money car buyers (are willing to) spend for their vehicle has a negative impact on the choice probability of mini, small, medium-sized and large cars, and a positive influence on the choice probability of more exclusive cars, i.e. executive and luxury cars as well as sport coupés when compared to SUVs. Also, diesel and alternative fuel vehicles are more likely to be chosen with greater budget. These results are reflecting the fact that more exclusive and larger vehicles, diesel vehicles, as well as generally all types of AFVs tend to cost more than their gasoline counterpart (ICCT, 2018).[20]

If the vehicle is funded by the employer it is more likely to be diesel-fueled, which was expected, as company vehicles usually are also larger vehicles (large, executive, luxury), and which also is totally in line with vehicle license data in Germany (KBA, 2018b).

If the vehicle was purchased recently, i.e. during the year prior to our survey, individuals were less likely to have chosen an AFV. This result makes sense, as at the time the survey was conducted, the supply of AFVs was still rather limited (early diffusion stage) so that an AFV as newest/next household vehicle for the most part was intended and not already purchased.

If the new vehicle is from a premium OEM, it is also more likely to be a medium-sized, large, executive, or luxury car, while it is less likely to be an MPV or 'other' vehicle. Further, when the vehicle manufacturer is a premium OEM, the choice of an AFV is less likely.

[20] Exactly this higher purchase price of AFVs is one of the main barriers to their adoption consistently found in the literature (e.g. Axsen et al., 2013; Egbue and Long, 2012; Daziano and Chiew, 2012; Graham-Rowe et al. 2012; Lane and Potter, 2007).

Interestingly, in our sample, sport coupés do not seem to significantly differ from SUVs regarding premium manufacturers. Generally, this attribute is not considered in the literature, whereas the influence of specific brands on the purchase probability of the different vehicles is studied occasionally. For instance, Bauer (2015) finds that VW and BMW have a negative effect on AFV purchase attitude in Germany, while Kia has a positive impact. Habibi et al. (2019) observe a positive impact of Ferrari and Bentley and a negative effect of all other brands, with Volvo being the base manufacturer in this Swedish case. Both findings thus roughly point in the same direction as our results, whereas the majority of studies do not show any clear-cut effect regarding premium OEMs (e.g. Ito et al., 2019; Østil et al., 2017; Xu et al., 2015; Bhat et al., 2009; Mannering et al., 2002).

4.5 Discussion and Policy Implications

4.5.1 Discussion of Results

As shown in our study mini, small, and medium-sized vehicles are remarkably similar with regard to the influence of observable factors on their purchase probability – environmental awareness, importance of fuel consumption and fuel costs, importance of size and spaciousness, number of children in the household, usage of carsharing services, main household vehicle, purchase price – but also concerning the impact of unobservable attributes, as is shown by the tree structure of our final model. This means, on the contrary, that smaller vehicles are in many respects very different to larger or more massive vehicles, such as SUVs (our base model). For instance, compared to SUVs mini, small, medium-sized, and large vehicles are less likely to be households' main vehicle and more likely to be chosen by childless households or driven less far throughout the year (annual mileage of mini and small vehicles).

SUVs, however, seem to be more similar to MPVs and 'others' (predominantly utility vehicles/cargo vans) and to also be correlated in unobserved attributes, as again reflected by the nesting structure of our model. A finding also supported by previous studies is that already owning SUVs, MPVs or pickup trucks decreases the likelihood of purchasing a further SUV (Paleti et al., 2011; Eluru et al., 2010). However, although related, MPVs are not perfect substitutes for SUVs, as their target groups are mainly suburban or rural families for whom vehicles' size and spaciousness is particularly important and horsepower as well as uniqueness and rarity is comparably unimportant in purchase decisions, respectively. In other words, SUVs are aiming at a much broader range of consumer segments, especially compared to MPVs but also smaller vehicles. For instance, as documented by Kim et al. (2006), elderly individuals with health problems prefer to purchase SUVs due to their favorable features, such as increased visibility, ease of entry and exit, and comfort, and not primarily because of their spaciousness or off-road capabilities. Moreover, safety is often referred to as an influencing factor for the choice and success of heavier vehicles such as SUVs (e.g. Hoen and Koetse, 2014; Cao et al., 2006), although this finding is not supported by our results. However, safety and reliability can be interpreted as a prerequisite in vehicle choice, independent of vehicle size or fuel type, as both factors seem to be very important in the whole sample.[21]

Unfortunately, this fact could potentially increase reluctance towards the new propulsion technologies, especially fuel cell electric vehicles (FCEVs) and BEVs, as due to their novelty and car buyers' lack of familiarity they are potentially perceived as being more unsafe, unreliable, and risky (e.g. Orlov and Kallbekken et al., 2019; Wang et al., 2018; Krause et al., 2013; Egbue and Long, 2012; Lane and Potter, 2007).

Fortunately, however, several similarities between buyers of specific fuel types and those of specific vehicle types can be found. For instance, smaller vehicles have commonalities with AFVs in two major aspects: those car buyers with a higher environmental attitude and placing greater emphasis on vehicles' fuel consumption and fuel cost are more likely to prefer mini, small, and medium-sized vehicles as well as AFVs. As economic and environmental reasons are found to be the major motivators to purchase an AFV (e.g. Biresselioglou et al., 2018; Li et al., 2017), buyers of small vehicles seem to be the most promising target group for switching to an alternative fuel.

Concerning their impact on CO_2 emissions, buyers of larger vehicles are the second and potentially even more important target group for actions taken by climate policy-makers and vehicle manufacturers to increase the adoption of alternative propulsion technologies. Individuals preferring larger vehicles are comparable to individuals who (intend to) chose an alternative fuel when it comes to the purchase price (SUVs). This is particularly important, as purchase price explains the greatest part of variance in our model and, thus, can be labeled as the most decisive factor in respondents' vehicle choice decisions – a result which is in line with the findings in Biresselioglou et al. (2018). Furthermore, MPVs as potential SUV substitutes and AFVs are less likely to be from a premium OEM, while medium-sized, large, executive, and luxury vehicles are more likely to be from one. Both results indicate that alternatively fueled

[21] Average stated importance of vehicle attributes (standard deviation in parentheses) in descending order: Reliability 4.43 (0.950), safety 4.30 (0.975), fuel consumption and fuel costs 4.22 (0.971), purchase price 4.15 (0.970), driving range on full tank/battery 3.92 (0.967), fuel availability (density of infrastructure) 3.89 (0.958), comfort 3.89 (0.916), motor vehicle tax 3.84 (0.973), size and spaciousness 3.75 (1.004), environmental friendliness 3.59 (1.000), appearance and design 3.56 (1.067), service station density 3.56 (0.987), fuel type 3.52 (1.023), horsepower 3.46 (0.993), image and design 3.01 (std. dev. 1.141), and uniqueness and rarity 2.66 (1.174).

larger vehicles can be successful but currently are receiving little attention from premium manufacturers. Finally, besides diesel cars, AFVs are potentially more likely to be purchased by individuals with higher annual mileage who are not purchasing the smallest vehicle types.

While the simultaneous accomplishment of both goals – adoption of AFVs and move to smaller vehicles – should be the first-best option, especially regarding environmental benefits, crash safety, or parking spaces, it could be prohibitive for individuals who rate size and spaciousness of the vehicle as very important or actually need a large vehicle (e.g. due to household size, i.e. the presence of children or mobility-challenged persons in the household). Thus, the second-best option for reaching the goal of sustainable mobility should be to enforce car buyers' switch from fossil to alternative fuels, when purchasing a large vehicle.

4.5.2 Policy Implications

To accomplish these goals, based on the results of our study and previous findings, first and foremost comparably easy-to-realize policy measures should be introduced, such as information campaigns (including energy labels), trials, or carsharing options for AFVs organized by manufacturers or municipalities, to promote them as environmentally friendly and cost-effective solutions for individual road transport – and to allow individuals to gain practical experience especially with BEVs. Such information campaigns would not only resonate with potential buyers of smaller cars as 'natural' target group of BEVs, but presumably also with buyers of larger vehicles. For instance, Mohamed et al. (2018), Higgins et al. (2017), and Hardman et al. (2016) emphasize that such 'high-end' customers should be targeted as early adopters of electrified vehicles, as they are more likely able and willing to pay the higher purchase prices of AFVs. Furthermore, this consumer segment is susceptible to the potential economic and environmental benefits of electric propulsion, as these large vehicles suffer from higher fuel consumption.[22] Our results also show that 'high-end' SUV buyers put more emphasis on vehicles' uniqueness and rarity in their purchase decisions, indicating that in the near future manufacturers could promote AFVs by using unique and innovative designs.

An information and triability strategy which takes all these aspects into account could lead to behavioral change, as knowledge about and familiarity with AFVs, as well as an increase in the importance of the propulsion technology in vehicle choice decisions, are all found to boost the likelihood of purchasing an AFV (see also e.g. Schlüter and Weyer, 2019; Jensen et al.

[22] In line with this, Teisl et al. (2008) indicate that although environmental information shows little influence on vehicle type choice, it can exert a significant impact on fuel type choice within a specific vehicle segment (e.g. choosing an electric instead of a fossil-fueled SUV).

2013; van Rijnsoever et al., 2009). That is, communication efforts and trials should focus on the main barriers for AFV adoption and aim at allaying the notion of AFVs as being unsafe or unreliable, as well as establishing confidence in recharging infrastructure, driving range, but also superiority regarding environmental impact and total cost of ownership (Haustein and Jensen, 2018). The latter is important, as a considerable amount of households is found to be unaware or unsure with regard to the monetary (Orlov and Kallbekken, 2019) and environmental (Graham-Rowe et al., 2012) savings potentials of energy-efficient vehicles. Moreover, the information should be distributed via a broad variety of media channels to increase its penetration, as the bandwidth of pre-purchase information sources car buyers rely on is diverse[23]. However, particularly peer or neighbor effects (social norm, signaling) should be accounted for, as they are consistently found to play a very important role in the decision-making process[24] (e.g. Bobeth and Matthies, 2018; Jansson et al., 2017b; Barth et al., 2016; Schuitema et al., 2013; Graham-Rowe et al., 2012).

Since vehicle buyers' motivation to adopt AFVs across all vehicle classes has been comparably low until today[25], communication efforts alone could be insufficient and should be accompanied by strong government policy, e.g. financial measures to stop the steady increase in SUV sales or initiate the change to an alternative fuel (Turcksin et al., 2013).[26] For instance, Langbroek et al. (2016) find that use-based incentives are relatively effective in increasing sales of electrified vehicles, as the lower running costs of AFVs are one of the main drivers of their adoption (e.g. Biresselioglu et al., 2018; Li et al., 2017; Barth et al., 2016), which is in line with our findings. That is, increasing the prices of conventional fuels or subsidizing alternative fuels and electricity could boost AFV sales.[27] However, as Dumortier et al. (2015) indicate, consumers underrate the long-term savings of AFVs compared to their up-front costs. Thus, since AFVs have higher purchase prices compared to their fossil-fueled counterparts and

[23] In our sample, potential car buyers' preferred pre-purchase information sources are websites of car manufacturers (62%), (local) car sellers (57%), test reports in car magazines (48%), friends, relatives, colleagues (31%), blogs, web forums (14%), automobile clubs (7%), vehicle conventions (2%), and others (8%).

[24] Regarding the decision on which vehicle to purchase next, 44% of the respondents in our sample state that they decide by themselves, while 51% decide with the partner or family, and 11% are additionally influenced by others (friends or colleagues 5%, experts or sellers 3%, and employers (company cars) 3%).

[25] One reason for this lack of motivation, besides the unfamiliarity with the new propulsion technologies or a lack of environmental awareness especially among buyers of SUVs, is assumed to be the individuals' expectation that BEVs will still technologically improve in the near future, making a present purchase economically more questionable (Egbue and Long, 2012).

[26] A combination of measures seems to be the means of choice, as incentives alone are also found to have little influence on potential adopters of BEVs who are lacking conviction or knowledge with regard to the technology (Egbue and Long, 2012).

[27] While the latter approach presumably is politically easier to implement, the former measure would be more in line with the 'polluter pays' principle, less vulnerable to rebound effects, and also more in line with the current debate regarding the introduction of a national or European CO_2 emissions tax.

purchase price is also found to be the most decisive factor in our study, additional purchase incentives could increase the adoption of AFVs (e.g. Bjerkan et al., 2016).

Finally, as motor vehicle taxes are found to decrease the purchase probability of diesel vehicles, these taxes could be increased to accelerate switching behavior in favor of AFVs, especially for larger vehicle types (as the tax is currently based on fuel type and engine displacement). Additionally, the possibilities to write-off taxes should be reduced for diesel-fueled company cars and instead increased for AFVs, as the dominance of diesel vehicles in fleets in Germany remains unchanged at a very high level of 84% (DAT, 2019).

4.6 Conclusion

Clean air legislations on the European and national level force car manufacturers to either diminish the fuel consumption of their conventionally fueled vehicle fleet through downsizing or to increase the sales figures of AFVs, or both. However, the steadily increasing sales figures of SUVs and unabated dominance of fossil-fueled vehicles indicate that current measures (especially on the side of vehicle manufacturers) are not having the desired effect. It is therefore necessary to investigate what drives German car buyers' preferences for specific vehicle types and fuel types in order to adjust supporting measures accordingly. Our study is based on revealed and stated preferences data, gathered in a nation-wide survey among 1500 respondents conducted in the summer of 2011. It extends previous studies focusing on the German market, by not solely focusing on fuel type choice but rather investigating the joint choice of vehicle types and fuel types, thus accounting for heterogeneity between buyers of different vehicle classes. Two model specifications were used, a standard MNL and an NL, with the results of the latter suggesting that buyers of smaller vehicles and those preferring larger vehicles, e.g. SUVs, as well as buyers preferring gasoline or diesel vehicles compared to those favoring AFVs, differ significantly regarding: socio-demographic, household, and neighborhood characteristics, as well as attitudes, preferences, and vehicle-related attributes. However, our results also indicate that connecting points between these consumer groups do exist, which could be used as starting points to either switch demand from larger vehicles to smaller vehicle types or from fossil fuel vehicles to AFVs – or both.

Based on our results and findings from previous studies, we discuss the prospects of information campaigns, vehicle trials (especially for BEVs) and (financial) policy incentives and conclude that several measures should be combined to increase their effectiveness. This study thus delivers useful information and results for political decision-makers and car manufacturers in order to review their strategic decisions on how the acceptance of and the demand for AFVs and non-SUVs could be raised effectively in the near future. However, at the same time, attention should be paid to the potential adverse effects of these different information and policy measures on vehicle design[28] as well as the usage frequency of vehicles and other means of transportation (possibility of a rebound effect if usage becomes less expensive or is labeled as environmentally harmless, leading to moral licensing).

Over time, the increase of AFV alternatives available in the market will exert a positive impact on AFV diffusion, as it becomes more likely that vehicle buyers will find a specific alternatively fueled vehicle that fits their needs (Hoen and Koetse, 2014; Mabit, 2014; Liu et al., 2014), so that the supporting measures could be reduced.

Our results are informative for other countries and vehicle markets as well, as we compare our results in great detail with the existing international literature, and highlight the respective similarities and differences in results. Furthermore, as stated in the introduction, the problems of increasing SUV sales and a slow uptake of AFVs exist throughout the entire EU and beyond.

However, our study also has its limitations. First and foremost, our data was gathered several years back, so that preferences for vehicle types and especially fuel types might have evolved. For instance, in the past few years the so-called 'Dieselgate' has negatively influenced preferences for this fuel type not only in Germany. At the same time SUV sales have taken off, and BEVs have seen many developments: increase in vehicle supply (more available variants) and demand, technological progress (battery reliability, driving range), increase in charging infrastructure, monetary and non-monetary incentives, and most importantly, social change (attitudes, knowledge and familiarity regarding BEVs through own experience, neighbor effects or media coverage). However, even today sales figures of AFVs in general and BEVs in particular are still rather low, as until now diesel vehicles have been predominantly substituted by gasoline vehicles and not AFVs, so that from that point of view, our data are still remarkably representative. This may also be due to the fact that our sample contains many respondents who intended to buy an AFV or actually had bought one and, thus, were ahead of their time. Nonetheless, a follow-up study with more recent data would be desirable.

Second, a separation of the different AFVs in subsequent research should be aimed at, which would allow for specific findings for BEVs, as BEVs have incommensurable characteristics compared to the other (alternative) fuel types.

[28] For instance, under the current legislation, electrically driven kilometers are counted as emission-free in order to support the diffusion of BEVs. However, this 'greenwashing' especially of (plug-in) hybrid SUVs has led to a detrimental trend towards even larger, heavier, more powerful, and more expensive vehicles in this segment.

Finally, in our study we focused on buyers of new vehicles only. Investigating the specifics of the used vehicles market, particularly with regard to BEVs and the importance and uncertainty of battery lifetime, seems to be a fruitful avenue for future research as well.

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APPENDICES

CONTENTS

A. Appendix of Chapter 1

Appendix A comprises two parts. Appendix A.1 summarizes each of the articles referenced in the review of the scientific literature on consumers' vehicle preferences in Section 1.4.1.2, while Appendix A.2 shows the questionnaire on which this dissertation is based (see also Section 1.4.2).

A.1 Literature Review

Appendix A.1 contains a comprehensive review of the scientific literature on private households' disaggregate vehicle and/or fuel type choice decisions – 159 studies (not counting the three articles contained in this thesis), published between 1979 and 2019 – which was updated continuously in the course of writing this dissertation. It is based on a systematic search of existing research papers which predominantly focused on articles published in peer-reviewed journals – but also included book chapters, working papers, dissertations, and scientific reports. For this purpose, various databases and search engines were used – such as Sciencedirect, JSTOR, EBSCO, and Goolge Scholar – and the search was focused on varyous combinations of the following keywords: vehicle, fuel, type, car, automobile, alternative, green, clean, electric, discrete, choice, decision, purchase, buy, adoption, intention, acceptance, demand, household, consumer, attitude, preference, willingness-to-pay, attribute. The search did not exclude specific vehicle or fuel types. This gave a considerable amount of studies, of which those with titles or abstracts not fitting the research objective were excluded. Inclusion criteria were the relevance of the articles to the research questions of this doctoral thesis (i.e. reasons for specific vehicle and fuel type choice decisions of individuals or private households) and the use of either real market data or hypothetical data from choice experiments or consumer surveys. Thus, only studies using empirical choice data were included. Research only explaining the reasons for owning a specific number of household vehicles was not considered (vehicle ownership models). In the selection of studies, greater emphasis was placed on recently published research to cope with the vast amount of search results, without restricting the review regarding the year of publication to also consider the most influential papers from the 20th century.

Table A.1: Study characteristics

Study	Dep. var.	Data	Data sources	Year of survey	Sample location	Sample size[2]	Econometric model
Fuel type choice							
Abdoolakhan (2010)	FT	SP	Survey with DCE (Internet)	2007	Perth, Australia	231	NL, LCM
Achtnicht (2012)	FT	SP	Survey with DCE (CAPI)	2007-2008	Germany	598	MNL, ML
Achtnicht et al. (2012)	FT	SP	Survey with DCE (CAPI)	2007-2008	Germany	598	MNL
Aguilar et al. (2015)	FT	SP	Survey with DCE (Internet and mail)	2011	US	2304	ML
Axsen et al. (2013)	FT	SP	Survey with DCE (Personal interview)	2011	Thornton, UK	21	MNL
Axsen et al. (2015)	FT	SP	Survey with DCE (Internet)	2013	Canada	1754	LCM
Axsen et al. (2016)	FT	SP	Survey with DCE (Internet)	2013	Canada	1754	MNL, LCM
Bahamonde-Birke and Hanappi (2016)	FT	SP	Survey with DCE (Internet)	2013	Austria	787	MNL, HC
Batley and Toner (2003)	FT	SP	Survey with DCE (Mail)	2002	Leeds and Harrogate, UK	~ 302	MNL, NL
Batley et al. (2004)	FT	SP	Survey with DCE (Mail)	2001	Leeds, UK	~ 113	MNL, ML
Bauer (2015)	FT	SP	Survey with DCE (Internet)	2012-2013	Bavaria, Baden-Wuerttemberg, Germany	423	ML[3]
Beck et al. (2011)	FT	SP	Survey with DCE (WAPI)	2009	Sydney, Australia	793	ML
Beck et al. (2013)	FT	SP	Survey with DCE (WAPI)	2009	Sydney, Australia	793	LCM
Beck et al. (2017)	FT	SP	Survey with DCE (Internet)	2011	Sydney, Australia	204	MNL, hybrid MNL
Beggs et al. (1981)	FT	SP	Survey with DCE (Personal interview)	N.A.	US, 9 cities with warm climate	193	ROL
Bočkarjova et al. (2013)	FT	SP	Survey with DCE (Internet)	2012	Netherlands	2977	NL
Bunch et al. (1993)	FT	SP	Survey with DCE (Mail)	1991	South Coast Air Basin, California, US	692	NL
Byun et al. (2018)	FT	SP	Survey with DCE (Internet)	2016	South Korea	615	ML
Calfee (1985)	FT	SP	Survey with DCE (Mail)	N.A.	Berkeley, US	51	MNL
Caulfield et al. (2010)	FT	SP	Survey with DCE (Mail)	2008	Ireland	168	MNL, NL
Cherchi (2017)	FT	SP	Survey with DCE (Internet)	2014-2015	Denmark	2363	HC
Dagsvik and Liu (2009)	FT	SP	Survey with DCE (Personal interview)	2001	Shanghai, China	100	ROL, mixed ROL
Dagsvik et al. (2002)	FT	SP	Survey with DCE (Mail)	N.A.	Norway	642	ML, ROL
Daziano (2015)	FT	SP	Survey with DCE (Mail and phone)	2002-2003	Canada, cities >250,000 population	866	MNP[3]
Daziano and Achtnicht (2014)	FT	SP	Survey with DCE (CAPI)	2007-2008	Germany	598	MNP
Daziano and Bolduc (2013)	FT	SP	Survey with DCE (Mail and phone)	2002-2003	Canada, cities >250,000 population	866	HC
Dimitropoulos (2014)	FT	SP	Survey with DCE (Internet)	2012-2013	Netherlands	1501	LCM, hybrid LCM
Eggers and Eggers (2011)	FT	SP	Survey with DCE (Internet)	2008	Germany	242	ML[3]
Ewing and Sarigöllü (1998)	FT	SP	Survey with DCE (Mail)	1994	Montreal, Canada	881	MNL

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Table A.1 *(continued)*

Study	Dep. var.	Data	Data sources	Year of survey	Sample location	Sample size[2]	Econometric model
Ewing and Sarigöllü (2000)	FT	SP	Survey with DCE (Mail)	1994	Montreal, Canada	881	MNL
Ferguson et al. (2018)	FT	SP	Survey with DCE (Internet)	2015	Canada	17,953	MNL, LCM
Glerum et al. (2014)	FT	SP	Survey with DCE (Internet)	2011	Switzerland	593	HC
Golob et al. (1993)	FT	SP	Survey with DCE (Mail)	1991	South Coast Air Basin, California, US	173	MNL
Hackbarth and Madlener (2013)	FT	SP	Survey with DCE (Internet)	2011	Germany	711	MNL, ML
Hackbarth and Madlener (2016)	FT	SP	Survey with DCE (Internet)	2011	Germany	711	MNL, LCM
Helveston et al. (2015)	FT	SP	Survey with DCE (CAPI; CAPI and internet)	2012-2013	Shanghai, Shenzhen, Chengdu, China; US	448; 384	MNL, ML
Hensher et al. (2011)	FT	SP	Survey with DCE (WAPI)	2009	Sydney, Australia	793	Generalized ML
Hensher et al. (2013)	FT	SP	Survey with DCE (WAPI)	2009	Sydney, Australia	793	MNL
Hensher et al. (2017)	FT	SP	Survey with DCE (WAPI)	2009	Sydney, Australia	235	ML
Hidrue et al. (2011)	FT	SP	Survey with DCE (Internet)	2009	US	3029	MNL, LCM
Hoen and Koetse (2014)	FT	SP	Survey with DCE (Internet)	2011	Netherlands	1802	MNL, ML
Horne et al. (2005)	FT	SP	Survey with DCE (Mail and phone)	2002-2003	Canada, cities >250,000 population	866	MNL
Ida et al. (2014)	FT	SP	Survey with DCE (Internet)	2011	Japan	1343	ML
Jacobs et al. (2016)	FT	SP	Survey with DCE (CAPI)	2013-2015	Germany	167	MNL
Jansson et al. (2017a)	FT	RP	Survey (Internet and mail)	2014	Sweden	1192	BNL
Jansson et al. (2017b)	FT	RP	Vehicle register	2008	Sweden	5610	BNL
Javid and Nejat (2017)	FT	RP	California Household Travel Survey; EIA gasoline price; NREL electricity price; NREL Alternative Fuels Data Center; Source Guides Renewable Energy Directory; Census	2012-2013	California, US	16,348	MNL, HC
Jensen et al. (2013)	FT	SP	Survey with DCE (Internet)	2010	Denmark	369	HC
Kim et al. (2014)	FT	SP	Survey with DCE (Internet)	2012	Netherlands	726	HC
Kim et al. (2016)	FT	SP	Survey with DCE (Internet)	2012	Netherlands	726	HC
Knockaert (2010)	FT	SP	Survey with DCE (CATI and mail)	2004	Flanders, Belgium	209	MNL, NL, ML
Krause et al. (2016)	FT	SP	Survey with DCE (Internet)	2011	US, 23 large cities from 14 states	961	MNL
Langbroek et al. (2016)	FT	SP	Survey with DCE (Internet)	2014	Stockholm, Sweden	269	ML
Lebeau et al. (2012)	FT	SP	Survey with DCE (Internet)	2011	Flanders, Belgium	1197	ML[3]
Li et al. (2013)	FT	SP	Survey (Internet)	2009	US	1516	BNP
Link et al. (2012)	FT	SP	Survey with DCE (Personal interview and phone)	2011	Eastern Austria	220	MNL
Mabit and Fosgerau (2011)	FT	SP	Survey with DCE (Internet)	2007	Denmark	2146	ML
Mabit et al. (2015)	FT	SP	Survey with DCE (Internet)	2007-2008	Denmark	2093	MNL, HC
Mannberg et al. (2014)	FT	RP	Vehicle register	2004-2008	Stockholm, Gothenburg, Malmö, Sweden	945,742	MNL, panel data BNP
Marra et al. (2012)	FT	SP	Survey with DCE (Internet)	2009	US	1668	ML

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Table A.1 *(continued)*

Study	Dep. var.	Data	Data sources	Year of survey	Sample location	Sample size[2]	Econometric model
Mau et al. (2008)	FT	SP	Survey with DCE (Internet)	N.A.	Canada, cities >250,000 population	1935	MNL
Nixon and Saphores (2011)	FT	SP	Survey with DCE (Internet)	2010	US	489	ROL, mixed ROL
Østil et al. (2017)	FT	RP	Vehicle register	1996-2011	Norway	1,617,303	NL
Parsons et al. (2014)	FT	SP	Survey with DCE (Internet)	2009	US	3029	MNL, LCM
Qian and Soopramanien (2011)	FT	SP	Survey with DCE (Internet)	N.A.	China	527	MNL, NL
Qian and Soopramanien (2015)	FT	SP	Survey with DCE (Internet)	2009	China	527	MNL, NL
Ramjerdi and Rand (2000)	FT	SP	Survey with DCE (Mail and phone)	1994	Norway	1222	MNL, NL, ROL
Rasouli and Timmermans (2016)	FT	SP	Survey with DCE (Internet)	2012	Netherlands	726	ML
Rouwendal and de Vries (1999)	FT[2]	RP	Dutch private car panel; Shell; Dutch Consumer Union	1991	Netherlands	2322	NL
Rudolph (2016)	FT	SP	Survey with DCE (Internet)	2013	Hamburg Metropolitan Area, Germany	875	ML
Sandór and Train (2004)	FT	SP	Survey with DCE (Mail and phone)	N.A.	California, US	500	ML
Sentürk et al. (2011)	FT	RP	Survey (Internet)	2009	Turkey	1974	MNL
Shin et al. (2012)	FT	SP	Survey with DCE (Personal interview)	2009	Seoul, South Korea	250	Mixed MDCEV
Smith et al. (2017)	FT	SP	Survey with DCE (Mail and internet)	N.A.	Perth, Australia	440	ML
Tanaka et al. (2014)	FT	SP	Survey with DCE (Mail)	2012	California, Michigan, New York, Texas, US; Japan	4202; 4000	ML
Train and Sonnier (2005)	FT	SP	Survey with DCE (Mail and phone)	N.A.	California, US	500	ML[3]
Valeri and Cherchi (2016)	FT	SP	Survey with DCE (Personal interview)	2013	Trieste, Bologna, Pesaro, Italy	121	ML, HC, structural equation model
Valeri and Danielis (2015)	FT	SP	Survey with DCE (Personal interview)	2013	Trieste, Bologna, Pesaro, Italy	121	MNL, ML
van Meerkerk et al. (2014)	FT	RP	Survey; Vehicle register; Statistics Netherlands; Dutch Tax and Customs Administration	2011	Netherlands	1790	MNL
Wang et al. (2017)	FT	SP	Survey with DCE (Internet)	N.A.	China	247	MNL, ML
Whitehead et al. (2014)	FT	RP	Sweden Central Bureau of Statistics	2008	Stockholm County, Sweden	28,502	MNL
Wolbertus et al. (2018)	FT	SP	Survey with DCE (Internet and personal interview)	N.A.	Rotterdam, The Hague, Leiden, Delft, The Netherlands	149	ML
Ziegler (2012)	FT	SP	Survey with DCE (CAPI)	2007-2008	Germany	598	MNP
Zito and Salerno (2004)	FT	SP	Survey with DCE (Mail)	N.A.	Palermo, Italy	469	MNL
Fuel and vehicle type choice							
Adler et al. (2003)	FT + VT	SP	Survey with DCE (Internet, mail, and phone)	2002	California, US	2182	NL
Ahn et al. (2008)	FT + VT	SP	Survey with DCE (Personal interview)	2005	Seoul, South Korea	280	MDCEV
Antolín et al. (2018)	FT + VT	RP	Vehicle register	2014	France	18,804	MNL, cross NL
Axsen et al. (2009)	FT + VT	SP + RP	Survey with DCE (Internet)	2006	Canada; California, US	535; 408	MNL, NL
Brownstone and Train (1999)	FT + VT	SP	Survey with DCE (CATI and mail)	1993	California, US	4654	MNL, ML, MNP

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Table A.1 *(continued)*

Study	Dep. var.	Data	Data sources	Year of survey	Sample location	Sample size[2]	Econometric model
Brownstone et al. (2000)	FT + VT	SP + RP	Survey with DCE (CATI and mail)	1993	California, US	4656	MNL, ML
Cirillo et al. (2017)	FT + VT	SP	Survey with DCE (Internet)	2014	Maryland, US	456	MNL, ML
Costa et al. (2019)	FT + VT	SP	Survey with DCE (Internet)	2016	Italy	278	MNL
Daziano (2013)	FT + VT	SP	Survey with DCE (Mail and phone)	N.A.	California, US	500	MNL, ML[3]
de Jong (1996)	FT + VT	RP	Survey (Mail); Consumer price indices	1992-1993	Netherlands	3802	MNL
DeShazo et al. (2017)	FT + VT	SP	Survey with DCE (Internet)	N.A.	California, US	1261	MNL
Dumortier et al. (2015)	FT + VT	SP	Survey (Internet)	2013	32 cities, US	2759	ROL
Habibi et al. (2019)	FT + VT	RP	Vehicle register; Ynnor vehicle dataset	2006-2007	Sweden	216,119	MNL, NL
Hackbarth and Madlener (2018)	FT + VT	SP + RP	Survey (Internet)	2011	Germany	1500	MNL, NL
Hahn et al. (2018)	FT + VT	SP	Survey with DCE (N.A.)	2015	Seoul, South Korea	758	MNL, NL, ML
He et al. (2012)	FT + VT[1]	RP	NHTS	2007-2009	US	23,998	NL
He et al. (2014)	FT + VT	RP	NHTS	2009	California, US	13,802	MNL
Hensher and Greene (2006)	FT + VT	SP + RP	Survey with DCE (Mail and personal interview)	1994	Sydney, Australia	~ 275	NL, ML
Hess et al. (2006)	FT + VT	SP	Survey with DCE (Mail and phone)	N.A.	California, US	500	ML
Hess et al. (2012)	FT + VT	SP	Survey with DCE (Internet and mail)	2008-2009	California, US	944	MNL, NL, ML, cross NL
Higgins et al. (2017)	FT + VT	SP	Survey with DCE (Internet)	2015	Canada	15,392	MNP
Ito et al. (2013)	FT + VT	SP	Survey with DCE (Internet)	2010	Japan	1531	MNL, NL
Ito et al. (2019)	FT + VT	SP	Survey with DCE (Internet)	2011	Japan	2408	ML
Jäggi et al. (2013)	FT + VT[1]	SP	Survey with DCE (CAPI)	2009	Switzerland	409	MDCEV
Kavalec (1999)	FT + VT	SP	Survey with DCE (CATI and mail)	1993	California, US	4552	ML
Lee and Cho (2009)	FT + VT	SP	Survey with DCE (Personal interview)	2003	Seoul, South Korea	492	ROL
Liu (2014)	FT + VT	RP	NHTS	2008-2009	US	7540	ML
Liu and Cirillo (2018)	FT + VT	SP	Survey with DCE (Internet)	2014	Maryland, US	456	MNL, dynamic discrete choice model
Mabit (2014)	FT + VT	RP	Vehicle register; Danish Automobile Association	2005-2008	Denmark	15,195	ML
Maness and Cirillo (2012)	FT + VT	SP	Survey with DCE (Internet)	2010	Maryland, US	34-83	MNL, ML
Musti and Kockelman (2011)	FT + VT	SP + RP	Survey (Internet); NHTS; EPA Fuel Economy Guide	2009	US	596	MNL
Paleti et al. (2011)	FT + VT	SP + RP	California Vehicle Survey	2008-2009	California, US	915	Copula-based MDCGEV
Potoglou and Kanaroglou (2007)	FT + VT	SP	Survey with DCE (Internet)	2005	Hamilton, Canada	482	NL
Shiau et al. (2009)	FT + VT	RP	Ward's Automotive Yearbook	2007	US	N.A.	ML

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Table A.1 *(continued)*

Study	Dep. var.	Data	Data sources	Year of survey	Sample location	Sample size[2]	Econometric model
Shin et al. (2015)	FT + VT	SP	Survey with DCE	2012	Seoul, Busan, Daegu, Inchon, Gwangju, Daejeon, South Korea	633	MDCP
Shin et al. (2018)	FT + VT[1]	SP	Survey with DCE (Personal interview)	2012	South Korea	639	Mixed MDCEV
Soto et al. (2018)	FT + VT	SP	Survey with DCE (Personal interview)	2013	Bogotá, Medellin, Cali, Baranquilla, Bucaramanga, Colombia	1065	MNL, HC
Tompkins et al. (1998)	FT + VT	SP	Survey with DCE (CATI and mail)	1995-1996	US	1149	MNL
Train and Weeks (2005)	FT + VT	SP	Survey with DCE (Mail and phone)	N.A.	California, US	500	ML[3], generalized ML
Xu et al. (2015)	FT + VT	RP	Survey (Internet)	2009, 2011, 2012	Japan	N.A.	MNP[3]
Vehicle type choice							
Adjemian et al. (2010)	VT	RP	BATS	2000-2001	San Francisco Bay Area, US	1157	Spatial BNL
Baltas and Saridakis (2013)	VT	SP	Survey	N.A.	N.A.	1357	MNL
Beggs and Cardell (1980)	VT	RP	Survey; Wharton Auto Characteristics Database; Federal Highway Administration	1977	Baltimore, US	326	MNL
Berkovec (1985)	VT	RP	National Transportation Survey; Vehicle register; Cambridge Systematics Inc. auto attributes file	1978	US	1048	NL
Berkovec and Rust (1985)	VT	RP	Survey (Personal interview); Cambridge Systematics Inc. auto attributes file	1978	US	237	NL
Bhat and Sen (2006)	VT[1]	RP	BATS; EPA Fuel Economy Guide	2000	San Francisco Bay Area, US	3500	MDCEV, mixed MDCEV
Bhat et al. (2009)	VT[1]	RP	BATS; Consumer Guide; EPA Fuel Economy Guide; GIS; Census	2000	San Francisco Bay Area, US	8107	Joint MDCEV-MNL
Biswas et al. (2014)	VT	SP + RP	Survey (Personal interview)	2014	West Bengal, India	100	MNL
Cao et al. (2006)	VT	RP	Survey (Mail)	2003	Northern California, US	1387	NL
Chiou et al. (2009)	VT[1]	RP	Survey (Mail)	2007	Taiwan	1419	MNL, NL
Choo and Mokhtarian (2004)	VT	RP	Survey (Mail)	1998	San Francisco Bay Area, US	1571	MNL
Eluru et al. (2010)	VT[1]	RP	BATS	2000	San Francisco Bay Area, US	5082	Copula-based MDCGEV
Hensher and Le Plastrier (1985)	VT	RP	Survey (Personal interview)	1980	Sydney, Australia	400	NL
Hocherman et al. (1983)	VT	RP	Survey	1979	Haifa, Israel	1300	NL
Kitamura et al. (1999)	VT	SP + RP	Survey (CATI and mail)	1993	South Coast Air Basin, California, US	1439	MNL
Kockelman and Zhao (2000)	VT[1]	RP	NPTS	1995-1996	US	30,949-32,596	MNL
Koo et al. (2012)	VT[1]	RP	TEMEP Household ICT/Energy Survey	2006-2008	Seoul, South Korea	154	ML, MDCEV
Kuwano et al. (2013)	VT[1]	RP	Survey	2006	Chugoku, Japan	500	Paired combination logit model, copula-based multivariate survival model

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Table A.1 *(continued)*

Study	Dep. var.	Data	Data sources	Year of survey	Sample location	Sample size[2]	Econometric model
Lave and Train (1979)	VT	RP	Survey (Personal interview); Automotive News Market Data Book	1976	Atlanta, Buffalo, Chicago, Denver, Indianapolis, Los Angeles, New Orleans, US	541	MNL
Liu et al. (2014)	VT[1]	RP	NHTS	2008-2009	District of Columbia, Maryland, Virginia, US	1420	MNP, MDCP
Mannering and Mahmassani (1985)	VT	RP	Household Transportation Panel; Vehicle attribute dataset	1979-1980	US	220	MNL
Mannering and Winston (1985)	VT	RP	National Interim Energy Consumption Survey; Household Transportation Panel	1978-1980	US	3842	MNL
Mannering and Winston (1991)	VT	RP	Survey; Automotive News Market Data Book	1989	US	488	NL
Mannering et al. (2002)	VT	RP	Survey; Automotive News Market Data Book; Consumer Reports; Edmunds car prices and reviews	1993-1995	US	654	NL
Manski and Sherman (1980)	VT	RP	Survey; Automotive News Almanac; Consumer Union Reports; Red Books; New vehicle list prices database	1976	US	875	MNL
Martin (2009)	VT	RP	EIA; Consumer Reports; Yahoo Autos; Automotive News; California Energy Commission; Chicago Metropolitan Agency for Planning	2007, 2009	California, US; Chicago, US	4110; 14,000	MNL
McCarthy (1996)	VT	RP	Survey; Automotive New Data Book; Car Book; Oil and Gas Journal; Census	1989	US	1564	MNL
McCarthy and Tay (1998)	VT	RP	Survey; Automotive New Data Book; Car Book; Oil and Gas Journal; Census	1989	US	1564	NL
Mohammadian and Miller (2002, 2003)	VT	RP	TACOS; EPA Fuel Economy Guide; Canadian Red Book	1998	Greater Toronto Area, Canada	597	NL
Noblet et al. (2006)	VT	SP	Survey with DCE (Mail)	2004-2005	Maine, US	1315	NL
Potoglou (2008)	VT	RP	Survey (Internet)	2005	Hamilton, Canada	642	MNL, ML
Prieto and Caemmerer (2013)	VT	RP	National Institute of Statistics and Economic Studies	N.A.	France	1968	MNL
Spissu et al. (2009)	VT[1]	RP	BATS; Consumer Guide; EPA Fuel Economy Guide; GIS; Census	2000	San Francisco Bay Area, US	~ 3770	Copula-based MDCGEV
Train (1986)	VT[1]	RP	NPTS; Consumer Reports; Automotive News Almanac; Red Book; Used Truck Byers Guide; EPA Fuel Economy Guide; Oil and Gas Journal; National Urban Mass Transit Statistic	1978	US	515	MNL
Train and Winston (2007)	VT	RP	Survey; Consumer Reports; Automotive News Market Data Book; Ward's Automotive Yearbook	2000	US	458	ML
Vekeman et al. (2004)	VT[1]	RP	Survey (Mail and phone); Guide de l'Auto; Natural Resources Canada Fuel Consumption Guide	1996-1997	Quebec, Canada	7225	MNL, ML
West (2007)	VT	RP	CES; EIA Petroleum Marketing Monthly	2001	US	4940	MNL

Notes: 1 = (average) annual or daily mileage; 2 = used in econometric analysis; 3 = (hierarchical) Bayesian estimation; FT = fuel type; VT = vehicle type; SP = stated preferences; RP = revealed preferences; DCE = discrete choice experiment; CATI = computer assisted telephone interview; CAPI = computer assisted personal interview; WAPI = web assisted personal interview; BATS = San Francisco Bay Area Travel Survey; NHTS = US National Household Travel Survey; CES = US Consumer Expenditure Survey; NPTS = US National Personal Transportation Survey; TACOS = Toronto Area Car Ownership Study; EPA = US Environmental Protection Agency; EIA = US Energy Information Administration; GIS = geographical information system; MNL = multinomial logit model; (C)NL = (cross) nested logit model; ML = mixed logit model; (M)ROL = (mixed) rank-ordered logit model; MNP = multinomial probit model; (M)MDCEV = (mixed) multiple discrete-continuous extreme value model; MDCGEV = joint multiple discrete-continuous generalized extreme value model; MDCP = multiple discrete–continuous probit model; BMOPT = Bayesian multivariate ordered probit and tobit model; LCM = latent class model; HC = hybrid choice model; BNP = binomial probit model; BNL = binomial logit model.

Table A.2: Fuel types

Study	CFV	NGV	HEV	BEV	FCEV	AFV	BV	PHEV	Others
Fuel type choice									
Abdoolakhan (2010)	✓[2]	✓[3]	✓[4]				✓[5]		
Achtnicht (2012)	✓[2]	✓	✓	✓	✓		✓		
Achtnicht et al. (2012)	✓[2]	✓	✓	✓	✓		✓		
Aguilar et al. (2015)	✓						✓[11]		
Axsen et al. (2013)	✓			✓					
Axsen et al. (2015)	✓		✓	✓				✓	
Axsen et al. (2016)	✓		✓	✓				✓	
Bahamonde-Birke and Hanappi (2016)	✓		✓	✓				✓	
Batley and Toner (2003)	✓					✓[7]			
Batley et al. (2004)	✓					✓			
Bauer (2015)	✓[2]	✓	✓	✓					
Beck et al. (2011)	✓[2]		✓						
Beck et al. (2013)	✓[2]		✓						
Beck et al. (2017)	✓[2]		✓	✓				✓	
Beggs et al. (1981)	✓			✓					
Bočkarjova et al. (2013)	✓		✓	✓					
Bunch et al. (1993)	✓			✓		✓			
Byun et al. (2018)	✓[2]			✓	✓				
Calfee (1985)	✓			✓					
Caulfield et al. (2010)	✓		✓			✓			
Cherchi (2017)	✓			✓					
Dagsvik and Liu (2009)	✓					✓			
Dagsvik et al. (2002)	✓	✓	✓	✓					
Daziano (2015)	✓		✓		✓	✓			
Daziano and Achtnicht (2014)	✓[2]	✓	✓	✓	✓		✓		
Daziano and Bolduc (2013)	✓	✓	✓		✓				
Dimitropoulos (2014)	✓			✓[10]		✓		✓	
Eggers and Eggers (2011)	✓		✓	✓				✓	
Ewing and Sarigöllü (1998)	✓			✓		✓			
Ewing and Sarigöllü (2000)	✓			✓		✓			
Ferguson et al. (2018)	✓		✓	✓				✓	
Glerum et al. (2014)	✓			✓					
Golob et al. (1993)	✓			✓		✓			
Hackbarth and Madlener (2013)	✓	✓	✓	✓	✓		✓	✓	
Hackbarth and Madlener (2016)	✓	✓	✓	✓	✓		✓	✓	
Helveston et al. (2015)	✓		✓	✓[9]				✓[9]	
Hensher et al. (2011)	✓[2]		✓						
Hensher et al. (2013)	✓[2]		✓						
Hensher et al. (2017)	✓[2]		✓						
Hidrue et al. (2011)	✓			✓					
Hoen and Koetse (2014)	✓[2]	✓	✓	✓	✓		✓	✓	
Horne et al. (2005)	✓	✓	✓		✓				
Ida et al. (2014)	✓		✓	✓				✓	
Jacobs et al. (2016)	✓			✓				✓	
Jansson et al. (2017a)	✓						✓		HEV/PHEV/BEV
Jansson et al. (2017b)	✓					✓			
Javid and Nejat (2017)	✓								BEV/PHEV
Jensen et al. (2013)	✓			✓					
Kim et al. (2014)				✓					
Kim et al. (2016)				✓					
Knockaert (2010)	✓[2]	✓		✓	✓	✓			
Krause et al. (2016)	✓		✓	✓				✓	
Langbroek et al. (2016)	✓			✓					
Lebeau et al. (2012)									
Li et al. (2013)			✓				✓		
Link et al. (2012)	✓		✓	✓					
Mabit and Fosgerau (2011)	✓		✓	✓	✓		✓		
Mabit et al. (2015)	✓		✓	✓			✓		
Mannberg et al. (2014)							✓		Others
Marra et al. (2012)	✓						✓[11]		
Mau et al. (2008)	✓		✓		✓				
Nixon and Saphores (2011)	✓	✓	✓	✓	✓				
Østil et al. (2017)	✓[2]		✓	✓					
Parsons et al. (2014)	✓			✓					
Qian and Soopramanien (2011)	✓		✓	✓					
Qian and Soopramanien (2015)	✓		✓	v					

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Table A.2 *(continued)*

Study	CFV	NGV	HEV	BEV	FCEV	AFV	BV	PHEV	Others
Ramjerdi and Rand (2000)	✓			✓		✓			
Rasouli and Timmermans (2016)				✓					
Rouwendal and de Vries (1999)	✓[2]	✓							
Rudolph (2016)	✓			✓	✓			✓	
Sandór and Train (2004)	✓		✓	✓					
Sentürk et al. (2011)	✓[2]	✓	✓						
Shin et al. (2012)	✓[2]		✓	✓					
Smith et al. (2017)	✓[2]			✓				✓	
Tanaka et al. (2014)	✓[1]			✓				✓	
Train and Sonnier (2005)	✓		✓	✓					
Valeri and Cherchi (2016)	✓[2]	✓[6]	✓	✓[8]					
Valeri and Danielis (2015)	✓[2]	✓[6]	✓	✓[8]					
van Meerkerk et al. (2014)	✓[2]	✓							
Wang et al. (2017)	✓			✓[9]					
Whitehead et al. (2014)	✓[8]			✓			✓		
Wolbertus et al. (2018)	✓			✓				✓	
Ziegler (2012)	✓[2]	✓	✓	✓	✓		✓		
Zito and Salerno (2004)	✓			✓					
Fuel and vehicle type choice									
Adler et al. (2003)	✓[2]		✓						
Ahn et al. (2008)	✓[2]	✓[6]	✓						
Antolín et al. (2018)	✓[2]		✓[6]	✓[6]					
Axsen et al. (2009)	✓		✓						
Brownstone and Train (1999)	✓	✓		✓			✓		
Brownstone et al. (2000)	✓	✓		✓			✓		
Cirillo et al. (2017)	✓		✓	✓					
Costa et al. (2019)	✓[2]								
Daziano (2013)	✓		✓	✓					
de Jong (1996)	✓[2]								
DeShazo et al. (2017)	✓[1]			✓				✓	
Dumortier et al. (2015)	✓		✓	✓				✓	
Habibi et al. (2019)	✓[2]	✓	✓			✓	✓		Clean car
Hackbarth and Madlener (2018)	✓[2]					✓			
Hahn et al. (2018)	✓		✓	✓				✓	
He et al. (2012)	✓		✓						
He et al. (2014)	✓		✓						
Hensher and Greene (2006)	✓	✓		✓					
Hess et al. (2006)	✓		✓	✓					
Hess et al. (2012)	✓[2]	✓	✓	✓			✓	✓	
Higgins et al. (2017)	✓		✓	✓				✓	
Ito et al. (2013)	✓		✓	✓	✓				
Ito et al. (2019)	✓		✓	✓[10]					
Jäggi et al. (2013)	✓[2]					✓			
Kavalec (1999)	✓	✓		✓			✓		
Lee and Cho (2009)	✓[2]								
Liu (2014)	✓		✓						
Liu and Cirillo (2018)	✓		✓	✓					
Mabit (2014)	✓[2]								
Maness and Cirillo (2012)	✓[2]		✓	✓		✓			
Musti and Kockelman (2011)	✓		✓					✓	Smart car
Paleti et al. (2011)	✓[2]	✓	✓	✓			✓	✓	
Potoglou and Kanaroglou (2007)	✓		✓			✓			
Shiau et al. (2009)	✓		✓						
Shin et al. (2015)	✓[2]		✓	✓					
Shin et al. (2018)	✓[2]		✓	✓					
Soto et al. (2018)	✓[2]	✓	✓	✓					
Tompkins et al. (1998)	✓	✓		✓			✓		
Train and Weeks (2005)	✓		✓	✓					
Xu et al. (2015)	✓[2]		✓	✓					

Notes: 1 = includes HEVs; 2 = two alternatives: gasoline and diesel; 3 = two alternatives: dedicated and multiple-fuel; 4 = three alternatives: petrol, LPG, ethanol; 5 = two alternatives: ethanol and bio-diesel; 6 = two alternatives: LPG and CNG; 7 = two alternatives: near-term and future; 8 = three alternatives: CFV, low CO_2 gasoline, and low CO_2 diesel; 9 = three alternatives depending on full-electric range, 10 = two alternatives: BEV with fixed battery and BEV with swappable battery; 11 = three alternatives: E10, E20, E85; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; AFV = alternative fuel vehicle; BV = biofuel vehicle; PHEV = plug-in hybrid electric vehicle.

Table A.3: Vehicle types

Study	Mini	Small	Medium	Large	Executive	Luxury	Sport coupé	MPV	SUV	Pick-up truck	Station wagon	Passenger car	Others
Fuel and vehicle type choice													
Adler et al. (2003)								✓[3]	✓[4]	✓[3]		✓[4]	
Ahn et al. (2008)								✓					Ordinary
Antolín et al. (2018)		✓	✓	✓		✓		✓	✓				
Axsen et al. (2009)		✓	✓	✓	✓			✓[1]	✓[4]	✓[3]			
Brownstone and Train (1999)							✓	✓	✓	✓	✓	✓	
Brownstone et al. (2000)							✓	✓	✓	✓	✓	✓	
Cirillo et al. (2017)		✓	✓	✓									
Costa et al. (2019)	✓								✓		✓		
Daziano (2013)	✓	✓		✓	✓			✓	✓[4]	✓[3]			
DeShazo et al. (2017)							✓	✓	✓	✓	✓		Sedan, hatchback
Dumortier et al. (2015)													Small/large, SUV/cross-utility vehicle
Habibi et al. (2019)						✓	✓[5]	✓[1]	✓				Sedan, hatchback, minibus
Hackbarth and Madlener (2018)	✓	✓	✓	✓	✓	✓	✓	✓	✓				Others
Hahn et al. (2018)		✓	✓	✓	✓								
He et al. (2012)	✓							✓[1]	✓	✓		✓	Multi activity vehicle
He et al. (2014)	✓							✓[1]	✓	✓		✓	Multi activity vehicle
Hensher and Greene (2006)		✓		✓	✓								
Hess et al. (2006)	✓	✓		✓	✓			✓	✓[4]	✓[3]			
Hess et al. (2012)		✓	✓	✓	✓		✓	✓[3]	✓[4]	✓[3]			Cross-utility vehicle[3]
Higgins et al. (2017)		✓	✓	✓		✓		✓	✓	✓			
Ito et al. (2013)		✓	✓				✓	✓			✓		Sedan, cabriolet, truck/bus, SUV/pick-up truck
Ito et al. (2019)		✓	✓				✓	✓			✓		Sedan, cabriolet, truck/bus, SUV/pick-up truck
Jäggi et al. (2013)	✓	✓	✓	✓		✓	✓	✓					Executive/minivan; Mini/small/medium[6], MPV/large/minivan[6], executive/luxury/sports[6]
Kavalec (1999)	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Lee and Cho (2009)		✓	✓	✓	✓								
Liu (2014)													
Liu and Cirillo (2018)		✓	✓	✓									
Mabit (2014)	✓	✓	✓	✓	✓			✓	✓				
Maness and Cirillo (2012)		✓		✓	✓			✓	✓	✓			
Musti and Kockelman (2011)		✓	✓	✓	✓	✓		✓	✓	✓			Cross-utility vehicle
Paleti et al. (2011)			✓					✓	✓	✓		✓	Cross-utility vehicle
Potoglou and Kanaroglou (2007)		✓	✓	✓	✓			✓	✓	✓			
Shiau et al. (2009)	✓	✓	✓	✓	✓	✓	✓						
Shin et al. (2015)									✓				Sedan
Shin et al. (2018)									✓			✓	
Soto et al. (2018)		✓							✓				Large/executive

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Table A.3 *(continued)*

Study	Mini	Small	Medium	Large	Executive	Luxury	Sport coupé	MPV	SUV	Pick-up truck	Station wagon	Passenger car	Others
Tompkins et al. (1998)	✓	✓	✓	✓	✓			✓[1]	✓[3]	✓[3]			
Train and Weeks (2005)													
Xu et al. (2015)		✓	✓				✓	✓	✓		✓		Sedan
Vehicle type choice													
Adjemian et al. (2010)			✓	✓	✓		✓[5]	✓	✓	✓	✓		
Baltas and Saridakis (2013)	✓	✓	✓	✓	✓	✓	✓[5]	✓	✓		✓		
Beggs and Cardell (1980)		✓	✓	✓	✓	✓							
Berkovec (1985)		✓[2]	✓	✓[3]	✓	✓[2]	✓[2]	✓	✓	✓			
Berkovec and Rust (1985)		✓	✓	✓[3]									Luxury/sports
Bhat and Sen (2006)								✓[1]	✓	✓		✓	
Bhat et al. (2009)		✓	✓	✓	✓		✓	✓[1]	✓	✓	✓		
Biswas et al. (2014)		✓					✓		✓				Sedan, Prestige
Cao et al. (2006)								✓	✓	✓		✓	
Chiou et al. (2009)		✓	✓	✓	✓								
Choo and Mokhtarian (2004)		✓	✓	✓	✓	✓	✓	✓	✓	✓			
Eluru et al. (2010)			✓		✓		✓	✓	✓	✓			
Kitamura et al. (1999)							✓[5]	✓	✓	✓			4-door sedan
Kockelman and Zhao (2000)								✓	✓	✓		✓	
Koo et al. (2012)									✓			✓	
Kuwano et al. (2013)		✓	✓	✓									
Lave and Train (1979)	✓	✓[3]	✓[3]	✓[3]		✓	✓						
Liu et al. (2014)		✓[2]	✓	✓[2]	✓[2]	✓	✓	✓	✓	✓			
Mannering and Winston (1991)						✓			✓				Others
Mannering et al. (2002)		✓	✓	✓	✓			✓	✓				
Manski and Sherman (1980)								✓	✓	✓		✓	Non-passenger car
Martin (2009)		✓	✓	✓	✓								
McCarthy (1996)						✓	✓					✓	Van/SUV/pick-up truck
McCarthy and Tay (1998)										✓		✓	Van/SUV
Mohammadian and Miller (2002, 2003)		✓	✓	✓	✓			✓					SUV/pick-up truck
Noblet et al. (2006)								✓	✓	✓		✓	
Potoglou (2008)								✓	✓	✓		✓	
Prieto and Caemmerer (2013)		✓	✓	✓		✓							
Spissu et al. (2009)			✓		✓		✓	✓	✓	✓			
Train (1986)	✓	✓[2]	✓	✓[2,3]	✓	✓		✓	✓	✓			
Train and Winston (2007)								✓[1]		✓		✓	Luxury/sports, SUV/station wagon
Vekeman et al. (2004)	✓	✓[3]	✓	✓	✓		✓	✓	✓	✓			
West (2007)								✓	✓	✓		✓	

Notes: 1 = two alternatives: minivan and van; 2 = two alternatives: domestic and foreign; 3 = two alternatives: usually compact or intermediate and standard; 4 = three alternatives: usually small or compact, mid-size, and large; 5 = two or three alternatives: coupe and sports car or coupe, cabriolet, and roadster; 6 = alternatives used in choice model A; 7 = alternatives used in BMOPT model; MPV = multi purpose vehicle; SUV = sport utility vehicle.

Table A.4: Dependent variables in studies with 'unsegmented' vehicles

Study	Dependent variable(s)
Fuel type choice	
Langbroek et al. (2016)	Chosen alternative plus 4 alternative vehicles (randomly selected from 262 vehicle types)
Fuel and vehicle type choice	
de Jong (1996)	Chosen alternative plus 19 alternative vehicles (randomly selected from 133 vehicle types (make-model) or about 1000 vehicle types (make-model-vintage))
He et al. (2012)	Chosen alternative plus 3 alternative vehicles ((randomly) selected from more than 262-300 vehicle types (make-model-fuel type))
Mabit (2014)	Chosen alternative plus 340, 390, 440, or 455 alternative vehicles (make-model-fuel type) in the respective year of purchase
Xu et al. (2015)	Chosen alternative plus 224-246 alternative vehicles (make-model-vehicle type-fuel type)
Vehicle type choice	
Bhat et al. (2009)	MNL: 5-33 vehicle types
Hensher and Le Plastrier (1985)	Chosen alternative plus 2 alternative vehicles (randomly selected from vehicle types (make-model-vintage) within same purchase price range)
Hocherman et al. (1983)	Chosen alternative plus 19 alternative vehicles (randomly selected from 950 vehicle types (make-model-vintage))
Koo et al. (2012)	Chosen alternative plus 10 alternative vehicles (10 most popular alternatives selected by large proportion of respondents)
Mannering and Mahmassani (1985)	Chosen alternative plus 92 alternative vehicles (make-model)
Mannering and Winston (1985)	Chosen alternative plus 9 alternative vehicles (randomly selected from more than 2000 vehicle types (make-model-vintage))
Mannering and Winston (1991)	Chosen alternative plus 9 randomly selected alternative vehicles (make-model-vintage)
Mannering et al. (2002)	Chosen alternative plus 9 alternative vehicles (randomly selected from 150-175 vehicle types (make-model))
Manski and Sherman (1980)	Chosen alternative plus 25 alternative vehicles (randomly selected from 600 vehicle types (make-model-vintage))
Martin (2009)	Chosen alternative plus 2113 alternative vehicles (make-model-vintage; aggregated to 4 vehicle classes)
McCarthy (1996)	Chosen alternative plus 14 alternative vehicles (randomly selected from 191 vehicle types (make-model)
McCarthy and Tay (1998)	Chosen alternative plus 9 alternative vehicles (randomly selected from 191 vehicle types (make-model))
Train and Winston (2007)	Chosen alternative plus 199 alternative vehicles (make-model)
Vekeman et al. (2004)	Chosen alternative plus 223 alternative vehicles (make-model-vintage; aggregated to 9 vehicle classes)

Notes: MNL = multinomial logit model.

Table A.5: Vehicle attributes and individual and household characteristics used in analysis

Study	Vehicle attributes	Individual and household characteristics
Fuel type choice		
Abdoolakhan (2010)	Purchase price, operating costs, performance, fuel efficiency, transmission, no. of doors	Age, gender
Achtnicht (2012)	Purchase price, operating costs, performance, emissions, fuel availability	Age, gender, education
Achtnicht et al. (2012)	Purchase price, operating costs, performance, emissions, fuel availability	Age, environmental attitude, vehicle usage
Aguilar et al. (2015)	Operating costs, fuel efficiency, ethanol source	Age, income, gender, region, attitude (ethanol avoidance)
Axsen et al. (2013)	Purchase price, performance, driving range, refueling time	Income, lifestyle
Axsen et al. (2015)	Purchase price, operating costs, driving range	Income, education, environmental attitude, HH size, region, recharging potential at home, lifestyle (technology-oriented, environment-oriented), liminality
Axsen et al. (2016)	Purchase price, operating costs, driving range	Income, education, recharging potential at home, attitudes (biospheric, altruistic), lifestyle (technology-oriented, environment-oriented)
Bahamonde-Birke and Hanappi (2016)	Purchase price, operating costs, performance, driving range, fuel availability, incentives, age, maintenance costs	Age, income, gender, education, environmental attitude, no. of vehicles, HH location, region, marital status, employment status, purpose of vehicle usage, user of carsharing
Batley and Toner (2003)	Purchase price, operating costs, performance, emissions, driving range, refueling time, residual value	
Batley et al. (2004)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, refueling location	Age, environmental attitude, no. of children, no. of vehicles
Bauer (2015)	Purchase price, operating costs, performance, driving range, manufacturer, design, equipment	Environmental attitude, attitude (AFV purchase, symbolic-affective), subjective norm, perceived behavioral control
Beck et al. (2011)	Purchase price, operating costs, performance, fuel efficiency, country of origin, registration fee, annual emissions charge, variable emissions charge, no. of seats	
Beck et al. (2013)	Purchase price, operating costs, performance, fuel efficiency, country of origin, registration fee, annual emissions charge, variable emissions charge, no. of seats	Age, environmental attitude, no. of children
Beck et al. (2017)	Purchase price, operating costs, emissions, driving range, fuel availability, refueling time	Environmental attitude, readiness to change
Beggs et al. (1981)	Purchase price, operating costs, performance, driving range, refueling time, air conditioning, warranty, no. of seats	Income, gender, education, HH size, region, commuter
Bočkarjova et al. (2013)	Generalized annual monetary costs, generalized annual charging time costs, generalized annual environmental costs, tow hitch	Consumer segment
Bunch et al. (1993)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, fuel efficiency, multiple-fuel capability	Age, income, gender, education, no. of workers, no. of vehicles, commute distance
Byun et al. (2018)	Purchase price, operating costs, emissions, fuel availability, refueling time	
Calfee (1985)	Purchase price, operating costs, performance, driving range, no. of seats	
Caulfield et al. (2010)	Operating costs, emissions, registration fee	Age, income, gender, importance of vehicle attributes, willingness to detour
Cherchi (2017)	Purchase price, operating costs, driving range, parking costs, no. of BEV parking spaces, BEV market share, next vehicle type	Gender, social signaling, prior participation in BEV survey, after-parking activity, negative information on BEVs ((need to change) behavior, range, parking options), injunctive norm
Dagsvik and Liu (2009)	Purchase price, performance, fuel efficiency, no. of seats	Income
Dagsvik et al. (2002)	Purchase price, performance, driving range, fuel efficiency	Age, gender
Daziano (2015)	Purchase price, operating costs, performance, fuel availability, incentives	Environmental attitude, attitudes (pro-safety, pro-performance, cost consciousness)
Daziano and Achtnicht (2014)	Purchase price, operating costs, performance, emissions, fuel availability	
Daziano and Bolduc (2013)	Purchase price, operating costs, performance, fuel availability, incentives	Age, income, gender, education, environmental attitude, commute mode

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Table A.5 *(continued)*

Study	Vehicle attributes	Individual and household characteristics
Dimitropoulos (2014)	Purchase price, operating costs, driving range, refueling time, incentives, residual value, additional detour time, main car replacement	Age, income, gender, education, environmental attitude, vehicle usage, long-term purchase decision
Eggers and Eggers (2011)	Purchase price, driving range	
Ewing and Sarigöllü (1998)	Purchase price, performance, emissions, driving range, refueling time, maintenance costs, commute fuel and parking costs, next vehicle type, selling price of predecessor vehicle	Age, gender, environmental attitude, no. of vehicles, consumer segment, WTP for ZEVs, home language, commute mode, home owner, commute time, average vehicle holding duration
Ewing and Sarigöllü (2000)	Purchase price, performance, emissions, driving range, refueling time, maintenance costs, commute fuel and parking costs	Environmental attitude, commute time
Ferguson et al. (2018)	Purchase price, performance, driving range, fuel availability, refueling time, incentives, maintenance costs, battery warranty, transaction type, next vehicle type	Age, gender, education, HH location, home language, time until next vehicle pruchase, fuel type of current vehicle, attitudes (WTP BEVs, cost-effectiveness BEVs, tolerance battery charging inconvenience, home charging possibility, battery warranty, energy security), importance of vehicle attributes
Glerum et al. (2014)	Purchase price, operating costs, incentives, battery leasing costs, year of purchase	Age, income, no. of children, no. of vehicles, attitudes (pro-battery leasing, pro-convenience), home language, commute mode
Golob et al. (1993)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, multiple-fuel capability	
Hackbarth and Madlener (2013)	Purchase price, operating costs, emissions, driving range, fuel availability, refueling time, incentives, next vehicle type	Age, education, environmental attitude, vehicle usage, recharging potential at home, often trips abroad
Hackbarth and Madlener (2016)	Purchase price, operating costs, emissions, driving range, fuel availability, refueling time, incentives, next vehicle type, transaction type	Age, education, environmental attitude, vehicle usage, attitude (technophilia)
Helveston et al. (2015)	Purchase price, operating costs, performance, country of origin, fast-charging capability	Age, income, gender, education, HH size, no. of children, no. of vehicles, marital status, attitudes (environmental appearance, status symbol), recharging potential at home
Hensher et al. (2011)	Purchase price, operating costs, performance, fuel efficiency, country of origin, registration fee, annual emissions charge, variable emissions charge, no. of seats	Gender, decision-maker type
Hensher et al. (2013)	Purchase price, operating costs, performance, fuel efficiency, country of origin, registration fee, annual emissions charge, variable emissions charge, no. of seats	Age, income, gender, employment status
Hensher et al. (2017)	Purchase price, operating costs, performance, fuel efficiency, registration fee, annual emissions charge, variable emissions charge, no. of seats	Age, income, gender, no. of licensed drivers in HH
Hidrue et al. (2011)	Purchase price, operating costs, performance, emissions, driving range, refueling time, next vehicle type, next fuel type	Age, income, gender, education, environmental attitude, no. of vehicles, vehicle usage, expected gasoline price, recharging potential at home, consumer segment
Hoen and Koetse (2014)	Purchase price, operating costs, driving range, refueling time, incentives, additional detour time, no. of variants in vehicle class, weight	Gender, no. of vehicles, HH location, vehicle usage, recharging potential at home, purpose of vehicle usage, commute distance, caravan owner, fuel type of current vehicle
Horne et al. (2005)	Purchase price, operating costs, performance, fuel availability, incentives	
Ida et al. (2014)	Purchase price, emissions, driving range, additional detour time, fuel costs savings, home plug-in capability	
Jacobs et al. (2016)	Purchase price, performance, driving range, fuel efficiency, refueling time, no. of seats, size	Owner of energy-efficient house
Jansson et al. (2017a)		Age, income, gender, education, environmental attitude, HH size, no. of children, no. of vehicles, HH location, personality (opinion leader / seeker), personal norm, social norm
Jansson et al. (2017b)		Age, income, gender, education, share of AFVs among others (family, neighbor, coworker), marital status, political attitude

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Table A.5 *(continued)*

Study	Vehicle attributes	Individual and household characteristics
Javid and Nejat (2017)	Operating costs	Age, income, gender, education, HH size, no. of vehicles, neighborhood characteristics, employment status, multiple jobs, user of carsharing, trip duration, home owner, housing type
Jensen et al. (2013)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, battery life, charging possibilities, next vehicle type, transaction type	Age, gender, environmental attitude, no. of vehicles, commute distance
Kim et al. (2014)	Purchase price, operating costs, performance, driving range, refueling time, refueling distance, reviews	Age, income, gender, education, environmental attitude, marital status, share of BEVs among others (friends and acquaintances, members of larger family, colleagues, peers in social network), attitudes (economic, battery, technological, innovation)
Kim et al. (2016)	Purchase price, operating costs, performance, driving range, refueling time, refueling distance, reviews	Age, income, gender, education, environmental attitude, marital status, share of BEVs among others (friends and acquaintances, members of larger family, colleagues, peers in social network), attitudes (battery, innovation)
Knockaert (2010)	Purchase price, operating costs, emissions, driving range, transmission, luggage space	Gender, HH size, social class
Krause et al. (2016)	Purchase price, driving range, refueling time	Income, gender, education, environmental attitude, no. of children, ethnic group, existing vehicle types in HH
Langbroek et al. (2016)	Purchase price, driving range, fuel availability, incentives	Stage-of-change, protection motivation
Lebeau et al. (2012)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, refueling time, brand-image-design-quality	
Li et al. (2013)	Leasing	Age, income, gender, education, environmental attitude, no. of children, HH location, region, vehicle usage, political attitude, utilization of transportation modes, time until next vehicle purchase, fuel type of current vehicle, detour frequency, source of environmental information, attitudes (energy production and security, availability and costs of BVs), ethnic group
Link et al. (2012)	Purchase price, operating costs, performance, emissions, driving range, refueling time, age, main car, transaction type	Age, income, gender, no. of children, attitudes (willingness to adapt to BEV requirements, willingness to buy BEV, accepted charging time), existing vehicle types in HH, mode choice experiment participation, experiment induced purchase decision change, decision factors, no. of BEV trips, garage owner, employment status
Mabit and Fosgerau (2011)	Purchase price, operating costs, performance, driving range, service, refueling frequency	Age, income, gender, HH size, no. of children
Mabit et al. (2015)	Purchase price, performance, driving range, annual costs, service, transaction type	Age, income, gender, HH size, no. of children, no. of workers, vehicle usage, appreciation of vehicle features
Mannberg et al. (2014)	Year of purchase	Age, income, gender, education, no. of children, no. of vehicles, HH location, region, fuel type of current vehicle, country of birth, workplace location, marital status, employment status
Marra et al. (2012)	Operating costs, emissions, refueling distance, share of fuel from imported sources	Lifestyle (potential activist, environmental, national interest)
Mau et al. (2008)	Purchase price, operating costs, driving range, fuel availability, incentives, warranty	
Nixon and Saphores (2011)	Purchase price, operating costs, driving range, refueling time	Age, gender, education, environmental attitude, region, consumer segment, attitude (oil import concern), existing vehicle types in HH
Østil et al. (2017)	Purchase price, operating costs, performance, resource cost share, size, no. of seats, no. of doors, luggage space, four/front-wheel-drive, manufacturer	
Parsons et al. (2014)	Purchase price, driving range, refueling time, incentives, next vehicle type, next fuel type	Age, income, gender, education, environmental attitude, no. of vehicles, vehicle usage, expected gasoline price, recharging potential at home, consumer segment

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Table A.5 *(continued)*

Study	Vehicle attributes	Individual and household characteristics
Qian and Soopramanien (2011)	Purchase price, operating costs, driving range, fuel availability, incentives	Age, income, gender, HH size, no. of children, no. of vehicles, no. of licensed drivers in HH, commute distance
Qian and Soopramanien (2015)	Purchase price, operating costs, driving range, fuel availability, incentives	Age, income, gender, HH size, no. of children, no. of licensed drivers in HH, commute distance
Ramjerdi and Rand (2000)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, refueling time, no. of seats, company car	Age, income, no. of vehicles, commute distance
Rasouli and Timmermans (2016)	Purchase price, operating costs, performance, driving range, refueling time, refueling distance, reviews	Age, income, gender, education, marital status, share of BEVs among others (friends and acquaintances, members of larger family, colleagues, peers in social network)
Rouwendal and de Vries (1999)	Operating costs, fixed costs	Age, income, gender
Rudolph (2016)	Purchase price, operating costs, incentives, refueling distance	Vehicle usage, public transportation usage, bike usage, annual transit pass ownership
Sandór and Train (2004)	Purchase price, operating costs, performance, driving range	
Sentürk et al. (2011		Age, income, gender, education, environmental attitude, no. of vehicles, vehicle usage, attitudes (alternative fuels, social responsibility, risk)
Shin et al. (2012)	Purchase price, operating costs, fuel availability, maintenance costs	Vehicle usage,
Smith et al. (2017)	Purchase price, operating costs, performance, emissions, driving range, refueling time, noise, battery capacity after 10 years	Gender, environmental attitude, social norm
Tanaka et al. (2014)	Purchase price, operating costs, emissions, driving range, fuel availability, home plug-in construction fee	
Train and Sonnier (2005)	Purchase price, operating costs, performance, driving range	
Valeri and Cherchi (2016)	Purchase price, operating costs, performance, driving range, refueling distance	Education, no. of vehicles, vehicle usage, employment status, purpose of vehicle usage, no. of licensed drivers in HH, habitual behavior
Valeri and Danielis (2015)	Purchase price, operating costs, performance, driving range, refueling distance	Age, income, gender, vehicle usage, garage owner, car expert
van Meerkerk et al. (2014)	Purchase price, operating costs, performance, age, annual road tax, weight, size	Income, HH size, vehicle usage
Wang et al. (2017)	Purchase price, driving range, incentives	Income, preference for small cars, attitudes (BEV awareness, BEV confidence, policy awareness)
Whitehead et al. (2014)		Age, income, gender, no. of children, no. of vehicles, HH location, commute distance, commute across boundary
Wolbertus et al. (2018)	Purchase price, driving range, fuel availability, parking costs, parking spot availability	
Ziegler (2012)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, fuel efficiency, size, company car, first-hand, next vehicle type	Age, gender, environmental attitude, no. of vehicles, purpose of vehicle usage
Zito and Salerno (2004)	Purchase price, average running time, average service life	Age, gender, garage owner
Fuel and vehicle type choice		
Adler et al. (2003)	Purchase price, operating costs, performance, incentives, maintenance costs, gradability	Income, HH size, region, vehicle type loyalty, vehicle size loyalty
Ahn et al. (2008)	Operating costs, performance, maintenance costs	Vehicle usage
Antolín et al. (2018)	Purchase price, performance, driving range, fuel efficiency	Income, education, HH size, no. of children, no. of vehicles, HH location
Axsen et al. (2009)	Purchase price, operating costs, performance, incentives	Income
Brownstone and Train (1999)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, size	Education, HH size, commute distance
Brownstone et al. (2000)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, age, size	Income, education, HH size
Cirillo et al. (2017)	Purchase price, operating costs, driving range, fuel efficiency, size	Age, gender, education, no. of workers, no. of vehicles, knowledge about fuel efficiency

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Table A.5 *(continued)*

Study	Vehicle attributes	Individual and household characteristics
Costa et al. (2019)	Purchase price, emissions	
Daziano (2013)	Purchase price, operating costs, performance, driving range	
de Jong (1996)	Operating costs, performance, country of origin, age, no. of variants in vehicle class, fixed costs, catalyzer	Income, engine displacement loyalty, fuel type loyalty, brand loyalty
DeShazo et al. (2017)	Purchase price, operating costs, driving range, incentives	Income, no. of children, no. of vehicles
Dumortier et al. (2015)		Age, income, gender, education, no. of vehicles, fuel type of current vehicle, type of information on vehicle costs, awareness of public charging stations in neighborhood
Habibi et al. (2019)	Purchase price, manufacturer, annual vehicle tax, tank volume, weight/horsepower, no. of variants in vehicle class	
Hackbarth and Madlener (2018)	Purchase price, company car, main car, premium manufacturer	Age, gender, environmental attitude, no. of children, no. of vehicles, HH location, vehicle usage, importance of vehicle attributes, user of carsharing, purpose of vehicle usage, attitudes (technophilia, environmental behavior, environmental mobility), knowledge about AFVs, time of purchase
Hahn et al. (2018)	Purchase price, operating costs, driving range, fuel availability	Age, income, gender, HH size, no. of vehicles, knowledge about AFVs
He et al. (2012)	Purchase price, fuel efficiency, country of origin, size	Income, education, vehicle usage, rating of vehicle attributes
He et al. (2014)	Purchase price, performance, fuel efficiency, country of origin, size	Income, education, no. of children, vehicle usage, social impact
Hensher and Greene (2006)	Purchase price, operating costs, performance, driving range, age, registration fee, luggage space	Income
Hess et al. (2006)	Purchase price, operating costs, performance, driving range	
Hess et al. (2012)	Purchase price, operating costs, performance, driving range, fuel availability, fuel efficiency, refueling time, incentives, age, maintenance costs	Income, HH size, no. of same vehicle type in HH, no. of same fuel type in HH
Higgins et al. (2017)	Purchase price, operating costs, performance, driving range, fuel availability, refueling time, incentives, maintenance costs, transaction type	Age, income, gender, education, HH size, no. of children, no. of workers, no. of vehicles, HH location, vehicle usage, importance of vehicle attributes, time until next vehicle purchase, home language
Ito et al. (2013)	Purchase price, operating costs, emissions, driving range, fuel availability, refueling time, manufacturer	Age, gender
Ito et al. (2019)	Purchase price, operating costs, emissions, driving range, fuel availability, refueling time, manufacturer	
Jäggi et al. (2013)	Operating costs	Age, income, gender, HH location, neighborhood characteristics, vehicle usage, availability of discount card for public transportation, no. of same vehicle type in HH, commute distance
Kavalec (1999)	Purchase price, operating costs, performance, emissions, driving range, fuel availability, refueling time, multiple-fuel capability, luggage space, size	Age
Lee and Cho (2009)	Purchase price, operating costs, fuel efficiency, annual vehicle tax	Age, gender, no. of vehicles, vehicle usage, marital status
Liu (2014)	Purchase price, operating costs, performance, size	Income, HH size, HH location
Liu and Cirillo (2018)	Purchase price, operating costs, driving range, fuel efficiency, size	Age, gender, education, no. of workers, no. of vehicles, knowledge about fuel efficiency
Mabit (2014)	Purchase price, operating costs, performance, no. of variants in vehicle class, airbag, transmission, no. of doors, weight, registration fee, year of purchase	Age, income, gender, HH size, no. of children, region, employment status, commute distance
Maness and Cirillo (2012)	Purchase price, operating costs, driving range, fuel efficiency, refueling time, incentives, age, size	Income, HH size, neighborhood characteristics, vehicle usage
Musti and Kockelman (2011)	Purchase price, operating costs	Age, income, gender, HH size, no. of vehicles, HH location
Paleti et al. (2011)	Purchase price, operating costs, performance, driving range, fuel availability, fuel efficiency, incentives, maintenance costs	Income, gender, education, HH size, no. of children, no. of workers, HH location, no. of same vehicle type in HH, ethnic group, presence of seniors in HH

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Table A.5 *(continued)*

Study	Vehicle attributes	Individual and household characteristics
Potoglou and Kanaroglou (2007)	Purchase price, operating costs, performance, emissions, fuel availability, incentives, maintenance costs	Age, income, gender, education, HH size, neighborhood characteristics, region, housing type, commute distance
Shiau et al. (2009)	Purchase price, operating costs, performance, country of origin, size	
Shin et al. (2015)	Purchase price, operating costs, fuel availability, smart car options	Age, income, gender, HH size, vehicle usage, usefulness of smart car options, driver, housing type
Shin et al. (2018)	Purchase price, operating costs, fuel availability, smart car options	
Soto et al. (2018)	Purchase price, operating costs, performance, driving range, fuel availability, annual taxes	Age, income, gender, education, environmental attitude, no. of vehicles, attitudes (green transportation policy support, pro-car use, technophilia)
Tompkins et al. (1998)	Purchase price, operating costs, performance, driving range, fuel availability, battery exchange cost, maintenance costs, multiple-fuel capability, luggage space, prestige	Neighborhood characteristics
Train and Weeks (2005)	Purchase price, operating costs, performance, driving range	
Xu et al. (2015)	Purchase price, fuel price, manufacturer	Income, HH size
Vehicle type choice		
Adjemian et al. (2010)		Age, income, gender, HH size, no. of vehicles, neighborhood characteristics, housing type, home owner, no. of licensed drivers in HH, ethnic group, employment status
Baltas and Saridakis (2013)		Income, gender, education, HH location, importance of vehicle attributes, objective driving skills, subjective driving skills, intention to purchase eco-car, information sources, involvement with cars, attachment to cars, purpose of vehicle usage, marital status
Beggs and Cardell (1980)	Purchase price, operating costs, performance, country of origin, age, luxury premium, weight, size	Age, income, education, HH size, no. of vehicles, distant parking, ethnic group, vehicle ownership
Berkovec (1985)	Purchase price, operating costs, country of origin, age, shoulder room, no. of seats	Income, HH size
Berkovec and Rust (1985)	Purchase price, operating costs, performance, country of origin, age, transaction type, turning radius, no. of seats, manufacturer	Age, income, HH size, HH location, vehicle type loyalty
Bhat and Sen (2006)	Operating costs	Income, gender, HH size, no. of children, no. of workers, neighborhood characteristics, presence of mobility-challenged individual in HH
Bhat et al. (2009)	Purchase price, operating costs, performance, emissions, four-wheel drive, premium fuel, no. of seats, luggage space, manufacturer	Age, income, gender, HH size, no. of children, no. of workers, HH location, neighborhood characteristics, ethnic group, presence of seniors in HH
Biswas et al. (2014)		Age, income, importance of vehicle attributes, employment status
Cao et al. (2006)		Age, income, gender, education, no. of children, no. of vehicles, neighborhood characteristics, home owner, neighborhood preferences, travel attitudes
Chiou et al. (2009)	Purchase price, operating costs, age, license tax, fuel tax, insurance costs, maintenance costs	Income, gender, education, neighborhood characteristics
Choo and Mokhtarian (2004)		Age, income, gender, education, no. of children, HH location, travel attitudes, personality, lifestyle, utilization of transportation modes, subjective mobility, employment status, presence of seniors in HH
Eluru et al. (2010)		Income, gender, HH size, no. of children, no. of workers, neighborhood characteristics, no. of same vehicle type in HH, home owner
Hensher and Le Plastrier (1985)	Purchase price, operating costs, performance, fuel efficiency, age, sales tax, maintenance costs, no. of seats, luggage space, weight, transaction type	Age, vehicle usage, experience index, brand loyalty, preference for vehicle newness, purpose of vehicle usage
Hocherman et al. (1983)	Purchase price, operating costs, performance, country of origin, age, transaction costs, luggage space, size	Age, income, HH size, no. of vehicles, vehicle usage, employment status, brand loyalty

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Table A.5 *(continued)*

Study	Vehicle attributes	Individual and household characteristics
Kitamura et al. (1999)		Age, income, gender, education, HH size, no. of workers, no. of vehicles, neighborhood characteristics, decision-maker type, housing type, purpose of vehicle usage, vehicle type loyalty, employment status, commute distance
Kockelman and Zhao (2000)	Purchase price	Income, HH size, no. of vehicles, neighborhood characteristics
Koo et al. (2012)	Purchase price, performance, fuel efficiency	Vehicle usage
Kuwano et al. (2013)	Purchase price, no. of seats	Age, HH size, no. of children, no. of workers, vehicle usage
Lave and Train (1979)	Purchase price, operating costs, performance, no. of seats, weight	Age, income, education, HH size, no. of vehicles, vehicle usage
Liu et al. (2014)	Purchase price, fuel efficiency, country of origin, age, shoulder room, luggage space, no. of variants in vehicle class	Income, HH size, no. of vehicles
Mannering and Mahmassani (1985)	Purchase price, operating costs, performance, country of origin, consumer report index, turning radius, weight, manufacturer, expected annual collision cost	Age, income, vehicle usage, past utilization of same make vehicle
Mannering and Winston (1985)	Purchase price, operating costs, performance, country of origin, age, shoulder room, luggage space, manufacturer	Age, income, HH size, vehicle usage, past utilization of same (make) vehicle
Mannering and Winston (1991)	Purchase price, fuel efficiency, country of origin, consumer report index, weight, manufacturer	Age, income, HH location, region, brand loyalty
Mannering et al. (2002)	Purchase price, operating costs, performance, country of origin, expected residual value, insurance costs, consumer report index, turning radius, airbag, manufacturer	Age, income, HH size, HH location, country of origin loyalty, vehicle leasing loyalty, brand loyalty
Manski and Sherman (1980)	Purchase price, operating costs, performance, country of origin, age, braking distance, noise, scrappage rate, transaction costs, turning radius, no. of seats, luggage space, weight	Age, income, education, HH size, no. of workers, no. of vehicles, HH location, region
Martin (2009)	Purchase price, operating costs, performance, incentives, consumer report index, no. of seats	Age, income, education, no. of children
McCarthy (1996)	Purchase price, operating costs, performance, country of origin, crash test index, manufacturer, size	Age, income, HH location, region, consumer satisfaction index, brand loyalty, no. of dealer visits
McCarthy and Tay (1998)	Purchase price, operating costs, country of origin, airbag, luggage space, size, manufacturer	Age, income, region, consumer satisfaction index, brand loyalty
Mohammadian and Miller (2002, 2003)	Purchase price, performance, weight, size	Age, income, gender, education, HH size, no. of children, no. of same vehicle type in HH, employment status
Noblet et al. (2006)	Purchase price, operating costs, emissions	Income, environmental attitude, purpose of vehicle usage
Potoglou (2008)		Education, no. of children, no. of vehicles, neighborhood characteristics, commute mode, home owner
Prieto and Caemmerer (2013)	Country of origin	Age, income, gender, education, HH size, no. of children, HH location, region, purpose of vehicle usage, employment status, credit financing, vehicle rank in HH fleet
Spissu et al. (2009)		Age, income, gender, HH size, no. of children, no. of workers, neighborhood characteristics, ethnic group, no. of same vehicle type in HH, presence of seniors in HH
Train (1986)	Purchase price, operating costs, performance, country of origin, age, transaction costs, no. of transactions required to obtain vehicles, prestige, shoulder room, luggage space, no. of variants in vehicle class	Income, HH size
Train and Winston (2007)	Purchase price, performance, fuel efficiency, country of origin, expected residual value, transmission, size, consumer report index, manufacturer, leasing	Age, income, gender, no. of children, HH location, neighborhood characteristics, country of origin loyalty, brand loyalty
Vekeman et al. (2004)	Purchase price, fuel efficiency	Age, income, gender, HH size, no. of children, no. of vehicles, HH location, region
West (2007)	Fuel price	Age, gender, education, no. of children, no. of workers, HH location, region, marital status, home owner, no. of licensed drivers in HH, ethnic group, no. of same vehicle type in HH, quarterly total expenditures

Notes: HH = household; AFV = alternative fuel vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; ZEV = zero-emission vehicle; WTP = willingness-to-pay.

Table A.6: DCE characteristics and attributes

Study	Ch.	Attr.	Lev.	Attributes
Fuel type choice				
Abdoolakhan (2010)	9	9	2-3	Fuel type, vehicle type, purchase price, operating costs, emissions[1], fuel availability[6], performance[1], transmission, no. of doors, new car, additional LPG tank, maintenance costs
Achtnicht (2012)	6	5	3-5	Fuel type, purchase price, operating costs, emissions, fuel availability, performance
Achtnicht et al. (2012)	6	5	3-5	Fuel type, purchase price, operating costs, emissions, fuel availability, performance
Aguilar et al. (2015)	6	3	3	Fuel type, operating costs, fuel efficiency, ethanol source
Axsen et al. (2013)	9	4	3	Fuel type, purchase price, driving range, refueling time, performance
Axsen et al. (2015)	6	5	2-4	Fuel type, purchase price, operating costs, driving range, refueling time[1], home plug-in capability
Axsen et al. (2016)	6	5	2-4	Fuel type, purchase price, operating costs, driving range, refueling time[1], home plug-in capability
Bahamonde-Birke and Hanappi (2016)	9	7	3-7	Fuel type, purchase price, operating costs[11], driving range, fuel availability, incentives, performance
Batley and Toner (2003)	5	8	4	Fuel type, purchase price, operating costs, emissions, driving range, refueling time, performance[8], residual value
Batley et al. (2004)	16	7	2-3	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, performance, refueling location
Bauer (2015)	12	7	2-5	Fuel type, purchase price, operating costs, driving range, performance, manufacturer, design, equipment
Beck et al. (2011)	4	9	2-5	Fuel type, vehicle type, purchase price, operating costs, performance, registration fee, annual emissions charge, variable emissions charge, fuel efficiency, no. of seats, country of origin
Beck et al. (2013)	4	9	2-5	Fuel type, vehicle type, purchase price, operating costs, performance, registration fee, annual emissions charge, variable emissions charge, fuel efficiency, no. of seats, country of origin
Beck et al. (2017)	4	6	N.A.	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time
Beggs et al. (1981)	1	8	2-4	Fuel type, purchase price, operating costs, driving range, refueling time[1], performance[8], air conditioning, warranty, no. of seats
Bočkarjova et al. (2013)	6	11	2-6	Fuel type, purchase price, operating costs, emissions, driving range[2], refueling time[3], residual value, fuel costs in 5 years, average detour time, tow hitch
Bunch et al. (1993)	5	6	2-4	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, performance
Byun et al. (2018)	4	5	2-3	Fuel type, purchase price, operating costs, emissions, fuel availability, refueling time
Calfee (1985)	30	5	N.A.	Fuel type, purchase price, operating costs, driving range, performance, no. of seats
Caulfield et al. (2010)	6	3	3	Fuel type, operating costs, emissions, registration fee
Cherchi (2017)	6	7	3	Fuel type, purchase price, operating costs, driving range, parking costs, no. of BEV parking spaces, BEV market share, social signaling
Dagsvik and Liu (2009)	15	4	2-18	Fuel type, purchase price, performance, fuel efficiency, no. of seats
Dagsvik et al. (2002)	15	4	N.A.	Fuel type, purchase price, driving range, performance, fuel efficiency
Daziano (2015)	4	5	2-4	Fuel type, purchase price, operating costs, fuel availability, incentives, performance
Daziano and Achtnicht (2014)	6	5	3-5	Fuel type, purchase price, operating costs, emissions, fuel availability, performance
Daziano and Bolduc (2013)	4	5	2-4	Fuel type, purchase price, operating costs, emissions[1], fuel availability, incentives, performance
Dimitropoulos (2014)	8	8	3	Fuel type, purchase price, operating costs, driving range, refueling time[3], incentives, residual value, additional detour time
Eggers and Eggers (2011)	2×6	2	3-4	Fuel type, purchase price, driving range
Ewing and Sarigöllü (1998)	9	8	3	Fuel type, purchase price, emissions, driving range, refueling time, performance, commute time, commute fuel and parking costs, maintenance costs
Ewing and Sarigöllü (2000)	9	8	3	Fuel type, purchase price, emissions, driving range, refueling time, performance, commute time, commute fuel and parking costs, maintenance costs
Ferguson et al. (2018)	4	11	2-3	Fuel type, purchase price, operating costs, emissions, driving range[14], fuel availability, refueling time[3], incentives, performance, maintenance costs, battery warranty
Glerum et al. (2014)	5	4	3-4	Fuel type, vehicle type[1], purchase price, operating costs, incentives, battery leasing costs, maintenance costs[1]
Golob et al. (1993)	5	6	2-4	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, performance, multiple-fuel capability
Hackbarth and Madlener (2013)	15	8	2-3	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time[4], incentives
Hackbarth and Madlener (2016)	15	8	2-3	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time[4], incentives

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Table A.6 *(continued)*

Study	Ch.	Attr.	Lev.	Attributes
Helveston et al. (2015)	16	5	2-5	Fuel type, purchase price, operating costs, performance, fast-charging capability, country of origin
Hensher et al. (2011)	4	9	2-5	Fuel type, vehicle type, purchase price, operating costs, performance, registration fee, annual emissions charge, variable emissions charge, fuel efficiency, no. of seats, country of origin
Hensher et al. (2013)	4	9	2-5	Fuel type, vehicle type, purchase price, operating costs, performance, registration fee, annual emissions charge, variable emissions charge, fuel efficiency, no. of seats, country of origin
Hensher et al. (2017)	8	9	2-5	Fuel type, purchase price, operating costs, performance, registration fee, annual emissions charge, variable emissions charge, fuel efficiency, no. of seats, country of origin
Hidrue et al. (2011)	2	6	4-8	Fuel type, purchase price, operating costs, emissions, driving range, refueling time, performance
Hoen and Koetse (2014)	8	7	3-4	Fuel type, purchase price, operating costs, driving range, refueling time, incentives, additional detour time, no. of available manufacturers/models
Horne et al. (2005)	4	5	2-4	Fuel type, purchase price, operating costs, emissions[1], fuel availability, incentives, performance
Ida et al. (2014)	8	6	2-4	Fuel type, purchase price, emissions, driving range, additional detour time, fuel costs savings, home plug-in capability
Jacobs et al. (2016)	8	N.A.	N.A.	Fuel type, purchase price, driving range, refueling time, performance, fuel efficiency, no. of seats, vehicle size
Jensen et al. (2013)	2×8	8	2-4	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, performance, battery life, charging possibilities
Kim et al. (2014)	16	11	4-8	Fuel type, purchase price, operating costs, driving range, refueling time, performance, refueling distance, share of BEVs among friends and acquaintances, share of BEVs among members of larger family, share of BEVs among colleagues, share of BEVs among peers in social network, reviews
Kim et al. (2016)	16	11	4-8	Fuel type, purchase price, operating costs, driving range, refueling time, performance, refueling distance, share of BEVs among friends and acquaintances, share of BEVs among members of larger family, share of BEVs among colleagues, share of BEVs among peers in social network, reviews
Knockaert (2010)	6	7	2-3	Fuel type, purchase price, operating costs[11], emissions, driving range, transmission, luggage space
Krause et al. (2016)	5	3	2	Fuel type, purchase price, operating costs[1], driving range, refueling time
Langbroek et al. (2016)	3	5	3-4	Fuel type, purchase price, driving range, fuel availability, incentives[15]
Lebeau et al. (2012)	10	9	5-10	Fuel type, purchase price, operating costs[11], emissions, driving range, fuel availability, refueling time, performance, brand-image-design-quality
Link et al. (2012)	8	8	4	Fuel type, purchase price, operating costs[5], emissions, driving range, refueling time, performance
Mabit and Fosgerau (2011)	12	6	N.A.	Fuel type, purchase price, operating costs, emissions[1], driving range, performance, service, refueling frequency
Mabit et al. (2015)	4-8	5		Fuel type, purchase price, emissions[1], driving range, performance, annual costs, service
Marra et al. (2012)	14	5	3-5	Fuel type, operating costs, emissions, refueling distance, ethanol source, share of fuel from imported sources
Mau et al. (2008)	18	6	3	Fuel type, purchase price, operating costs, driving range, fuel availability, incentives, warranty
Nixon and Saphores (2011)	9	5	2-3	Fuel type, purchase price, operating costs, emissions[1], driving range, refueling time
Parsons et al. (2014)	2	4	4-8	Fuel type, purchase price, operating costs[1], emissions[1], driving range[1], refueling time[1], performance[1], annual cash back payment, required plug-in time per day, minimum guaranteed driving range
Qian and Soopramanien (2011)	8	5	3	Fuel type, purchase price, operating costs, driving range, fuel availability, incentives
Qian and Soopramanien (2015)	8	5	3	Fuel type, purchase price, operating costs, driving range, fuel availability, incentives
Ramjerdi and Rand (2000)	2	8	2-3	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time, performance, no. of seats
Rasouli and Timmermans (2016)	16	11	4-8	Fuel type, purchase price, operating costs, driving range, refueling time, performance, refueling distance, share of BEVs among friends and acquaintances, share of BEVs among members of larger family, share of BEVs among colleagues, share of BEVs among peers in social network, reviews
Rudolph (2016)	8	6	3-7	Fuel type, purchase price, operating costs, incentives[13], refueling distance
Sandór and Train (2004)	15	4	3-14	Fuel type, vehicle type, purchase price, operating costs, driving range, performance
Shin et al. (2012)	4	4	3-4	Fuel type, purchase price, operating costs, fuel availability, maintenance costs
Smith et al. (2017)	6	9	3	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time, performance, noise, battery capacity after 10 years
Tanaka et al. (2014)	8	6	2-4	Fuel type, purchase price, operating costs, emissions, driving range, fuel availability, home plug-in construction fee
Train and Sonnier (2005)	15	4	3-14	Fuel type, vehicle type, purchase price, operating costs, driving range, performance
Valeri and Cherchi (2016)	12	5	3-4	Fuel type, purchase price, operating costs, driving range, performance, refueling distance
Valeri and Danielis (2015)	12	5	3-4	Fuel type, purchase price, operating costs, driving range, performance, refueling distance

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Table A.6 *(continued)*

Study	Ch.	Attr.	Lev.	Attributes
Wang et al. (2017)	3	11	3-4	Fuel type, purchase price, driving range, incentives[16]
Wolbertus et al. (2018)	9	5	3	Fuel type, purchase price, operating costs[1], driving range, fuel availability, refueling time[1,3], parking costs, parking spot availability, road tax[1]
Ziegler (2012)	6	5	3-5	Fuel type, purchase price, operating costs, emissions, fuel availability, performance
Zito and Salerno (2004)	8	3	2	Fuel type, purchase price, operating costs[1], driving range[1], refueling time[1], performance[1], average running time, average service life, place of refueling[1], motor vehicle tax[1], insurance costs[1]
Fuel and vehicle type choice				
Adler et al. (2003)	8	6	4	Fuel type, vehicle type[9], purchase price, operating costs, incentives, performance, gradability, maintenance costs
Ahn et al. (2008)	1	4	4	Fuel type, vehicle type, operating costs, performance, fuel efficiency, maintenance costs
Axsen et al. (2009)	18	5	3	Fuel type, purchase price, operating costs, emissions[1], incentives, performance, fuel efficiency
Brownstone and Train (1999)	2	13	2-4	Fuel type, vehicle type[9], purchase price, operating costs[3], emissions, driving range, fuel availability, refueling time[3], performance[8], multiple-fuel capability, luggage space
Brownstone et al. (2000)	2	13	2-4	Fuel type, vehicle type[9], purchase price, operating costs[3], emissions, driving range, fuel availability, refueling time[3], performance[8], multiple-fuel capability, luggage space
Cirillo et al. (2017)	18	3	4	Fuel type, vehicle type, purchase price, driving range, fuel efficiency
Costa et al. (2019)	9	2	3-4	Fuel type, vehicle type, purchase price, emissions
Daziano (2013)	15	4	3-14	Fuel type, vehicle type, purchase price, operating costs, driving range, performance
DeShazo et al. (2017)	4	6	2-4	Fuel type, vehicle type, purchase price, operating costs[14], driving range[14], incentives
Dumortier et al. (2015)	1	0	0	Fuel type, vehicle type[1], purchase price[1], operating costs[1], emissions[1], driving range[1], refueling time[1], fuel efficiency[1], 5-year fuel cost savings[1], monthly TCO[1]
Hahn et al. (2018)	6	4	2-3	Fuel type, vehicle type, purchase price, operating costs, driving range, fuel availability
Hensher and Greene (2006)	3	7	2-4	Fuel type, vehicle type, purchase price, operating costs, driving range, performance, registration fee, luggage space, vehicle age
Hess et al. (2006)	15	4	3-14	Fuel type, vehicle type, purchase price, operating costs, driving range, performance
Hess et al. (2012)	8	10	2-4	Fuel type, vehicle type, purchase price, operating costs, driving range, fuel availability, refueling time, incentives, performance, fuel efficiency, vehicle age, maintenance costs
Higgins et al. (2017)	4	12	2-3	Fuel type, vehicle type, purchase price, operating costs, emissions, driving range[14], fuel availability, refueling time[3], incentives[7], performance, maintenance costs, battery warranty
Ito et al. (2013)	8	7	2-4	Fuel type, vehicle type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time, manufacturer
Ito et al. (2019)	8	7	2-4	Fuel type, vehicle type, purchase price, operating costs, emissions, driving range, fuel availability, refueling time, manufacturer
Jäggi et al. (2013)	6	4	2-5	Fuel type, vehicle type, operating costs, performance, vehicle age, annual mileage
Kavalec (1999)	2	13	2-4	Fuel type, vehicle type[9], purchase price, operating costs[3], emissions, driving range, fuel availability, refueling time[3], performance[8], multiple-fuel capability, luggage space
Lee and Cho (2009)	4	4	3-4	Fuel type, vehicle type, purchase price, operating costs, annual vehicle tax, fuel efficiency
Liu and Cirillo (2018)	18	3	4	Fuel type, vehicle type, purchase price, driving range, fuel efficiency
Maness and Cirillo (2012)	1	3-4	N.A.	Fuel type, vehicle type[17a], purchase price[17a], operating costs[17b], emissions[17a], driving range[17a], fuel availability[17b], incentives[17c], fuel efficiency[17a,b], fuel tax[17b]
Musti and Kockelman (2011)	4	3	N.A.	Fuel type, vehicle type, purchase price, operating costs, external costs
Potoglou and Kanaroglou (2007)	8	7	4	Fuel type, vehicle type, purchase price, operating costs, emissions, fuel availability, incentives, performance, maintenance costs
Shin et al. (2015)	6	4	2-4	Fuel type, vehicle type, purchase price, operating costs, fuel availability, smart car options
Shin et al. (2018)	3	4	2-4	Fuel type, vehicle type, purchase price, operating costs, fuel availability, smart car options
Soto et al. (2018)	10	5	2-3	Fuel type, vehicle type, purchase price, operating costs, driving range, fuel availability, annual taxes
Tompkins et al. (1998)	2	20	2-6	Fuel type, vehicle type[9], purchase price, operating costs, driving range[10], fuel availability, refueling time[3], performance[8], battery exchange costs, multiple-fuel capability, fuel efficiency, reliability, luggage space, lease option, new car, country of origin, prestige, warranty, maintenance costs

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Table A.6 *(continued)*

Study	Ch.	Attr.	Lev.	Attributes
Train and Weeks (2005)	15	4	3-14	Fuel type, vehicle type, purchase price, operating costs, driving range, performance
Vehicle type choice				
Noblet et al. (2006)	1	3	N.A.	Vehicle type, purchase price, emissions[12], fuel efficiency

Notes: 1 = attributes are constant (one level) or are calculated from other attributes; 2 = two attributes: minimum and maximum driving range; 3 = two attributes: home and station; 4 = two attributes: refueling and recharging time; 5 = two attributes: per 100 km and per year; 6 = two attributes: in and outside the metropolitan area; 7 = two attributes: cash incentives and non-cash incentives; 8 = two attributes: acceleration and top speed; 9= two attributes: vehicle class and body type; 10 = two attributes: first and secondary fuel; 11 = two attributes: fuel costs and operation costs; 12 = two attributes: criteria pollution and global warming pollution score; 13 = three attributes: CO_2 tax, direct subsidy, and parking fee; 14 = two attributes: electric and gasoline; 15 = two attributes: parking benefits and bus lane usage; 16 = nine attributes: road toll exemption, purchase tax exemption, vehicle and vessle tax exemption, parking fee exemption, insurance fee exemption, public charging fee exemption, purchase restriction recission, driving restriction recission, bus lane usage; 17a, b, c = (a) vehicle technology experiment , (b) fuel type experiment, (c) taxation policy experiment; Ch. = number of consecutive choice tasks in the survey; Attr. = number of attributes (without counting fuel type and vehicle type) in the choice task; Lev. = number of levels per attribute; TCO = total costs of ownership; BEV = battery electric vehicle.

Table A.7: Results of the fuel type choice literature

Study	CFV	HEV	BEV	NGV / BV	Others
Fuel type choice					
Achtnicht et al. (2012)	**BASE (diesel)**; Gasoline: Minimum driving range ⊖, mileage ⊖, age ⊕	Minimum driving range ⊖, mileage ⊖, env. awareness ⊕	Minimum driving range ⊖, env. awareness ⊕, age ⊖	BV: Minimum driving range ⊖, env. awareness ⊕; NGV: Minimum driving range ⊖, age ⊖	FCEV: Minimum driving range ⊖, mileage ⊖, env. awareness ⊕
Aguilar et al. (2015)	Gasoline: Age ⊕, region (West ⊕), attitude (ethanol avoidance ⊕)			**BASE (BV E10)**; BV E85: Age ⊖, female ⊖, attitude (ethanol avoidance ⊖)	
Bahamonde-Birke and Hanappi (2016)	**BASE (gasoline)**	Age ⊖, env. awareness ⊕	Age ⊖, env. awareness ⊕		PHEV: Age ⊖, env. awareness ⊕
Batley et al. (2004)	Gasoline: Age ⊖, env. awareness ⊖, children in HH ⊖, no. of vehicles ⊕				**BASE (AFV)**
Bauer (2015)[1]	Gasoline: Env. awareness ⊖, attitude (AFV purchase ⊖); Diesel: Env. awareness ⊖, attitude (AFV purchase ⊖, symbolism ⊕), perceived behavioral control ⊕	Attitude (AFV purchase ⊕), perceived behavioral control ⊖	Env. awareness ⊕, attitude (AFV purchase ⊕), perceived behavioral control ⊖	NGV: Attitude (symbolism ⊖)	
Caulfield et al. (2010)[1]	Gasoline: Importance of vehicle attributes (fuel consumption ⊖, performance ⊕)	Willingness to detour ⊕, male ⊖, income ⊕, small vehicle ⊕, importance of vehicle attributes (purchase price ⊕)			AFV: Willingness to detour ⊕, age ⊕, income ⊕, importance of vehicle attributes (reliability ⊕, emissions ⊕)

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Cherchi (2017)	Gasoline: Social signaling*prior participation in BEV survey ⊖		Negative information on BEVs ((need to change) behavior, range, parking options ⊖), injunctive norm ⊕, BEV market share*no prior participation in BEV survey ⊕		**BASE (no vehicle)**
Daziano (2015)	**BASE (gasoline)**	Env. Awareness ⊕, attitude (pro-safety ⊖)			AFV: Env. Awareness ⊖, attitude (pro-safety ⊕); FCEV: Env. Awareness ⊕, attitude (pro-safety ⊖)
Daziano and Bolduc (2013)	**BASE (gasoline)**	Env. awareness ⊕			AFV: Env. awareness ⊕; FCEV: Env. awareness ⊕
Ewing and Sarigöllü (1998)	**BASE (gasoline)**		Age ⊖, vehicle cost minimizer ⊖, env. awareness ⊕, WTP for ZEV ⊕		AFV: Age ⊖, home owner ⊕, no. of vehicles ⊖, env. awareness ⊕, WTP for ZEV ⊕
Ewing and Sarigöllü (2000)	**BASE (gasoline)**		Env. awareness ⊕		AFV: Env. awareness ⊕
Glerum et al. (2014)	Gasoline: Income ⊖, age ⊕, recent vehicle purchase ⊕, commute by public transportation ⊖, Renault buyer ⊕, no. of vehicles*Renault buyer ⊖, French speaking ⊕		**BASE**		
Hackbarth and Madlener (2013)	**BASE (gasoline)**	Mini / small vehicle ⊖	Age ⊖, env. awareness ⊕, home-charging possibility ⊕, share of city trips ⊕, mini / small vehicle ⊕	BV: Env. awareness ⊕, education ⊕; NGV: Share of city trips ⊖	PHEV: Env. awareness ⊕, home-charging possibility ⊕, education ⊕; Hydrogen: Env. awareness ⊕
Helveston et al. (2015)	**BASE (gasoline)**	US: Income ⊖, children in HH ⊖, attitude (environmental appearance ⊕); China: Attitude (env. appearance ⊕)	US: Income ⊖, education ⊕, married ⊖, HH size ⊖, attitude (environmental appearance / status symbol ⊕); China: Married ⊕, children in HH ⊖, home charging possibility ⊕, no. of vehicles ⊕, attitude (env. appearance ⊕, status symbol ⊖)		PHEV: US: Income ⊖, female ⊖, attitude (environmental appearance / status symbol ⊕); China: HH size ⊕, married ⊕, children in HH ⊖, home charging possibility ⊕, attitude (env. appearance ⊕, status symbol ⊖)
Hensher et al. (2011)		**BASE**; Male ⊖			
Hensher et al. (2013)		**BASE**; Male ⊖			
Hensher et al. (2017)	Gasoline: Influence of secondary decision-maker ⊕ (age ⊕, male ⊖), primary decision-maker (age ⊖); Diesel: Influence of secondary decision-maker (male ⊖), primary decision-maker (age ⊖)	**BASE**; Influence of secondary decision-maker ⊕ (age ⊕)			
Hidrue et al. (2011)	**BASE (gasoline)**		Age ⊖, education ⊕, env. awareness ⊕, home-charging possibility ⊕, small / medium vehicle, buyer of new products ⊕, expecting increasing fuel prices ⊕, no. of long drives ⊖, next vehicle purchase is HEV ⊕		

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Hoen and Koetse (2014)	**BASE (gasoline)**	Commute frequency ⊖, presence of vehicles in HH (diesel ⊕, NGV ⊖), caravan ⊖	Commute frequency ⊖, mileage ⊖, presence of vehicles in HH (diesel ⊕, NGV ⊖), caravan ⊖, vehicle usage (holidays ⊕), home-charging possibility ⊕	BV: Commute frequency ⊖, presence of vehicles in HH (diesel / NGV ⊖), caravan ⊖	PHEV: Commute frequency ⊖, presence of vehicles in HH (diesel / NGV ⊖), caravan ⊖; FCEV: Commute frequency ⊖, mileage ⊖, presence of vehicles in HH (diesel / NGV ⊖), caravan ⊖
Jacobs et al. (2016)	**BASE (gasoline)**		Owner of energy-efficient house ⊕		PHEV: Owner of energy-efficient house ⊕
Jansson et al. (2017a)	**BASE (gasoline)**			BV: Social norm ⊕, male ⊕, HH size ⊕	HEV/PHEV/BEV: Personal norm ⊕, env. awareness ⊖, personality (opinion leader ⊕, opinion seeker ⊖), age ⊕, income ⊕, HH size ⊕, children in HH ⊕
Jansson et al. (2017b)	**BASE (gasoline)**				AFV: share of AFVs among others (neighbor, family ⊕), income ⊕, education ⊕, age ⊕, female ⊕, green party voter ⊕
Javid and Nejat (2017)	**BASE (gasoline)**				PHEV/BEV: Income ⊕, carsharing user ⊕, education ⊕
Jensen et al. (2013)	**BASE (gasoline)**		Mini / small / medium vehicle ⊕, used vehicle ⊕, no. of vehicles ⊕, male ⊖, env. awareness ⊕		
Kim et al. (2014)	**BASE (gasoline)**		Male ⊕, age ⊖, children in HH ⊕, education ⊕, income ⊕, positive reviews ⊕, share of BEVs among friends and acquaintances / members of larger family ⊕, env. awareness ⊕, attitude (innovation ⊕, economic / battery / technological ⊖)		
Kim et al. (2016)	**BASE (gasoline)**		Education ⊕, positive reviews ⊕, share of BEVs among members of larger family ⊕, env. Awareness ⊕, attitude (innovation ⊕, battery ⊖)		
Knockaert (2010)	**BASE (gasoline)** ; Diesel: Male ⊖, HH size ⊕		Social class ⊕	NGV: HH size ⊕	AFV: Male ⊖, HH size ⊕
Krause et al. (2016)	**BASE (gasoline)**	Env. awareness ⊕, income ⊕, presence of HEV in HH ⊕	Male ⊕, env. awareness ⊕, education ⊕, presence of HEV in HH ⊕, no. of children ⊕		PHEV: Env. awareness ⊕, education ⊕, presence of HEV in HH ⊕, no. of children ⊕
Langbroek et al. (2016)	**BASE (gasoline)**		Stage-of-change (self-efficacy / response efficacy ⊕)		

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Li et al. (2013)	**BASE (gasoline)**	Age ⊕, Caucasian ⊖, male ⊖, Republican ⊖, children in HH ⊖, rural ⊖, corn producing county ⊕, presence of HEV in HH ⊕, mileage ⊖, detour frequency ⊕, concerned with climate change ⊕, contra biofuels ⊕, beliefs (oil dependency threats national security ⊕, unavailability of biofuels ⊕), env. information sources (magazines / internet / friends ⊕)		BV: Age ⊖, education ⊕, income ⊖, rural ⊕, clean air act county ⊖, region (South / West ⊕), presence of vehicles in HH (HEV ⊖, BV ⊕), leasing ⊖, detour frequency ⊕, years until next purchase ⊕, concerned with climate change ⊕, contra biofuels ⊖, beliefs (oil dependency threats national security ⊕, unavailability of biofuels ⊖, expensiveness of BVs ⊖), env. information sources (magazines ⊕)	
Link et al. (2012)[1]	Gasoline: Main vehicle ⊕, small vehicle ⊖, vehicle age ⊖, no replacement planned ⊕, part-time employed ⊕, male ⊕, age ⊕, children in HH ⊕, income ⊕, garage owner ⊖, trips made with BEV ⊖, WTP for BEV ⊖, willingness to purchase BEV ⊖, accepted charging time ⊖, reason for decision (time exposure ⊕, environment ⊖, running costs ⊖)	Main vehicle ⊕, small vehicle ⊕, vehicle age ⊕, no replacement planned ⊕, part-time employed ⊖, male ⊕, age ⊕, children in HH ⊖, income ⊕, garage owner ⊖, trips made with BEV ⊕, WTP for BEV ⊖, willingness to purchase BEV ⊖, accepted charging time ⊕, reason for decision (time exposure ⊕, environment ⊖, running costs ⊕)	Main vehicle ⊖, small vehicle ⊖, vehicle age ⊖, no replacement planned ⊖, part-time employed ⊖, male ⊖, age ⊖, children in HH ⊖, income ⊖, garage owner ⊕, trips made with BEV ⊖, WTP for BEV ⊕, willingness to purchase BEV ⊕, accepted charging time ⊕, reason for decision (time exposure ⊖, environment ⊕, running costs ⊕)		
Mabit and Fosgerau (2011)	**BASE (gasoline)**		Male ⊖		FCEV: Male ⊖
Mabit et al. (2015)	**BASE (gasoline)** ; Diesel: Service ⊕	Employed ⊕, appreciation of vehicle features ⊕	Male ⊖, employed ⊕, appreciation of vehicle features ⊕	BV: Employed ⊕, appreciation of vehicle features ⊕	
Mannberg et al. (2014)	**BASE (gasoline)**			BV: Congestion tax ⊕, presence of BV in HH ⊕, education ⊕, region (Stockholm / Göteborg ⊕, Malmö ⊖), age ⊖, works in city center ⊕, married ⊕, no. of children ⊕, unemployed / retired ⊖, partner owns car ⊖, non-European / non-American origin ⊖	

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Nixon and Saphores (2011)	**BASE (gasoline)**	Education ⊕, env. awareness ⊕, concerned with oil imports ⊕, SUV ⊖	Age ⊕, env. awareness ⊕, concerned with oil imports ⊕, pick-up / minivan ⊖, region (Northeast ⊖)	NGV: Env. awareness ⊕, concerned with oil imports ⊕, region (Northeast ⊖)	FCEV: Age ⊖, env. awareness ⊕, concerned with oil imports ⊕, pick-up / SUV ⊖
Qian and Soopramanien (2011)	**BASE (gasoline)**	No. of children ⊖, no. of drivers ⊖, income ⊕, no. of vehicles ⊕, commute distance ⊖, male ⊖	No. of children ⊖, no. of drivers ⊖, HH size ⊕, income ⊕, no. of vehicles ⊕, commute distance ⊖, male ⊖		
Ramjerdi and Rand (2000)	Gasoline: Non-vehicle HH ⊖, income ⊕, age (young / old ⊕)		Commute distance ⊖		**BASE (AFV)**
Rasouli and Timmermans (2016)	**BASE (gasoline)**		Male ⊖, age ⊖, children in HH ⊕, education (middle specialized / higher vocational ⊕, middle general / middle vocational / university ⊖), income ⊕, positive reviews ⊕, share of BEVs among friends and acquaintances / members of larger family ⊖		
Rouwendal and de Vries (1999)	**BASE (gasoline)** ; Diesel: Male ⊕, age ⊖			NGV: Male ⊕, age ⊖	
Rudolph (2016)	**BASE (gasoline)**				ZEV: Mileage ⊕, annual transit pass ⊕, bike usage ⊕, public transportation usage ⊕
Sentürk et al. (2011)	**BASE (gasoline)** ; Diesel: No. of vehicles ⊖, env. awareness ⊕, male ⊖, perception of AFVs ⊕	No. of vehicles ⊖, env. awareness ⊕, social responsibility ⊕, age ⊕, perception of AFVs ⊕		NGV: No. of vehicles ⊖, env. awareness ⊕, perception of AFVs ⊕	
Smith et al. (2017)	**BASE (diesel)**; Male ⊕		Social norm ⊕		
Valeri and Cherchi (2016)	**BASE (gasoline)**; Habitual behavior ⊖; Diesel: Education ⊖			NGV: Habitual behavior ⊕	
Valeri and Danielis (2015)	**BASE (gasoline)**		Garage owner ⊕		
Wang et al. (2017)	**BASE (gasoline)**		Income ⊕, attitude (BEV awareness / policy awareness ⊖, BEV confidence ⊕)		
Whitehead et al. (2014)	**BASE (gasoline, diesel)**; Low CO_2 gasoline: Region (Stockholm cordon ⊕), distance from inner-city ⊖, commute distance ⊕, income ⊖, no. of vehicles ⊕, age ⊖, female ⊕; Low CO_2 diesel: Region (Stockholm cordon ⊕), commute distance ⊕, no. of vehicles ⊕, age ⊖, female ⊕		Region (Stockholm cordon ⊕), commute across boundary ⊕, distance from inner-city ⊖, commute distance ⊕, income ⊕, no. of children ⊖, age ⊕	BV: Region (Stockholm cordon ⊕), commute across boundary ⊕, region (Stockholm cordon)*commute across boundary ⊕, distance from inner-city ⊖, commute distance ⊕, income ⊖, no. of children ⊖, no. of vehicles ⊖	

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Ziegler (2012)	**BASE (gasoline)** ; Diesel: Mileage ⊕, minimum driving range ⊕, main vehicle usage (commute ⊖), first-hand vehicle ⊖	First-hand vehicle ⊖	Mileage ⊕, minimum driving range ⊕, age ⊖, env. awareness ⊕	BV: Company vehicle ⊕, age ⊖, env. awareness ⊕, no. of vehicles ⊕, first-hand vehicle ⊖; NGV: Age ⊖, male ⊕, main vehicle usage (commute ⊕)	FCEV: Minimum driving range ⊕, age ⊖, male ⊕, env. awareness ⊕, small vehicle ⊕
Zito and Salerno (2004)	**BASE (gasoline)**		Age ⊖, female ⊕, garage owner ⊕		
Fuel and vehicle type choice					
Adler et al. (2003)	**BASE (gasoline)**	Region (San Diego ⊖, LA / San Fransisco / Sacramento ⊕)			
Antolín et al. (2018)	**BASE (diesel)**	Income ⊕, education ⊕, no. of vehicles ⊖, rural ⊖	Education ⊕, rural ⊕		
Brownstone and Train (1999)	**BASE (gasoline)**		Commute frequency ⊖, education ⊕	BV: Education ⊕	
Brownstone et al. (2000)	**BASE (gasoline)**		Education ⊕, pick-up / sport coupé ⊖		
Bunch et al. (1993)	**BASE (gasoline)**; Income ⊕		Education ⊕, age ⊖, 1-car HH ⊖, SUV ⊖		
Cirillo et al. (2017)	**BASE (gasoline)**	Age ⊖, education*male ⊖	Age ⊖, education*male ⊕		Current vehicle: no. of workers ⊖, no. of vehicles ⊕
DeShazo et al. (2017)	**BASE (gasoline)**		Sedan / hatchback / SUV / pick-up / van / coupé ⊖		
Dumortier et al. (2015)	**BASE (gasoline)**	Education*passenger car ⊕, information about TCO*passenger car ⊕, age ⊖, awareness of public charging stations ⊕, income*SUV ⊖, presence of AFV in HH ⊕	Education*SUV ⊖, information about TCO*passenger car ⊕, awareness of public charging stations ⊕, age ⊖, income*SUV ⊕		PHEV: No. of passenger cars ⊖, information about TCO*passenger car ⊕, awareness of public charging stations ⊕, age ⊖, presence of AFV in HH*passenger car ⊕
Hackbarth and Madlener (2018)	**BASE (gasoline)** ; Diesel: Env. mobility ⊖, importance of vehicle attributes (vehicle tax / uniqueness ⊖, fuel type ⊕), children in HH ⊕, main vehicle ⊕, mileage ⊕, company car ⊕				AFV: Env. behavior ⊕, knowledge about AFVs ⊕, importance of vehicle attributes (fuel consumption and cost / fuel type ⊕, horsepower ⊖), rural ⊖, mileage ⊕, recent vehicle purchase ⊖, premium OEM ⊖
Hahn et al. (2018)	**BASE (gasoline)**; Male*large / executive vehicle ⊕, age*large vehicle ⊖, no. of vehicles*small vehicle ⊖, income*executive vehicle ⊕	Income*smalle vehicle ⊖, HH size*executive vehicle ⊕	Male*executive vehicle ⊕, age*large / executive vehicle ⊕, no. of vehicles*executive vehicle ⊖, income*large / executive vehicle ⊕, knowledge about AFVs*small / medium / large / executive vehicles ⊕		PHEV: Male*vehicle type (small ⊕, medium ⊖), no. of vehicles*executive vehicle ⊖, income*small / medium vehicle ⊖, HH size*large vehicle ⊕
He et al. (2012)	**BASE (gasoline)**	Highway driver ⊖			
He et al. (2014)	**BASE (gasoline)**	Education ⊕, social impact ⊕			
Hensher and Greene (2006)	**BASE (gasoline)**		Small vehicle ⊖		AFV: Small vehicle ⊖

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Higgins et al. (2017)	**BASE (gasoline)**	Urban*large / SUV / pick-up ⊕, income*small / SUV / pick-up ⊕, age*luxury / MPV / SUV / pick-up ⊖, education*medium / SUV ⊕, French speaking*small / medium vehicle ⊖, female*small ⊕, importance of vehicle attributes (fuel economy*small / medium / large / MPV / SUV / pick-up ⊕, emissions reduction*small / medium / large / luxury / MPV / SUV / pick-up ⊕, performance*MPV / SUV ⊖, spaciousness*SUV ⊖, cargo space*large vehicle ⊖, maintenance costs*small / medium vehicle ⊖, technology*small / medium / large / SUV ⊕)	Urban*small / medium / large / MPV / SUV / pick-up ⊕, HH size*small / medium / SUV / pick-up ⊕, income*large / luxury / MPV ⊕, age*small / medium / large / luxury / MPV / SUV / pick-up ⊖, children in HH* medium vehicle ⊖, education*small/ medium / MPV / SUV / pick-up ⊕, no. of vehicles*medium vehicle ⊕, mileage*medium / MPV ⊖, time until next vehicle purchase (small ⊕, pick-up ⊖), replacement vehicle*small / medium / luxury / MPV / SUV ⊖, French speaking*small / large / luxury/ SUV ⊕, female*medium / large / luxury / SUV ⊖, importance of vehicle attributes (fuel economy*small / medium / large / luxury / SUV / pick-up ⊕, emissions reduction*small / medium / large / luxury / MPV / SUV / pick-up ⊕, performance*MPV / SUV / pick-up ⊖, luxuriousness*large vehicle ⊖, spaciousness*small / medium / large / luxury / SUV ⊖, cargo space*small / large / MPV ⊖, maintenance costs (medium vehicle ⊖, large vehicle ⊕), technology*large / SUV ⊕)		PHEV: Urban*large / SUV / pick-up ⊕, income*small / medium / large / luxury / MPV / SUV ⊕, age*small / medium / large / luxury / MPV / SUV / pick-up ⊖, education*small/ medium / MPV / SUV ⊕, no. of workers*small vehicle ⊖, no. of vehicles*small / pick-up ⊖, mileage*MPV ⊖, time until next vehicle purchase*small / medium / large / SUV ⊕, French speaking*large / luxury ⊕, female*medium / large / luxury / SUV ⊖, importance of vehicle attributes (fuel economy*small / medium / large / luxury / MPV / SUV / pick-up ⊕, emissions reduction*small / medium / large / luxury / MPV / SUV / pick-up ⊕, performance*luxury / MPV / SUV / pick-up ⊖, luxuriousness*medium / large vehicle ⊖, spaciousness*small / large / SUV ⊖, cargo space*smedium / large vehicle ⊖, maintenance costs*small / medium ⊖, technology*large / SUV ⊕)
Jäggi et al. (2013)	**BASE (diesel)**				AFV: Income ⊖, fuel costs ⊕, commute distance ⊕, male ⊖, urban ⊕, presence of same vehicle type in HH ⊕, accessibility of public transportation ⊕
Lee and Cho (2009)	**BASE (gasoline)** ; Diesel: Female*small / medium / large vehicle ⊖, married*small / medium / large vehicle ⊕, married*executive vehicle ⊖, mileage* small / medium / large vehicle ⊕, mileage*executive vehicle ⊖				
Liu (2014)	**BASE (gasoline)**	Income ⊕, HH size ⊖, suburban / urban ⊕			
Liu and Cirillo (2018)	**BASE (gasoline)**	Age ⊖	Age ⊖, education*male ⊕		Current vehicle: no. of workers ⊖, no. of vehicles ⊕

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Table A.7 *(continued)*

Study	CFV	HEV	BEV	NGV / BV	Others
Mabit (2014)	**BASE (gasoline)**; Diesel: Commute distance ⊕, age ⊖, male ⊕, region (Copenhagen ⊖)				
Musti and Kockelman (2011)	**BASE (gasoline)**	Age ⊕, HH size ⊖, female ⊕			PHEV: Age ⊕, HH size ⊕, income ⊕, no. of vehicles ⊖, urban ⊕
Paleti et al. (2011)	**BASE (gasoline)**; Presence of vehicles in HH (small cross utility vehicle / van ⊖), replaced vehicle (medium / small cross utility vehicle / pick-up ⊖); Diesel: No. of female adults ⊖, income ⊕, rural ⊕, education ⊕, children in HH (older ⊕), no. of full-time workers ⊕, presence of vehicles in HH (medium / large / SUV / pick-up ⊕), replaced vehicle (large / SUV / pick-up ⊕, gasoline ⊖)	No. of male adults ⊖, income ⊕, suburban ⊖, rural ⊕, education ⊕, seniors in HH ⊕, no. of part-time workers from home ⊕, presence of vehicles in HH (medium / large / SUV / pick-up ⊕, small cross utility vehicle / van ⊖), replaced vehicle (pick-up ⊖, gasoline ⊕)	No. of female adults ⊕, suburban ⊖, education ⊕, children in HH (younger ⊕), Caucasian ⊕, presence of vehicles in HH (medium / large / SUV ⊕), replaced vehicle (gasoline ⊖)	BV: Income ⊖, suburban ⊖, education ⊕, seniors in HH ⊖, no. of full-time workers from home ⊖, presence of vehicles in HH (medium / large / SUV / pick-up ⊕), replaced vehicle (pick-up ⊖, gasoline ⊕); NGV: Caucasian ⊖, no. of workers from home (full-time ⊖, part-time ⊕), presence of vehicles in HH (medium / large / SUV ⊕)	PHEV: No. of male adults ⊖, income ⊕, suburban ⊖, education ⊕, Caucasian ⊖, no. of full-time workers from home ⊖, presence of vehicles in HH (medium / large / SUV / pick-up ⊕), replaced vehicle (pick-up ⊖, large / van / gasoline ⊕)
Potoglou and Kanaroglou (2007)	**BASE (gasoline)**	Education ⊕, income ⊕, region (Burlington ⊕)			AFV: Age ⊖, region (Burlington ⊕)
Shin et al. (2015)	**BASE (gasoline)**; Diesel: Male ⊕, income ⊖, usefulness of vehicle features (voice command ⊖, smart apps ⊕), non-driver ⊖, mileage ⊕	Male ⊕, income ⊕, age ⊖, usefulness of vehicle features (smart apps ⊕), non-driver ⊖, mileage ⊕	Male ⊕, income ⊕, age ⊖, usefulness of vehicle features (connectivity ⊖), non-driver ⊖, mileage ⊕		
Soto et al. (2018)	**BASE (gasoline)**; Diesel: Env. awareness ⊕, attitude (green transportation policy support ⊕, pro-car use ⊖)	Env. awareness ⊕, attitude (green transportation policy support ⊕)	Env. awareness ⊕, attitude (green transportation policy support / technophilia ⊕, pro-car use ⊖)	NGV: Env. awareness ⊕	
Tompkins et al. (1998)	**BASE (gasoline)**				AFV: No of vehicles on road ⊕

Notes: 1 = model without base alternative; ⊕ = positive effect; ⊖ = negative effect; ZEV = zero-emission vehicle; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; AFV = alternative fuel vehicle; BV = biofuel vehicle; PHEV = plug-in hybrid electric vehicle; MPV = multi purpose vehicle; SUV = sport utility vehicle; OEM = original equipment manufacturer; Env. = environmental; Pop. = population; HH = household; WTP = willingness-to-pay; TCO = total costs of ownership.

Table A.8: Results of the vehicle type choice literature

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Fuel and vehicle type choice										
Antolín et al. (2018)		**BASE;** No. of adults ⊖, no. of children ⊖	Income ⊕	Income ⊕	Luxury: Income ⊕, no. of vehicles ⊕		Income ⊕	Income ⊕		
Brownstone et al. (2000)				**BASE**	**BASE (executive)**	HH size ⊖	HH size ⊕			
DeShazo et al. (2017)						No. of vehicles ⊕			**BASE**	
Hackbarth and Madlener (2018)	Female ⊕, env. awareness ⊕, importance of vehicle attributes (fuel consumption and costs ⊕, size ⊖), children in HH ⊖, carsharing user ⊕, main vehicle ⊖, mileage ⊖	Age ⊖, female ⊕, env. awareness ⊕, importance of vehicle attributes (fuel consumption and costs ⊕, size ⊖), children in HH ⊖, carsharing user ⊕, main vehicle ⊖, mileage ⊖	Env. awareness ⊕, importance of vehicle attributes (size / uniqueness ⊖), children in HH ⊖, carsharing user ⊕, main vehicle ⊖, premium OEM ⊕	Technophilia ⊕, importance of vehicle attributes (uniqueness ⊖, driving range ⊕), no. of vehicles ⊖, main vehicle ⊖, premium OEM ⊕	Executive: Env. awareness ⊕, premium OEM ⊕; Luxury: No. of vehicles ⊖, premium OEM ⊕	Technophilia ⊕, importance of vehicle attributes (size ⊖, appearance and design ⊕)	Importance of vehicle attributes (size ⊕, horsepower / uniqueness ⊖), children in HH ⊕, no. of vehicles ⊖, rural ⊕, premium OEM ⊖	**BASE**		Others: Importance of vehicle attributes (size⊕, horsepower / appearance and design ⊖), main vehicle usage (commute ⊖), main vehicle ⊖, mileage ⊖, premium OEM ⊖
He et al. (2014)			**BASE**				No. of children ⊕	No. of children ⊖		
Hess et al. (2012)		**BASE**		HH size ⊕, AFV ⊕	Executive: HH size ⊕, AFV ⊖					
Ito et al. (2013)		**BASE**	**BASE**			HH size ⊕, female ⊖			Female ⊖	Convertible / Sedan: Age ⊖
Jäggi et al. (2013)	**BASE (diesel)**; Gasoline: Commute distance ⊕, male ⊖, age ⊕, presence of same vehicle type in HH ⊕	Income ⊖, commute distance ⊕, age ⊕, presence of same vehicle type in HH ⊕	Income ⊖, commute distance ⊕, urban ⊕, presence of same vehicle type in HH ⊕	Income ⊕, commute distance ⊕, age ⊕, urban ⊕, presence of same vehicle type in HH ⊕	Executive: Income ⊕, commute distance ⊕, urban ⊖, presence of same vehicle type in HH ⊕; Luxury: Urban ⊕, age ⊕, commute distance ⊕, male ⊕, presence of same vehicle type in HH ⊕	Income ⊕, commute distance ⊕, urban ⊖, presence of same vehicle type in HH ⊕	Income*diesel ⊖, income*gasoline ⊕, commute distance ⊕, male ⊖, age ⊕, presence of same vehicle type in HH ⊕			
Kavalec (1999)							Age ⊕		Age ⊕	**BASE (passenger car)**; Station wagon: Age ⊕
Mabit (2014)	Single HH ⊕, children in HH ⊕	Single HH ⊕	**BASE**	Children in HH ⊕	Executive: Children in HH ⊕		Single HH ⊖, children in HH ⊕			

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Table A.8 *(continued)*

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Musti and Kockelman (2011)		Income ⊖, age ⊕	Income ⊖, age ⊕, female ⊖	Income ⊖, age ⊖, urban ⊕			HH size ⊕, no. of vehicles ⊕, suburban ⊕	HH size ⊕, suburban ⊕	No. of vehicles ⊖	**BASE (cross-utility vehicle)**
Paleti et al. (2011)			Income ⊕, education ⊕, children in HH (younger ⊖), Caucasian ⊕, no. of part-time workers from home ⊕, presence of vehicles in HH (large / small cross-utility vehicle / SUV / van ⊕, medium / pick-up ⊖), replaced vehicle (large / small cross-utility vehicle / SUV / pick-up ⊖, medium / gasoline ⊕)	No. of male adults ⊕, income ⊕, seniors in HH ⊕, Caucasian ⊕, no. of workers (full-time ⊖ / part-time ⊕, presence of vehicles in HH (large / SUV / van / pick-up ⊖), replaced vehicle (large / SUV / van / pick-up ⊕)			No. of male adults ⊕, income ⊕, education ⊕, children in HH (younger ⊕), no. of workers from home (full-time / part-time ⊕), presence of vehicles in HH (medium / large / SUV / van / pick-up ⊖), replaced vehicle (van ⊕)	No. of adults ⊕, income ⊕, sub-urban ⊕, education ⊕, children in HH (younger ⊕), no. of workers from home (full-time / part-time ⊕), presence of vehicles in HH (medium / large / SUV / van / pick-up ⊖), replaced vehicle (SUV / van ⊕)	No. of male adults ⊕, income ⊕, sub-urban / rural ⊕, education ⊖, no. of part-time workers ⊕, presence of vehicles in HH (medium / large / SUV / pick-up ⊖), replaced vehicle (large / gasoline ⊖, SUV / pick-up ⊕)	**BASE (no vehicle)**; Small cross utility vehicle: Income ⊕, education ⊕, children in HH ⊖, presence of vehicles in HH (medium / large / SUV / pick-up ⊖), replaced vehicle (small cross-utility vehicle / gasoline ⊕)
Potoglou and Kanaroglou (2007)		**BASE**					HH size ⊕	Pop. density ⊖		
Shin et al. (2015)								Income ⊖, age ⊖, non-driver ⊕, mileage ⊕		**BASE (sedan)**
Xu et al. (2015)		**BASE**	HH size ⊖				HH size ⊕	HH size ⊖		Sedan / station wagon: HH size ⊖
Vehicle type choice										
Adjemian et al. (2010)[1]			Pop. density ⊕, income ⊖, HH size ⊖, no. of licensed drivers ⊕, age ⊖, job (construction ⊖, transportation ⊖)	Spatially aggregated ownership ⊕, pop. density ⊖, no. of vehicles ⊖, age ⊕, Asian ⊕, job (transportation ⊖, legal ⊕)	Executive: Income ⊕, no. of vehicles ⊕, age ⊕; Luxury: Spatially aggregated ownership ⊕, income ⊕, age ⊕, Black ⊕	Income ⊕, no. of vehicles ⊕, HH size ⊖, home owner ⊖, no. of licensed drivers ⊖, female ⊕, age ⊖, Black ⊕	HH size ⊕, home owner ⊕, no. of licensed drivers ⊖, female ⊖, job (finance ⊖)	Home owner ⊕, age ⊖	Spatially aggregated ownership ⊕, income ⊖, no. of vehicles ⊕, age ⊖, Asian ⊖, job (agriculture ⊕, construction ⊕)	Station wagon: Pop. density ⊖, age of house ⊕, no. of vehicles ⊖, no. of licensed drivers ⊕

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Table A.8 *(continued)*

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Baltas and Saridakis (2013)	Importance of vehicle attributes (image ⊕, quality ⊕, interior ⊖), male ⊖, income ⊖, married ⊕, objective driving skills ⊖, willingness to purchase ZEV ⊕, main vehicle usage (commute ⊖), information sources (friends / relatives ⊕, brochures ⊖, internet ⊕), consumer involvement with cars (social status ⊖, interpersonal ⊕), attachment to cars ⊖	Importance of vehicle attributes (technical ⊕, interior ⊖, driving ⊕), male ⊖, married ⊖, urban ⊖, objective driving skills ⊖, subjective driving skills ⊖, information sources (brochure ⊕, own knowledge ⊕)	Importance of vehicle attributes (interior ⊖, driving ⊕), income ⊖, education ⊕, objective driving skills ⊖, willingness to purchase ZEV ⊖, main vehicle usage (commute ⊖, family ⊕), information sources (friends / relatives ⊕, internet ⊕, own knowledge ⊕), involvement with cars (emotional ⊕), attachment to cars ⊖	Importance of vehicle attributes (costs ⊕, performance ⊕), income ⊖, married ⊕, objective driving skills ⊖, willingness to purchase ZEV ⊖, main vehicle usage (commute ⊖, family ⊕), information sources (own knowledge ⊕)	Executive: Urban ⊕, main vehicle usage (family ⊕), information sources (own knowledge ⊕); Luxury: Importance of vehicle attributes (interior ⊖, image ⊕), urban ⊕, willingness to purchase ZEV ⊖, main vehicle usage (commute ⊖), information sources (internet ⊕, own knowledge ⊕), involvement with cars (social status ⊕)	Importance of vehicle attributes (costs ⊖, technical ⊕, performance ⊕, image ⊕, interior ⊖, driving ⊕), male ⊖, married ⊖, urban ⊕, willingness to purchase ZEV ⊖, main vehicle usage (entertainment ⊕, family ⊕), information sources (friends / relatives ⊕, brochures ⊕, showrooms ⊕, magazines / TV ⊖, internet ⊕, own knowledge ⊕), involvement with cars (emotional ⊕, interpersonal ⊕, social status ⊕), attachment to cars ⊖	Importance of vehicle attributes (quality ⊕, equipment ⊖), male ⊖, married ⊕, urban ⊕, main vehicle usage (work ⊖), information sources (magazines ⊖)	**BASE**		Station wagon: Importance of vehicle attributes (interior ⊖, performance ⊕, quality ⊕), male ⊖, urban ⊖, subjective driving skills ⊖, main vehicle usage (commute ⊖), information sources (brochures ⊕, own knowledge ⊕)
Bhat and Sen (2006)							Children in HH ⊕, HH size ⊕, mobility-challenged person in HH ⊕, no. of workers ⊖, income ⊖	Children in HH ⊕, pop. density ⊖	Income ⊖, no. of males ⊕, pop. density ⊖	**BASE (passenger car)**

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Table A.8 *(continued)*

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Bhat et al. (2009)		Income ⊖, children in HH ⊕, no. of workers ⊕, suburban ⊖, residential acres within 1 mile ⊕, age ⊖, male ⊖, Asian / other ⊕	Income ⊖, children in HH ⊕, seniors in HH ⊕, no. of workers ⊕, suburban ⊖, residential acres within 1 mile ⊕, age ⊖, male ⊖, Asian ⊕	Income ⊖, children in HH ⊕, seniors in HH ⊕, HH size ⊕, residential acres within 1 mile ⊖, age ⊕, Asian ⊕	Executive: Income ⊖, seniors in HH ⊕, HH size ⊕, no. of workers ⊖, suburban ⊖, no. of HH in multi-family dwellings ⊖, age ⊕, male ⊕, Black / Hispanic / Other ⊕	**BASE (new coupé)**; Old coupé: Income ⊖, age ⊕, male ⊕	Minivan: Income ⊖, children in HH ⊕, HH size ⊕, no. of workers ⊖, commercial acres within 1 mile ⊖, age ⊕, male ⊕, Asian / Other ⊕; Van: Income ⊖, children in HH ⊖, seniors in HH ⊕, HH size ⊕, residential acres within 1 mile ⊖, age ⊕, male ⊕, Asian / Hispanic ⊖	Income ⊕, children in HH ⊕, HH size ⊕, commercial acres within 1 mile ⊖, age ⊖, male ⊖, Asian ⊕	Income ⊖, HH size ⊕, no. of workers ⊕, suburban / rural ⊕, employment density ⊖, Black / Asian ⊖, residential / commercial acres within 1 mile ⊖, male ⊕	Station wagon: Income ⊖, seniors in HH ⊕, HH size ⊕, commercial acres within 1 mile ⊖, pop. density ⊕, male ⊕, Black ⊖
Biswas et al. (2014)		**BASE**						Importance of vehicle attributes (technical aspects ⊖, dimensions / reputation / technical specifications ⊕), employed ⊕, income ⊕		Sedan: Importance of vehicle attributes (technical aspects ⊖, dimensions / reputation / technical specifications ⊕), employed ⊕, income ⊕
Cao et al. (2006)							Home owner ⊕, no. of children ⊕, age ⊕, neighborhood preferences (outdoor spaciousness ⊕, accessibility ⊖)	No. of children ⊕, income ⊕, neighborhood preferences (outdoor spaciousness ⊕), travel attitudes (pro-bike / walk ⊕, safety of car ⊕), commute distance ⊕	Female ⊖, education ⊖, no. of vehicles ⊕, neighborhood preferences (outdoor spaciousness ⊕, accessibility ⊖), travel attitudes (pro-bike / walk ⊕, pro-transit ⊖)	**BASE (passenger car)**
Chiou et al. (2009)		**BASE**		Male ⊕, transit density ⊕	Executive: Male ⊕, transit density ⊕					

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Table A.8 *(continued)*

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Choo and Mokhtarian (2004)		Travel attitude (pro-high density ⊕), lifestyle (workaholic ⊖), travel liking ⊖, age ⊖, education ⊕, income ⊖, female ⊕, urban ⊕	Travel attitude (pro-high density ⊕), subjective mobility ⊖, education ⊕, female ⊕	Travel attitude (pro-high density ⊕), lifestyle (organizer ⊕), education ⊕, income ⊕, female ⊕, no. of children ⊕, no. of seniors ⊕, employed ⊖, job (sales ⊕)	Executive: Female ⊕, no. of seniors ⊕; Luxury: Travel attitude (travel dislike / pro-high density ⊕), lifestyle (frustrated ⊖, status seeking ⊕), objective mobility ⊕, education ⊕, income ⊕, female ⊕, no. of seniors ⊕, urban ⊕, employed ⊖, sales ⊕	Lifestyle (workaholic ⊖, status seeking ⊕), subjective mobility (short distance ⊕, long distance ⊖), age ⊖, education ⊕, female ⊕	Lifestyle (calm ⊕), education ⊕, no. of children ⊕, female ⊕, employed ⊖	Travel attitude (pro-high density ⊕), lifestyle (frustrated ⊖), age ⊖, education ⊕, income ⊕, female ⊕	**BASE**	
Eluru et al. (2010)			HH size ⊖, no. of children ⊕, no. of workers ⊕, female ⊕, income ⊖, home owner*neo-urbanist ⊖		Executive: HH size ⊕, no. of children*neo-urbanist ⊖, no. of workers ⊖, female ⊕, income ⊖, home owner*conv. ⊕, walk-time to transit stop ⊕, presence of coupé in HH ⊕	**BASE (coupé conv. neighborhood)**; No. of children*neo-urbanist ⊖, house owner*neo-urbanist ⊖	HH size ⊕, no. of children ⊕, income ⊖, home owner ⊕, walk-time to transit stop ⊕, presence of vehicles in HH (coupé ⊕, van ⊖)	No. of children ⊕, female*conv. ⊖, income ⊖, home owner*conventional ⊕, presence of vehicles in HH (coupé ⊕, pick-up / van ⊖)	HH size ⊕, no. of children*neo-urbanist ⊖, no. of workers ⊕, income ⊖, home owner*conv. ⊕, land-use mix ⊖, no. of zones accessible by bike within 6 miles ⊖, presence of vehicles in HH (coupé ⊕, van ⊖)	
Kitamura et al. (1999)						Vehicle type loyalty ⊕, age ⊕, male ⊖, no. of workers ⊕, income ⊖, single family house ⊖ no. of vehicles ⊖, pop. density ⊕, no. of licensed drivers ⊖, accessibility by car ⊖	Age ⊕, male ⊖, HH size ⊕, no. of vehicles ⊖, retail employees per acre ⊕	Vehicle type loyalty ⊖, male ⊖, income ⊕, accessibility of public transit ⊖, pop. density ⊕	**BASE**; employed ⊕, main vehicle usage (commute ⊖), income ⊖, group housing ⊖	4-door sedan: Vehicle type loyalty ⊕, age ⊕, male ⊖, education ⊕, commute distance ⊕, participated in purchase decision ⊖, no. of licensed drivers ⊕, no. of vehicles ⊖, accessibility by car ⊖, pop. density ⊕

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Table A.8 *(continued)*

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Kockelman and Zhao (2000)							HH size ⊕, pop. density ⊖, no. of vehicles ⊕	HH size ⊕, pop. density ⊖, income ⊕, no. of vehicles ⊕	HH size ⊖, pop. density ⊖, income ⊖, no. of vehicles ⊕	**BASE (passenger car)**
Kuwano et al. (2013)		**BASE**	Age ⊕, mileage ⊕	Age ⊕, mileage ⊕						
Lave and Train (1979)	**BASE**; No. of vehicles ⊕, HH size ⊕	No. of vehicles ⊕		Income ⊕, mileage ⊕, HH size ⊕	Luxury: Income ⊕, mileage ⊕, HH size ⊕	No. of vehicles ⊕				
Liu et al. (2014)[1]						No. of vehicles ⊕	No. of vehicles ⊖	No. of vehicles ⊖	No. of vehicles ⊕	Passenger car: No. of vehicles ⊖
Mannering et al. (2002)	**BASE**	Manufacturer (US ⊕, non-US ⊖)					HH size*US manufacturer ⊕	HH size ⊕		
McCarthy (1996)[1]			Urban ⊕							Passenger car: Index rating (crash test / consumer satisfaction ⊕)
Mohammadian and Miller (2002, 2003)		Job (professional ⊕), no. of same vehicle type in HH ⊕		Job (manager ⊕), no. of same vehicle type in HH ⊕	Executive: Job (manager ⊕), no. of same vehicle type in HH ⊕, male ⊕		**BASE**; Male ⊕, no. of children per adult ⊕	Job (manager ⊕), no. of same vehicle type in HH ⊕, male ⊕, education ⊖, age ⊖	Job (manager ⊕), no. of same vehicle type in HH ⊕, male ⊕, education ⊖, age ⊖	
Noblet et al. (2006)							**BASE**	Main vehicle usage (commute ⊕, hauling ⊖)		Passenger car: Main vehicle usage (commute ⊕, hauling ⊖)
Potoglou (2008)							No. of children ⊕, home owner ⊕	Non-vehicle commute ⊖, entropy index ⊖	No. of vehicles ⊕, home owner ⊕, education ⊖	**BASE (passenger car)**
Prieto and Caemmerer (2013)		**BASE (Used)**; New: Income ⊕, credit financing ⊕, city size ⊕, age ⊕, vehicle rank in HH fleet ⊖	Credit financing ⊕, male ⊕, vehicle rank in HH fleet ⊖; New: Income ⊕, unemployed ⊖, city size ⊕, age ⊕,; Used: children in HH ⊕	Credit financing ⊕, city size ⊕, HH size ⊕, children in HH ⊕, age ⊕, education ⊕, male ⊕, vehicle rank in HH fleet ⊖, manufacturer (French ⊖)	Luxury: Income ⊕, credit financing ⊕, HH size ⊕, children in HH ⊕, age ⊕, male ⊕, vehicle rank in HH fleet ⊖, manufacturer (French ⊖)					

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Table A.8 *(continued)*

Study	Mini	Small	Medium	Large	Executive / Luxury	Sport coupés	MPV	SUV	Pick-up truck	Others
Spissu et al. (2009)			**BASE**		Executive: Age ⊕, male ⊕, Hispanic ⊖, income ⊕, no. of children ⊕, no. of seniors ⊕, no. of workers ⊕, walk-time to transit stop ⊕, presence of same vehicle type in HH ⊕	Age ⊕, male ⊕, Hispanic / Asian ⊖, income ⊕, no. of children ⊖, no. of workers ⊖, employment density ⊖, land-use mix ⊖, presence of same vehicle type in HH ⊕	Age ⊕, male ⊖, Black ⊖, income ⊕, no. of children ⊕, no. of seniors ⊕, no. of workers ⊖, HH size ⊕, walk-time to transit stop ⊕, commercial / industrial acres within 1 mile ⊖, presence of same vehicle type in HH ⊖	Age ⊕, male ⊕, Asian / Other ⊖, income ⊕, no. of children ⊕, no. of seniors ⊖, no. of workers ⊖, commercial / industrial acres within 1 mile ⊖	Age ⊕, male ⊕, Black / Asian / Other ⊖, income ⊖, no. of children ⊕, employment density ⊖, land-use mix ⊖, no. of zones accessible by bike within 6 miles ⊖, walk-time to transit stop ⊕, presence of same vehicle type in HH ⊖	
Vekeman et al. (2004)	Income ⊖	**BASE;** Income ⊖	Income ⊕	Income ⊕, male ⊕, no. of vehicles ⊖, HH size ⊕, no. of children (younger ⊖, older ⊕), age (medium ⊕), rural ⊕, region (Montreal belt ⊖)	Executive: Income ⊕, male ⊕, no. of vehicles ⊖, HH size ⊕, no. of children (younger ⊕, older ⊖), age (medium ⊕), rural ⊕, region (Montreal belt ⊖)	Income ⊕, male ⊕, no. of vehicles ⊕, HH size ⊖, no. of children (younger ⊖, older ⊕), age ⊕, rural ⊕, region (Montreal belt ⊖)	Male ⊕, no. of vehicles ⊖, HH size ⊕, no. of children ⊕, age (medium ⊕), rural ⊕, region (Montreal belt ⊖)	Male ⊕, no. of vehicles ⊖, HH size ⊕, no. of children ⊕, age (medium ⊕), rural ⊕, region (Montreal belt ⊖)	Income ⊖, male ⊕, no. of vehicles ⊕, HH size ⊖, no. of children ⊕, age ⊖, rural ⊕, region (Montreal belt ⊖)	
West (2007)							Total expenditures ⊕, vehicle type loyalty ⊕, married ⊕, children in HH ⊕, age ⊕, home owner ⊕, education ⊕, no. of licensed drivers ⊖, no. of workers ⊖, Asian / Black ⊖, region (Midwest ⊕)	Total expenditures ⊕, vehicle type loyalty ⊕, presence of passenger car in HH ⊕, home owner ⊕, no. of licensed drivers ⊖	Presence of vehicle in HH (passenger car ⊖, SUV ⊕), vehicle type loyalty ⊕, male ⊕, education ⊖, Asian / Black ⊕, urban ⊖, region (Midwest / South / West ⊕)	**BASE (passenger car)**; Total expenditures ⊖, vehicle type loyalty ⊕, presence of 'other vehicle' in HH ⊖, male ⊖, married ⊖, children in HH ⊖, spouse education ⊕, age ⊖, home owner ⊖, no. of licensed drivers ⊕, Asian / Black ⊕, urban ⊕, region (Midwest / South / West ⊖)

Notes: 1 = model without base alternative; ⊕ = positive effect; ⊖ = negative effect; Truck = non-car vehicles; ZEV = zero-emission vehicle; AFV = alternative fuel vehicle; MPV = multi purpose vehicle; SUV = sport utility vehicle; OEM = original equipment manufacturer; Pop. = population; Env. = environmental; HH = household.

Table A.9: Estimation results: Significant main effects of vehicle attributes

Study	Vehicle attributes – Significant effects
Fuel type choice	
Abdoolakhan (2010)	NL: Purchase price ⊖, fuel costs ⊖, no. of doors ⊕, engine size ⊖; LCM with 2 classes: Class 1: Fuel costs ⊖, fuel consumption ⊖, automatic transmission ⊖; Class 2: Fuel costs ⊖, fuel consumption ⊕, automatic transmission ⊕
Achtnicht (2012)	Purchase price ⊖, fuel costs ⊖, emissions ⊖, fuel availability ⊕, horsepower ⊕
Achtnicht et al. (2012)	Purchase price ⊖, fuel costs ⊖, emissions ⊖, fuel availability*BEV ⊕, fuel availability*gasoline ⊖, horsepower ⊕
Aguilar et al. (2015)	Fuel costs ⊖, fuel efficiency ⊕
Axsen et al. (2013)	Purchase price ⊖, acceleration ⊕, driving range ⊕
Axsen et al. (2015)	LCM with 5 classes: Class 1: Purchase price ⊖, home charging possibility*BEV ⊕; Class 2: Purchase price ⊖, fuel costs ⊖, home charging possibility*BEV / PHEV ⊕; Class 3: Purchase price ⊖, fuel costs ⊖, driving range*PHEV ⊕, home charging possibility*PHEV ⊕; Class 4:Purchase price ⊖, fuel costs ⊖, driving range*PHEV / BEV ⊕, home charging possibility*PHEV ⊕; Class 5:Purchase price ⊖, fuel costs ⊖
Axsen et al. (2016)	LCM with 5 classes: Class 1: Purchase price ⊖, home charging possibility*BEV ⊕; Class 2: Purchase price ⊖, fuel costs ⊖, home charging possibility*BEV / PHEV ⊕; Class 3: Purchase price ⊖, fuel costs ⊖, driving range*PHEV ⊕, home charging possibility*PHEV ⊕; Class 4:Purchase price ⊖, fuel costs ⊖, driving range*PHEV / BEV ⊕, home charging possibility*PHEV ⊕; Class 5:Purchase price ⊖, fuel costs ⊖; MNL for subgroup of 'Pioneers': Purchase price ⊖, fuel costs ⊖, driving range*BEV / PHEV ⊕, home charging possibility*BEV / PHEV ⊕
Bahamonde-Birke and Hanappi (2016)	Purchase price ⊖, fuel costs ⊖, maintenance costs ⊖, horsepower ⊕, driving range*BEV ⊕, fuel availability*BEV ⊕, incentive*BEV ⊕
Batley and Toner (2003)	Purchase price ⊖, operating costs ⊖, driving range ⊕, refueling time ⊖, emissions ⊖, top speed ⊕, acceleration ⊕, residual value ⊕
Batley et al. (2004)	Purchase price ⊖, operating costs ⊖, top speed ⊕, fuel availability ⊕, emissions ⊖, driving range ⊕, refueling at home ⊖
Bauer (2015)	Purchase price ⊖, operating costs ⊖, horsepower ⊕, driving range ⊕, design (sporty ⊕, futuristic / ordinary ⊖), equipment (base ⊖, premium ⊕), manufacturer (Toyota / Renault / Kia ⊖, BMW /VW ⊕)
Beck et al. (2011)	Purchase price ⊖, fuel costs ⊖, registration fee ⊖, fuel efficiency ⊖, engine size ⊖, no. of seats ⊕, South Korean manufacturer ⊖, emissions charge (variable / annual ⊖)
Beck et al. (2013)	LCM with 4 Classes: Class 1: Purchase price ⊖, fuel costs ⊖, registration fee ⊖, fuel efficiency ⊕, engine size ⊖, no. of seats ⊕, manufacturer (Japanese / European / American ⊕, South Korean ⊖), emissions charge (variable / annual ⊖); Class 2: Purchase price ⊖, fuel costs ⊖, fuel efficiency ⊖, engine size ⊖, no. of seats ⊕, manufacturer (Japanese / European / South Korean ⊖), emissions charge (variable / annual ⊖); Class 3: Purchase price ⊖, fuel costs ⊖, registration fee ⊖, engine size ⊖, no. of seats ⊖, manufacturer (European / American ⊕), annual emissions charge ⊖; Class 4: Purchase price ⊖, fuel costs ⊖, registration fee ⊖, fuel efficiency ⊖, engine size ⊖, no. of seats ⊕, manufacturer (Japanese / European / South Korean ⊕), annual emissions charge ⊖
Beck et al. (2017)	Purchase price ⊖, fuel costs ⊖, emissions ⊖, refueling time ⊖, fuel availability ⊕
Beggs et al. (1981)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, warranty ⊕, warranty*BEV ⊕, top speed ⊕
Bočkarjova et al. (2013)	Annual costs ⊖, recharging costs (fast / slow ⊖), emissions costs ⊖, tow hitch ⊕
Bunch et al. (1993)	Purchase price ⊖, fuel costs ⊖, fuel efficiency*gasoline ⊖, driving range ⊕, driving range*pick-up / van ⊕, driving range *sport coupé / compact pick-up / no purchase intention ⊖, fuel availability ⊕, emissions ⊖, performance*BEV ⊕
Byun et al. (2018)	Purchase price ⊖, emissions ⊖, fuel availability ⊕
Calfee (1985)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, top speed ⊕, no. of seats ⊕
Caulfield et al. (2010)	Fuel costs ⊖, registration fee ⊖, emissions ⊖
Cherchi (2017)	Purchase price ⊖, purchase price*medium / MPV / large / others ⊕, fuel costs ⊖, driving range ⊕, parking costs ⊖, no. of BEV parking spaces ⊕
Dagsvik and Liu (2009)	Purchase price ⊕, fuel efficiency ⊕, horsepower ⊕
Dagsvik et al. (2002)	Purchase price ⊖, fuel efficiency ⊕, top speed ⊕, driving range ⊕
Daziano (2015)	Purchase price ⊖, fuel costs ⊖, fuel availability ⊕, incentive (express lane access ⊕), horsepower ⊕

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Table A.9 *(continued)*

Study	Vehicle attributes – Significant effects
Daziano and Achtnicht (2014)	Purchase price ⊖, fuel costs ⊖, emissions ⊖, fuel availability ⊕, horsepower ⊕
Daziano and Bolduc (2013)	Purchase price ⊖, fuel costs ⊖, incentive (express lane access ⊕), fuel availability ⊕, horsepower ⊕
Dimitropoulos (2014)	LCM with 5 classes: Class 1: Purchase price ⊖, fuel costs ⊖, residual value ⊕, additional detour time ⊖, driving range ⊕, recharging time (at home / station ⊖), incentive (road tax exemption ⊕); Class 2: Purchase price ⊖, fuel costs ⊖; Class 3: Purchase price ⊖, fuel costs ⊖, driving range ⊕, incentive (road tax exemption ⊕); Class 4: Purchase price ⊖, fuel costs ⊖, residual value ⊕, driving range ⊕, incentive (road tax exemption ⊕); Class 5: Purchase price ⊖, fuel costs ⊖, residual value ⊕, additional detour time ⊖, driving range ⊕, incentive (road tax exemption ⊕)
Eggers and Eggers (2011)	Purchase price ⊖, purchase price*BEV / PHEV ⊕
Ewing and Sarigöllü (1998)	Purchase price ⊖, Purchase price*pick-up / van / SUV ⊕, maintenance costs ⊖, acceleration ⊕, acceleration*sport coupé ⊕, emissions ⊖, refueling time ⊖, commute time ⊖, commute fuel and parking costs ⊖, driving range ⊕
Ewing and Sarigöllü (2000)	Purchase price ⊖, maintenance costs ⊖, acceleration ⊕, emissions ⊖, refueling time ⊖, commute time ⊖, commute fuel and parking costs ⊖, driving range ⊕
Ferguson et al. (2018)	LCM with 4 classes: Class 1: Purchase price ⊖, maintenance costs ⊖, driving range (gasoline / electric ⊕), acceleration ⊕, recharging time (public ⊖), battery warranty ⊕, incentive (subsidy / free parking / toll exemption ⊕); Class 2: Purchase price ⊖, maintenance costs ⊖, driving range (gasoline ⊕), recharging time (public ⊖), battery warranty ⊕, incentive (subsidy ⊕, free parking ⊖); Class 3: Purchase price ⊖, maintenance costs ⊖, driving range (gasoline / electric ⊕), acceleration ⊕, recharging time (public ⊖), fuel availability ⊕, battery warranty ⊕, incentive (subsidy / free parking / HOV lane usage ⊕); Class 4: Purchase price ⊖, maintenance costs ⊖, driving range (electric ⊕), acceleration ⊕, recharging time (public ⊖, home/work ⊕), fuel availability ⊕, battery warranty ⊕, incentive (subsidy / free parking ⊕)
Glerum et al. (2014)	Purchase price ⊖, purchase price*Renault ⊕, operating costs ⊖, battery leasing costs ⊖, incentive (purchase subsidy ⊕)
Golob et al. (1993)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, fuel availability ⊕, emissions ⊖, performance*BEV ⊕
Hackbarth and Madlener (2013)	Purchase price ⊖, fuel costs ⊖, emissions ⊖, driving range ⊕, fuel availability ⊕, recharging time ⊖, incentive (vehicle tax exemption / free parking and bus lane usage ⊕)
Hackbarth and Madlener (2016)	LCM with 6 classes: Class 1: Purchase price ⊖, fuel costs ⊖, emissions ⊖, driving range ⊕, fuel availability ⊕, recharging time ⊖, incentive (vehicle tax exemption / free parking and bus lane usage ⊕); Class 2: Purchase price ⊖, fuel costs ⊖, emissions ⊖, driving range ⊕, fuel availability ⊕, incentive (vehicle tax exemption/ free parking and bus lane usage ⊕); Class 3: Purchase price ⊖, fuel costs ⊖, driving range ⊕, refueling time ⊖, incentive (vehicle tax exemption / free parking and bus lane usage ⊕); Class 4: Purchase price ⊖, fuel costs ⊖, emissions ⊖, fuel availability ⊕; Class 5: Purchase price ⊖, fuel costs ⊖, emissions ⊖, driving range ⊕, fuel availability ⊕, recharging time ⊖, incentive (vehicle tax exemption / free parking and bus lane usage ⊕); Class 6: Purchase price ⊖, fuel costs ⊖, emissions ⊖, driving range ⊕, fuel availability ⊕, recharging time ⊖, incentive (vehicle tax exemption / free parking and bus lane usage ⊕)
Helveston et al. (2015)	Purchase price ⊖, fuel costs ⊖, acceleration time ⊖, fast-charging capability (⊕ in China), manufacturer (US ⊕ in US, ⊖ in China), Japanese (in China) / Chinese / South Korean ⊖)
Hensher et al. (2011)	Purchase price ⊖, fuel costs ⊖, registration fee ⊖, fuel efficiency ⊕, engine size ⊖, no. of seats ⊕, emissions charge (variable /annual ⊖), South Korean manufacturer ⊖
Hensher et al. (2013)	Purchase price ⊖, fuel costs ⊖, registration fee ⊖, fuel efficiency ⊕, engine size ⊖, no. of seats ⊕, emissions charge (variable / annual ⊖), purchase price*South Korean manufacturer ⊖
Hensher et al. (2017)	Purchase price ⊖, fuel costs ⊖, registration fee ⊖, engine size ⊖, no. of seats ⊕, emissions charge (variable / annual ⊖)
Hidrue et al. (2011)	LCM with 2 classes: Class 1: Purchase price ⊖, fuel costs ⊖, driving range ⊕, acceleration ⊕, emissions ⊖, recharging time ⊖; Class 2: Purchase price ⊖, driving range ⊕, acceleration ⊕, emissions ⊖, recharging time ⊖
Hoen and Koetse (2014)	Purchase price ⊖, purchase price*vehicle weight ⊕, operating costs ⊖, operating costs*vehicle weight ⊕, driving range ⊕, recharging time ⊖, refueling time ⊖, additional detour time ⊖, no. of alternatives in vehicle class ⊕, safety*vehicle weight ⊕
Horne et al. (2005)	Purchase price ⊖, fuel costs ⊖, incentive (express lane access ⊕), fuel availability ⊕, horsepower ⊕
Jacobs et al. (2016)	Purchase price ⊖, horsepower ⊕, vehicle size ⊕, no. of seats ⊕, charging time ⊖, driving range ⊕, fuel consumption ⊖
Javid and Nejat (2017)	Gasoline price*BEV ⊕, fuel availability ⊕
Jensen et al. (2013)	Purchase price ⊖, Purchase price*mini / small / medium ⊖, fuel costs ⊖, driving range ⊕, emissions ⊖, top speed ⊕, recharging location (battery station / work / city center / train station ⊕)
Kim et al. (2014)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, charging time ⊖, top speed ⊕, refueling distance ⊖
Kim et al. (2016)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, charging time ⊖, top speed ⊕, refueling distance ⊖

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Table A.9 *(continued)*

Study	Vehicle attributes – Significant effects
Knockaert (2010)	Purchase price ⊖, annual costs ⊖, fuel costs ⊖, luggage space ⊕, emissions ⊖, driving range ⊕
Krause et al. (2016)	Purchase price parity ⊕, driving range parity*BEV ⊕, driving range parity*HEV / PHEV ⊖, charging time parity*BEV ⊕, charging time parity*HEV ⊖
Langbroek et al. (2016)	Purchase price ⊖, driving range ⊕, incentive (parking benefits / access bus lanes ⊕), availability of public charging ⊕
Link et al. (2012)	Purchase price ⊖, operating costs ⊖, driving range ⊕, recharging time ⊖, emissions ⊖, horsepower ⊕
Mabit and Fosgerau (2011)	Purchase price ⊖, annual costs ⊖, acceleration ⊕, refueling frequency ⊖, service ⊕
Mabit et al. (2015)	Purchase price ⊖, annual costs ⊖, acceleration ⊕, driving range ⊕, service ⊕
Marra et al. (2012)	Fuel costs ⊖, share of fuel from imported sources ⊖, refueling distance ⊖, emissions ⊖
Mau et al. (2008)	Purchase price ⊖, fuel costs ⊖, incentive (purchase subsidy ⊕), driving range ⊕, warranty ⊕
Nixon and Saphores (2011)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, refueling time ⊖
Østil et al. (2017)	Purchase price ⊖, operating costs ⊖, resource cost share ⊕, vehicle size ⊕, luggage space ⊕, four-wheel-drive ⊕, five seats ⊕, no. of doors ⊕, manufacturer (Toyota / VW / Ford / Opel / Peugeot / Volvo / Audi / Nissan / Mitsubishi / Mazda / Hyundai / Skoda / BMW / Mercedes / Renault / Honda / Suzuki / Citroen / Saab / Subaru ⊕)
Parsons et al. (2014)	LCM 1 with 2 classes: Class 1: Purchase price ⊖, fuel costs ⊖, driving range ⊕, acceleration ⊕, emissions ⊖, recharging time ⊖; Class 2: Purchase price ⊖, driving range ⊕, acceleration ⊕, emissions ⊖, recharging time ⊖; LCM 2 with two classes: Class 1: V2G ⊕, purchase price ⊖, annual cash back payment ⊕, driving range ⊕, required plug-in time per day ⊖; Class 2: V2G ⊖, purchase price ⊖, annual cash back payment ⊕, driving range ⊕, required plug-in time per day ⊖
Qian and Soopramanien (2011)	Purchase price ⊖, operating costs ⊖, fuel availability ⊕, driving range ⊕
Ramjerdi and Rand (2000)	Purchase price ⊖, operating costs ⊖, driving range ⊕, emissions ⊖, no. of seats ⊕, top speed ⊕
Rasouli and Timmermans (2016)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, charging time ⊖, top speed ⊕, refueling distance ⊖
Rouwendal and de Vries (1999)	Operating costs ⊕
Rudolph (2016)	Purchase price ⊖, fuel costs ⊖, incentive (subsidy ⊕, parking fee / emission-based tax ⊖), refueling distance ⊖, none option*mileage ⊕
Sandór and Train (2004)	Purchase price ⊖, operating costs ⊖, driving range ⊕, performance ⊕
Shin et al. (2012)	Purchase price ⊖, fuel costs ⊖, maintenance costs ⊖, fuel availability ⊕
Smith et al. (2017)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, emissions ⊕, noise ⊖, charging time ⊖, engine size ⊕
Tanaka et al. (2014)	Purchase price ⊖, fuel costs*California ⊖, driving range ⊕, emissions ⊖, fuel availability ⊕, home plug-in construction costs ⊖
Train and Sonnier (2005)	Purchase price ⊖, operating costs ⊖, driving range ⊕, performance ⊕
Valeri and Cherchi (2016)	Purchase price ⊖, operating costs ⊖, driving range ⊕, refueling distance ⊖
Valeri and Danielis (2015)	Purchase price ⊖, operating costs ⊖, refueling distance*NGV ⊖
van Meerkerk et al. (2014)	Vehicle tax ⊖, vehicle size ⊕, vehicle age ⊖
Wang et al. (2017)	Purchase price ⊖, driving range ⊕, incentive (purchase restriction recission / driving range recission / bus lane usage / public charging fee exemption / parking fee exemption / road toll exemption / purchase tax exemption / insurance charge exemption / vehicle and vessel tax exemption ⊕)
Wolbertus et al. (2018)	Purchase price ⊖, driving range*BEV ⊕, fuel availability ⊕, parking costs*BEV ⊖, parking spot availability*BEV ⊕
Ziegler (2012)	Purchase price ⊖, fuel costs ⊖, emissions ⊖, fuel availability ⊕, horsepower ⊕, horsepower*diesel / hydrogen ⊕
Zito and Salerno (2004)	Annual costs ⊖, average running time ⊖, average service life ⊕
Fuel and vehicle type choice	
Adler et al. (2003)	Purchase price ⊖, maintenance costs ⊖, fuel costs ⊖, gradability ⊕, acceleration ⊕, incentive (tax exemption / free parking ⊕), vehicle type and size inertia ⊕
Ahn et al. (2008)	Maintenance costs ⊖, fuel costs ⊖, engine size ⊕
Antolín et al. (2018)	Horsepower ⊕
Axsen et al. (2009)	Purchase price ⊖, fuel costs ⊖, horsepower ⊕, incentive (purchase subsidy ⊕)
Brownstone and Train (1999)	Purchase price ⊖, fuel costs ⊖, acceleration ⊕, top speed ⊕, driving range ⊕, fuel availability ⊕, emissions ⊖, luggage space ⊕, vehicle size ⊕

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Table A.9 *(continued)*

Study	Vehicle attributes – Significant effects
Brownstone et al. (2000)	Purchase price ⊖, fuel costs ⊖, acceleration ⊕, top speed ⊕, driving range ⊕, fuel availability ⊕, emissions ⊖
Cirillo et al. (2017)	Purchase price ⊖, driving range ⊕, vehicle size ⊕
Costa et al. (2019)	Purchase price ⊖, emissions ⊖
Daziano (2013)	Purchase price ⊖, operating costs ⊖, driving range ⊕, performance ⊕
de Jong (1996)	Annual costs ⊖, no. of alternatives in vehicle class ⊕, German manufacturer ⊕, engine size ⊕, catalyser ⊕, vehicle age ⊖
DeShazo et al. (2017)	Driving range ⊕, incentive (express lane access ⊕), body type (compact / mid-size ⊖)
Habibi et al. (2019)	Purchase price ⊖, vehicle tax ⊖, vehicle tax*diesel ⊕, tank volume ⊕, weight/horsepower ⊖, manufacturer (compared to Volvo: Benteley / Ferrari ⊕, all others ⊖)
Hackbarth and Madlener (2018)	Purchase price*diesel / AFV / executive / luxury / sport coupé ⊕, purchase price*mini / small / medium / large ⊖
Hahn et al. (2018)	Purchase price ⊖, operating costs*small / medium / large ⊖, fuel availability ⊕, driving range*medium / executive ⊕
He et al. (2012)	Purchase price ⊖, fuel consumption ⊖, manufacturer (European / Japanese / South Korean ⊕)
He et al. (2014)	Purchase price ⊖, fuel efficiency ⊖, fuel price*HEV ⊕, manufacturer (European / Japanese ⊕, South Korean ⊖), width*length ⊕, acceleration ⊕
Hensher and Greene (2006)	Purchase price ⊖, operating costs ⊖, vehicle age ⊖, driving range ⊕, acceleration ⊕, engine size*micro / small / medium car ⊕
Hess et al. (2006)	Purchase price ⊖, operating costs ⊖, driving range ⊕, performance ⊕
Hess et al. (2012)	Purchase price ⊖, fuel costs ⊖, maintenance costs ⊖, vehicle age ⊖, acceleration ⊕, fuel availability ⊕, fuel efficiency ⊕, incentive (tax credit ⊕)
Higgins et al. (2017)	Purchase price ⊖, fuel costs*medium / large / pick-up ⊖, maintenance costs*small / medium / large / MPV / SUV ⊖, gasoline driving range ⊕, electric driving range*small / medium / large / SUV ⊕, acceleration*medium / large / luxury / SUV / pick-up ⊕, fuel availability*small / medium vehicle ⊕, charging time public*medium / luxury / MPV ⊖, battery warranty ⊕, incentive (cash incentive ⊕, free parking*large / SUV ⊕, free parking*pick-up ⊖, HOV lane usage*small / large / SUV ⊕)
Ito et al. (2013)	Purchase price ⊖, operating costs ⊖, driving range ⊕, manufacturer (Mitsubishi / Toyota / Honda ⊕, Nissan ⊖)
Ito et al. (2019)	Purchase price ⊖, operating costs ⊖, emissions ⊖, charging time ⊖, driving range ⊕, fuel availability ⊕, manufacturer (Toyota / Honda ⊕)
Jäggi et al. (2013)	Fuel costs ⊖, fuel costs*diesel*large / luxury ⊕
Kavalec (1999)	Purchase price ⊖, fuel costs ⊖, acceleration ⊕, top speed ⊕, driving range ⊕, fuel availability ⊕, emissions ⊖
Lee and Cho (2009)	Purchase price ⊖, fuel costs ⊖, fuel efficiency ⊕, vehicle tax ⊖
Liu (2014)	Purchase price ⊖, fuel costs ⊖, vehicle size ⊕, horsepower to vehicle weight ⊕
Liu and Cirillo (2018)	Purchase price ⊖, fuel costs ⊖, driving range ⊕, fuel efficiency ⊕, vehicle size ⊕
Mabit (2014)	Purchase price and vehicle tax ⊖, operating costs ⊖, no. of airbags ⊕, automatic transmission ⊕, no. of doors ⊕, horsepower ⊕, engine size⊕, no. of alternatives in vehicle class ⊕, vehicle weight ⊕
Maness and Cirillo (2012)	Purchase price ⊖, fuel costs ⊖, mileage tax ⊖, fuel efficiency ⊕, driving range ⊕, vehicle size ⊖, vehicle age ⊖, recharging time ⊖, incentive (tax credit / toll discount ⊕)
Musti and Kockelman (2011)	Purchase price ⊖, fuel costs ⊖
Paleti et al. (2011)	Purchase price ⊖, fuel costs ⊖, maintenance costs ⊖, acceleration ⊕, fuel efficiency ⊕, incentive (express lane access / free parking / tax credit / toll reduction/ purchase subsidy ⊕), fuel availability ⊖, driving range ⊕
Potoglou and Kanaroglou (2007)	Maintenance costs ⊖, fuel costs ⊖, acceleration time ⊖, fuel availability ⊕, incentive (purchase tax exemption ⊕)
Shiau et al. (2009)	Purchase price ⊖, operating costs ⊖, horsepower to vehicle weight ⊕, vehicle size ⊕, foreign vehicle ⊖
Shin et al. (2015)	Purchase price ⊖, fuel costs ⊖, fuel availability ⊕, smart car options ⊕
Shin et al. (2018)	Purchase price ⊖, fuel costs ⊖, fuel availability ⊕, smart car options ⊕
Soto et al. (2018)	Purchase price ⊖, fuel costs ⊖, annual taxes ⊖, fuel availability ⊕, driving range ⊕
Tompkins et al. (1998)	Purchase price ⊖, fuel costs ⊖, maintenance costs ⊖, battery costs ⊖, acceleration ⊕, prestige ⊕, driving range ⊕, top speed ⊕, emissions ⊖
Train and Weeks (2005)	Purchase price ⊖, operating costs ⊖, driving range ⊕, performance ⊕
Xu et al. (2015)	Purchase price ⊖, gasoline price (CFV ⊖, HEV ⊕), manufacturer (Toyota / Honda / Nissan / Mazda / Suzuki / Mitsubishi / Subaru / Daihatsu / Lexus ⊖)

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Table A.9 *(continued)*

Study	Vehicle attributes – Significant effects
Vehicle type choice	
Beggs and Cardell (1980)	Purchase price ⊖, fuel costs ⊖, vehicle size *van / pick-up ⊕,
Berkovec (1985)	Purchase price ⊖, no. of seats ⊕, no. of alternatives in vehicle class ⊕, vehicle age ⊖, new vehicle ⊖, difference in seat space ⊕
Berkovec and Rust (1985)	Purchase price ⊖, fuel costs ⊖, manufacturer (AMC / Chrysler ⊖, Ford / foreign manufacturer ⊕)
Bhat and Sen (2006)	Operating costs ⊖
Bhat et al. (2009)	Purchase price ⊖, fuel costs ⊖, luggage space ⊕, horsepower ⊕, engine size ⊖, four-wheel drive ⊖, manufacturer (Ford / Honda / Toyota / VW / Cadillac / Dodge ⊕), emissions ⊖, premium fuel ⊖
Chiou et al. (2009)	Purchase price ⊖, fuel costs ⊖, vehicle tax ⊖, insurance costs ⊖, maintenance costs ⊖
Hensher and Le Plastrier (1985)	Sales tax of purchase price ⊖, vehicle quality ⊕, maintenance costs ⊖, luggage space ⊕, fuel efficiency ⊕, fuel costs claimed as tax credit ⊕, vehicle age ⊖, additional vehicle / replacement ⊕
Hocherman et al. (1983)	Purchase price ⊖, operating costs ⊖, engine size ⊕, vehicle age ⊖, horsepower to vehicle weight ⊕
Kockelman and Zhao (2000)	Purchase price ⊖
Koo et al. (2012)	Purchase price ⊖, energy efficiency ⊕, engine size ⊕
Kuwano et al. (2013)	Purchase price ⊖, no. of seats ⊖
Lave and Train (1979)	Purchase price ⊖, no. of seats ⊕
Liu et al. (2014)	Purchase price ⊖, shoulder room ⊕, luggage space ⊕, no. of alternatives in vehicle class ⊕, fuel efficiency ⊕, foreign manufacturer ⊖
Mannering and Mahmassani (1985)	Purchase price ⊖, turning radius ⊖, horsepower*domestic manufacturer ⊕, consumer report index*domestic manufacturer ⊕, expected annual collision cost*domestic manufacturer ⊖, manufacturer (Ford ⊕)
Mannering and Winston (1985)	Purchase price ⊖, shoulder room ⊕, manufacturer (Ford ⊕, Chrysler / foreign manufacturer ⊖), vehicle age ⊖
Mannering and Winston (1991)	Purchase price ⊖, fuel efficiency ⊕, vehicle weight ⊕, consumer report index (repair ⊕), vintage pre-1980*manufacturer (GM / Chrysler / Japanese ⊖), vintage 1980s*manufacturer (GM / Ford / Chrysler ⊕)
Mannering et al. (2002)	Purchase price ⊖, fuel costs ⊖, airbag ⊕, consumer report index (repair ⊕), turning radius*US manufacturer ⊕, residual value ⊕, manufacturer (Ford / GM / Chrysler/ Japanese ⊖), expected insurance costs ⊖
Manski and Sherman (1980)	Purchase price ⊖, operating costs ⊖, no. of seats ⊕, luggage space ⊕, acceleration time ⊕, breaking distance ⊖, noise level ⊖, scrappage probability ⊖, transaction costs ⊖, vintage 1969-1976 ⊖, vintage pre-1967 ⊕, foreign manufacturer ⊕
Martin (2009)	Purchase price minus purchase incentive ⊖, operating costs ⊖, consumer report index (rattle ⊖, fuel system / body type / climate system / exhaust system / paint / power equipment / residual value / performance ⊕)
McCarthy (1996)	Purchase price ⊖, operating costs ⊖, horsepower ⊕, vehicle size ⊕, dealer visits ⊕, dealer visits*country of origin ⊕, manufacturer (Chrysler / Ford / GM / Japanese ⊕)
McCarthy and Tay (1998)	Purchase price ⊖, operating costs ⊖, airbag ⊕, vehicle size ⊕, luggage space ⊕, consumer satisfaction index ⊕, manufacturer (GM / Ford / Japanese ⊕)
Mohammadian and Miller (2002, 2003)	Purchase price ⊖, performance ⊕, vehicle fleet weight*small / medium ⊖, vehicle size*van / SUV / pick-up ⊕
Noblet et al. (2006)	Emissions ⊖
Train (1986)	Purchase price ⊖, operating costs ⊖, transaction costs ⊖, no. of alternatives in vehicle class ⊕, variance of shoulder room around mean for class/vintage⊕, vehicle age ⊕, prestigious car (2-car HH ⊕)
Train and Winston (2007)	Purchase price ⊖, horsepower to vehicle weight ⊕, automatic transmission ⊕, vehicle size ⊕, manufacturer (European / South Korean ⊕)
Vekeman et al. (2004)	Fuel consumption ⊖

Notes: ⊕ = positive effect; ⊖ = negative effect; CFV = conventional fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle; AFV = alternative fuel vehicle; PHEV = plug-in hybrid electric vehicle; MPV = multi purpose vehicle; SUV = sport utility vehicle; HH = household; V2G = vehicle-to-grid; HOV = high-occupancy vehicle; MNL = multinomial logit model; NL = nested logit model; LCM = latent class model.

Table A.10: Estimation results: Significant interactions of vehicle attributes and socio-economic variables

Study	Attribute interactions – Significant effects
Fuel type choice	
Achtnicht (2012)	Purchase price*intended purchase price ⊕, emissions*female ⊖, emissions*age ⊕, emissions*education ⊖
Achtnicht et al. (2012)	Purchase price*intended purchase price ⊕, emissions*env. awareness ⊖
Aguilar et al. (2015)	Ethanol source (Cellulosic)*age ⊖, ethanol source (cellulosic / corn)*income ⊖, ethanol source (cellulosic)*region (West ⊕), fuel costs*income (low / high ⊕), fuel costs*region (Midwest ⊖, Gulf Coast ⊕), fuel costs*ethanol avoidance ⊕, fuel efficiency*income⊕, fuel efficiency*region (Midwest / West ⊕), fuel efficiency*ethanol avoidance ⊖
Bahamonde-Birke and Hanappi (2016)	Purchase price*income ⊕, horsepower*male ⊖
Bauer (2015)	Purchase price*attitude (symbolism ⊕), purchase price*subjective norm ⊕, purchase price*perceived behavioral control ⊕, operating costs*env. awareness ⊖, operating costs*attitude (symbolism ⊕), horsepower*attitude (AFV purchase ⊖, symbolism ⊕), horsepower*env. awareness ⊖, horsepower*subjective norm ⊖, design (sporty / futuristic ⊕, ordinary / classic ⊖)*attitude (symbolism), design (sporty ⊖, classic ⊕)*env. awareness, design (sporty)*perceived behavioral control ⊕, equipment (premium)*attitude (symbolism ⊕), equipment (premium)*subjective norm ⊖, manufacturer (BMW / VW ⊖, Kia ⊕)*attitude (AFV purchase), manufacturer (Kia / Renault ⊖, BMW ⊕)*attitude (symbolism), manufacturer (BMW)*env. awareness ⊖, manufacturer (Renault ⊖, Kia ⊕)*subjective norm
Beck et al. (2017)	PHEVs and BEVs: Driving range*env. concerns (peak oil / air quality ⊕, availability of renewables ⊖), emissions*readiness to change (travel behavior / incentives ⊕)
Beggs et al. (1981)	HH size to no. of seats ⊖, air conditioning*income ⊕, air conditioning*region (Boston / Seattle ⊖)
Bunch et al. (1993)	Fuel costs*commute distance ⊖, driving range*female ⊖, driving range*no. of workers ⊕
Byun et al. (2018)	Refueling time*driver ⊖, operating costs*driver ⊖
Cherchi (2017)	Parking costs*social signaling*CFV ⊕, no. of BEV parking spaces*work-related after-parking activity ⊕
Dagsvik et al. (2002)	Fuel consumption*male ⊖, fuel consumption*male*age ⊖, top speed*male ⊕, driving range*male ⊕
Daziano (2015)	Horsepower*pro-performance attitude ⊕, fuel costs*cost-consciousness ⊖
Dimitropoulos (2014)	Purchase price*income (high / unreported ⊕)
Ewing and Sarigöllü (1998)	Maintenance costs*French speaking ⊕, acceleration* female ⊕, acceleration*age ⊖, acceleration*carsharing ⊕, driving range*female ⊖, driving range*age ⊖, emissions*WTP for ZEV ⊖, emissions*duration of ownership ⊖, commute time*duration of ownership ⊖, commute fuel and parking costs*female ⊖, commute fuel and parking costs*age ⊕
Glerum et al. (2014)	Purchase price*importance of vehicle attributes (convenience ⊖), purchase price*recent vehicle purchase ⊖, battery leasing costs*importance of vehicle attributes (leasing ⊖)
Hackbarth and Madlener (2013)	Purchase price*intended purchase price ⊕, emissions*env. awareness ⊖
Helveston et al. (2015)	US: Purchase price*income ⊕, operating costs*income ⊕, purchase price*age ⊕, operating costs*age ⊕, operating costs*children in HH ⊕, purchase price*education ⊕, operating costs*education ⊕, purchase price*no. of vehicles ⊕, operating costs*no. of vehicles ⊕, purchase price*attitude (status symbol ⊕); China: Operating costs*income ⊖, purchase price*HH size ⊕, operating costs*HH size ⊕, purchase price*education ⊖, operating costs*education ⊖, purchase price*attitude (env. appearance ⊖), operating costs*attitude (env. appearance ⊕), purchase price*attitude (status symbol ⊖)
Hensher et al. (2013)	Purchase price*age ⊖, purchase price*full-time employed ⊖, purchase price*income ⊕, purchase price*diesel ⊖, purchase price*male*HEV ⊖
Hidrue et al. (2011)	Purchase price*intended purchase price ⊕
Hoen and Koetse (2014)	Purchase price*mileage ⊕, purchase price*female ⊖, purchase price*intended purchase price ⊕, operating costs*female ⊖, operating costs*intended purchase price ⊕, driving range*mileage ⊕, driving range*recharging at home ⊕, incentives*urban ⊕, safety*urban ⊕, safety*commute frequency ⊕
Jensen et al. (2013)	Purchase price*used vehicle ⊖, purchase price*no purchase ⊕, recharging at work*commute distance ⊕
Knockaert (2010)	Emissions*female ⊖, emissions*HH size ⊖, luggage space*HH size ⊕, luggage space*social class ⊖
Langbroek et al. (2016)	Purchase price*protection motivation (pre-contemplation / contemplation / preparation / action / maintenance ⊖)
Mabit and Fosgerau (2011)	Purchase price*children in HH ⊖, purchase price*income ⊕, purchase price*HH size ⊕, driving range*age ⊖, acceleration*male ⊕
Mabit et al. (2015)	Purchase price*age ⊕, purchase price*income ⊕, purchase price*HH size ⊕, annual costs* commute distance ⊖, acceleration*male ⊕, acceleration*age ⊖, driving range*age ⊖, driving range*commute distance ⊕

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Table A.10 *(continued)*

Study	Attribute interactions – Significant effects
Marra et al. (2012)	Emissions*lifestyle (potential activist / environmental ⊖, national interest ⊕)
Rouwendal and de Vries (1999)	Income - fixed vehicle costs ⊕
Smith et al. (2017)	Emissions*env. concerns ⊖
Valeri and Danielis (2015)	Purchase price*female ⊕, purchase price*income ⊕, operating costs*female ⊕, operating costs*income ⊕, driving range*female ⊖, driving range*non-BEV*income ⊕, acceleration*non-BEV*age ⊕, acceleration*female ⊕, driving range*BEV*income ⊖, acceleration*BEV*income ⊕
van Meerkerk et al. (2014)	Purchase price*income ⊕, operating costs*income ⊕, operating costs*mileage ⊖, horsepower*income ⊕, vehicle weight*HH size ⊕
Wang et al. (2017)	Driving range*income ⊕, driving range*preference for small cars ⊖, driving range*attitude (BEV awareness / BEV confidence ⊕, policy awareness ⊖)
Fuel and vehicle type choice	
Adler et al. (2003)	Purchase price*income ⊕, maintenance costs*income ⊖, vehicle size*HH size ⊕
Antolín et al. (2018)	Purchase price*income ⊖, fuel consumption*income ⊖
Brownstone and Train (1999)	Vehicle size*HH size ⊕
Cirillo et al. (2017)	Fuel efficiency*knowledge about fuel efficiency*BEV ⊖
DeShazo et al. (2017)	Purchase price*income ⊖
He et al. (2012)	Fuel consumption*mileage ⊖, fuel consumption*highway driver ⊖
He et al. (2014)	Fuel efficiency*mileage ⊖
Hensher and Greene (2006)	Purchase price*income ⊕
Hess et al. (2012)	Purchase price*income ⊕
Kavalec (1999)	Fuel costs*age ⊖, driving range*age ⊖, acceleration*age ⊕, top speed*age ⊖
Liu and Cirillo (2018)	Fuel efficiency*knowledge about fuel efficiency ⊕
Mabit (2014)	Operating costs*male ⊕, operating costs*commute distance ⊖, purchase price and vehicle tax*male ⊕, purchase price and vehicle tax*unemployed ⊖, purchase price and vehicle tax *children in HH ⊖, purchase price and vehicle tax*income ⊕, vehicle weight*children in HH ⊕
Maness and Cirillo (2012)	Mileage tax*mileage ⊖, vehicle age*mileage ⊖
Potoglou and Kanaroglou (2007)	Purchase price*income ⊖, acceleration*female ⊖, acceleration*HH size ⊕, fuel availability*no. of long distance commuters ⊕
Shin et al. (2015)	Purchase price*age ⊕, purchase price*mileage ⊕, fuel costs*income ⊖, fuel costs*age ⊖, fuel costs*mileage ⊕
Xu et al. (2015)	Purchase price*income ⊕
Vehicle type choice	
Beggs and Cardell (1980)	Purchase price*vehicle not owned ⊕, vehicle size to HH size ⊖, vehicle size to HH size*sport coupé ⊖, vehicle weight*age ⊖, foreign manufacturer*age ⊖, foreign manufacturer*education ⊕
Berkovec (1985)	Purchase price*income ⊕, no. of seats*HH size ⊕
Berkovec and Rust (1985)	No. of seats*HH size ⊕, horsepower to vehicle weight*age ⊖, turning radius*pop. density ⊖, vehicle age*income ⊖
Bhat et al. (2009)	No. of seats*HH size ⊕
Chiou et al. (2009)	Vehicle age*income ⊖, vehicle age*male ⊕, vehicle age*education ⊖
Hensher and Le Plastrier (1985)	Vehicle weight*main vehicle usage (commute ⊕), no. of seats*main vehicle usage (holidays ⊕), no. of additional seats*no. of passengers normally carried ⊖, luggage space*main vehicle usage (holidays ⊕), acceleration*main vehicle usage (towing ⊕), fuel efficiency*mileage ⊕
Hocherman et al. (1983)	Purchase price*income ⊕, purchase price*age ⊕, horsepower*age ⊖
Lave and Train (1979)	Vehicle weight*age ⊕, vehicle weight*education ⊕, horsepower to weight*age ⊕
Liu et al. (2014)	Purchase price*income ⊕, vehicle age*no. of vehicles ⊕
Mannering and Mahmassani (1985)	Fuel costs*mileage ⊖, vehicle weight*age ⊕, turning radius*age ⊕
Mannering and Winston (1985)	Fuel costs*mileage ⊖, shoulder room*HH size ⊕, horsepower to engine size*age⊖, luggage space*HH size ⊕

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Table A.10 *(continued)*

Study	Attribute interactions – Significant effects
Mannering and Winston (1991)	Japanese manufacturer*region (Pacific coast ⊕), Japanese manufacturer*urban ⊕, US manufacturer*age ⊕, US manufacturer *income ⊖
Mannering et al. (2002)	Horsepower*income ⊕
Manski and Sherman (1980)	Purchase price*income⊕, purchase price*education ⊖, operating costs*income⊕, operating costs*education ⊖, operating costs*rural ⊕, vehicle weight*age ⊕, luggage space*HH size ⊕, acceleration*age ⊕, turning radius*urban ⊕, scrappage probability*no. of workers ⊖, foreign manufacturer*region (coast ⊕), foreign manufacturer*education ⊕, purchase price*education*no. of vehicles ⊕, operating costs*income*no. of vehicles ⊖, no. of pre-1967 vehicles*income ⊖, no. of pre-1967 vehicles*age ⊕, no. of foreign vehicles*region (coast ⊕), no. of foreign vehicles*education ⊕
Martin (2009)	Consumer report index (residual value)*education ⊕, no. of seats*children in HH ⊕
McCarthy (1996)	US manufacturer*region (Pacific coast ⊖), US manufacturer*age ⊕
McCarthy and Tay (1998)	Japanese manufacturer*region (Pacific coast ⊕), US manufacturer*age ⊕
Noblet et al. (2006)	Income - total cost of ownership ⊖
Train (1986)	Purchase price*income ⊕, operating costs*income ⊕, shoulder room*HH size ⊕, luggage space*HH size ⊕, horsepower*income ⊕
Train and Winston (2007)	Consumer report index (repair)*female*age ⊕
West (2007)	Real gasoline price*MPV / pick-up ⊖, real gasoline price*passenger car ⊕

Notes: ⊕ = positive effect; ⊖ = negative effect; ZEV = zero-emission vehicle; CFV = conventional fuel vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle; AFV = alternative fuel vehicle; PHEV = plug-in hybrid electric vehicle; MPV = multi purpose vehicle; HH = household; WTP = willingness-to-pay; Env. = environmental; Pop. = population.

Table A.11: Estimation results: Significant fuel/vehicle type-unspecific effects of socio-economic variables

Study	Socio-economics variables – Significant effects
Fuel type choice	
Abdoolakhan (2010)	LCM: Class 1: No. of fuel efficiency measures applied ⊕; Class 2: BASE
Axsen et al. (2015)	LCM: Class 1 ('PEV-enthusiast'): HH size ⊕, region (Alberta / British Columbia / Ontario ⊕), lifestyle (technology-oriented / environment-oriented ⊕), env. awareness ⊕; Class 2 ('PHEV-oriented'): income ⊕, region (British Columbia ⊕), lifestyle (env.-oriented ⊕), env. awareness ⊕; Class 3 ('HEV-oriented'): HH size ⊖, income ⊕, education ⊖, region (Alberta / British Columbia ⊕), lifestyle (env.-oriented ⊕), env. awareness ⊕, liminality ⊕; Class 4 ('HEV-leaning'): BASE; Class 5 ('CFV-oriented'): HH size ⊖, education ⊖, lifestyle (technology-oriented ⊖), env. awareness ⊖, liminality ⊕
Axsen et al. (2016)	LCM: Class 1 ('PEV-enthusiast'): Lifestyle (technology-oriented / env.-oriented ⊕), env. awareness ⊕; Class 2 ('PHEV-oriented'): Lifestyle (env.-oriented ⊕); Class 3 ('HEV-oriented'): Education ⊖; Class 4 ('HEV-leaning'): BASE; Class 5 ('CFV-oriented'): Education ⊖
Beck et al. (2013)	LCM: Class 1 (\`Diesel drivers\`): BASE; Class 2 ('Captive cynics'): Age ⊕, attitude (drivers of polluting cars should pay ⊕, vehicle emissions charge effective way to reduce emissions ⊖); Class 3 ('Car lovers'): Age ⊕, no. of children ⊖, attitude (vehicles main cause of climate change ⊕, encourage people to use env. friendly transportation ⊖); Class 4 ('Green vehicle friendly'): Attitude (Climate change important issue ⊖, vehicles main cause of climate change / drivers of polluting cars should pay ⊕)
Dimitropoulos (2014)	LCM: Class 1 ('*Status quo* captives'): BASE; Class 2 ('Combustion engine diehards'): Env. awareness ⊖, female ⊕, age ⊕, education ⊖, mileage ⊖; Class 3 ('Price conscious buyers'): Env. awareness ⊕, female ⊕, mileage ⊖, often abroad trips ⊖, main car replacement ⊖; Class 4 ('Full electric optimists'): Env. awareness ⊕, female ⊕, education ⊖, often abroad trips ⊖, long-term purchase decision ⊕; Class 5 ('PHEV enthusiasts'): -
Ferguson et al. (2017)	LCM: Class 1 ('ICE-oriented'): Female ⊖, education ⊖, French speaking ⊕, time until next vehicle purchase ⊖, presence of HEV in HH ⊖, next vehicle is economy car ⊕, attitude (WTP BEVs ⊖, cost-effectiveness BEVs ⊖, no home charging possibility ⊖, battery warranty ⊖, energy security support ⊖), importance of vehicle attributes (emissions ⊖, fuel efficiency ⊖); Class 2 ('HEV-oriented'): BASE; Class 3 ('PHEV-oriented'): Age ⊖, female ⊖, education ⊕, French speaking ⊕, time until next vehicle purchase ⊕, additional vehicle ⊖, presence of HEV in HH ⊖, next vehicle is economy car ⊕, attitude (WTP BEVs ⊖, cost-effectiveness BEVs ⊕, tolerance battery charging inconvenience ⊕, no home charging possibility ⊖, battery warranty ⊕, energy security support ⊕), importance of vehicle attributes (emissions ⊖, fuel efficiency ⊕), urban ⊕; Class 4 ('BEV-oriented'): Age ⊖, female ⊖, education ⊕, French speaking ⊕, time until next vehicle purchase ⊕, additional vehicle ⊕, presence of HEV in HH ⊖, next vehicle is economy car ⊕, attitude (WTP BEVs ⊖, cost-effectiveness BEVs ⊕, tolerance battery charging inconvenience ⊕, no home charging possibility ⊖, battery warranty ⊕, energy security support ⊕), importance of vehicle attributes (emissions ⊖, fuel efficiency ⊕), urban ⊕
Hackbarth and Madlener (2016)	LCM: Class 1 ('Car dependents'): Vehicle segment ⊕, technophilia ⊖, env. awareness ⊖, age ⊕, education ⊕; Class 2 ('Fuel cost savers'): Vehicle segment ⊕, technophilia ⊕, env. awareness ⊖, age ⊕, mileage ⊖; Class 3 ('CFV buyers'): Vehicle segment ⊕, env. awareness ⊖, age ⊕, mileage ⊖; Class 4 ('PHEV enthuisiasts'): Vehicle segment ⊕, technophilia ⊖, age ⊕; Class 5 ('Purchase price sensitives'): Vehicle segment ⊕, env. awareness ⊖, age ⊕, mileage ⊖, education ⊕, additional vehicle ⊕; Class 6 ('AFV aficionados'): BASE
Hidrue et al. (2011)	LCM: Class 1 ('EV-oriented'): Age ⊖, education ⊕, expected gasoline price ⊕, HEV owner ⊕, recharging potential at home ⊕, buyer of small/medium car ⊕, long trips ⊕, env. awareness ⊕, innovator ⊕; Class 2 ('GV oriented'): BASE
Parsons et al. (2014)	LCM: Class 1 ('EV-oriented'): Age ⊖, male ⊕, income ⊖, expected gasoline price ⊕, HEV owner ⊕, recharging potential at home ⊕, buyer of small/medium car ⊕, long trips ⊕, env. awareness ⊕, innovator ⊕; Class 2 ('GV oriented'): BASE
Valeri and Cherchi (2016)	Long distance trips ⊕
Fuel and vehicle type choice	
de Jong (1996)	Brand loyalty (German⊕, others⊕), no change of engine size class ⊕, fuel type loyalty ⊕, income ⊕
He et al. (2012)	Rating of vehicle attributes (exterior attractiveness, interior attractiveness, storage and space usage, audio system, seats, HVAC, driving dynamics, engine and transmission, visibility and safety ⊕)
Jäggi et al. (2013)	Marginal utility of additional vehicle usage (class ⊕, income ⊖)
Vehicle type choice	
Hensher and Le Plastrier (1985)	Experience index ⊕, brand loyalty ⊕
Hocherman et al. (1983)	Brand loyalty ⊕, no. of same make cars in HH ⊕, mileage ⊕, HH size ⊕, age ⊕, income ⊖
Mannering and Mahmassani (1985)	Past utilization of same make vehicle ⊕
Mannering and Winston (1985)	Past utilization of same make vehicle⊕
Mannering and Winston (1991)	Brand loyalty (GM / Ford / Chrysler / US others / major Japanese ⊕)
Mannering et al. (2002)	Brand loyalty (GM / Chrysler / Ford / Japanese / European ⊕), loyalty to vehicle leasing ⊕
Manski and Sherman (1980)	No. of vehicles vintage 1969-1976 ⊕, no. of foreign vehicles ⊖
McCarthy (1996)	Brand loyalty⊕, urban ⊕
McCarthy and Tay (1998)	Brand loyalty⊕
Train (1986)	No. of transaction required to obtain vehicles ⊖
Train and Winston (2007)	No. of dealerships within 50 mile range ⊕, brand loyalty (GM / Ford / Chrysler / Japanese / European ⊕)

Notes: ⊕ = positive effect; ⊖ = negative effect; CFV = conventional fuel vehicle; GV = gasoline vehicle; HEV = hybrid electric vehicle; (B)EV = battery electric vehicle; AFV = alternative fuel vehicle; PHEV = plug-in hybrid electric vehicle; ICE = internal combustion engine; HVAC = heating, ventilation, and air conditioning; HH = household; Env. = environmental; WTP = willingness-to-pay; LCM = latent class model.

Table A.12: Estimation results: Alternative-specific constants – Fuel types

Study	Fuel type preferences (descending order)
Fuel type choice	
Abdoolakhan (2010)	NL: Gasoline, diesel[1], HEV[1], LPG, dual LPG, B20, E20HEV, LPGHEV, E20; LCM: Class 1: LPG, dual LPG, B20[1], E20[1], gasoline, diesel[1], HEV[1], E20HEV[1], LPGHEV; Class2: LPGHEV[1], gasoline, HEV[1], diesel[1], E20HEV[1], B20, LPG, E20, Dual LPG
Achtnicht (2012)	Diesel, gasoline, HEV, NGV, FCEV, BV, BEV
Achtnicht et al. (2012)	NGV, gasoline, HEV, FCEV, BV, BEV[1], diesel
Aguilar et al. (2015)	E20, E85, E10, gasoline
Axsen et al. (2013)	BEV[1], CFV[1]
Axsen et al. (2015)	Class 1: BEV, PHEV, HEV, CFV; Class 2: PHEV, HEV, CFV, BEV; Class 3: HEV, CFV, PHEV, BEV[1]; Class 4: HEV, CFV, PHEV[1], BEV; Class 5: CFV, BEV[1], HEV, PHEV
Axsen et al. (2016)	Class 1: BEV, PHEV, HEV, CFV; Class 2: PHEV, HEV, CFV, BEV; Class 3: HEV, CFV, PHEV, BEV[1]; Class 4: HEV, CFV, PHEV[1], BEV; Class 5: CFV, BEV[1], HEV, PHEV; Pioneers: PHEV, BEV, CFV, HEV[1]
Bahamonde-Birke and Hanappi (2016)	HEV[1], PHEV[1], CFV, BEV[1]
Batley et al. (2004)	AFV, CFV
Bauer (2015)	HEV, BEV, NGV, diesel, gasoline
Beck et al. (2011)	Gasoline, HEV, Diesel
Beck et al. (2013)	LCM A: Class 1: Gasoline, HEV, diesel[1]; Class 2: HEV, gasoline, diesel; Class 3: HEV, diesel, gasoline; LCM B: Class 1: Diesel, gasoline, HEV; Class 2: HEV, gasoline, diesel; Class 3: Gasoline, diesel, HEV; Class 4: HEV, gasoline[1], diesel
Beck et al. (2017)	PHEV[1], gasoline[1], BEV, diesel[1], HEV
Beggs et al. (1981)	Gasoline, BEV
Bočkarjova et al. (2013)	HEV, CFV, BEV
Bunch et al. (1993)	Multi-fuel, AFV, BEV, gasoline, HEV
Byun et al. (2018)	Driver group: FCEV, BEV, gasoline, diesel[1]; Non-driver group: BEV, FCEV, gasoline, diesel[1]
Calfee (1985)	BEV, CFV
Cherchi (2017)	BEV, CFV
Dagsvik and Liu (2009)	AFV, CFV[1]
Dagsvik et al. (2002)	HEV, NGV, BEV, CFV
Daziano and Achtnicht (2014)	Gasoline, diesel[1], HEV[1], FCEV[1], NGV, BV, BEV
Daziano and Bolduc (2013)	CFV, HEV, FCEV, NGV
Dimitropoulos (2014)	LCM: Class 1: CFV/AFV, PHEV[1], BEV with swappable battery, BEV with fixed battery; Class 2: CFV/AFV, PHEV, BEV with swappable battery, BEV with fixed battery; Class 3: BEV with swappable battery[1], PHEV[1], BEV with fixed battery[1], CFV/AFV; Class 4: BEV with swappable battery, PHEV, BEV with fixed battery, CFV/AFV; Class 5: PHEV, CFV/AFV, BEV with swappable battery[1], BEV with fixed battery[1]
Eggers and Eggers (2011)	HEV, BEV350, BEV250, REEV150, CFV, REEV100, BEV150
Ewing and Sarigöllü (1998)	AFV, BEV, CFV
Ewing and Sarigöllü (2000)	AFV, BEV, CFV
Ferguson et al. (2018)	LCM: Class1: CFV, HEV, PHEV, BEV; Class 2: HEV, PHEV, CFV, BEV; Class 3: PHEV, HEV, BEV, CFV[1]; Class 4: BEV, PHEV, HEV, CFV
Glerum et al. (2014)	BEV, CFV
Golob et al. (1993)	BEV, AFV[1], multi-fuel[1], CFV, HEV[1]
Hackbarth and Madlener (2013)	CFV, PHEV, BEV, NGV, HEV, BV, FCEV
Hackbarth and Madlener (2016)	LCM: Class1: PHEV[1], BEV[1], CFV, HEV[1], FCEV[1], BV, NGV; Class 2: all fuel types[1]; Class 3: CFV, NGV, HEV, FCEV, BV, BEV, PHEV; Class 4: PHEV, HEV[1], CFV, BV, FCEV, BEV, NGV; Class 5: PHEV[1], CFV, NGV[1], BEV[1], HEV[1], BV, FCEV; Class 6: BEV, PHEV, BV, FCEV, NGV[1], HEV[1], CFV
Helveston et al. (2015)	PHEV40[1], PHEV20[1], PHEV10[1], CFV, HEV[1], BEV150, BEV75, BEV100
Hensher et al. (2011)	Gasoline, HEV, diesel
Hensher et al. (2013)	Gasoline, HEV, diesel
Hensher et al. (2017)	Gasoline[1], HEV, diesel
Hidrue et al. (2011)	LCM: Class 1: BEV, CFV; Class 2: CFV, BEV
Hoen and Koetse (2014)	CFV, flex-fuel, HEV, PHEV, FCEV, BEV
Horne et al. (2005)	FCEV, HEV, CFV, AFV
Jacobs et al. (2016)	N.A.
Jansson et al. (2017b)	CFV, AFV
Javid and Nejat (2017)	CFV, PHEV / BEV
Jensen et al. (2013)	CFV, BEV
Kim et al. (2014)	BEV, CFV[1]
Kim et al. (2016)	CFV, BEV
Knockaert (2010)	Diesel, HEV[1], gasoline, AFV, FCEV[1], LPG, BEV[1]
Krause et al. (2016)	Gasoline, HEV, PHEV, BEV
Langbroek et al. (2016)	BEV, CFV
Li et al. (2013)	Flex-fuel, HEV
Link et al. (2012)	CFV, HEV[1], BEV
Mabit and Fosgerau (2011)	FCEV, HEV, BV, BEV, CFV

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Table A.12 *(continued)*

Study	Fuel type preferences (descending order)
Mabit et al. (2015)	HEV, BEV[1], BV[1], CFV
Mannberg et al. (2014)	non-E85, E85
Marra et al. (2012)	E85, gasoline / E10
Mau et al. (2008)	FCEV, CFV, HEV (only in small market share scenario HEV>CFV)
Nixon and Saphores (2011)	HEV[1], CFV, FCEV[1], BEV[1], CNG[1]
Parsons et al. (2014)	LCM: Class 1: BEV, CFV; Class 2: CFV, BEV
Qian and Soopramanien (2011)	HEV, CFV, BEV
Ramjerdi and Rand (2000)	CFV, AFV, BEV
Rasouli and Timmermans (2016)	Gasoline, BEV
Rouwendal and de Vries (1999)	Gasoline, diesel, LPG
Rudolph (2016)	CFV, FCEV, PHEV, BEV
Sandór and Train (2004)	CFV, HEV, BEV
Sentürk et al. (2011)	Diesel[1], gasoline, LPG[1], HEV
Shin et al. (2012)	Baseline: BEV[1], gasoline, HEV[1], diesel[1]; Satiation: BEV, HEV, diesel, gasoline
Smith et al. (2017)	Best choice data: PHEV, BEV[1], diesel, gasoline; Worst choice data: Diesel, gasoline, PHEV, BEV
Train and Sonnier (2005)	HEV, CFV, BEV
Valeri and Cherchi (2016)	Diesel[1], gasoline, CNG[1], HEV[1], BEV with leased battery, LPG, BEV with owned battery
Valeri and Danielis (2015)	LPG, CNG, diesel, HEV[1], gasoline, BEV with leased battery[1], BEV with owned battery[1]
van Meerkerk et al. (2014)	Gasoline, diesel, LPG
Wang et al. (2017)	BEV360, CFV, BEV240, BEV120
Whitehead et al. (2014)	CFV, BV, low CO_2 diesel, BEV, low CO_2 petrol
Wolbertus et al. (2018)	BEV, PHEV, CFV[1]
Ziegler (2012)	Gasoline, diesel, HEV[1], NGV[1], FCEV, BV, BEV
Zito and Salerno (2004)	CFV, BEV
Fuel and vehicle type choice	
Adler et al. (2003)	Gasoline, diesel, HEV
Ahn et al. (2008)	Gasoline, CNG[1], diesel, LPG, HEV
Antolín et al. (2018)	Diesel small, gasoline small, diesel medium, diesel SUV, diesel MPV, gasoline medium, gasoline HEV, gasoline MPV, gasoline SUV, diesel HEV, diesel large, BEV[1], diesel luxury, gasoline large, gasoline luxury
Axsen et al. (2009)	SP: HEV, CFV; RP: CFV, HEV
Brownstone and Train (1999)	CNG, methanol, gasoline, BEV
Brownstone et al. (2000)	Methanol, NGV, gasoline, BEV
Cirillo et al. (2017)	Current[1], HEV, gasoline, BEV
Costa et al. (2019)	Diesel, gasoline
Daziano (2013)	HEV, CFV, BEV
de Jong (1996)	Gasoline, diesel
DeShazo et al. (2017)	CFV, PHEV, BEV
Dumortier et al. (2015)	Passenger car: PHEV, HEV, BEV[1], gasoline; SUV: HEV[1], PHEV[1], BEV[1], gasoline
Habibi et al. (2019)	BV, clean fuel, gasoline, HEV[1], NGV, diesel
Hackbarth and Madlener (2018)	Gasoline small, gasoline mini, gasoline mdeium, diesel mini, diesel small, diesel medium, AFV small, AFV mini, AFV medium, gasoline MPV, gasoline others, gasoline large, gasoline SUV, diesel others[1], diesel MPV[1], diesel large[1], diesel SUV, gasoline luxury[1], gasoline executive, AFV MPV, AFV large, AFV others, AFV SUV, diesel executive, diesel luxury, AFV luxury, AFV executive, gasoline sport coupé, diesel sport coupé, AFV sport coupé
Hahn et al. (2018)	Small: CFV, HEV[1], BEV[1], PHEV; Medium: BEV, PHEV, HEV, CFV; Large: PHEV, HEV, CFV, BEV[1]; Executive: PHEV, BEV, HEV, CFV
He et al. (2012)	HEV, CFV
He et al. (2014)	CFV, HEV
Hensher and Greene (2006)	AFV, BEV, CFV
Hess et al. (2006)	HEV, CFV, BEV
Hess et al. (2012)	PHEV, E85, clean diesel[1], HEV[1], CFV, CNG, BEV
Higgins et al. (2017)	CFV, HEV luxury[1], PHEV luxury, HEV MPV[1], HEV pick-up, HEV SUV, HEV medium, HEV large, PHEV small, PHEV medium, PHEV MPV, PHEV SUV, PHEV large, BEV luxury, BEV SUV, PHEV pick-up, BEV MPV, BEV small, BEV medium, BEV pick-up, BEV large
Ito et al. (2013)	HEV, CFV, BEV, FCEV
Ito et al. (2019)	BEV with fixed battery (recharging time: 15 min, 10 min, 30 min), BEV with swappable battery, HEV, CFV
Jäggi et al. (2013)	Diesel subcompact[1], gasoline subcompact, gasoline mid-size, gasoline compact[1], gasoline full-size[1], AFV[1], diesel compact[1], gasoline micro, gasoline sport coupé, diesel mini MPV, diesel full-size, gasoline mini MPV, diesel mid-size, diesel luxury, gasoline luxury[1]
Kavalec (1999)	Methanol, multi-fuel, NGV, CFV, BEV
Lee and Cho (2009)	Diesel, gasoline
Liu (2014)	HEV, CFV
Liu and Cirillo (2018)	Current / gasoline, HEV, BEV
Mabit (2014)	Non-diesel, diesel
Maness and Cirillo (2012)	Model A: Current gasoline, new gasoline, HEV, BEV; Model B. Current gasoline, new gasoline, BEV, AFV, PHEV, diesel; Model C: Current gasoline, HEV, new gasoline, BEV

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Table A.12 *(continued)*

Study	Fuel type preferences (descending order)
Musti and Kockelman (2011)	HEV, PHEV, CFV
Paleti et al. (2011)	Gasoline, HEV, diesel, flex-fuel, PHEV, BEV, CNG
Potoglou and Kanaroglou (2007)	HEV[1], CFV, AFV[1]
Shiau et al. (2009)	HEV, CFV
Shin et al. (2015)	Base: HEV[1], gasoline, diesel, BEV; Satiation: Gasoline, diesel, HEV, BEV
Shin et al. (2018)	HEV[1], gasoline, diesel, BEV
Soto et al. (2018)	small BEV, large / executive BEV, SUV diesel, large / executive NGV, small NGV, SUV NGV[1], gasoline, large / executive HEV[1], SUV HEV[1], small HEV[1]
Tompkins et al. (1998)	National: BEV, CFV, NGV, multi-fuel[1]; California: BEV, multi-fuel[1], NGV[1], CFV
Train and Weeks (2005)	HEV, CFV, BEV
Xu et al. (2015)	Gasoline, HEV, diesel, BEV

Notes: 1 = insignificant alternative-specific constant in estimated model; CFV = conventional fuel vehicle; NGV = natural gas vehicle; CNG = compressed natural gas; LPG = liquefied petroleum gas; HEV = hybrid electric vehicle; BEV = battery electric vehicle; REEV = range-extended electric vehicle; FCEV = fuel cell electric vehicle; AFV = alternative fuel vehicle; BV = biofuel vehicle (ethanol: E10, E20, E85; biodiesel: B20); PHEV = plug-in hybrid electric vehicle; MPV = multi purpose vehicle; SUV = sport utility vehicle; NL = nested logit model; LCM = latent class model; SP = stated preferences; RP = revealed preferences; Without estimated alternative-specific constants: Østil et al. (2017), Jansson et al. (2017a), Tanaka et al. (2014), Lebeau et al. (2012), Batley and Toner (2003), Daziano (2015), Caulfield et al. (2010).

Table A.13: Estimation results: Alternative-specific constants – Vehicle types

Study	Vehicle type preferences (descending order)
Fuel and vehicle type choice	
Adler et al. (2003)	Passenger car (mid-size / large, compact, subcompact), SUV, pick-up, van
Ahn et al. (2008)	Ordinary, MPV
Antolín et al. (2018)	Diesel small, gasoline small, diesel medium, diesel SUV, diesel MPV, gasoline medium, gasoline HEV, gasoline MPV, gasoline SUV, diesel HEV, diesel large, BEV[1], diesel luxury, gasoline large, gasoline luxury
Axsen et al. (2009)	Canada: Small, van, SUV, large, pick-up; California: Small, SUV, large, pick-up, van
Brownstone and Train (1999)	SUV, sport coupé, passenger car, van, pick-up, station wagon
Brownstone et al. (2000)	Sport coupé, SUV, mini SUV[1], mid-size / large, compact / subcompact / mini, pick-up, van, station wagon
Costa et al. (2019)	SUV, station wagon, mini
Daziano (2013)	Mid-size SUV, large SUV, mid-size, large, minivan, full pick-up, small SUV, compact pick-up, small, mini
DeShazo et al. (2017)	Compact sedan, mid-size sedan, compact SUV, mid-size SUV, full-size sedan, full-size SUV, hatchback , sport coupé, pick-up, station wagon, van
Dumortier et al. (2015)	Passenger car, SUV
Habibi et al. (2019)	Luxury, hatchback, SUV, cabriolet, sport coupé, minivan, sedan, MPV, minibus
Hackbarth and Madlener (2018)	Gasoline small, gasoline mini, gasoline medium, diesel mini, diesel small, diesel medium, AFV small, AFV mini, AFV medium, gasoline MPV, gasoline others, gasoline large, gasoline SUV, diesel others[1], diesel MPV[1], diesel large[1], diesel SUV, gasoline luxury[1], gasoline executive, AFV MPV, AFV large, AFV others, AFV SUV, diesel executive, diesel luxury, AFV luxury, AFV executive, gasoline sport coupé, diesel sport coupé, AFV sport coupé
He et al. (2012)	Mini, minivan, passenger car (premium, compact, medium, large), pick-up[1], SUV, MAV, van
He et al. (2014)	Passenger car (compact, medium, large, premium), pick-up, mini, multi activity vehicle, SUV, minivan, van
Hensher and Greene (2006)	Upper medium B[1], luxury[1], light commercial, four-wheeler, upper medium A[1], large[1], light truck, medium[1], small[1], micro[1]
Hess et al. (2006)	Mid-size SUV, mid-size, large SUV[1], large, minivan, full pick-up, small SUV, compact pick-up, small, mini
Hess et al. (2012)	Small cross utility vehicle, compact SUV, large SUV[1], small cross-utility SUV[1], mid-size SUV[1], mid-size, mid-size cross-utility vehicle[1], compact pick-up[1], sport coupé[1], subcompact, compact van[1], pick-up[1], compact[1], large[1]
Higgins et al. (2017)	CFV, HEV luxury[1], PHEV luxury, HEV MPV[1], HEV pick-up, HEV SUV, HEV medium, HEV large, PHEV small, PHEV medium, PHEV MPV, PHEV SUV, PHEV large, BEV luxury, BEV SUV, PHEV pick-up, BEV MPV, BEV small, BEV medium, BEV pick-up, BEV large
Ito et al. (2013)	Sedan, SUV / pick-up, large /station wagon / minivan, subcompact / compact, sport coupé, truck / bus
Ito et al. (2019)	SUV/pick-up truck[1], minivan[1], subcompact / compact / convertible / truck / bus[1], sport coupé[1], station wagon, sedan
Jäggi et al. (2013)	Public transportation, diesel subcompact[1], gasoline subcompact, mid-size gasoline, compact gasoline[1], full-size gasoline[1], AFV[1], compact diesel[1], micro gasoline, sport coupé gasoline, mini MPV diesel, full-size diesel, mini MPV gasoline, mid-size diesel, luxury / sport coupé diesel, luxury gasoline[1]
Kavalec (1999)	SUV, sport coupé, passenger car (large, mid-size, compact, subcompact, mini[1]), van, truck, station wagon

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Table A.13 *(continued)*

Study	Vehicle type preferences (descending order)
Liu (2014)	Passenger car, SUV / truck
Mabit (2014)	Executive, large, SUV, small, micro, MPV, compact
Musti and Kockelman (2011)	SP data: Luxury, PHEV, large, HEV, executive / cross-utility vehicle, van, SUV, compact, smart car, subcompact; RP data: Others, cross-utility vehicle, luxury
Paleti et al. (2011)	No vehicle, compact, passenger car, pick-up, SUV, small cross-utility vehicle, van
Potoglou and Kanaroglou (2007)	SUV, van, pick-up, mid-size, large, subcompact, compact[1]
Shiau et al. (2009)	Luxury[1], sport coupé, executive, medium, large, small, mini
Shin et al. (2015)	SUV, sedan
Shin et al. (2018)	SUV[1], passenger car
Tompkins et al. (1998)	National: Small SUV, large SUV[1], mid-size, large[1], minivan, small, work-truck, neighborhood vehicle; California: Small SUV, large SUV, large, mid-size, small[1], neighborhood vehicle, minivan, work-truck
Train and Weeks (2005)	Mid-size SUV, mid-size, large SUV[1], large, minivan, full pick-up, small SUV, compact pick-up, small, mini
Xu et al. (2015)	Before rebate program: Small[1], medium, sedan, station wagon, minivan, SUV[1], sport coupé[1]; After rebate program: Small, compact, minivan, station wagon, sedan, SUV[1], sport coupé[1]
Vehicle type choice	
Adjemian et al. (2010)	Station wagon, pick-up[1], sportscar[1], coupé[1], compact[1], mid-size[1], minivan[1], SUV[1], large, premium
Baltas and Saridakis (2013)	Supermini, small family, station wagon[1], roadster[1], mini[1], medium[1], MPV, cabrio, luxury, coupé, large
Beggs and Cardell (1980)	Mid-size, full-size[1], compact, subcompact
Berkovec (1985)	1-car HH: Truck, sport coupé[1], passenger car, van[1], SUV[1]; 2-car HH: Truck, passenger car, SUV[1], sport coupé[1], van; 3-car HH: Truck, passenger car, sport coupé[1], SUV[1], van[1]
Berkovec and Rust (1985)	Mid-age compact, old standard, old intermediate, mid-age subcompact, new intermediate, mid-age standard, new standard, new luxury, old compact, new compact, old subcompact[1], new subcompact, mid-age intermediate, mid-age luxury[1], old luxury[1]
Bhat and Sen (2006)	Passenger car, pick-up, SUV, minivan, van
Bhat et al. (2009)	Old SUV, new compact, new mid-size, old pick-up, old compact, new pick-up, old subcompact, new subcompact, new station wagon, old sport coupé, old mid-size, new SUV[1], new sport coupé, old station wagon[1], old large sedan, old minivan, new minivan, old van, new large sedan, new van
Biswas et al. (2014)	Mini, sedan, SUV, sport coupé[1], prestige[1]
Cao et al. (2006)	Passenger car, pick-up, minivan, SUV
Chiou et al. (2009)	New large, new compact, new medium, old large, new small, old compact[1], old medium[1], old small
Choo and Mokhtarian (2004)	Small[1], pick-up, compact, sport coupé, mid-size, SUV, minivan / van, large, luxury
Eluru et al. (2010)	CN large sedan, CN / NU compact sedan[1], CN sport coupé, NU large sedan[1], NU sport coupé, CN / NU SUV, CN / NU pick-up, CN / NU van
Hensher and Le Plastrier (1985)	Station wagon, non-station wagon
Kitamura et al. (1999)	2-door coupé, 4-door sedan, pick-up, SUV, sportscar, van
Kockelman and Zhao (2000)	Passenger car, pick-up, SUV, minivan
Koo et al. (2012)	Passenger car, SUV
Kuwano et al. (2013)	Small, medium[1], large[1]
Lave and Train (1979)	Luxury[1], intermediate[1], standard A / B[1], sport coupé[1], compact A / B[1], subcompact B[1], subsubcompact, subcompact A[1]
Liu et al. (2014)	Passenger car, pick-up / SUV
Mannering and Winston (1991)	Non-SUV, SUV
Mannering et al. (2002)	US SUV, non-US SUV, mid-size, compact, US minivan, large, US subcompact, non-US subcompact
Manski and Sherman (1980)	Non-passenger car, passenger car
McCarthy (1996)	SUV / van / pick-up, passenger car, sport coupé, luxury
McCarthy and Tay (1998)	SUV / van, pick-up, passenger car
Mohammadian and Miller (2002, 2003)	SUV / pick-up, compact, subcompact, mid-size[1], van, executive[1]
Noblet et al. (2006)	Passenger car, truck, SUV, van
Potoglou (2008)	Passenger car, SUV, van, pick-up
Prieto and Caemmerer (2013)	Used small, used medium[1], used small, used large, new medium, used luxury, new large / luxury
Spissu et al. (2009)	SUV[1], compact, pick-up, large, sport coupé, van
Train (1986)	Pick-up, van[1], passenger car , SUV
Train and Winston (2007)	SUV / station wagon[1], pick-up[1], passenger car, luxury / sport coupé[1], van / minivan
Vekeman et al. (2004)	Small, sport coupé, van, medium, SUV, pick-up, executive

Notes: 1 = insignificant alternative-specific constant in estimated model; CFV = conventional fuel vehicle; HEV = hybrid electric vehicle; BEV = battery electric vehicle; AFV = alternative fuel vehicle; PHEV = plug-in hybrid electric vehicle; MPV = multi purpose vehicle; SUV = sport utility vehicle; MAV = multi activity vehicle; Truck = non-car vehicles; HH = household; NU = neo-urbanist neighborhood; CN = conventional neighborhood; SP = stated preferences; RP = revealed preferences; Without estimated alternative-specific constants: West (2007), Martin (2009), Mannering and Mahmassani (1985), Mannering and Winston (1985), Hocherman et al. (1983), de Jong (1996), Liu and Cirillo (2018), Cirillo et al. (2017), Hahn et al. (2018), Soto et al. (2018), Lee and Cho (2009), Maness and Cirillo (2012).

Table A.14: Additional estimations and simulations

Study	WTP	Marginal effects / elasticities	Simulations / forecasts
Fuel type choice			
Abdoolakhan (2010)		Direct elasticities for purchase price and fuel costs	Impact of different purchase price and fuel costs scenarios on on vehicle (fuel type) choice probabilities
Achtnicht (2012)	WTP for CO_2 emissions		
Achtnicht et al. (2012)	WTP for fuel availability		Impact of changes in fuel availability on vehicle (fuel type) choice probabilities
Aguilar et al. (2015)		Elasticity of ethanol use with respect to gasoline price	Impact of fuel efficiency, ethanol source, and gasoline price on market share of different biofuels
Axsen et al. (2015)	WTP for fuel costs, home charging, and all fuel types		
Axsen et al. (2016)	WTP for fuel costs, home charging, and all fuel types		
Batley and Toner (2003)			Test for ability to correctly forecast market shares of vehicles (fuel type) for extreme attribute levels
Batley et al. (2004)	WTP for all vehicle attributes and fuel types	Direct elasticities for purchase price, fuel costs, fuel availability, and driving range	
Beck et al. (2011)		Direct elasticities for all vehicle attributes	
Beck et al. (2013)		Direct elasticities for all vehicle attributes	
Beggs et al. (1981)			Impact of different levels of socio-dempgraphic characteristics on preferences for vehicle attributes
Bočkarjova et al. (2013)	WTP for all vehicle attributes and fuel types		
Bunch et al. (1993)		Iso-probability trade-offs of driving range, fuel availability, emissions, and fuel costs with purchase price	Impact of changes in fuel costs, driving range, and fuel availability on vehicle choice probabilities
Byun et al. (2018)	WTP for all vehicle attributes		Market share forecast of the different fuel types until 2030 and analysis of the impact of purchase price subsidies and increase in fuel availability on choice probabilities
Calfee (1985)			Impact of different purchase price, fuel costs, top speed, and driving range scenarios on market shares of vehicles (fuel type)
Cherchi (2017)			Calculation of contribution of each attribute to the utility difference between CFVs and BEVs in 6 multi-attribute scenarios for mini/small cars
Dagsvik and Liu (2009)		Direct elasticities of purchase price, horsepower and fuel costs in different scenarios	Impact of purchase price, fuel costs, fuel consumption, and horsepower on probability of car ownership
Dagsvik et al. (2002)	Compensating variation for all fuel types	Direct elasticity for purchase price	Market shares of vehicles (fuel type) for different driving range levels
Daziano (2015)	Annual implicit discount rates for energy savings		Market shares of vehicles (fuel type) in 4 different scenarios (increase gasoline costs, horsepower of HEVs, maximum pro-environment consumers, and cost-conscious consumers)
Daziano and Achtnicht (2014)			Impact of changes in fuel availability (for BEVs and FCEVs) on market share of vehicles (fuel type)
Daziano and Bolduc (2013)	WTP for all vehicle attributes		Impact of 7 different multi-attribute scenarios on market shares of vehicles (fuel type)
Dimitropoulos (2014)	WTP for all vehicle attributes and fuel types		
Eggers and Eggers (2011)			Impact of changes in purchase price and driving range on vehicle (fuel type) market shares (especially BEVs) over time (adoption frequency in the upcoming decade)

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Table A.14 *(continued)*

Study	WTP	Marginal effects / elasticities	Simulations / forecasts
Ewing and Sarigöllü (1998)		Marginal effects for all vehicle attributes	Impact of changes in emissions, purchase price, driving range, and recharging time in 11 scenarios on choice probabilities of vehicles (fuel type)
Ewing and Sarigöllü (2000)		Marginal effects for all vehicle attributes	Impact of changes in emissions, purchase price, driving range, and recharging time in 11 scenarios on choice probabilities of vehicles (fuel type)
Glerum et al. (2014)	WTP for battery leasing costs	Direct elasticity for purchase price (for BEVs)	Market shares of vehicles in a specific realistic base case
Hackbarth and Madlener (2013)	WTP of all vehicle attributes		Impact of 8 different multi-attribute scenarions on market shares of vehicles (fuel type)
Hackbarth and Madlener (2016)	WTP of all vehicle attributes; compensating variation for all vehicle attributes		
Helveston et al. (2015)	WTP for all vehicle attributes		Choice probabilities of all fuel types with and without purchase price subsidy
Hensher et al. (2011)		Direct elasticities for all vehicle attributes	
Hensher et al. (2013)		Direct elasticities for all vehicle attributes	
Hensher et al. (2017)		Direct elasticities for all vehicle attributes	
Hidrue et al. (2011)	WTP for all vehicle attributes and six specific BEV configurations (regarding range, emissions, charging time, acceleration)		
Hoen and Koetse (2014)	WTP for driving range, recharging/refueling time, additional detour time, number of models, and abolishment of road tax exemption		
Horne et al. (2005)			GHG emissions of vehicle fleet and market shares of vehicles (fuel type) in 3 scenarios (emissions tax, incentives) in the CIMS model
Javid and Nejat (2017)		Marginal effects of carsharing user, income, education, charging station per capita, gasoline price and plug-in electric vehicle	
Jensen et al. (2013)	WTP for all vehicle attributes	Direct and cross elasticities for all vehicle attributes	
Knockaert (2010)			Evolution of passenger and freight transportation kilometers, emissions and external costs, impact of emission and levelled tax on market shares of the private car stock (fuel type) and emissions in the TREMOVE model
Krause et al. (2016)		Marginal effects for all independent variables (vehicle attributes and socio-demographic variables) for all fuel types	
Langbroek et al. (2016)	WTP for all vehicle attributes		
Lebeau et al. (2012)			Impact of purchase price, fuel costs, charging time, fuel availability, battery leasing, and battery capacity scenarios on market shares of vehicles (fuel type)
Li et al. (2013)		Marginal effects for all socio-demographic variables	
Link et al. (2012)			Impact of fuel costs and incentives (monetary, non-monetary) on market shares of vehicles (fuel type) over time
Mabit and Fosgerau (2011)	WTP for all vehicle attributes and fuel types		Impact of purchase price, operating costs, acceleration, and driving range in 2 scenarios on market share of vehicles (fuel type)
Mabit et al. (2015)	WTP for annual costs and driving range	Direct elasticities of purchase price	
Mannberg et al. (2014)			Trend analysis

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Table A.14 *(continued)*

Study	WTP	Marginal effects / elasticities	Simulations / forecasts
Marra et al. (2012)	WTP for fuel type, refueling distance, share of fuel from imported sources, and emissions		
Mau et al. (2008)	WTP for fuel costs, subsidy, warranty, fuel availability, fuel efficiency, and all fuel types		Market share of HEVs over time in CIMS model
Østil et al. (2017)	WTP for fuel type, resource cost share, fuel costs, four/front-wheel drive, no. of seats, and no. of doors		Impact of changes in the different vehicle purchase tax components and fuel costs on vehicles' fuel type, emissions (CO_2 and NO_x), curb weight, and horsepower and on the annual tax revenues
Parsons et al. (2014)	WTP for all vehicle attributes and for eight specific V2G contract configurations displayed in annual cash back and upfront costs (regarding daily plug-in time and minimum guaranteed driving range)		
Qian and Soopramanien (2011)		Direct and cross elasticities for all vehicle attributes (dependent on vehicle ownership status)	
Rouwendal and de Vries (1999)		Direct elasticity for purchase price	
Rudolph (2016)			Choice probabilities of vehicles (fuel types) for different scenarios (purchase price subsidy, CO_2 tax, free parking, fuel costs, charging infrastructure) for 4 different mobility groups (everyday car drivers, every day public transportation users, muiltimodal user with car affinity, multimodal users with public transportation affinity)
Sentürk et al. (2011)		Marginal effects for all socio-demographic variables	
Shin et al. (2012)			Change in car usage (from RP data) and emissions after the introduction of HEVs and BEVs, purchase price subsidies, and tax incentives
Tanaka et al. (2014)	WTP for all vehicle attributes		Impact of purchase price and technological innovationsof on the market shares of vehicles (fuel type) in the US and Japan
Valeri and Cherchi (2016)		Direct elasticities for operating costs, purchase price, driving range, refueling distance and choice probabilities of the different fuel types, segmented by socio-economic variables (education, main purpose of vehicle usage = business)	
Valeri and Danielis (2015)			Market shares of vehicles (fuel type) in different multi-attribute scenarios (regarding subsidy, driving range, purchase price (CFVs, BEVs))
van Meerkerk et al. (2014)		Direct and cross elasticities for purchase price and fuel costs	Impact of vehicle sales tax reform and fuel price on choice probability of new vehicles (fuel type)
Wang et al. (2017)	WTP for all vehicle attributes		
Whitehead et al. (2014)			Impact of congestion tax exemption on market share of new, exempt energy efficient vehicles (fuel type) for different buyer groups (segmented by home location)
Zito and Salerno (2004)		Direct elasticities for annual costs, daily running time, and vehicle life	Annual differences in TCO of BEVs compared to CFVs calculated for different battery lifes and annual mileages; TCO difference between owning a BEV or a CFV and BEV carsharing
Fuel and vehicle type choice			
Ahn et al. (2008)			Usage (mileage) of the different vehicles (fuel type) and change in fuel consumption and emissions after introduction of new vehicle alternatives (HEV, CNG and HEV)

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Table A.14 *(continued)*

Study	WTP	Marginal effects / elasticities	Simulations / forecasts
Antolín et al. (2018)	WTP for fuel consumption and horsepower	Direct and cross elasticities for purchase price	Market shares of the different vehicles (fuel and vehicle types) in 3 scenarios (do nothing, registration tx increase, technological innovation)
Axsen et al. (2009)	Monetary values for parameters in the CIMS model		HEV market share and vehicle fleet GHG emissions in 3 scenarios (purchase subsidy, feebate, emission tax)
Brownstone et al. (2000)			Market shares of vehicles in 37 multi-attribute scenarios
Cirillo et al. (2017)	WTP for fuel efficiency, driving range, and vehicle size	Direct and cross elasticities for purchase price and fuel costs	
Costa et al. (2019)	WTP for all vehicle attributes		
Daziano (2013)	WTP and compensating variation for driving range	Direct elasticity for driving range, range equivalent	
de Jong (1996)			Ownership, usage, emissions, and fuel consumption of vehicle types in different scenarios (fuel costs, road tax, income)
DeShazo et al. (2017)			Evaluation of different rebate policy designs (estimation of additional number of vehicles sold and total costs of the program)
Habibi et al. (2019)			Comparison of actual and predicted market shares of the different manufacturers and BVs
Hahn et al. (2018)		Direct elasticities of purchase price, operating costs, fuel availability, and driving range for the different vehicle and fuel types	
He et al. (2014)			Comparison of choice probabilities of models with and without social impact variable
Hensher and Greene (2006)	WTP for driving range		Impact of purchase price, acceleration, and vehicle age on the market shares of vehicles (vehicle and fuel type) in 5 scenarios
Hess et al. (2012)			Impact of purchase price reduction for subcompact, compact, and mid-size PHEVs on the market shares of vehicles (vehicle and fuel type)
Higgins et al. (2017)		Marginal effects of age on all fuel types in the medium and luxury segment	Impact of incentives on choice probabilities of fuel types in the medium and luxury segment in 3 scenarios (no incentives, Ontario incentives, Ontario incentives and altered alternative and respondent characteristics)
Ito et al. (2013)	WTP for charging options (fuel availability + charging time, crusing range depending on the charging options available)		Impact of availability of battery swapping stations on the market shares of vehicles (fuel type)
Ito et al. (2019)	WTP for fuel availability and driving range for BEVs with fixed and swappable bateries		Impact of fuel availability on the choice probabilities BEVs with fixed and swappable bateries
Kavalec (1999)			Impact of age on the valuation of vehicle attributes
Lee and Cho (2009)			Impact of purchase price, fuel costs, fuel efficiency, and taxes on market shares of diesel passenger cars in all vehicle segments in mulit-attribute scenarios
Liu (2014)	WTP for HEVs		Impact of tax incentives on the choice probability of HEVs in all vehicle segments
Liu and Cirillo (2018)			Market share forecast of different fuel types in the different models (repeated vs. one-time purchase), impact of changes in purchase prices, fuel costs, fuel efficiency, and recharging range on market shares
Mabit (2014)	WTP for all vehicle attributes and vehicle types		Vehicles' average fuel efficiency and market share of diesel vehicles with and without tax reform and fuel cost increase
Musti and Kockelman (2011)		Direct elasticity for mileage (dependent on socio-demographic variables)	Market shares, mileage and emissions of the different vehicles (fuel and vehicle types) in 2034 in 3 scenarios (PHEV purchase price subsidy, feebates, gasoline price increase)

(continued on next page)

Table A.14 *(continued)*

Study	WTP	Marginal effects / elasticities	Simulations / forecasts
Potoglou and Kanaroglou (2007)	WTP for maintenance costs, fuel costs, acceleration, tax incentive, and emissions		
Shiau et al. (2009)			Simulation of vehicle fuel economy under various fuel prices, fuel economy standards, and penalty levels
Shin et al. (2018)			Impact of introducing BEVs and smart car options in the vehicole market on choice probability and vehicle usage
Soto et al. (2018)	WTP for fuel costs, fuel availability, driving range and annual taxes	Direct and cross elasticities for purchase price, fuel costs, fuel availability, driving range, and annual taxes	Impact of 13 different multi-attribute scenarios (changes in vehicle attributes and attitudes) on market shares of fuel types
Train and Weeks (2005)	WTP for all vehicle attributes and fuel types		
Vehicle type choice			
Beggs and Cardell (1980)	WTP for vehicle size	Trade-offs of fuel costs and depreciated luxury premium with purchase price; marginal effects of all vehicle attributes (2nd dataset)	
Berkovec (1985)			Impact of 3 different gasoline price scenarios on vehicle fuel efficiency, scrappage rate, and sales rates of the vehicle types
Berkovec and Rust (1985)	WTP for operating costs, number of seats, and vehicle age		
Bhat and Sen (2006)			Impact of operating costs on market shares of the vehicle types
Bhat et al. (2009)			Impact of built environment attributes (bike lane density, residential density) and fuel costs on vehicle type ownership and usage
Chiou et al. (2009)			Ownership, usage, emissions, and fuel consumption of vehicle types in different scenarios (purchase price, fuel costs, access to public transportation)
Eluru et al. (2010)			Impact of HH size, number of employed individuals, number of females per HH, land use mix value of the neighborhood, and number of zones accessible by bicycle within a six mile radius on market shares of the vehicle types, residential location, and vehicle usage
Koo et al. (2012)	WTP for all vehicle attributes		
Kuwano et al. (2013)			Impact of operating costs, holding costs, purchase costs on number of vehicle replacements, market shares of vehicles, mileage, holding duration, and emissions
Lave and Train (1979)			Impact of fuel prices and excise taxes on purchase prices on market shares of the vehicle types
Liu et al. (2014)			Impact of income, residential density, and fuel costs on ownership and usage of vehicle types per HH
Mannering and Mahmassani (1985)	WTP for fuel costs, collision costs, horsepower, and consumer report cost index	Direct elasticity for purchase price, fuel costs, collision costs, horsepower, consumer report cost index, and income	
Mannering and Winston (1985)	WTP for fuel costs	Direct elasticity (vehicle choice and usage) for purchase price, fuel costs, and income	
Mannering and Winston (1991)	WTP for brand loyalty	Marginal effects for additional brand loyal purchases; Direct elasticities for all vehicle attributes	Impact of brand loyalty on sales and market share of the vehicle types (new passenger cars and light trucks) during the 1990s
Manski and Sherman (1980)	WTP for exess seat, luggage space, fuel costs, and vehicle weight		
Martin (2009)	WTP for fuel costs		Impact of HEV tax credits and gasoline tax on market shares, fuel consumption, and GHG emissions of vehicle types

(continued on next page)

Table A.14 *(continued)*

Study	WTP	Marginal effects / elasticities	Simulations / forecasts
McCarthy and Tay (1998)		Direct and cross elasticities of purchase price and fuel costs	
Prieto and Caemmerer (2013)		Marginal effects for all independent variables	
Spissu et al. (2009)			Impact of fuel prices on vehicle type choice and usage
Train (1986)	WTP for all vehicle attributes		Impact of purchase prices of BEVs, fuel costs, income, and non-availability of AFVs on the number of vehicles, fuel types, fuel consumption, and mileage until 2000 (plus sensitivity analysis)
Train and Winston (2007)		Direct and cross elasticities for purchase price	Calculation of the purchase price reduction of US manufacturers to attain 1990s market share in 2000
Vekeman et al. (2004)		Direct and cross elasticities for SUV fuel consumption and sedan purchase price	Impact of age and children on vehicle type choice probabilities

Notes: CFV = conventional fuel vehicle; CNG = compressed natural gas; HEV = hybrid electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; AFV = alternative fuel vehicle; BV = biofuel vehicle; PHEV = plug-in hybrid electric vehicle; SUV = sport utility vehicle; V2G = vehicle-to-grid; GHG = greenhouse gas; HH = household; WTP = willingness-to-pay; TCO = total costs of ownership; RP = revealed preferences; CIMS = framework for infrastructure interdependency modeling and analysis; TREMOVE = transport and emissions simulation model.

A.2 Questionnaire of the Vehicle Purchase Survey (in German)

Einführung

Mit dieser Befragung möchten wir die Einflussfaktoren untersuchen, die bei der Entscheidung für einen Personenkraftwagen (PKW) mit konventionellen (z.B. Benzin oder Diesel), aber auch alternativen Kraftstoffen bzw. Antriebskonzepten (z.B. Wasserstoff oder Elektroantrieb) eine Rolle spielen. Außerdem werden wir Sie in diesem Fragebogen auch zu Ihrer aktuellen Automobilnutzung befragen.
Die Umfrage dauert ca. 30 Minuten.
Vielen Dank für Ihre Unterstützung!

Screeningfragen

Scr 1. Haben Sie sich in den vergangenen 12 Monaten einen PKW (nur Neuwagen) angeschafft (privater Kauf oder Dienstwagen)?

- ☐ Ja *Programmierhinweis: Weiter mit Frage 1*
- ☐ Nein

Scr 2. Planen Sie, in den kommenden 12 Monaten einen PKW (nur Neuwagen) anzuschaffen (privater Kauf oder Dienstwagen)?

- ☐ Ja
- ☐ Nein *Programmierhinweis: Ende der Befragung*

PKW Kauf und Nutzung

1. Wie viele PKW gibt es in Ihrem Haushalt (inklusive Dienstwagen)?

- ☐ Keinen *Programmierhinweis: Weiter mit Frage 4*
- ☐ Einen
- ☐ Zwei
- ☐ Drei
- ☐ Vier und mehr

Programmierhinweis: Auf Basis von Scr 2 und Frage 1 erfolgt eine Aufteilung der Teilnehmer in drei Gruppen, in deren Abängigkeit die Fragen 3-19 variieren können:

- *Gruppe A: PKW-Kauf in den vergangenen 12 Monaten*
- *Gruppe B: PKW-Kauf in den kommenden 12 Monaten geplant und kein PKW im Haushalt vorhanden*
- *Gruppe C: PKW-Kauf in den kommenden 12 Monaten geplant und PKW im Haushalt vorhanden*

2. Machen Sie hier bitte Angaben zu dem PKW, den Sie am häufigsten benutzen.

Marke und Modell ______________________________

Kraftstoff / Antriebsart

- ☐ Diesel
- ☐ Normalbenzin / Superbenzin
- ☐ Gas (Erdgas, Autogas)
- ☐ Hybrid
- ☐ Plug-in Hybrid
- ☐ Elektrisch
- ☐ Wasserstoff
- ☐ Biokraftstoff (Bioethanol E85 oder Biodiesel B100)
- ☐ Sonstige

Baujahr __________

Segment

- ☐ Microwagen (z.B. Smart Fortwo, Fiat Panda, VW Lupo, Renault Twingo usw.)
- ☐ Kleinwagen (z.B. Opel Corsa, Nissan Micra, Peugeot 206, VW Polo, Renault Clio usw.)
- ☐ Kompaktklasse (z.B. VW Golf, Toyota Corolla, Mercedes A-Klasse, Skoda Fabia usw.)
- ☐ Mittelklasse (3er BMW, Toyota Avensis, VW Passat, Audi A4 usw.)
- ☐ Obere Mittelklasse (z.B. Audi A6, Volvo V70, 5er BMW, Peugeot 607 usw.)
- ☐ Oberklasse (z.B. Mercedes S-Klasse, Audi A8, Jaguar XJ, 7er BMW usw.)
- ☐ SUV / Geländewagen (z.B. Toyota RAV4, Subaru Forester, VW Touareg, Land Rover usw.)
- ☐ Mini-Van / Großraum-Van (z.B. Opel Zafira und Meriva, Renault Espace und Kangoo, VW Sharan und Touran, Chrysler Voyager usw.)
- ☐ Roadster / Sportwagen (z.B. BMW Z4, Audi TT, Porsche 911, Toyota Celia usw.)
- ☐ Sonstige

Programmierhinweis: Gruppe A weiter mit Frage 3, Gruppe C weiter mit Frage 4

3. Ist dieser PKW, den Sie am häufigsten benutzen, auch der PKW, den sie zuletzt angeschafft haben?

- ☐ Ja *Programmierhinweis: Weiter mit Frage 7*
- ☐ Nein *Programmierhinweis: Weiter mit Frage 6*

4. Haben Sie schon eine ungefähre Vorstellung von Ihrem zukünftigen PKW?

- ☐ Ja *Programmierhinweis: Weiter mit Frage 6*
- ☐ Nein

5. Sie haben angegeben, noch keine genaue Vorstellung von Ihrem zukünftigen PKW zu haben. Versuchen Sie bitte dennoch, die aus Ihrer heutigen Sicht wahrscheinlichste Kraftstoff- bzw. Antriebsart und das wahrscheinlichste Fahrzeugsegment dieses PKW zu wählen.

Kraftstoff / Antriebsart

- ☐ Diesel
- ☐ Normalbenzin / Superbenzin
- ☐ Gas (Erdgas, Autogas)
- ☐ Hybrid
- ☐ Plug-in Hybrid
- ☐ Elektrisch
- ☐ Wasserstoff
- ☐ Biokraftstoff (Bioethanol E85 oder Biodiesel B100)
- ☐ Sonstige

Segment

- ☐ Microwagen (z.B. Smart Fortwo, Fiat Panda, VW Lupo, Renault Twingo usw.)
- ☐ Kleinwagen (z.B. Opel Corsa, Nissan Micra, Peugeot 206, VW Polo, Renault Clio usw.)
- ☐ Kompaktklasse (z.B. VW Golf, Toyota Corolla, Mercedes A-Klasse, Skoda Fabia usw.)
- ☐ Mittelklasse (3er BMW, Toyota Avensis, VW Passat, Audi A4 usw.)
- ☐ Obere Mittelklasse (z.B. Audi A6, Volvo V70, 5er BMW, Peugeot 607 usw.)
- ☐ Oberklasse (z.B. Mercedes S-Klasse, Audi A8, Jaguar XJ, 7er BMW usw.)
- ☐ SUV / Geländewagen (z.B. Toyota RAV4, Subaru Forester, VW Touareg, Land Rover usw.)
- ☐ Mini-Van / Großraum-Van (z.B. Opel Zafira und Meriva, Renault Espace und Kangoo, VW Sharan und Touran, Chrysler Voyager usw.)
- ☐ Roadster / Sportwagen (z.B. BMW Z4, Audi TT, Porsche 911, Toyota Celia usw.)
- ☐ Sonstige

6. A: Machen Sie hier bitte Angaben zu dem PKW, den Sie zuletzt angeschafft haben.
B/C: Sie haben angegeben, schon eine ungefähre Vorstellung von Ihrem zukünftigen PKW zu haben. Machen Sie hier bitte Angaben zu diesem PKW, gemäß dem aktuellen Stand Ihrer Planung.

Marke und Modell ______________________________

Kraftstoff / Antriebsart

- ☐ Diesel
- ☐ Normalbenzin / Superbenzin
- ☐ Gas (Erdgas, Autogas)
- ☐ Hybrid
- ☐ Plug-in Hybrid
- ☐ Elektrisch
- ☐ Wasserstoff
- ☐ Biokraftstoff (Bioethanol E85 oder Biodiesel B100)
- ☐ Sonstige

Baujahr __________

Segment
- ☐ Microwagen (z.B. Smart Fortwo, Fiat Panda, VW Lupo, Renault Twingo usw.)
- ☐ Kleinwagen (z.B. Opel Corsa, Nissan Micra, Peugeot 206, VW Polo, Renault Clio usw.)
- ☐ Kompaktklasse (z.B. VW Golf, Toyota Corolla, Mercedes A-Klasse, Skoda Fabia usw.)
- ☐ Mittelklasse (3er BMW, Toyota Avensis, VW Passat, Audi A4 usw.)
- ☐ Obere Mittelklasse (z.B. Audi A6, Volvo V70, 5er BMW, Peugeot 607 usw.)
- ☐ Oberklasse (z.B. Mercedes S-Klasse, Audi A8, Jaguar XJ, 7er BMW usw.)
- ☐ SUV / Geländewagen (z.B. Toyota RAV4, Subaru Forester, VW Touareg, Land Rover usw.)
- ☐ Mini-Van / Großraum-Van (z.B. Opel Zafira und Meriva, Renault Espace und Kangoo, VW Sharan und Touran, Chrysler Voyager usw.)
- ☐ Roadster / Sportwagen (z.B. BMW Z4, Audi TT, Porsche 911, Toyota Celia usw.)
- ☐ Sonstige

7. A: Hat dieser PKW einen anderen Wagen ersetzt oder ist er als zusätzliches Fahrzeug hinzugekommen?

- ☐ Ersatz für anderen PKW
- ☐ Zusätzlicher PKW

C: Wird Ihr zukünftiger PKW einen anderen Wagen ersetzen oder wird er als zusätzliches Fahrzeug hinzugekommen?

- ☐ Ersatz für den PKW, der am häufigsten genutzt wird
- ☐ Ersatz für einen PKW, der aber nicht am häufigsten genutzt wird
- ☐ Zusätzlicher PKW

8. A: Wie hoch war der Kaufpreis Ihres zuletzt angeschafften PKW ungefähr?
B/C: Wenn Sie einmal an Ihren zukünftigen PKW denken: Welchen Betrag (Kaufpreis) erwägen Sie ungefähr auszugeben? Falls Sie es noch nicht genau wissen, schätzen Sie bitte.

- ☐ Bis 10.000 €
- ☐ 10.001 - 20.000 €
- ☐ 20.001 - 30.000 €
- ☐ 30.001 - 40.000 €
- ☐ 40.001 - 50.000 €
- ☐ 50.001 - 70.000 €
- ☐ Über 70.000 €

9. A: Wie haben Sie den zuletzt angeschafften PKW finanziert?
B/C: Wie werden Sie die Anschaffung Ihres zukünftigen PKW aller Voraussicht nach finanzieren?

- ☐ Barzahlung
- ☐ Privatkredit
- ☐ Leasing
- ☐ Hauptsächlich / vollständig vom Arbeitgeber finanziert
- ☐ Andere Finanzierungsmethode
- ☐ Weiß nicht

10. A: Welches waren Ihre Hauptinformationsquellen vor der Anschaffung des neuen PKW?
B/C: Welches sind Ihre Hauptinformationsquellen vor der Anschaffung des neuen PKW?
Bitte wählen Sie bis zu drei Antworten aus.

- ☐ Internetseiten der Fahrzeughersteller
- ☐ Freunde, Kollegen und Verwandte
- ☐ Testberichte (z.B. Autozeitschriften)
- ☐ Fahrzeughändler (vor Ort)
- ☐ Automobilclubs
- ☐ Internetforen / Blogs
- ☐ Automobilmessen
- ☐ Sonstige

11. A: Haben Sie die Wahl für den neuen PKW alleine getroffen oder hatten andere Personen Einfluss auf die Entscheidung?
B/C: Treffen Sie die Wahl für den neuen PKW alleine oder haben andere Personen Einfluss auf die Entscheidung?
Bitte wählen Sie bis zu drei Antworten aus.

- ☐ Ich allein
- ☐ Ganze Familie (Ehefrau/-mann, Lebensgefährte/-in, Kinder usw.)
- ☐ Freunde, Kollegen
- ☐ Händler, Experten
- ☐ Arbeitgeber (Dienstwagen)
- ☐ Andere

12. A: Zu welchem Zweck nutzen Sie Ihren zuletzt angeschafften PKW hauptsächlich?
B/C: Zu welchem Zweck werden Sie Ihren neuen PKW hauptsächlich nutzen?

- ☐ Fahrt zur Arbeit, Ausbildungsstätte / Schule
- ☐ Private Erledigungen (z.B. Fahrt zum Einkaufen, Kino, Sport, Arzt usw.)
- ☐ Ausflugsfahrt / Urlaubsfahrt
- ☐ Geschäftliche / dienstliche Erledigungen
- ☐ Sonstige

13. A: Wie viele Kilometer fahren Sie mit Ihrem zuletzt angeschafften PKW durchschnittlich pro Jahr?
B/C: Wie viele Kilometer werden Sie voraussichtlich mit Ihrem neuen PKW durchschnittlich pro Jahr fahren?

- ☐ Bis 5.000 km
- ☐ 5.001 - 10.000 km
- ☐ 10.001 - 20.000 km
- ☐ 20.001 - 30.000 km
- ☐ 30.001 - 40.000 km
- ☐ Mehr als 40.000 km

14. A: Wie viele Kilometer fahren Sie mit Ihrem zuletzt angeschafften PKW an einem durchschnittlichen Werktag?

B/C: Wie viele Kilometer werden Sie voraussichtlich mit Ihrem neuen PKW an einem durchschnittlichen Werktag fahren?

- ☐ Bis 50 km
- ☐ 51 - 100 km
- ☐ 101 - 150 km
- ☐ 151 - 200 km
- ☐ Über 200 km *Programmierhinweis: Weiter mit Frage 16*

15. A: An wie vielen Tagen pro Jahr legen Sie mit Ihrem zuletzt angeschafften PKW eine Strecke von mehr als 200 km zurück?

B/C: An wie vielen Tagen pro Jahr werden Sie voraussichtlich mit Ihrem neuen PKW eine Strecke von mehr als 200 km zurücklegen?

- ☐ 0 - 6
- ☐ 7 - 12
- ☐ 13 - 24
- ☐ 25 - 50
- ☐ Über 50

16. A: Wie teilen sich Ihre PKW-Fahrten pro Jahr in etwa auf die folgenden Straßenarten auf?

B/C: Wie werden sich voraussichtlich Ihre PKW-Fahrten pro Jahr in etwa auf die folgenden Straßenarten aufteilen?
Die Angaben sollten insgesamt 100% ergeben.

Stadtverkehr __________
Landstraße __________
Autobahn __________

Kenntnisstand und Informationen über Antriebstechnologien

17. Wie gut kennen Sie die folgenden alternativen PKW-Kraftstoffe und PKW-Antriebstechnologien?

	Könnte ich gar nicht erklären 1	2	3	4	Könnte ich gut erklären 5
Gasbetriebener PKW (Erdgas, Autogas)	☐	☐	☐	☐	☐
Hybrid-PKW	☐	☐	☐	☐	☐
Plug-in Hybrid-PKW	☐	☐	☐	☐	☐
Batteriebetriebener PKW („Elektroauto“)	☐	☐	☐	☐	☐
Wasserstoffbetriebener PKW (Brennstoffzelle)	☐	☐	☐	☐	☐
Biokraftstoffbetriebener PKW (Biodiesel B100, Bioethanol E85)	☐	☐	☐	☐	☐

18. Im Folgenden erhalten Sie eine kurze Übersicht über die Eigenschaften und Besonderheiten der verschiedenen Antriebstechnologien.

Gasbetriebenes Fahrzeug (Erdgas, Autogas): Fahrzeug, das entweder mit verdichtetem Erdgas (CNG – Compressed Natural Gas) oder mit einem flüssigen Propan-Butan-Gemisch (Autogas bzw. LPG – Liquified Petroleum Gas) als Kraftstoff betrieben wird und mit einem Verbrennungsmotor als Antriebsaggregat ausgestattet ist.

Hybrid-Fahrzeug: Fahrzeug, welches gleichzeitig über einen konventionellen Benzin- oder Dieselmotor und einen Elektroantrieb verfügt. Hierbei gibt es verschiedene Formen. Ein Mikrohybrid hat keinen Elektromotor. Er nutzt lediglich zurück gewonnene Bremsenergie zur Versorgung der Fahrzeugelektrik. Ein milder Hybrid nutzt ebenfalls Bremsenergie zum Laden der Batterie, ist jedoch auch mit einem kleinen Elektromotor ausgestattet, welcher beim Anfahren den Verbrennungsmotor unterstützt. Demgegenüber ist ein Vollhybrid neben dem Verbrennungsmotor auch mit einem Elektromotor ausgestattet, welcher das Fahrzeug auch alleine antreiben kann, wenn wenig Antriebsleistung benötigt wird, wie z.B. beim Langsamfahren oder Einparken. Der Strom für den Elektroantrieb wird dabei vom konventionellen Motor im Fahrzeug erzeugt und in einer kleinen Batterie gespeichert.

Plug-in Hybrid-Fahrzeug (engl. meist PHEV für Plug-in Hybrid Electric Vehicle): Hybrid-Fahrzeug mit größerer Batterie, die zusätzlich über das Stromnetz und nicht mehr ausschließlich durch den Verbrennungsmotor aufgeladen werden kann und gelegentlich auch als Steckdosenhybrid bezeichnet wird. Die größere Batteriekapazität erlaubt es auch längere Strecken bis in der Regel max. 60 km ausschließlich im reinen Elektrobetrieb zurücklegen zu können. Der Verbrennungsmotor wird lediglich verwendet, um darüber hinaus gehende Strecken zu ermöglichen.

Batteriebetriebenes Fahrzeug: Fahrzeug, das ausschließlich mit einem Elektromotor ausgestattet ist und durch elektrische Energie angetrieben wird und deshalb umgangssprachlich auch Elektroauto genannt wird. Der Motor wird von einer wiederaufladbaren Batterie gespeist, die entweder an jeder beliebigen Steckdose oder an speziellen Schnelllade-Steckdosen mit höher Leistung geladen werden kann und durch ihre Kapazität oder "Größe" die Reichweite der Fahrzeuge bestimmt.

Wasserstoffbetriebenes Fahrzeug: Fahrzeug, in dem flüssiger oder komprimierter gasförmiger Wasserstoff in einem Verbrennungsmotor verbrannt oder in einer Brennstoffzelle in elektrische Energie umgewandelt wird, die dann einen Elektromotor antreibt.

Biokraftstoffbetriebenes Fahrzeug (Biodiesel B100, Bioethanol E85): Fahrzeug, das mit aus nachwachsender Biomasse (z.B. Soja, Raps, Zuckerrohr oder -rüben, Restholz usw.) gewonnenem Kraftstoff betrieben wird und mit einem hierfür speziell angepassten Verbrennungsmotor als Antriebsaggregat ausgestattet ist. Biokraftstoffe sind nicht mit dem in Deutschland erhältlichen E10 (Superbenzin mit 10 % Bioethanolbeimischung) zu verwechseln, sondern sie bestehen aus 85-100 % Bioethanol bzw. Biodiesel und dementsprechend nur einer geringen oder gar keiner Beimischung von herkömmlichem Super- und Normalbenzin oder Diesel.

Discrete Choice Experiment

19. A: Sie haben sich in den letzten 12 Monaten einen Neuwagen gekauft. Stellen Sie sich nun bitte vor, Sie müssten heute nochmals dieselbe Entscheidung treffen. [...]

B/C: Sie planen, sich in den kommenden 12 Monaten einen Neuwagen zu kaufen. Stellen Sie sich nun bitte vor, Sie müssten bereits heute diese Entscheidung treffen. [...]

[...] Wir stellen Ihnen im Folgenden mehrere PKW zur Auswahl, die durch verschiedene Merkmale beschrieben sind. Die zur Auswahl gestellten PKW unterscheiden sich nur in den präsentierten

Merkmalen und sind ansonsten absolut identisch, z.B. hinsichtlich Marke, Farbe, Motorleistung, Fahrzeugsegment usw.
Stellen Sie sich bitte vor, die dargestellten PKW wären die einzigen, die zur Auswahl stehen und Sie müssten einen dieser PKW heute kaufen. Bitte versuchen Sie, jeweils jenen PKW zu wählen, den Sie am ehesten kaufen würden.
Welchen dieser Neuwagen würden Sie kaufen?

Antrieb	Plug-in Hybrid	Hybrid	Elektrisch	Benzin / Super
Kaufpreis	31.250 Euro	25.000 Euro	18.750 Euro	25.000 Euro
Kraftstoffkosten (pro 100 km)	5 Euro	25 Euro	15 Euro	25 Euro
CO_2 Emissionen (% der Emissionen heutiger Durchschnitts-PKW Ihres bevorzugten Fahrzeugsegments)	0%	75%	100%	50%
Reichweite pro Tankfüllung	1000 km	700 km	100 km	400 km
Tankstellennetz (% aller Tankstellen, die den Kraftstoff anbieten)	60%	60%	20%	100%
Tankzeit	10 Minuten	10 Minuten		5 Minuten
Dauer des Batterieladevorgangs	6 Stunden		10 Minuten	
Anreiz			KFZ-Steuerbefreiung	
	●	●	●	●

Figure A.1: Example choice set of the discrete choice experiment

Source: Own illustration.

Programmierhinweis: Die folgenden Erläuterungen bei ‚Mouse-over' einblenden

Kaufpreis: Geldbetrag, den der Käufer des PKW an den Verkäufer entrichten muss, um Eigentümer des Wagens zu werden. Der Kaufpreis für vergleichbare Fahrzeuge kann sich dabei, aufgrund von Unterschieden in den Kosten der verschiedenen Antriebstechnologien oder aufgrund von staatlichen finanziellen Fördermaßnahmen, stark unterscheiden.

Kraftstoffkosten: Die durchschnittlichen Kraftstoffkosten pro 100 km Fahrstrecke ergeben sich aus der für diese Strecke benötigten Kraftstoffmenge bzw. Strommenge und dem durchschnittlichen Kraftstoffpreis bzw. Strompreis. D.h. einem PKW mit einem durchschnittlichen Kraftstoffverbrauch von z.B. 10 Liter Superbenzin auf 100 km und einem Kraftstoffpreis von 1,50 € pro Liter entstehen Kraftstoffkosten von 15 € pro 100 km. Die Kraftstoffkosten pro 100 km können deshalb stark schwanken, je nachdem wie hoch der Kraftstoff- bzw. Stromverbrauch oder der Kraftstoff- bzw. Strompreis ist.

CO_2-Emissionen (in % der Emissionen heutiger Durchschnitts-PKW Ihres bevorzugten Fahrzeugsegments): Die CO_2-Emissionen der jeweiligen PKW-Antriebe entstehen entweder bei der Verbrennung des Kraftstoffs im Motor des PKW oder bei der Herstellung des Kraftstoffs bzw. Stroms. D.h. je nach Höhe des Anteils erneuerbarer Energiequellen bei der Strom- oder Wasserstofferzeugung bzw. je nach verwendeter Pflanzenart und der Form ihres Anbaus bei der Biokraftstoffherstellung,

variieren auch die CO_2-Emissionen dieser PKW-Antriebe – und zwar von „emissionsfrei“ (0%) bis zu „vergleichbar mit einem heutigen PKW“ (100%).

Reichweite pro Tankfüllung: Die Reichweite eines Fahrzeugs gibt an, wie viele Kilometer im Durchschnitt mit einer Tankfüllung und/oder einer Batterieladung gefahren werden können, bevor man wieder auftanken bzw. aufladen muss. Die mögliche Reichweite bestimmt sich aus dem Kraftstoff- bzw. Stromverbrauch des Fahrzeugs und dem Fassungsvermögen des Tanks bzw. der Batterie.

Tankstellennetz (in % aller Tankstellen, die diesen Kraftstoff anbieten): Die Dichte des Tankstellennetzes gibt an, wie viele der vorhandenen Tankstellen den jeweiligen Kraftstoff führen.

Tankzeit: Die Tankzeit gibt an, wie viele Minuten der gesamte Tankvorgang in Anspruch nimmt, d.h. vom Volltanken des PKW bis zur Bezahlung.

Dauer des Batterieladevorgangs: Die Ladedauer gibt an, wie viele Minuten bzw. Stunden das komplette Aufladen der Batterie in Anspruch nimmt. Die Anschlussleistung der Steckdose bestimmt hierbei die Geschwindigkeit des Ladevorgangs, sodass sich die Ladedauer zwischen Haushaltssteckdose und speziellen Schnelllade-Steckdosen stark unterscheiden kann. Auch Batteriewechselstationen können den Ladevorgang beträchtlich verkürzen.

Anreiz:

- *KFZ-Steuerbefreiung:* Verbrauchsarme bzw. umweltfreundliche PKW werden dahingehend vom Staat gefördert, dass für diese PKW keine KFZ-Steuer entrichtet werden muss.
- *Kostenloses Parken und Nutzung von Busspuren:* Umweltfreundliche PKW oder solche, die keine lokalen Emissionen (wie z.B. Feinstaub oder Lärm) verursachen, erhalten gewisse Sonderrechte. So dürfen diese PKW z.B. überall kostenlos parken und auch sonst eigentlich nur für Busse oder Taxis reservierte Fahrspuren nutzen.

Kriterien beim PKW Kauf

20. Wie wichtig sind Ihnen persönlich folgende Merkmale beim PKW-Kauf?

	Ganz und gar nicht wichtig 1	2	3	4	Sehr wichtig 5
Ansehen der Marke, Image	☐	☐	☐	☐	☐
Größe, Geräumigkeit	☐	☐	☐	☐	☐
Aussehen des PKW, Design	☐	☐	☐	☐	☐
Umweltfreundlichkeit	☐	☐	☐	☐	☐
Bequemlichkeit, Komfort	☐	☐	☐	☐	☐
Zuverlässigkeit	☐	☐	☐	☐	☐
Kaufpreis	☐	☐	☐	☐	☐
Kraftstoffverbrauch, Kraftstoffkosten	☐	☐	☐	☐	☐
Servicenetz	☐	☐	☐	☐	☐
Besonderheit, Ungewöhnlichkeit des Autos	☐	☐	☐	☐	☐
Reichweite pro Tankfüllung	☐	☐	☐	☐	☐
Dichte des Tankstellennetzes (Anzahl der Tankstellen)	☐	☐	☐	☐	☐
Sicherheit	☐	☐	☐	☐	☐
Motorleistung (PS)	☐	☐	☐	☐	☐
Treibstoff-, Antriebsart	☐	☐	☐	☐	☐
KFZ-Steuer und Versicherungskosten	☐	☐	☐	☐	☐

Technikinteresse, Umwelteinstellung und Umweltverhalten

21. Bitte geben Sie an, wie sehr Sie den folgenden Aussagen zustimmen.

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll und ganz zu 5
Ich interessiere mich sehr für Autos.	☐	☐	☐	☐	☐
Ich unterhalte mich oft mit Freunden, Kollegen oder meiner Familie über Autos.	☐	☐	☐	☐	☐
Ich beschäftige mich gerne mit der Funktionsweise neuer Technologien.	☐	☐	☐	☐	☐
Wissenschaft und Technik werden viele Umweltprobleme lösen, ohne dass wir unsere Lebensweise ändern müssen.	☐	☐	☐	☐	☐
Wenn wir so weitermachen wie bisher, steuern wir auf eine Umweltkatastrophe zu.	☐	☐	☐	☐	☐
Es beunruhigt mich, wenn ich daran denke, unter welchen Umweltverhältnissen unsere Kinder und Enkelkinder wahrscheinlich leben müssen.	☐	☐	☐	☐	☐
Es gibt Grenzen des Wachstums, die unsere industrialisierte Welt schon überschritten hat oder sehr bald erreichen wird.	☐	☐	☐	☐	☐
Nach meiner Einschätzung wird das Umweltproblem in seiner Bedeutung von vielen Umweltschützern stark übertrieben.	☐	☐	☐	☐	☐
Wenn ich Zeitungsberichte über Umweltprobleme lese oder entsprechende Fernsehsendungen sehe, bin ich oft empört und wütend.	☐	☐	☐	☐	☐
Zugunsten der Umwelt sollten wir alle bereit sein, unseren derzeitigen Lebensstandard einzuschränken.	☐	☐	☐	☐	☐
Ohne zusätzliche politische Maßnahmen wird sich die Umweltsituation dramatisch verschlechtern.	☐	☐	☐	☐	☐
Derzeit ist es immer noch so, dass sich der größte Teil der Bevölkerung wenig umweltbewusst verhält.	☐	☐	☐	☐	☐
Umweltschutzmaßnahmen sollten auch dann durchgesetzt werden, wenn dadurch Arbeitsplätze verloren gehen.	☐	☐	☐	☐	☐
Ich bin (weiterhin) bereit, meine Urlaubsgewohnheiten mehr in	☐	☐	☐	☐	☐

	Stimme überhaupt nicht zu 1	2	3	4	Stimme voll und ganz zu 5
Einklang mit dem Umweltschutz zu bringen (z.B. Verzicht auf Fernflugreisen oder Kurztrips mit sogenannten Billigfliegern, „sanfter“ Tourismus).					
Ich bin (weiterhin) bereit, für wirklich umweltfreundliche Produkte etwas mehr zu zahlen, als für herkömmliche Artikel.	☐	☐	☐	☐	☐
Ich bin dafür, in den Innenstädten und Naherholungsgebieten grundsätzlich den Autoverkehr einzuschränken, wenn dafür gute Nahverkehrslinien und Radwegnetze geschaffen werden.	☐	☐	☐	☐	☐
Die Rolle des Autos als Umweltverschmutzer wird übertrieben.	☐	☐	☐	☐	☐
Wenn man auf das Autofahren angewiesen ist, hat man kaum Möglichkeiten in diesem Bereich etwas für den Klimaschutz zu tun.	☐	☐	☐	☐	☐
Die meisten Leute, die mir wichtig sind, erwarten von mir, dass ich ein Auto mit möglichst niedrigem Verbrauch (oder gar kein Auto) fahre.	☐	☐	☐	☐	☐

22. Im Folgenden haben wir verschiedene Handlungen zusammengestellt, die im Alltag eine Rolle spielen. Sagen Sie mir bitte anhand dieser Liste, wie häufig Sie diese Handlungen ausführen.

	Bisher nicht 1	2	3	4	Immer 5
Ich kaufe gezielt Produkte, die bei ihrer Herstellung und Nutzung die Umwelt nur gering belasten.	☐	☐	☐	☐	☐
Ich achte beim Kauf von Haushaltsgeräten auf einen niedrigen Energieverbrauch.	☐	☐	☐	☐	☐
Ich kaufe gezielt Obst und Gemüse aus meiner Region.	☐	☐	☐	☐	☐
Wenn ich die Möglichkeit dazu habe, fahre ich mit öffentlichen Verkehrsmitteln oder dem Fahrrad statt mit dem Auto.	☐	☐	☐	☐	☐
Bei kürzeren Wegen (bis zu 2 km) lasse ich das Auto stehen und fahre mit dem Fahrrad oder gehe zu Fuß.	☐	☐	☐	☐	☐
In meiner Freizeit benutze ich das Auto, z.B. für Ausflüge, Kurzurlaube, Besuche oder Fahrten zu Freizeitaktivitäten	☐	☐	☐	☐	☐

	Bisher nicht 1	2	3	4	Immer 5
Ich achte beim Einkaufen auf Produkte mit dem „Blauen Engel“.	☐	☐	☐	☐	☐
Ich achte darauf, elektronische Geräte vollständig auszuschalten, also nicht im Stand-by-Betrieb zu lassen.	☐	☐	☐	☐	☐
Ich drossle meine Heizung im Winter, wenn ich meine Wohnung für mehr als 4 Stunden verlasse.	☐	☐	☐	☐	☐
Ich spende Geld an eine Umweltorganisation (z.B. Greenpeace, BUND, WWF) bzw. engagiere mich aktiv in einer Umweltorganisation.	☐	☐	☐	☐	☐

23. Die Stromlieferanten bieten an, dass man Öko-Strom beziehen kann, d.h. Strom, der aus erneuerbaren Energien (Solarenergie, Windenergie, Wasserkraft usw.) stammt. Beziehen Sie bereits Öko-Strom?

- ☐ Ja
- ☐ Nein
- ☐ Weiß nicht

Weitere Verkehrsmittelnutzung

24. Wie oft verknüpfen Sie bei Ihren täglichen Wegen zwei oder mehrere Verkehrsmittel? Z.B. Park & Ride (PKW und öffentliche Nahverkehrsmittel wie S-Bahn, Straßenbahn, Bus), PKW und Bahn, Car-Sharing und öffentliche Nahverkehrsmittel oder Rad und öffentliche Nahverkehrsmittel.

- ☐ Seltener als monatlich
- ☐ Seltener als einmal pro Woche, aber mindestens einmal im Monat
- ☐ Einmal pro Woche
- ☐ Mehrmals pro Woche
- ☐ (Fast) täglich

25. Besitzen Sie eine Dauerfahrkarte für den öffentlichen Personenverkehr (z.B. Bahn, S-Bahn, Straßenbahn, Bus)?
Mehrfachnennungen sind möglich.

- ☐ Ja, eine Jahresfahrkarte
- ☐ Ja, eine Monats- oder Wochenfahrkarte
- ☐ Ja, ein Semester- oder Jobticket
- ☐ Ja, eine BahnCard
- ☐ Nein

26. Bilden Sie PKW-Fahrgemeinschaften mit Arbeitskollegen?

- ☐ Ja, regelmäßig
- ☐ Ja, gelegentlich
- ☐ Nein

27. Sind Sie Mitglied bei einer Car-Sharing-Organisation?

- ☐ Ja
- ☐ Nein

Allgemeine demographische Informationen

28. Wie viele Personen, Sie eingeschlossen, leben in Ihrem Haushalt?

- ☐ Eine, nämlich ich alleine *Programmierhinweis: Weiter mit Frage 31*
- ☐ Zwei
- ☐ Drei
- ☐ Vier
- ☐ Fünf oder mehr

29. Wie viele Kinder unter 18 Jahren leben in Ihrem Haushalt?

- ☐ Keine
- ☐ Eins
- ☐ Zwei
- ☐ Drei oder mehr

30. In welchem Postleitzahlengebiet wohnen Sie?

Postleitzahl (5-stellig):___________

31. Bitte schätzen Sie die Lage Ihres Wohnortes ein.

- ☐ Ländliche Region
- ☐ Vorort einer Stadt
- ☐ Stadt, aber nicht zentral
- ☐ Stadtzentrum (Innenstadt, innenstadtnah, Stadtteilzentrum)

32. Wohnen Sie zur Miete oder im Eigentum?

- ☐ Miete
- ☐ Eigentum
- ☐ Sonstiges

33. Haben Sie einen ständigen PKW-Stellplatz mit Zugang zu einer Steckdose?
Mehrfachnennungen sind möglich.

- ☐ Ja, zu Hause
- ☐ Ja, am Arbeitsplatz
- ☐ Ja, auf einem öffentlichen Parkplatz / in einem öffentlichen Parkhaus
- ☐ Nein

34. Wie beurteilen Sie die Belastung durch Verkehrslärm und Verkehrsabgase in Ihrer Wohnstraße?

- ☐ 1 = Sehr gering
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 = Sehr hoch

35. Wie beurteilen Sie die Anbindung Ihres Wohnorts an das öffentliche Personenverkehrsnetz (z.B. Bahn, S-Bahn, Straßenbahn, Bus)?

- ☐ 1 = Sehr schlecht
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5 = Sehr gut

36. Ihr Geschlecht:

- ☐ Weiblich
- ☐ Männlich
- ☐ Keine Angabe

37. In welchem Jahr sind Sie geboren?

Geburtsjahr: 19 __

38. Welches ist Ihr höchster allgemeiner Bildungsabschluss?

- ☐ Schule beendet ohne Abschluss
- ☐ Hauptschulabschluss / Abschluss einer Volksschule bzw. Polytechnischen Oberschule (bis zur 8. oder 9. Klasse)
- ☐ Realschulabschluss (mittlere Reife) bzw. Abschluss einer Polytechnischen Oberschule (bis zur 10. Klasse)
- ☐ Fachhochschulreife, Abschluss Fachoberschule
- ☐ Abitur (allgemeine oder fachgebundene Hochschulreife), Abschluss einer Erweiterten Oberschule (bis zur 12. Klasse)
- ☐ Hochschulabschluss (z.B. Universität, Akademie, Fachhochschule)

39. Welche berufliche Tätigkeit üben Sie derzeit hauptsächlich aus?

- ☐ Selbstständige/r
- ☐ Beamtin/Beamter
- ☐ Angestellte/r
- ☐ Arbeiter/in
- ☐ Auszubildende/r
- ☐ Student/in
- ☐ Rentner/in, Pensionär/in
- ☐ Nicht berufstätig
- ☐ Sonstiges

40. Wie hoch ist das durchschnittliche monatliche Nettoeinkommen Ihres Haushalts insgesamt?
Hier meinen wir alle Einkünfte (z.B. Lohn, Gehalt, Einkommen aus selbstständiger Tätigkeit, Rente oder Pension, Mieteinnahmen, öffentliche Beihilfen, Kindergeld, sonstige Einkünfte…) aller Haushaltsmitglieder abzüglich Steuern und Sozialversicherungsbeiträgen.

- ☐ Unter 2.000 €
- ☐ 2.001 - 3.000 €
- ☐ 3.001 - 4.000 €
- ☐ 4.001 - 5.000 €
- ☐ 5.001 - 6.000 €
- ☐ 6.001 € oder mehr
- ☐ Keine Angabe

B. Appendix of Chapter 3

Table B.1: Literature overview

Study	Location	Model	Fuel types	Attributes (non-linear functional form)	Main results[1]
Abdoolakhan (2010)	Australia	NL, LCM	CFV, NGV, HEV, BV	Purchase price, fuel costs, performance, fuel efficiency, vehicle type (d), number of doors (d)	Complementary preference for AFVs (especially NGVs) in 2 consumer groups; choice of AFVs influenced by female ⊕, age ⊖; demand with respect to purchase price and fuel costs is very inelastic; scenario analysis: major demand shift from CFVs to NGVs/BVs in the future, although CFVs will further dominate the market
Achtnicht (2012)	Germany	MNL, ML	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability, performance	CFVs preferred over AFVs; WTP for emissions reduction varies with female ⊕, education ⊕, budget ⊕, age ⊖
Achtnicht et al. (2012)	Germany	MNL	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability (q), performance	CFVs preferred over AFVs; choice of AFVs influenced by desired driving range ⊖, environmental awareness ⊕, age*BEV/NGV ⊖, annual mileage*HEV/FCEV ⊖; WTP for increase in fuel availability varies with fuel type (BEV>CFV), budget ⊕, current fuel availability ⊖
Axsen et al. (2013)	UK	MNL	CFV, BEV	Purchase price, driving range (ln), refueling time (ln), performance	Liminal lifestyle influences choice of BEVs ⊕; consumer perceptions of BEVs change through social influence (diffusion, translation, reflexivity); methodological finding: advantages of multi-method approach (reflexive layers of social influence framework + discrete choice experiment) due to ability to model dynamic consumer preferences
Batley et al. (2004)	UK	MNL, ML	CFV, AFV		AFVs preferred over CFVs; WTP for CFVs varies with age ⊖, environmental awareness ⊖, car owner ⊕, children ⊕; scenario analysis: demand for AFVs is elastic and more sensitive to purchase price than demand for CFVs, while fuel costs, driving range and fuel availability are inelastic; AFVs need substantial support (technical, legislative, fiscal) to achieve significant market shares
Beck et al. (2013)	Australia	LCM	CFV, HEV	Purchase price, fuel costs, performance, vehicle type (d), registration and emissions charges, fuel efficiency, number of seats, country of origin (d)	Choice of AFVs and valuation of vehicle attributes influenced by age, children, environmental awareness; mainly differences in consumer 'greenness' cause variation in preferences for an emission charge; methodological finding: advantages of model with attitudinal information (more detailed segmentation of the population)

(continued on next page)

Table B.1 *(continued)*

Study	Location	Model	Fuel types	Attributes (non-linear functional form)	Main results[1]
Daziano (2013)	USA	MNL, ML	CFV, HEV, BEV	Purchase price, fuel costs, driving range (ln), performance (d), vehicle type (d)	HEVs preferred over CFVs/BEVs; 4 different welfare measures for driving range improvements show that BEVs need substantial financial support (WTP, CV lower than current battery production costs); methodological finding: advantages of models with nonparametric heterogeneity distributions
Daziano and Achtnicht (2014)	Germany	MNP	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability, performance	CFVs preferred over AFVs; scenario analysis: increasing fuel availability of BEVs/FCEVs to 100% more than triples their market shares; methodological finding: advantages of models with Bayes estimator
Eggers and Eggers (2011)	Germany	ML	CFV, HEV, BEV, PHEV	Purchase price (d), driving range (d)	AFVs without driving range limitation preferred over CFVs; scenario analysis: HEVs will dominate the market (even with significant price increase), PHEVs and BEVs are purchased much less often; BEVs have to meet minimum requirements (driving range, recharging infrastructure, purchase price) to be adopted
Ewing and Sarigöllü (2000)	Canada	MNL	CFV, BEV, AFV	Purchase price, emissions (d), driving range (d), refueling time (d), performance (d), commuting time and costs, maintenance costs	AFVs preferred over CFVs; choice of AFVs influenced by environmental awareness ⊕; scenario analysis: price subsidies, fast-charging and driving range improvements significantly increase market share of AFVs (especially BEVs), exceeding those of CFVs
Hackbarth and Madlener (2013)	Germany	MNL, ML	CFV, NGV, HEV, BEV, FCEV, BV, PHEV	Purchase price, fuel costs, emissions, driving range, fuel availability, refueling time, incentives (d)	CFVs preferred over AFVs; choice of AFVs influenced by environmental awareness ⊕, age*BEV ⊖, share of city trips*BEV ⊕, plug-in possibility*PHEV/BEV ⊕, education*PHEV/BEV ⊕, small car*BEV ⊕; heterogeneity (e.g. budget ⊕) in WTP for vehicle attributes; scenario analysis: even with massive attribute improvements CFVs will dominate the market and demand for BEVs/FCEVs will remain small
Hess et al. (2012)	USA	MNL, NL, ML, CNL	CFV, NGV, HEV, BEV, BV, PHEV	Purchase price, fuel costs, emissions, driving range (ln), fuel availability (d), incentives (d), vehicle type (d), fuel efficiency, vehicle age (d), maintenance costs	PHEVs/BVs preferred over CFVs/other AFVs; WTP for vehicle attributes varies with income ⊕; scenario analysis: demand increase for specific fuel-vehicle-type combinations draws market shares from other vehicle types with same fuel and from vehicles of same type but with different fuel; methodological finding: advantages of cross-nested logit model in analysis of multi-dimensional choices (simultaneous vehicle-fuel-type choice)
Hidrue et al. (2011)	USA	MNL, LCM	CFV, BEV	Purchase price, fuel costs, emissions (d), driving range (d), refueling time (d), performance (d)	Complementary preferences for BEVs in 2 consumer groups; choice of BEVs influenced by age ⊖, education ⊕, environmental awareness ⊕, plug-in possibility ⊕, small car ⊕, number of long drives ⊖, expected fuel price increase ⊕, etc.; heterogeneity in WTP for vehicle attributes; scenario analysis: driving range, charging time, emissions, and acceleration have to drastically improve before BEVs conquer the mass market

(continued on next page)

Table B.1 *(continued)*

Study	Location	Model	Fuel types	Attributes (non-linear functional form)	Main results[1]
Hoen and Koetse (2014)	Netherlands	MNL, ML	CFV, NGV, HEV, BEV, FCEV, BV, PHEV	Purchase price, fuel costs, driving range, refueling time incentives (d), additional detour time, number of models	CFVs preferred over AFVs; choice of AFVs and valuation of vehicle attributes influenced by annual mileage ⊖, commute frequency ⊖, current fuel diesel/LPG ⊖, plug-in possibility*BEV ⊕, incentives*urban ⊕, driving range*annual mileage ⊕, purchase price/monthly costs*budget ⊕, etc.; heterogeneity in WTP for vehicle attributes; scenario analysis: even for massively improved AFVs considerable negative preferences remain
Ito et al. (2013)	Japan	MNL, NL	CFV, HEV, BEV, FCEV	Purchase price, fuel costs, emissions (d), driving range (q), fuel availability (d), refueling time (d), vehicle type (d), manufacturer (d)	HEVs preferred over CFVs and BEVs/FCEVs; complementary WTP for increase in fuel availability and driving range for FCEVs and BEVs; scenario analysis: battery-exchange stations can be efficient with low BEV market shares, high subsidies needed to reach governmental BEV diffusion targets
Link et al. (2012)	Austria	MNL	CFV, HEV, BEV	Purchase price (sqr), fuel costs (ln), emissions, driving range (ln), refueling time (q), performance (sqr)	CFVs preferred over AFVs; (antagonistic to CFVs/HEVs) choice of BEVs influenced by age ⊖, income ⊖, male ⊖, main car ⊖, vehicle age ⊖, part-time employed ⊖, garage ⊕, willingness to buy BEV ⊕, accepted charging time ⊕, reasons for decision environmental/operating costs ⊕, etc.; scenario analysis: moderate technological development and fuel price increase can lead to considerable market shares of HEVs/BEVs
Parsons et al. (2014)	USA	MNL, LCM	CFV, BEV	Purchase price, fuel costs, emissions (d), driving range (d), refueling time (d), performance (d), annual cash back payment	See Hidrue et al. (2011); additional comparison of BEVs with/without V2G-contracts; WTP for improvement of V2G contract attributes varies with consumer group; scenario analysis: consumers require higher compensation for V2G-BEVs than can be generated with V2G services, i.e. V2G does not seem to be able to increase BEV demand
Potoglou and Kanaroglou (2007)	Canada	NL	CFV, HEV, AFV	Purchase price, fuel costs, emissions (d), fuel availability (d), incentives (d), performance (d), vehicle type (d), maintenance costs	Choice of AFVs and valuation of vehicle attributes influenced by age*AFV ⊖, education*HEV ⊕, performance*male/single household ⊕, fuel availability*long distance commuters ⊕; WTP for vehicle attributes varies with income ⊕
Ziegler (2012)	Germany	MNP	CFV, NGV, HEV, BEV, FCEV, BV	Purchase price, fuel costs, emissions, fuel availability, performance	CFVs preferred over AFVs; choice of AFVs influenced by age ⊖, environmental awareness ⊕, male*NGV/FCEV ⊕, annual mileage*BEV ⊕, desired driving range*BEV/FCEV ⊕, desired horsepower*FCEV ⊕, car used for commute*NGV ⊕, company car*BV ⊕, small vehicle*FCEV ⊕, multiple vehicle household*BV ⊕, etc.; methodological finding: advantages of models with taste persistency effects

Notes: 1 = almost all studies find that the main vehicle attributes significantly impact vehicle choice in the expected direction, i.e. negative influence of purchase price, fuel costs, maintenance costs and other vehicle charges, emissions, refueling/recharging time, and positive influence of driving range, fuel availability, fuel efficiency, performance, number of doors/seats, and governmental incentives; ⊕ = positive effect; ⊖ = negative effect; CFV = conventional fuel vehicle; AFV = alternative fuel vehicle; NGV = natural gas vehicle; HEV = hybrid electric vehicle; PHEV = plug-in hybrid electric vehicle; BEV = battery electric vehicle; BV = biofuel vehicle; FCEV = fuel cell electric vehicle; MNL = multinomial logit model; NL = nested logit model; ML = mixed logit model; MNP = multinomial probit model; LCM = latent class model; CNL = cross-nested logit model; d = dummy; ln = logarithmic; q = quadratic; sqr = square root.

Table B.2: Sample choice card

	Plug-in Hybrid	Hybrid	Electric	Gasoline or Diesel
Purchase price	31,250 Euro	25,000 Euro	18,750 Euro	25,000 Euro
Fuel cost per 100 km	5 Euro	25 Euro	15 Euro	25 Euro
CO_2 emissions (% of today's average car)	0%	75%	100%	50%
Driving range	1000 km	700 km	100 km	400 km
Fuel availability (% of stations)	60%	60%	20%	100%
Refueling time	10 min	10 min		5 min
Battery recharging time	6 h		10 min	
Policy incentives			No vehicle tax	

Table B.3: Marginal willingness-to-pay for changes in vehicle attributes (in €/100 km of fuel cost increase)

	MNL	LCM								
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Mean	Std. dev.	$Prob_{WTP>0.9}$
Purchase price reduction of €1000	1.079	0.895	0.395	1.259	0.659	3.911	1.156	1.52	1.144	0.9896 (Class 5)
Incentive 1 (No vehicle tax)	4.380	6.041	1.254	21.800	0.070†	4.091	20.481	8.643	7.752	0.9349 (Class 3)
Incentive 2 (Free parking and bus lane access)	3.034	3.967	1.114	17.819	4.665†	1.108†	15.507	6.61	6.181	0.9735 (Class 3)
CO_2 emissions abatement by 1%										0.9987 (Class 6)
at 100%	0.010	0.014	0.003	-0.008†	0.021	0.007	0.060	0.015	0.020	
at 50%	0.020	0.027	0.006	-0.017†	0.043	0.013	0.120	0.030	0.040	
at 1%	1.018	1.364	0.322	-0.832†	2.143	0.651	6.011	1.509	1.987	
Driving range increase by1 km										0.9760 (Class 1)
at 100 km	0.103	0.310	0.037	0.189	0.064†	0.071	0.102	0.131	0.089	
at 500 km	0.021	0.062	0.007	0.038	0.013†	0.014	0.020	0.026	0.018	
at 1000 km	0.010	0.031	0.004	0.019	0.006†	0.007	0.010	0.013	0.009	
Fuel availability increase by 1%										0.9789 (Class 1)
at 20%	0.229	0.860	0.034	0.095†	0.426	0.137	0.288	0.300	0.263	
at 60%	0.076	0.287	0.011	0.032†	0.142	0.046	0.096	0.100	0.088	
at 99%	0.046	0.174	0.007	0.019†	0.086	0.028	0.058	0.061	0.053	
Battery recharging time reduction by 1 min										0.9973 (Class 6)
at 6 h	0.004	0.009	0.001†	0.011†	0.002†	0.005	0.011	0.006	0.004	
at 1 h	0.023	0.056	0.004†	0.063†	0.014†	0.030	0.064	0.038	0.022	
at 10 min	0.136	0.335	0.026†	0.378†	0.084†	0.179	0.383	0.231	0.130	

Notes: † indicates WTP values based on insignificant attribute coefficients; MNL = multinomial logit model; LCM = latent class model.

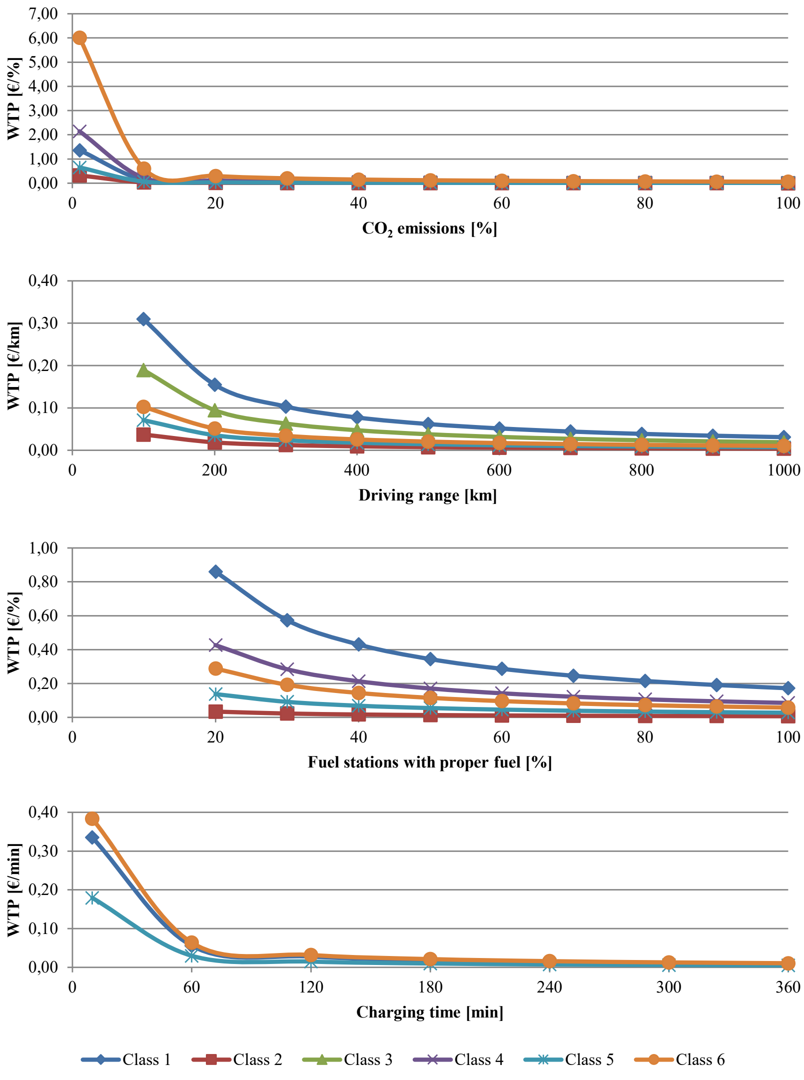

Figure B.1: Marginal willingness-to-pay for changes in vehicle attributes (in €/100 km of fuel cost increase)

Source: Own simulation results.

C. Appendix of Chapter 4

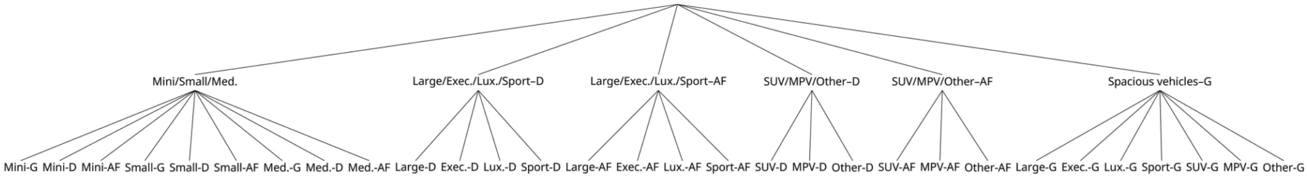

Figure C.1: Structure of the estimated nested logit model

Source: Own illustration.

Notes: G = gasoline; D = diesel; AF = alternative fuel; Med. = medium; Exec. = executive; Lux. = luxury; Sport = sport coupé; SUV = sport utility vehicle; MPV = multi purpose vehicle.

Table C.1: Results of the principal component analysis

No.	Component	Cronbach's alpha	Statement	Mean	Std.dev.	Loading	h^2
1	Environmental awareness	0.861	Without additional policy measures, the environmental situation will worsen dramatically.	3.51	1.042	0.791	0.607
			If we continue with business as usual, we are heading for an environmental catastrophe.	3.51	1.078	0.772	0.664
			Currently, it is still the case that the majority of the population behaves environmentally unconscious.	3.71	0.948	0.770	0.515
			There are limits to growth, which have already been exceeded by our industrialized world or which will be reached very soon.	3.50	1.006	0.734	0.528
			It worries me when I think of the environmental conditions our children and grandchildren will probably have to live in.	3.46	1.056	0.715	0.622
			When I read newspaper reports or see TV shows about environmental problems, I'm often disgusted and angry.	3.21	1.014	0.702	0.512
			For the sake of the environment, we should all be willing to limit our current standard of living.	3.37	1.024	0.614	0.604
2	Technophilia	0.784	I am very interested in cars.	3.22	1.123	0.873	0.773
			I often talk with friends, colleagues or my family about cars.	2.99	1.071	0.817	0.716
			I like to keep busy with the operation of new technologies.	3.39	1.082	0.798	0.642
3	Environmental behavior 1 (purchase and donation)	0.747	I donate money to an environmental organization (e.g. Greenpeace, BUND, WWF, etc.) or am involved actively in an environmental organization.	2.23	1.271	0.847	0.679
			I pay attention for products with the 'Blue Angel' certificate, when I'm shopping.	2.74	1.125	0.821	0.700
			I specifically buy products that pollute the environment only slightly in their manufacture and use.	3.08	1.016	0.677	0.684
4	Environmental scepticism	0.718	The role of the car as a polluter is exaggerated.	3.10	1.127	0.821	0.690
			In my estimation, the environmental problem is greatly exaggerated in its importance by many environmentalists.	2.76	1.156	0.809	0.728
			Science and technology will solve many environmental problems, without us having to change our way of life.	3.03	1.035	0.729	0.559
5	Environmental behavior 2 (energy saving)	0.663	I pay attention to a low energy consumption, when I'm buying household appliances.	4.08	0.948	0.780	0.622
			I make sure that electronic devices are switched off completely, i.e. not left in stand-by mode.	3.78	1.103	0.763	0.617
			I throttle my heating in winter, when I leave my apartment for more than 4 hours.	3.75	1.167	0.704	0.537
6	Environmental mobility	0.733	If I have the chance, I use the public transportation or bicycle instead of the car.	3.27	1.248	0.888	0.785
			At shorter distances (up to 2 km) I leave the car at home and go by bicycle or walk instead.	3.61	1.154	0.867	0.762
			I am in favor of limiting car traffic in the inner cities and recreational areas, if good public transportation lines and cycle path networks are created in return.	3.34	1.185	0.578	0.544

Notes: Extraction method: Principal component analysis; Rotation method: Promax with Kaiser normalization; Loading = degree of association between the statement and the factor; h^2 = communality.

Table C.2: Correlation matrix for extracted components

	Env. awareness	Technophilia	Env. behavior 1	Env. scepticism	Env. behavior 2	Env. mobility
Env. awareness	1.000	0.140	0.413	-0.341	0.353	0.450
Technophilia	0.140	1.000	0.193	0.287	0.126	0.034
Env. behavior 1	0.413	0.193	1.000	-0.114	0.227	0.381
Env. scepticism	-0.341	0.287	-0.114	1.000	-0.138	-0.270
Env. behavior 2	0.353	0.126	0.227	-0.138	1.000	0.361
Env. mobility	0.450	0.034	0.381	-0.270	0.361	1.000

Notes: Extraction method: Principal component analysis; Rotation method: Promax with Kaiser normalization; Env. = environmental; Env. behavior 1 = purchase and donation behavior; Env. behavior 2 = energy saving behavior.

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Road transportation is responsible for an increasing share of global greenhouse gas and local air pollutant emissions. Consequently, it plays a central role in fighting climate change and major human health challenges, as well as reducing the associated societal costs. This dissertation investigates the preferences of German private households when making their vehicle purchase decisions – i.e. choices of a specific fuel type or propulsion technology and a specific body type – and primarily discusses the measures needed to increase the adoption of alternative fuel vehicles (AFVs), explicitly taking car buyers' preference heterogeneity into account. For this purpose, actual and hypothetical vehicle purchases of recent or potential future buyers of new passenger cars are assessed in three distinct but interrelated parts. Based on data gathered in a nationwide survey and by applying various specifications of logistic regression models, willingness-to-pay values for vehicle attribute improvements are calculated, and future market shares of different AFVs are predicted for a broad range of possible technical improvements or policy actions in a scenario analysis. Building upon these results, recommendations are derived in order to support decision-makers in creating tailored and economically viable products, marketing and communication strategies, or policy measures to encourage car buyers' body type shifting (e.g. from larger to smaller vehicles), fuel type switching (e.g. from fossil-fueled vehicles to AFVs), or both.

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