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ESSAYS ON CONSUMER CHOICES RELEVANT TO CLIMATE CHANGE: STATED PREFERENCE EVIDENCE FROM GERMANY

Martin Achtnicht

FCN | Future Energy Consumer Needs and Behavior

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Essays on Consumer Choices Relevant to Climate Change: Stated Preference Evidence from Germany

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Doctoral Thesis
by

Martin Achtnicht

April 2013

It is, perhaps, worth stressing that economic problems arise always and only in consequence of change. So long as things continue as before, or at least as they were expected to, there arise no new problems requiring a decision, no need to form a new plan.

—Friedrich A. Hayek (1945, p.523)

Abstract

One of the major challenges that our world faces today and in the future is human-induced climate change. The primary cause of global warming, leading to climate change, is the burning of fossil fuels for energy and transport, which increases the concentration of greenhouse gases in the atmosphere. Energy efficiency and renewable energy sources are considered by many as the proverbial "silver bullet" to avoid the worst climate change scenarios. However, the support for and success of any effort to improve energy efficiency and expand renewable energies strongly depends on preferences and choices of consumers.

In four distinct but related essays, the present doctoral thesis examines consumer preferences for alternative-fuel vehicles and building energy retrofits. It makes use of data from two dedicated Germany-wide surveys, one of car buyers and the other of house owners. Each of these surveys included a discrete choice experiment, where respondents were faced with hypothetical choice situations. The car buyers were asked to select the car they preferred most from sets of seven vehicles with different fuel types. The house owners, on the other hand, first selected their preferred retrofit alternative from binary choice sets and then indicated whether they would actually undertake the selected retrofit activity if it were on the market. Similar choice experiments have been used before in transportation and energy research. But in contrast to previous studies, this work includes a wider range of alternative fuels and explicitly considers environmental benefits of energy retrofits.

Based on the choice data, barriers to the widespread adoption of alternative-fuel vehicles and building energy retrofits are identified, and it is examined to what extent environmental aspects influence consumer choice behavior in Germany. The doctoral thesis confirms existing evidence on the impact of fuel availability on demand for alternative-fuel vehicles, primarily coming from North America, in the

German context (Chapter 2). It makes important contributions to the growing, but heterogeneous literature that seeks to elicit willingness to pay for carbon abatements, carbon offsets, or climate policy in general (Chapters 3 and 4). Finally, it attempts to explain the persistent low retrofit rate in Germany and makes suggestions on how to stimulate energy retrofits in an effective and cost-efficient way (Chapter 5).

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Chapter 1

Introduction

One of the major challenges that our world faces today and in the future is human-induced climate change. The primary cause of global warming, leading to climate change, is the burning of fossil fuels for energy and transport, which increases the concentration of greenhouse gases in the atmosphere. Energy efficiency and renewable energy sources are considered by many as the proverbial "silver bullet" to avoid the worst climate change scenarios. However, the support for and success of any effort to improve energy efficiency and expand renewable energies strongly depends on preferences and choices of consumers.

In four distinct but related essays, the present doctoral thesis examines consumer preferences for alternative-fuel vehicles and building energy retrofits. It makes use of data from two dedicated Germany-wide surveys, one of car buyers and the other of house owners, each including a discrete choice experiment. Although each thesis chapter is based on a stand-alone journal article or working paper and thus includes a separate introduction, in this introductory chapter I provide a broader rationale for the research conducted—the "big picture," so to speak. I start with giving some background about climate change, its impacts, and the current policy framework, thereby establishing the meaningful starting point of everything to follow (1.1). Then, I describe the economists' view of the nature of the climate change problem, using the concept of market failure to justify government intervention, and emphasize the need for stated preference methods in cost-benefit analyses of climate policy (1.2). Finally, I discuss the focus and contribution of the empirical work done within the scope of this thesis, including its limitations (1.3).

1.1 Anthropogenic climate change: An inconvenient truth

The Earth's atmosphere is responsible for making life as we know it possible on our planet. It consists of several layers and is composed of a mixture of gases, primarily nitrogen and oxygen, but also different trace gases, and various aerosols. Some of the atmosphere's trace gases absorb infrared thermal radiation, which otherwise would be radiated out into space, re-radiate it back toward the Earth's surface, and thereby warm the planet—the natural greenhouse effect (Le Treut et al., 2007). Accordingly, these trace gases are called greenhouse gases (GHGs); the most prominent examples are water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4).

The amount of CO_2 in the atmosphere has increased tremendously since the beginning of the Industrial Revolution in the middle of the eighteenth century. Since then, humans burn fossil fuels—coal, oil, and natural gas—on a large scale to make use of the energy stored therein, in order to power different kinds of internal and external combustion engines. During the combustion process, CO_2 is released to the atmosphere, where it may stay for several hundred years. However, the higher concentration of CO_2 in the atmosphere causes increased radiative forcing, leading to a warming of the Earth's surface, and ultimately resulting in climate change (IPCC, 2007).

The basic idea that variations in atmospheric CO_2 concentration may influence the Earth's surface temperature and climate—the carbon dioxide theory—was developed in the nineteenth century, but controversially discussed until the 1950s and beyond (Plass, 1956). Considering the world's economic and technological development, and hoping for a better understanding of the potential impact of atmospheric CO_2 on weather and climate, Revelle and Suess (1957) anticipated as early as 1957 that:

> *[...] human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future. Within a few centuries we are returning to the atmosphere and oceans the concentrated organic carbon stored in sedimentary rocks over hundreds of millions of years.*
>
> —Revelle and Suess (1957, p.19)

After some fifty years more of this global "geophysical experiment," the evidence for the effects of anthropogenic emissions of CO_2 on the climate is overwhelming;

many scientists even speak of this geological era as the “Anthropocene” (Crutzen, 2002). In particular two reports attracted a lot of attention in this regard and raised the awareness for the problem that is known as global climate change to a broader audience: the Stern Review on the Economics of Climate Change of 2006 and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) of 2007.

The IPCC report provides a comprehensive assessment of current knowledge on climate change, its causes, effects, as well as possible adaptation and mitigation options. It shows the direct link between human activity and climate change, and concludes that “[m]ost of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations” (IPCC, 2007, p.39) coming from fossil-fuel use, land-use change, and agriculture. Carbon dioxide is being identified to be the main driver of climate change; its atmospheric concentration in 2005 was 379 parts per million (ppm) and thus exceeded any pre-industrial level ever measured in ice cores by far. A doubling of atmospheric CO_2 concentrations is estimated to increase the global average surface temperature by about 3 ℃. Accordingly, depending on the emissions scenario, the likely range of global average warming by the end of this century is projected to be between 1.1 ℃ and 6.4 ℃, relative to the period 1980–1999. Such temperature changes would be accompanied by a significant sea-level rise as well as more frequent extreme weather and climate events, and thus would have severe impacts on freshwater resources, ecosystems, coasts, food production, industry, human health, and so forth, with regionally varying patterns (IPCC, 2007).

The Stern Review, compiled by Lord Nicholas Stern for the British government, analyzes the economic impacts of climate change and climate change mitigation, and discusses important policy challenges related to mitigation and adaptation measures. The Review’s main conclusion is that “[t]he benefits of strong, early action on climate change outweigh the costs” (Stern, 2006, p.i). Under a business-as-usual emissions scenario, the total damages from climate change are estimated to equal an annual loss of income in the range of 5 to 20%, depending on whether non-market impacts, a higher responsiveness of the climate system, and weights for regional differences in vulnerability to climate damages are included or not. In its cost-benefit analysis, the Review focuses on a climate policy that aims to stabilize the atmospheric GHG concentration level at 550 ppm CO_2-equivalent. Stabilization at this level is expected to require global emission reductions of 25% by 2050, relative to the levels at the time of the Review's publication. The related annual abatement costs are estimated to be around 1% of global income. The Stern Review cites reducing demand, avoiding deforestation, increased energy efficiency, and switching to low-emission technologies as feasible options to reduce GHG emissions. However, it is pointed out by Stern (2006) that taking mitigation actions needs to be encouraged by means of an appropriate climate and energy policy, including putting a price on carbon, supporting the development of low-emission technologies, and removing barriers to behavioral change.

After the Stern Review was released, an intense scholarly debate among economists has emerged concerning the Review's formal analysis, assumptions, and policy recommendations (e.g., Mendelsohn, 2006; Tol and Yohe, 2006; Arrow, 2007; Dietz et al., 2007; Nordhaus, 2007; Weitzman, 2007). The main criticism is related to Stern's use of a very low interest rate for discounting future costs and benefits of climate change mitigation. A lower discount rate puts a greater weight of importance on far-future events, implying that future climate damages become more costly today, or, to put it the other way round, avoided damages become more beneficial. Weitzman (2007) emphasizes the central role of discounting in the political and scientific discussion on appropriate responses to human-induced climate change as follows:

> *Global climate change unfolds over a time scale of centuries and, through the power of compound interest, what to do now is hugely sensitive to the discount rate that is postulated. In fact, it is not an exaggeration to say that the biggest uncertainty of all in the economics of climate change is the uncertainty about which interest rate to use for discounting.*
>
> —Weitzman (2007, p.705)

Stern is criticized for relying on ethical judgements rather than economic reasoning when justifying the chosen discount rate. It is argued by the critics that the strong conclusions of the Stern Review, suggesting urgent and immediate GHG emission reductions, do not hold if market-based discount rates are used in the cost-benefit analysis. Besides the very low discount rate, ignoring the possibility of adaptation is another factor that makes it very likely that the negative impacts of climate change are overestimated in the Stern Review (e.g., Mendelsohn, 2006; Tol and Yohe, 2006).

Nevertheless, there is general consensus in the scientific community that mitigation actions are needed—also in the near term—to limit global warming and its adverse impacts on future generations (e.g., Yohe et al., 2004; Tol and Yohe, 2006; Arrow, 2007; IPCC, 2007; Weitzman, 2007; Nordhaus, 2010).

Up to now, the United Nations Framework Convention on Climate Change (UNFCCC), adopted in 1992 and entering into force in 1994, is the most important international treaty addressing climate change. It aims at stabilizing atmospheric GHG concentrations at a level that would avoid "dangerous" climate change. Since 1995 the implementation of the UNFCCC and related legal instruments are reviewed at annual meetings, the Conferences of the Parties (COPs). The 1997 meeting in Kyoto, Japan (COP 3), resulted in the adoption of the Kyoto Protocol, which entered into force in 2005. The Kyoto Protocol establishes legally binding, quantified GHG emission limitation and reduction targets for developed countries (Annex-I Parties). Its overall objective is to reduce Annex-I Parties' GHG emissions by at least 5% relative to 1990 levels over the first commitment period 2008–2012. More ambitious reduction targets for 2020 were formulated at the COP 16 held in Cancún, Mexico, in 2010. For example, the European Union (EU) and its member states target a 20% emission reduction by 2020 relative to 1990 levels. In the Cancún Agreements, the UNFCCC Parties also officially recognized, for the first time, the urgency of keeping global warming below 2 ℃ above pre-industrial levels.

However, natural scientists and climate researchers warn that aiming at limiting the average global temperature rise to 2 ℃ above pre-industrial levels is not enough, because "[g]lobal average warming is not the only kind of climate change that is dangerous, and long-lived greenhouse gases are not the only cause of dangerous climate change" (Lenton, 2011a, p.7). Rather, so-called "tipping elements," i.e. large-scale "subsystems of the Earth system that [...] can be switched—under certain circumstances—into a qualitatively different state by small perturbations" (Lenton et al., 2008, p.1786), are crucial for climate change. Anthropogenic global warming could trigger a critical threshold point of several tipping elements, so-called "tipping point," where such a subsystem qualitatively changes its future state, posing a significant risk in itself and affecting short-term natural hazards and extremes (Lenton et al., 2008; Kriegler et al., 2009; Lenton, 2011b). But so could anthropogenic aerosols in the Earth's atmosphere and other factors that influence the net energy fluxes (Lenton, 2011a).

The most policy-relevant tipping elements in the climate system are the Arctic sea-ice, the Greenland ice sheet, the West Antarctic ice sheet, the Atlantic thermohaline circulation, the El Niño-Southern Oscillation, the Indian summer monsoon, the Sahara/Sahel and West African monsoon, the Amazon rainforest, and the boreal forest (Lenton et al., 2008). In terms of the sensitivity of the tipping elements to global average warming and the uncertainty about the underlying physical mechanisms, Lenton et al. (2008) conclude that tipping the Arctic sea-ice and the Greenland ice sheet are the greatest and most likely threats to society. In order to reduce the risks of passing climate tipping points, climate scientists suggest the development and use of global climate monitoring and early warning systems (Travis, 2010; Lenton, 2011b), and separate targets for long-lived GHGs and other, shorter-lived radiative-forcing agents (Lenton, 2011a).

Given this "inconvenient truth," I will outline in the next section the way economists think about the problem of global climate change and to what extent they can contribute to its solution.

1.2 What economists can do about climate change

1.2.1 Market failures as rationale for climate policy

The science of economics is basically concerned with the allocation of scarce resources in order to maximize social welfare. The scope of economists' interest is diverse and ranges from human and natural resources to consumer goods and services. One of the discipline's key findings is the first theorem of welfare economics, which is based on the idea of the *invisible hand* by Adam Smith. It states that, under certain conditions, competitive private market allocations are Pareto-efficient (e.g., Stiglitz, 1991). An allocation is Pareto-efficient if no individual can be made better off without making some other individual worse off. This efficiency criterion guarantees that there is no waste of resources, an important and fundamental concept in economics.

The problem is that the conditions under which markets are perfectly efficient are very restrictive and rarely met in the real world. Whenever public goods, externalities, natural monopolies, increasing returns to scale, imperfect or asymmetric information, transaction costs, taxes, common properties, or other kinds of distortions are present, the first theorem of welfare economics does not apply (Fullerton and Stavins, 1998). All such phenomena are subsumed under the term "market failure" (e.g., Bator, 1958) and may give rise to government intervention.

GHG emissions and related global climate change are "the greatest and widest-ranging market failure ever seen," according to Stern (2006, p.i), and an example of a negative externality of human activity. GHGs, such as CO_2 and CH_4, are emitted by burning fossil fuels in order to generate power, heat buildings, run vehicles, or produce goods and services, as well as by deforestation and agriculture. Without regulatory action, the negative consequences of these activities remain unconsidered by individuals and firms, because market prices do not reflect the total social costs. As a consequence, the amount of GHG emissions from human activity exceeds the social optimum.

Alternatively to this Pigouvian view, one can think of the climate change problem also from a Coaseian perspective. The Earth's atmosphere can be seen as a global common-pool or open-access resource with limited GHG carrying capacity. Individuals and firms use this resource and increase its scarcity by emitting GHGs. As there are no property rights, this use is free of charge. However, the total social costs of exploiting the Earth's atmosphere are then not considered, leading to its overuse.

No matter what way we look at it, the result remains the same: markets are not perfectly efficient when the full social costs of GHG emissions are not reflected in market prices. The extensive literature of environmental and resource economics is mainly devoted to the analysis of this or similar problems and discusses how the underlying market failure can be adequately addressed. The different policy measures available to governments or other regulatory bodies can be broadly classified in two categories: command-and-control regulations and market-based instruments. Here, only the basic ideas behind these approaches will be briefly outlined. Comprehensive overviews and further details can be found in several textbooks (e.g., Feess, 1998; Kolstad, 2000), book chapters (e.g., Stavins, 2003), or journal articles (e.g., Cropper and Oates, 1992).

Under command-and-control regulations, covered entities are required to meet certain standards, such as emission, efficiency, or technology-based standards. If they do not comply, they face fines and penalties. Market-based instruments, such as taxes or cap-and-trade systems, provide economic incentives to overcome the underlying market failure. A carbon tax, for example, puts a price on CO_2 emissions to internalize the social costs of the negative externality. The price signal encourages regulated entities to consider their emissions as costly input and to undertake abatement. Unlike such a price-based approach, in a cap-and-trade system an overall level of CO_2 emissions (the so-called "cap") is defined by issuing a limited number of tradable permits. Regulated entities are required to hold one permit for each unit of CO_2 emitted. The scarcity introduced this way leads to a market price for permits, which again incentivizes abatement. Other market-based instruments are market friction reductions (e.g., liability rules, information programs[1]) and government subsidy reductions (Stavins, 2003).

The usual economic criteria for comparing the different environmental policy approaches are cost effectiveness, environmental effectiveness, information requirements, transaction costs, and dynamic incentives for technology adoption and diffusion. Command-and-control regulations can achieve any environmental goal, if appropriately designed in terms of controls and fines, but only at unnecessary high costs due to ignoring differences in marginal abatement costs.[2] The main advantage of market-based instruments is that abatement occurs at the lowest aggregate costs. Regulated entities will abate emissions as long as this is cheaper than paying the tax or permit price. Because all entities face the same tax or permit price, this leads to the equalization of marginal abatement costs (MAC) across them, which is the necessary and sufficient condition for cost-effectiveness. Moreover, market-based instruments also tend to provide better dynamic incentives to develop and adopt new, cleaner technologies than command-and-control (e.g., Milliman and Prince, 1989; Jaffe and Stavins, 1995; Newell et al., 1999; Requate and Unold, 2003).

It should be noted that, so far, we have spoken only of achieving *any* environmental goal by different policy measures. In order to ensure a Pareto-efficient allocation, standards, taxes, and caps would have to be set appropriately. In the case of command-and-control, this requires the knowledge of each entity's individual MAC curve, whereas for market-based instruments the knowledge of the

[1] Allcott (2011) and Allcott and Mullainathan (2011) provide recent evidence on the effectiveness of non-price-based, behavioral interventions in reducing energy use and GHG emissions.

[2] Only if differentiated standards based on each entity's marginal abatement cost curve are set, cost-effectiveness is achievable by command-and-control.

aggregate MAC curve is sufficient.

For the mentioned reasons, economists commonly propose the use of market-based instruments rather than inflexible and cost-ineffective standards. Nevertheless, the command-and-control approach has its merits when it comes to highly localized environmental problems with threshold damage functions (Hahn and Stavins, 1992). In this particular case, it is important that a given environmental standard is not violated at each emission source. This is certainly not the case with the climate change problem. Because GHGs mix uniformly in the Earth's atmosphere, it does not matter where they are emitted.

Accordingly, it does not matter where an emission reduction takes place, or by whom, in terms of its impact on climate protection, but only the total amount of reduction. It is this mixing characteristic of GHGs that makes climate protection to a global public good. That is, nobody can be prevented from enjoying the benefits of climate protection once it has been provided (non-excludability), and anyone's enjoying of climate protection does not affect others' ability to enjoy it (non-rivalry). This gives rise to the problem of free-riding, which makes collective action and global climate agreements so important—but at the same time so difficult (Barrett and Toman, 2010; Ostrom, 2010; Stavins, 2011).

1.2.2 Valuing the benefits of climate policy

Once market failures are identified and the need for government intervention is theoretically justifiable, the following questions remain: What regulatory action is most appropriate and what public expenditures are reasonable to achieve an environmental goal? Economists are aware that resources are generally limited, but this holds particularly true for public funds. Therefore, political decision-makers face important trade-offs when allocating this money between competing interests. Arrow et al. (1996) propose the use of cost-benefit analysis to improve the quality of the policy process and its outcome. Cost-benefit analysis compares the favorable (benefits) and unfavorable effects (costs) of proposed policies, and thereby helps to inform decisions.[3] However, while (direct) costs of regulations are relatively straightforward to estimate, benefits are often uncertain and more difficult to value in monetary terms in practice. In addition, information on marginal costs

[3]It should be noted that Arrow et al. (1996) point out that noneconomic factors, such as fairness and process, may also be important for regulatory decision-making.

and marginal benefits of regulations are required to meet the efficiency criterion, but difficult to obtain. But most importantly, Arrow et al. (1996) point out the following:

> *Whenever possible, values used to quantify benefits and costs in monetary terms should be based on trade-offs that individuals would make [...]. Benefit-cost analysis is premised on the notion that the values to be assigned to program effects—favorable or unfavorable—should be those of the affected individuals, not the values held by economists, moral philosophers, environmentalists, or others.*
>
> —Arrow et al. (1996, p.222)

This reflects the concept of *consumer's sovereignty*, which is central to neoclassical economic theory and basically says that it is the individual who decides what is good for himself and what is not (Lerner, 1972).

The benefits of environmental regulation are formally defined as the aggregation of individuals' willingness to pay (WTP) for reducing or preventing environmental damages or, depending on the concrete situation, individuals' willingness to accept (WTA) compensation for tolerating the environmental damages (Revesz and Stavins, 2007). The sources of benefits that accrue from environmental protection to individuals are diverse and comprise both use values and non-use, or passive use, values. In terms of climate protection, for example, an individual may directly benefit from a lower risk of malaria (use value), but also may simply value the fact that the climatic living conditions are preserved for later generations (non-use value). It should be noted that, according to economic theory, the benefits of achieving a specific climate target should not alter with the policy instrument that is finally chosen to achieve the target (Kotchen et al., 2011).

Environmental goods are typically non-market goods, and thus there is no market price that could be used to evaluate the benefits of a given environmental regulation. Hence, other methods are needed and have been developed by economists. In principle, there are two categories of techniques to measure benefits of non-market goods: revealed preference (RP) and stated preference (SP) methods (e.g., Cropper and Oates, 1992; Revesz and Stavins, 2007). In RP methods, namely the averting behavior approach, the weak complementarity approach, and the hedonic pricing approach, WTP values are indirectly inferred from actual choices made by individuals in related markets. In contrast, SP methods, such as contingent valuation (CV) and discrete choice experiments (DCEs), rely on direct questioning of individuals, requiring them to trade-off the environmental good at hand with other goods in a hypothetical choice scenario.

In general, methods of RP are favored by economists as they are theoretically sound and based on actual decisions with real money at stake. The main criticism of SP methods is related to their hypothetical nature. Because SP surveys involve the possibility of biased answers, the obtained WTP values are argued to be less reliable (e.g., Cropper and Oates, 1992; Diamond and Hausman, 1994). Possible reasons for biases are strategic behavior by survey respondents or simply their unfamiliarity with the non-market good to be valued. If, for example, respondents expect to be taxed for the provision of a public good according to their stated WTP, it is in their interest to understate their true WTP (e.g., Samuelson, 1954; Bergstrom, 1976; Weimann, 2005). They know that their true preferences are private (problem of asymmetric information) and that no one can prevent them from consuming the public good once it has been provided; hence, free-riding would be individually rational. However, when it comes to capturing the total economic value of environmental and climate protection, which includes both use and non-use values, SP methods are the only feasible alternative that can be used (e.g., Cropper and Oates, 1992; Revesz and Stavins, 2007; Kotchen et al., 2011; Carson, 2012). As Carson et al. (2001) so aptly state:

> *Without stated preference survey methods, though, economists have to admit that they are not measuring the passive use aspects of environmental and other non-market goods, and that these are the aspects about which people may care about most. A benefit-cost analysis that omits these considerations will at best be incomplete and at worst completely misleading.*
>
> —Carson et al. (2001, p.197)

To sum up, it can be concluded that, despite the mentioned methodological problems, SP surveys are an important tool in measuring individual preferences and WTP for climate protection. Such information enables the regulatory authority to define appropriate goals, to value the benefits, and to determine the political acceptability of its climate policy. Without them, it is very likely that human and financial resources are wasted and, hence, social welfare is decreased.

1.3 Focus and contribution of the doctoral thesis

Within the scope of this doctoral thesis, two SP surveys of consumers in Germany were conducted and analyzed—one concerning alternative-fuel vehicles, the other concerning building energy retrofits. The overall aim was to study individual preferences on highly energy-relevant and thus (given the current energy mix in the German road transport and residential sectors) climate-relevant durable goods. In particular, this work examines to what extent environmental aspects influence consumer choice behavior. For this, DCEs are used to obtain WTP estimates for reducing CO_2 emissions. Another focus of this work is on identifying barriers to the widespread adoption of renewable energy, energy-efficient, and low-carbon technologies in the transport and building sectors, namely alternative-fuel vehicles and building energy retrofits. Demographic and socioeconomic differences in preferences for these technologies are also studied.

Individual road transport and residential buildings are of major concern to European and German climate policy, as will be outlined in the following. However, the effectiveness and costs of any government policy intervention will ultimately depend on consumer behavior. Thus, findings of this doctoral thesis, which are based on micro-level data, do not only contribute to the academic literature, but also have implications for the ongoing climate policy debate. Below, I will give some background information on the surveys used to collect the micro-level data, more details are presented in the respective chapters. Furthermore, I will provide non-technical executive summaries for each of the four chapters of this doctoral thesis. In these summaries, I will briefly motivate the specific research questions addressed and outline the scientific contribution of each chapter. More detailed explanations and literature reviews are provided in the chapters themselves. Then, in a subsequent section, I will finally discuss limitations of this research work, mainly from a methodological perspective.

1.3.1 Transport and buildings in the focus of climate policy

In today's modern world, the prosperity of developed human societies heavily depends on adequate energy supply. Within the European Union 27 countries (EU-27), a total of 1157.7 million metric tons of oil equivalent (Mtoe) of energy was consumed in 2007 (European Commission, 2010b). Approximately 27% thereof was used to fuel road transport, while household demand accounted for another 25%. Thus, the sectors of road transport and private households are, together with industry, the largest energy consumers in Europe. The vast majority of this energy is produced from combustion of fossil fuels, resulting in climate-relevant CO_2 emissions. In the EU-27, on average, more than nine metric tons of CO_2 per capita were released in 2007 (European Commission, 2010b).

In order to address the challenges of global climate change and energy security, the EU adopted the so-called Climate Action and Renewable Energy Package in December 2008, which sets out several ambitious emission and energy targets. By 2020, according to this policy package, EU's GHG emissions shall be reduced by at least 20%, renewable energies shall make up 20% of EU's energy production, and 20% of EU's energy consumption shall be saved through energy efficiency (European Commission, 2008). The European Union Greenhouse Gas Emissions Tradings System (EU ETS) is the most important instrument in achieving these targets. It covers power plants and energy-intensive industrial plants that together account for almost half of the EU's total CO_2 emissions. However, the climate and energy package also emphasizes the importance of contributions of sectors not covered by the EU ETS, such as transport and buildings. For these non-ETS sectors a 10% cut in emissions below 2005 levels is targeted for 2020 (European Commission, 2008). In its recently adopted energy strategy, the EU reemphasized the crucial role of the transport sector and existing building stock in making progress on its decarbonisation path, and named them as "the sectors with the largest potential to make energy efficiency gains" (European Commission, 2010a, p.6).

Germany, being the largest consumer of energy and the largest emitter of GHGs within EU-27, recently developed a long-run energy concept in order to conform with the overall EU strategy on climate change and energy. Essential elements of the concept are the increase of energy efficiency and the use of renewable energy sources, particularly in the building and transport sectors. Germany aims at reducing the heat demand of buildings by 20% by 2020 and by 80% by 2050 (German Federal Government, 2010). Therefore, it is planned to double the annual building energy retrofit rate from currently around 1% to 2%. In addition, the German federal government set the target of having one million electric vehicles on Germany's roads by the end of this decade. By 2030 even six million electric vehicles are projected (German Federal Government, 2010). Other alternative low-emission fuels, such as biofuels, shall also be supported. Overall, the implementation of Germany's energy concept is expected to require investments of €20 billions annually.

1.3.2 Stated preference data of German consumers

With the aim of studying individual preferences on highly energy-relevant durable goods, two Germany-wide SP surveys were conducted, each including a DCE. The first one was on the subject of alternative-fuel vehicles. Between August 2007 and March 2008, approximately six hundred potential car buyers were surveyed through computer-assisted personal interviews, mainly taking place in car showrooms. Within the interview, respondents were faced with hypothetical car choice situations. Concretely, they were asked to select the car they preferred most from sets of seven vehicles. The vehicles themselves were characterized by a number of vehicle attributes, such as purchase price, fuel costs, and emission performance. In particular, the vehicles differed in the type of fuel they use. Compared to previous studies, a wider range of alternative fuels or propulsion technologies was included in this experiment; namely gasoline, diesel, hybrid, LPG/CNG, biofuel, hydrogen, and electric cars. By surveying only potential car buyers, it was ensured that respondents were familiar with car purchase decisions.

The second survey was on the subject of building energy retrofits. In June 2009, more than four hundred owner-occupiers of single-family, semidetached, and row houses were surveyed by the market research company GfK. After a telephone screening, house owners were interviewed face-to-face in their homes using the computer. During the choice experiment, each respondent selected their preferred retrofit alternative from binary choice sets, each consisting of one heating and one insulation alternative for their houses. Here, both the heating and the insulation alternatives were rather generic; they were characterized by the same set of attributes, including acquisition costs and heating cost savings. In contrast to previous studies, environmental benefits of energy retrofits in terms of reduced CO_2 emissions were explicitly included in this DCE. After respondents had indicated their preferences, they were asked whether they would actually undertake the selected retrofit activity if it were on the market. Since only house owners can make retrofit decisions independently, tenants were excluded from this survey.

1.3.3 Chapter 2

Chapter 2 studies the impact of fuel availability on demand for alternative-fuel vehicles and is based on the same-titled journal article by Achtnicht et al. (2012). Existing empirical evidence, primarily from North America, indicates that the lack of a widespread service station network for alternative fuels may constitute a barrier to the adoption of alternative-fuel vehicles (e.g., Bunch et al., 1993; Brownstone et al., 1996; Greene, 1996; Horne et al., 2005). In addition, economic theory suggests that network externalities associated with the existing fueling infrastructure for conventional fuels (i.e. gasoline and diesel) may deter consumers from switching to new, incompatible technologies; sometimes referred to as "excess inertia" (Farrell and Saloner, 1985, 1986). On the other hand, installing fueling infrastructure for alternative fuels requires large investments that will only be profitable for service station owners if the number of alternative-fuel vehicles considerably increases. The complementary relationship between vehicle demand and fueling infrastructure availability—an example of the proverbial "chicken-and-egg" problem—raises important questions concerning the potential need for political intervention. Yet a number of crucial questions remain unanswered, especially in the German context, and are addressed in this chapter: What impact does fuel availability actually have on car purchase decisions? How much are consumers willing to pay for a larger service station network? And would consumers really switch to vehicles running on alternative fuels if a fully developed network of service stations existed?

By analyzing the choice data from the 2007–2008 survey of potential car buyers in Germany, it is shown in this chapter that demand for alternative-fuel vehicles strongly depends on the availability of fueling infrastructure. The importance that car buyers attach to fuel availability is reflected in substantial WTP for an expanded service station network. It is therefore concluded that a failure to significantly expand the network of stations for alternative fuels would significantly hamper the adoption of alternative-fuel vehicles in the near future. Since hydrogen and electric cars are likely to remain more costly than their conventional counterparts due to the still very expensive fuel cells and batteries, the barriers to widespread adoption of these alternative technologies are considerable. Fuel availability and price, however, are not the only factors that govern demand for alternative-fuel vehicles. The econometric results presented in Chapter 2 demonstrate that other factors are also important, such as consumer age, environmental awareness, desired vehicle range, and expected annual mileage driven. Furthermore, it is demonstrated through simulations that consumers distinguish between types of fuel, even when all other vehicle attributes are identical. Especially biofuel and electric cars are currently unpopular among German car buyers. Such cars would still capture small market shares even if the associated fueling station infrastructure is significantly expanded.

1.3.4 Chapter 3

Chapter 3 makes use of the same survey data as Chapter 2, but looks at German car buyers' willingness to pay to reduce CO_2 emissions; it is based on the same-titled journal article by Achtnicht (2012). The starting point of the chapter's analysis concerns the fact that, from 2012 onwards, new passenger cars registered in the EU have to comply with certain CO_2 emission performance standards, which are decided by the EU as part of its climate and energy package. Needless to say, the implementation of such emission standards is dubious from an economic perspective. It is likely that they do not equal the marginal abatement costs of different car manufacturers, and thus achieve emission reductions at unnecessarily high costs. But in view of the present EU regulation, it is interesting to see what role a car's CO_2 emissions play at all in vehicle choices. This knowledge would help both car manufacturers to adopt an appropriate strategy and policymakers to value the benefits of this regulation. Therefore, in this chapter the following research questions are addressed: Do car buyers care about the environment? Or, more precisely: Do CO_2 emissions have a negative impact on car purchase decisions in Germany? And, if yes: How much are German car buyers willing to pay for emission reductions?

The econometric results demonstrate that Germans consider CO_2 emission performance as a relevant factor when selecting a car. The less carbon is emitted per kilometer, the more attractive the car becomes. This also results in a relatively high WTP for low-emission vehicles. Overall, the chapter fits into a growing, but heterogeneous literature that seeks to elicit WTP for carbon abatements, carbon offsets, or climate policy in general (e.g., Berrens et al., 2004; Hersch and Viscusi, 2006; Viscusi and Zeckhauser, 2006; Brouwer et al., 2008; Kotchen et al., 2011). In addition, it contributes to another strand of literature that examines whether and how individual characteristics, such as age, sex, or education, influence the environmental attitudes and behavior of consumers. Here, it turns out that women, younger, and more educated individuals seem to be more concerned about climate change and hence willing to pay more for low-emission vehicles. In particular, the observed age effect is very robust and is supported by the findings of Hersch and Viscusi (2006) and Kotchen et al. (2011). Considering the expected demographic changes in Germany, i.e. an ageing population, this might have important implications for the general public's support of climate change policies in the future.

1.3.5 Chapter 4

In Chapter 4, which is based on the same-titled journal article by Achtnicht (2011), similar research questions as in Chapter 3 are addressed, but this time in the context of residential buildings. Domestic space and water heating are considered to be of particular relevance for future climate and energy policy. This is due to the fact that they together dominate residential energy use and that their carbon emissions are not covered by the EU ETS. Energy retrofits in residential buildings are therefore likely to result in effective mitigation of CO_2 emissions. Given that the used heating equipment and the installed insulation system determine the residential energy use for years and even decades, it is essential for policymakers and researchers to better understand the preferences underlying house owners' retrofit decisions. Empirical results from previous consumer preference studies suggest that cost benefits of energy-saving measures are not the only factor that drives decisions (e.g., Poortinga et al., 2003; Sadler, 2003; Banfi et al., 2008). In this chapter, for the first time to the best of my knowledge, the role of environmental benefits in such decisions is explicitly examined. In particular, the following research questions are addressed: Do environmental benefits in terms of reduced emissions of CO_2 matter in energy retrofit choices? And, if yes: How much are German house owners willing to pay for emission reductions?

The choice data from the 2009 survey of German house owners that is analyzed here contains both heating cost savings and carbon emission savings associated with retrofit alternatives. Thus, trade-offs between profitability and environmental factors can be modeled. Interestingly, it turns out that the impact of environmental benefits differs significantly between heating and insulation systems. While higher CO_2 savings increase the likelihood of a heating alternative to be selected, they seem to play no role at all in terms of insulation choices. Accordingly, economically meaningful WTP estimates are only derived for CO_2 emission reductions associated with heating systems. Chapter 4 therefore does not only add to the existing literature on consumer preferences for energy-saving measures, but also makes important contributions to the WTP literature cited above. In particular, its results make obvious that the WTP for reducing CO_2 emissions is highly dependent on the respective context in which the WTP is elicited, as well as on the reduction measure that respondents face. Other related WTP studies used samples from different countries and population groups (e.g., Harvard graduate students; Viscusi and Zeckhauser, 2006), different methods (e.g., CV; Kotchen et al., 2011), and different (hypothetical) reduction vehicles (e.g., carbon offsets by paying higher prices for airline tickets; Brouwer et al., 2008). Also, evidence of Tversky and Kahneman (1981) suggests that the outcome of choice, and hence WTP, may be influenced by the way a choice problem is framed (e.g., whether CO_2 emission reductions are presented in absolute or relative terms). However, in this chapter, although using one sample, the same elicitation method, and relative CO_2 reductions in each case, the WTP still differs depending on whether CO_2 is reduced by replacing outdated heating equipment or by improving thermal insulation. As a consequence, there is no unique carbon price.

1.3.6 Chapter 5

Chapter 5 identifies key drivers and barriers for the adoption of building energy retrofits in Germany. It is based on the same-titled working paper by Achtnicht and Madlener (2012) and makes use of the same survey data as Chapter 4. According to the results of Chapter 4, house owners take (at least partly) into account the negative environmental externalities associated with their residential energy use when opting for a retrofit measure. This is good news for Germany's policymakers, as it suggests that individual choice behavior would improve the social welfare. Nevertheless, although supported by public funding, energy retrofit activities are still low in Germany. This discrepancy indicates that important economic, technical, and behavioral factors influencing retrofit decisions are still not well understood and not properly addressed by current policy design. For example, the choice experiment abstracted from market barriers, such as imperfect information and transaction costs, that may prevent investments in energy-efficient technologies in the real world (e.g., Howarth and Andersson, 1993). Phenomena such as the status-quo bias, known from the experimental literature (e.g., Kahneman et al., 1991), may be an additional source of inertia in adopting energy retrofits. By considering respondents' own stated reasons for and against retrofitting, and by including the status-quo alternative in the choice analysis, this chapter provides some empirical evidence on factors that influence retrofit decisions for Germany. It thus contributes to the existing literature on drivers and barriers which comes mostly from other countries, such as the United States (e.g., Cameron, 1985) and Switzerland (e.g., Jakob, 2007; Alberini et al., 2011).

The results of Chapter 5 suggest that the likelihood of energy retrofit activities is increased if the following requirements can be met: First, house owners must be able to afford financially to undertake such retrofits. The lack of financial resources was the third most frequently stated barrier against energy retrofits, and robust income effects are identified in the econometric analysis. Second, energy retrofits must be (perceived as) profitable. The most frequently stated reason for investing in energy retrofits were high energy costs, while uncertainty about whether such measures will pay off constitute an important barrier, according to respondents. Also, higher energy cost savings and lower payback periods made retrofit alternatives more likely to be selected over the status quo in the choice experiment. And third, there must be a favorable opportunity, such as a heating system that needs replacement or a building envelope that is due for renovation. The latter point seems to be of particular importance in order to explain the persistent low retrofit rate in Germany. The results suggest that most house owners wait until building components are approaching the end of their useful life, before considering options for renovation or replacement. Through simulations, it is further shown that professional energy advice can provide strong incentives for house owners to retrofit their homes. Increased use of energy advisory services may also help to alleviate the problem of imperfect information on the part of consumers. In view of problems related to other policy options, energy advice thus seems to be worthy of being supported by public funding in order to stimulate building energy retrofits in an effective and cost-efficient way.

1.3.7 Discussion of study limitations

The sources of data used in the present doctoral thesis are surveys using DCEs. Thus, the study heavily relies on SP responses. The use of an SP approach was considered to be suitable given the focus and purpose of the study. First, by collecting SP data it was ensured that technologies not yet ready for the market, such as hydrogen cars, could be included in the choice analysis. For such technologies, there simply is no RP data available. Second, another common problem with RP data is that information on the non-chosen alternatives (i.e. the underlying choice set of consumers) are not readily obtained. In contrast, using SP methods provides the researcher with full information and control over available alternatives and their attributes. And third, in reality there is a one-to-one correlation between fuel consumption and associated CO_2 emissions, which is reflected in carbon emission factors for fossil fuels. Therefore, it is problematic to isolate the pure effects of cost and environmental benefits on consumer choices using RP data.[4]

Some economists, however, are critical of the use of SP in economic analyses. The critics doubt the credibility, validity, and reliability of SP responses (e.g., Anonymous, 1992; Diamond and Hausman, 1994; Hausman, 2012). In their arguments, they mainly refer to anomalies that are often subsumed under the term "embedding effect," introduced by Kahneman and Knetsch (1992), and that basically imply that stated WTP values do not appropriately reflect differences in the scope of the public good to be valued. An oft-cited example is a CV study in which Canadians expressed a WTP for preserving fish stocks in all Ontario lakes that was only slightly higher than the WTP for preserving fish stocks in only the Muskoka area, a small part of the Ontario province (e.g., Kahneman and Knetsch, 1992). One potential reason for such anomalies, cited in the literature, is the hypothetical character of surveys. Because stated choices lack any real economic commitment, respondents possibly do not fully take into account their budget constraints (hypothetical bias). Another explanation presented by the critics suggests that sometimes respondents have no preferences for the public good involved. Exemplarily, Diamond and Hausman (1994) argue that "[t]his absence of preferences shows up as inconsistency in responses across surveys and implies that the survey

[4]For a thorough discussion of when the use of an SP approach might be beneficial, see Louviere et al. (2000) and Hensher et al. (2005).

responses are not satisfactory bases for policy" (p.63).

It should be noted, however, that Diamond, Hausman, and other opponents of SP methods aim their criticism primarily at CV surveys, and that their arguments are weakened by findings of other studies regarding CV (e.g., Hanemann, 1994; Smith and Osborne, 1996; Carson et al., 2001). Moreover, DCEs such as used in this doctoral thesis are considered to address some of the limitations of the CV method (e.g., Adamowicz et al., 1994; Murphy et al., 2005; List et al., 2006). In the meta-analysis by Murphy et al. (2005), for example, choice-based valuation methods are found to significantly reduce hypothetical bias compared to open-ended CV questions. Although choices made by respondents in DCEs remain, of course, *stated*, choosing "the most preferred alternative from a set of alternatives [...] is a very common experience" (Adamowicz et al., 1994, p.21). Choice tasks in DCEs might thus be more realistic and easier to perform than providing a maximum WTP for an unfamiliar, non-market good as in CV studies. Further, in the DCEs analyzed in this work, respondents were not required to directly choose between several levels of public good provision at different given prices or costs. Rather, WTP for the public good in question—i.e. climate protection—is elicited indirectly by considering (saved) CO_2 emissions as an attribute of the alternatives, namely alternative-fuel vehicles and building energy retrofits. As only car buyers and house owners, respectively, were surveyed, the respondents were likely to be familiar with the choice tasks they faced, to fully understand them, and to provide credible and reliable answers. Conducting face-to-face interviews, preceded by careful pretests, further ensured the reliability of responses, as suggested by Arrow et al. (1993).

As a byproduct of the attempt to create more realistic choice scenarios, a new issue arose. Instead of asking people directly, WTP for saved CO_2 emissions was derived indirectly from stated choices for cars and energy retrofits, as described above. Now, however, relatively strong assumptions on annual mileage and annual residential emissions, respectively, had to be made in order to convert the derived WTP values into a WTP per metric ton of CO_2, the common unit in the climate policy debate. Average values available from other data sources were used for the conversion in this work. For passenger cars, an annual mileage of 14,300 km and a ten-year period of use were assumed, based on data published by the German Institute for Economic Research (DIW, 2008) and the Federal Motor Transport

Authority (KBA, 2008). For residential buildings, annual CO_2 emissions of 6.5 metric tons were assumed, based on own calculations using figures from the Federal Ministry of Transport (BMVBS, 2007). Given the absence of individual data on these variables, the use of averages is the best and most feasible approach. Nevertheless, the thus obtained WTP values, expressed in terms of euro per metric ton of CO_2 (€/tCO_2), are only a rough approximation and very sensitive to changes in the assumptions. Therefore, a cautious interpretation of them is appropriate. I will refer to this issue in the respective chapters.

Besides these methodological aspects, there is another concerning the scope of this research that ought to be taken into account. The study focuses solely on consumer choices for products/technologies that are relevant to household energy use and carbon emissions. Behavioral changes, such as changing driving and energy-consuming habits, are not considered here, although they may also be important in reducing the negative effects of satisfying human wants. What is more, using more energy-efficient equipment may induce additional consumption of energy services due to lower effective energy costs. Car drivers, for example, are likely to use a fuel-efficient car more intensively than a less fuel-efficient car, as driving becomes cheaper.[5] This is just one example of what the economic literature refers to as (direct) "rebound effect" (e.g., Sorrell and Dimitropoulos, 2008; Sorrell et al., 2009; van den Bergh, 2011). As a result of rebound, energy savings from technical efficiency improvements are lower than expected, if not offset completely. This has important implications for climate and energy policy. Any policy attempting to effectively reduce energy use and associated emissions needs to address the problem of rebound seriously (van den Bergh, 2011). However, this is beyond the scope of the present doctoral thesis.

[5] Frondel and Vance (2009) and Frondel et al. (2012) provide some empirical evidence based on estimated fuel-price elasticities of vehicle kilometers traveled and fuel consumption from Germany.

Chapter 2

The Impact of Fuel Availability on Demand for Alternative-Fuel Vehicles

2.1 Introduction

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

In this paper, we study the impact of fuel availability on demand for alternative-fuel vehicles. The lack of a widespread service station network for alternative fuels may constitute a barrier to the adoption of alternative-fuel vehicles. Furthermore, network externalities associated with the existing fueling infrastructure for gasoline and diesel may deter consumers from switching to new, incompatible technologies (e.g., Katz and Shapiro, 1986, 1985); sometimes also referred to as "excess inertia"

(Farrell and Saloner, 1986, 1985). Expanding the availability of alternative fuels, however, requires large investments. The installation of fueling infrastructure for alternative fuels will only be profitable for service station owners if demand, i.e. the number of vehicles using alternative fuels, considerably increases. The complementary relationship between vehicle demand and fueling infrastructure availability is often described as a "chicken-and-egg" problem, a problem that raises important questions concerning the potential need for political intervention. Yet crucial questions remain unanswered: What impact does fuel availability actually have on car purchase decisions? How much are consumers willing to pay for a larger service station network? Would consumers really switch to vehicles running on alternative fuels if a fully developed network of service stations existed? The answers to these questions would help us to decide whether public subsidies for the development of a service station network for alternative fuels are economically justified.

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

The paper is organized as follows. Section 2.2 describes the survey and the data used. Section 2.3 introduces the discrete choice model. The empirical results are presented in Section 2.4, with the parameter estimates discussed in Subsection 2.4.1, the simulation results in Subsection 2.4.2, and the willingness-to-pay estimates in Subsection 2.4.3. The last section summarizes and concludes.

2.2 Survey design

In this paper, we analyze data from a Germany-wide survey of potential car buyers that was administered between August 2007 and March 2008 as a computer-assisted personal interview (CAPI). The survey was designed to garner insights into consumer preferences for alternative-fuel vehicles. A total of approximately 600 interviews were conducted at various car dealerships and branch offices of TÜV, the German authority responsible for certifying vehicle roadworthiness.[1] The respondents were picked randomly, but had to be of legal age and possess a valid driver's license. The sample comprises individuals from different regions in Germany (eastern and western Germany, urban and rural areas) and various demographic and socioeconomic groups (in terms of age, gender, education, income, etc.). It thus provides a broad cross-section of the target population, i.e. potential car buyers in Germany, although it is not entirely representative. Compared with the official data available from KBA (2009) and MiD (2010), it seems that more educated individuals are over-represented, whereas women and individuals aged 40 to 49 years are under-represented in the sample; see Table 2.1 for more details.

In the survey, respondents participated in a choice experiment involving alternative-fuel vehicles.[2] In each choice set, respondents were presented with seven hypothetical vehicles and asked to select the car they preferred most. The alternatives were characterized by the following six attributes: purchase price; fuel costs per 100 km; engine power; CO_2 emissions per km; fuel availability (given by the service station network size); and fuel type. Respondents were asked to assume that the presented hypothetical alternatives only differed with regard to these attributes, but were otherwise identical. Table 2.2 gives details on the attribute levels.

By using this stated preference approach, it was possible to consider every fuel type that is currently available or might be of importance in the future. To examine potential alternative-specific effects related to fuel type, however, it was necessary to include each fuel once in each choice set (thus "labeling" the choice experiment; see Hensher et al., 2005). We pooled different drive systems and fuel types into broader categories such as "hybrid" or "biofuel", as otherwise the total

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

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

Table 2.1: Summary of sample statistics

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

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

Table 2.2: Attributes and attribute levels in the choice experiment

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

[a] average of the lower and upper bounds for the next car indicated by the respondent
[b] only applied to non-fossil fuel types (i.e. biofuel, hydrogen, and electric)
[c] not applied to conventional fuel types (i.e. gasoline and diesel)

Table 2.3: Summary of the vehicles intended for purchase

Survey question	Obs.	Mean	Std.Dev	Min	Max
Vehicle class					
Small/subcompact cars	598	0.145	0.353	0	1
Compact cars	598	0.283	0.450	0	1
Mid/Full-size cars	598	0.336	0.472	0	1
Mid/Full-size luxury cars	598	0.119	0.323	0	1
(Compact) Minivan	598	0.052	0.222	0	1
SUV	598	0.028	0.166	0	1
Sports car, roadster etc.	598	0.037	0.188	0	1
Age of the car					
new car	598	0.328	0.469	0	1
(up to) 1 year old/demonstration car	598	0.304	0.460	0	1
1–3 years old used car	598	0.204	0.403	0	1
4–7 years old used car	598	0.127	0.333	0	1
more than 7 years old used car	598	0.037	0.188	0	1
Purchase price					
Maximum (in €1000)	598	23.0	16.3	1	150
Minimum (in €1000)	598	18.5	14.3	0	100
Engine power					
Maximum (in hp)	598	141.8	63.3	50	555
Minimum (in hp)	598	112.5	52.4	0	500
Expected annual mileage (in 1000 km)	598	19.5	15.0	2	170
Desired vehicle range (in km)	598	632.7	170.2	100	1100

number of alternatives would have become too large. Nevertheless, the resulting 7×6 choice set design was still relatively demanding for respondents. However, based on the results of a pretest, we concluded that the experimental design was appropriate and not overly challenging. For a more detailed discussion of the issue of choice complexity, see Achtnicht (2012), who uses the same data set.

The attributes "purchase price" and "engine power" were customized. Respondents were asked beforehand to describe the vehicle they intended to buy, indicating upper and lower bounds for price and horsepower, which were then averaged and used as individual reference or pivot. This pivot or customization approach is common in the transportation literature and it increases the relevancy of attribute levels and choice scenarios (e.g., Hoyos, 2010; Hensher et al., 2005). A detailed summary of the vehicles intended for purchase by the respondents is presented in Table 2.3.

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

2.3 Model specification

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

$$U_{nj} = V_{nj}(x_j, z_n) + \varepsilon_{nj}, \tag{2.1}$$

where $V_{nj}(x_j, z_n)$ is a deterministic (observed) utility component, depending on attributes x_j of alternative j and demographic variables z_n of person n, and ε_{nj} is an IID extreme value type I (unobserved) stochastic component. Under these assumptions, and given utility-maximizing behavior, it can be shown that the probability person n chooses alternative i takes the following closed form (e.g., Train, 2003):

$$P_{ni} = \frac{\exp(V_{ni})}{\sum_{j=1}^{J} \exp(V_{nj})}. \tag{2.2}$$

In a previous working paper of this study, we used a nested logit model in order to relax the *independence from irrelevant alternatives* (IIA) assumption that is inherent to standard logit. In any reasonable nesting structure that we tested,

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

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

Table 2.4: Variable definitions

Variable name	Definition
Purchase price	Purchase price in €1000
Purchase price × Low UPB	Purchase price in €1000 if respondent indicates an upper price bound that is below the sample median of €20,000
Fuel costs	Fuel costs in € per 100 km
Engine power	Engine power in hp
CO_2 emissions	CO_2 emissions in g per km
CO_2 emissions × Less environmentally aware	CO_2 emissions in g per km if respondent is less environmentally aware than the sample average
Fuel availability	Percentage of service stations where the respective fuel type is available
Fuel availability^2	Square of the percentage of service stations where the respective fuel type is available
Gasoline	1 if fuel type is gasoline; zero otherwise
Hybrid	1 if fuel type is hybrid; zero otherwise
LPG/CNG	1 if fuel type is LPG or CNG; zero otherwise
Biofuel	1 if fuel type is biofuel; zero otherwise
Hydrogen	1 if fuel type is hydrogen; zero otherwise
Electric	1 if fuel type is electric; zero otherwise
Fuel type × Fuel availability	Percentage of service stations where the respective fuel type is available (if fuel type is *fuel type*); zero otherwise
Fuel type × Range	Desired vehicle range in km (if fuel type is *fuel type*); zero otherwise
Fuel type × Mileage	Expected annual mileage in 1000 km (if fuel type is *fuel type*); zero otherwise
Fuel type × Less environmentally aware	1 if respondent is less environmentally aware than the sample average (and fuel type is *fuel type*); zero otherwise
Fuel type × Age	Age of the respondent in years (if fuel type is *fuel type*); zero otherwise

however, the introduced dissimilarity parameters were rather close to 1 and the associated null hypothesis of homoscedasticity could not be rejected by a likelihood ratio test. Therefore, we finally decided on using a standard logit specification.

The explanatory (or independent) variables entering the model and the underlying hypotheses are briefly discussed in the following; Table 2.4 gives further details. The deterministic component of utility V_{nj} is, as usual, specified linearly in parameters. First and foremost, we include the attributes used in the choice experiment. While the correlation of purchase price, fuel costs, and CO_2 emissions with the probability of being chosen is expected to be negative, it should be positive for engine power and fuel availability. The different fuel types are included as alternative-specific constants (ASC), with diesel serving as the base alternative.

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

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

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

We also try to capture the influence of the respondents' age on their stated choices. Our assumption is that older consumers may show a certain reluctance to purchase unknown or innovative products. Finally, we control for whether preferences for fuel types differ in relation to the intensity of private car use. For

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

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

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

this reason, we include both the expected annual mileage and desired vehicle range in the model as interaction variables with the ASC.

2.4 Empirical results and discussion

2.4.1 Parameter estimates

Table 2.5 shows the estimation results. Note that interaction terms regarding different fuel types have to be interpreted with reference to diesel, which is the base fuel type. The coefficient of purchase price has, as expected, a negative sign and is statistically highly significant. We further find that individuals who indicated an UPB below €20,000 are much more price-sensitive.[8] Their price coefficient, which is given by the sum of the coefficients for “Purchase price” and “Purchase price × Low UPB,” is almost three times as large. This implies a much lower WTP for improvements in other passenger car attributes; we will consider this in our discussion about WTP for an enlarged fueling infrastructure below. Fuel costs and engine power are also highly significant in the model, and both have the expected signs.

Low vehicle emissions also seem to play an important role in car purchase decisions, although their importance strongly depends on individual environmental awareness. The results suggest that the utility value of a vehicle for environmentally aware consumers is affected more negatively by higher CO_2 emissions than it is for other consumers. It would therefore appear that the extensive public discussion surrounding CO_2 emissions and climate change has had an impact on the preferences of German consumers. German consumers are aware of the drawbacks of high CO_2 emissions, and this awareness factors into vehicle purchase decisions (see Achtnicht, 2012, for more on this topic). Likewise, it seems that environmental awareness influences individual preferences for fuel types, irrespective of their CO_2 emissions. Compared to diesel, alternative fuels are particularly preferred by environmentally aware individuals.

Other factors that appear to influence individual choices are age, desired vehicle range, and expected annual mileage. In particular, the estimation results suggest

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

Table 2.5: The estimated standard logit model

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

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

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

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

2.4.2 Simulations

In order to illustrate what impact fuel availability has on car purchase decisions, we simulate three different scenarios. Based on the estimated model, we analyze how the average choice probabilities for alternative-fuel vehicles change under different

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

Table 2.6: Simulation scenarios and results

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

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

fueling infrastructure scenarios. For this purpose we use standard cars that are identical in all respects except for fuel type and fuel availability. For all other attributes, we use approximate mean values from the sample data. This leads us to define a standard car with a purchase price of €20,700, fuel costs of €11.67 per 100 km, engine power of 127 hp, and CO_2 emissions of 128 g per km. The choice probabilities are first predicted separately for each individual in the sample, and after that the predicted probabilities are averaged. Any difference in choice probabilities that may be observed can then be attributed to the used fuel type and the size of the associated service station network. The scenarios and simulation results are presented in detail in Table 2.6.

In scenario 1 we look at a stylized and simplified version of the status quo in Germany.[10] For gasoline-fueled, diesel-fueled, and hybrid cars almost every service station is convenient; the density of the service station network is thus set at 100% in each instance. For LPG/CNG we assign a density of 50%. Finally, for the future or embryonic technologies of biofuel, hydrogen, and electric cars we set a density of 10% to guarantee at least a minimum level of availability. The resulting choice probabilities illustrate the strong impact of fuel availability: the higher the level of fuel availability, the higher the demand for each respective vehicle type. Gasoline, diesel, and hybrid cars each capture approximately 25% of demand, with

[10] In Germany there are approximately 15,000 service stations (including freeway service stations). Based on an online search, we find the following current figures with respect to alternative fuels: LPG/CNG can be refueled on 6,280/892 service stations; biofuel (here E85, consisting of 85% ethanol and 15% gasoline) on 345; hydrogen on 8; and for electric cars there are 512 charging stations.

(slight) advantages for the conventional technologies. LPG/CNG cars, with their 50% density of service stations, also have a fair chance of being chosen (13.4%). However, biofuel, hydrogen, and electric cars only capture a small sliver of demand in this scenario.

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

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

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

2.4.3 Willingness to Pay

From the estimated model, we can derive the marginal WTP for an expanded service station network, i.e. the amount that a person is willing to pay additional to the baseline price p for a marginal increase of one percentage point in the baseline level of fuel availability $a < 100$, without a change in utility. Since the squared fuel availability a^2 also enters the model, the WTP does not fit with the ratio of the corresponding coefficients of the linear terms. Due to the fixed utility level, Equation (2.3) has to hold:

$$\beta_p p + \beta_a a + \beta_{a^2} a^2 + c \overset{!}{=} \beta_p(p + \mathrm{WTP}) + \beta_a(a+1) + \beta_{a^2}(a+1)^2 + c, \qquad (2.3)$$

where β_p, β_a, and β_{a^2} denote the estimated coefficients of the price and fuel availability variables, respectively, and c is the value that the remaining explanatory variables of the model contribute to the deterministic component of utility V_{nj}. Simple algebraic transformations of Equation (2.3) result in the following WTP equation:

$$\mathrm{WTP} = -\frac{\beta_a + \beta_{a^2}(2a+1)}{\beta_p}. \qquad (2.4)$$

Note that Equation (2.4) in particular provides the WTP for a marginal increase of a given level of fuel availability a with respect to diesel-fueled cars and individuals who intend to buy a car that costs €20,000 or more. For other fuel types the respective alternative-specific fuel-availability coefficient simply has to be added to the numerator, whereas the coefficient of the interacted price variable has to be added to the denominator in order to derive the marginal WTP of individuals with a low UPB.

In our calculations, we let the baseline level of fuel availability a vary from 10 to 90% (at intervals of 10) and derive the marginal WTP with respect to diesel and electric cars, for both individuals with a high UPB and those with a low UPB.

Table 2.7: The marginal WTP (in €1000) for greater fuel availability

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

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

Since all alternative-specific fuel-availability coefficients aside from the electric one do not differ significantly from zero, the WTP with respect to diesel can also be interpreted as an approximation of the WTP with respect to gasoline, hybrid, LPG/CNG, biofuel, and hydrogen cars. Table 2.7 shows the results in detail.

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

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

2.5 Conclusions

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

However, fuel availability and price are not the only factors that govern demand for alternative-fuel vehicles. Other factors also play a role, including consumer age, environmental awareness, desired vehicle range, and expected annual mileage driven. Our simulations demonstrate that consumers distinguish between different types of fuel, even when all other vehicle attributes are identical. In particular, our results show that biofuel and electric cars are currently unpopular among German car buyers,[11] and that even with the significant expansion of fueling station infrastructure, which would certainly serve to support wider adoption, such cars would still capture small market shares. Given the current efforts to promote alternative fuels, this finding is critical. A key task for future research will thus be to examine whether, to what extent, and under what circumstances consumer preferences for different fuel types may change over time.

[11] This finding is confirmed by Hackbarth and Madlener (2011), using a more recent sample of German car buyers.

Chapter 3

German Car Buyers' Willingness to Pay to Reduce CO_2 Emissions

3.1 Introduction

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

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

Consequently, motorized individual transport plays a major role in the political debate on climate change. The European Commission has set the goal of reducing GHG emissions by 20% by 2020, compared to 1990 (European Commission, 2008). To ensure that the EU will achieve its climate targets, the European Parliament

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

approved the EU's energy and climate package. Part of this package is a regulation which sets emission performance standards for new passenger cars registered in the EU. More concretely, the whole car industry has to comply with an average of 120 g of CO_2 per km between 2012 and 2015, with interim targets. The long-term target for 2020 is an average of 95 g of CO_2 per km (in 2008, new passenger cars emit 153 g of CO_2 per km on average; T&E, 2009). Manufacturers who exceed the specified standard will have to pay penalties. For each gram exceeding the target, €95 times the number of new passenger cars will have to be paid from 2019 onwards. In the transitional period between 2012 and 2018 the penalty for the first three exceeding grams is considerably lower (i.e. €5 for the first gram, €15 for the second gram, and €25 for the third gram).

From an economic point of view this measure has to be regarded critically. Generally, standards are not cost-efficient. Unlike market-based instruments (i.e. taxes and tradable permits), CO_2 emission standards will not equal the marginal abatement costs of different manufacturers (e.g., Kolstad, 2000). Moreover, market-based instruments perform better than standards in providing incentives for firms to adopt advanced abatement technology and to develop such new technology (Requate, 2005). As a consequence the EU environmental targets will be achieved—if at all[2]—at unnecessarily high costs.

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

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

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

German car buyers.

In addition, we study the impact of specific demographic characteristics on the respondents' stated choices. Scientific literature discusses whether age, education, gender and income influence consumers' perceptions of environmental issues and their related willingness to pay. The existing results are ambiguous. For example, Hersch and Viscusi (2006) find that older people have a significantly lower willingness to pay higher gasoline prices in order to protect the environment. The authors further provide evidence that the level of support for this environmental policy measure increases with the respondents' education and, to a lesser extent, income levels. Gender is not influential in this study. However, the results of Torgler et al. (2008) indicate that women have stronger preferences towards the environment. On average, for example, women are more likely than men to state a high willingness to pay for environmental protection. In their recent study Daziano and Bolduc (2011) also analyze stated vehicle choices, using a hybrid choice model. Their findings provide some evidence that women, older people and more educated people are more concerned about environmental issues, while income has no significant effect in the car choice context. By contrast, Hsu et al. (2008) identify income as a strong determinant of the willingness to support gasoline tax increases.[3] They also find some effects of educational level and gender (i.e. women are more likely to support gasoline tax increases), but not of age. To contribute to this discussion we derive the willingness to pay for CO_2 abatement, depending on the respondents' gender, age, and educational level.

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

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

are allowed to vary or not. We use a mixed logit specification since it fits our data better than standard logit, and through further improvements in computer performance the additional expenditure of time is reasonable.

The paper is organized as follows: The data and the methods used are described in detail in Section 3.2. In Section 3.3 the results of our econometric analysis are presented. The final Section 3.4 summarizes and concludes.

3.2 Data and methods

3.2.1 Description of the survey

The data analyzed in this paper comes from a Germany-wide survey among potential car buyers. The survey was designed to study people's preferences regarding cars with alternative propulsion technologies and fuel types. It was conducted via computer-assisted personal interviewing (CAPI), from August 2007 to March 2008.[4] The interviews took place in showrooms of car dealers of different brands and in selected offices of the technical inspection authority. The respondents were picked randomly among consumers of all population groups. Only two restrictions were made. Firstly, respondents should be of age and have a valid driving license. And secondly, they should intend to replace an existing car or to buy a new car in the near future, or at least could imagine doing it in principle. The approximately 600 interviews that have been conducted[5], covered people from different regions in Germany (Eastern vs. Western Germany, urban vs. rural areas) and various demographic groups. The sample provides a broad cross-section of the target population, i.e. potential car buyers from Germany. However, while individuals with a higher education entrance qualification are over-represented, women and indi-

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

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

viduals aged 40 to 49 years are under-represented. Therefore, the paper's results are valid first and foremost (but not only) for the sample used. Table 3.2 compares the demographic profile of the sample with the population shares.[6]

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

Table 3.1 gives the attribute levels used in the choice experiment. A particular focus of the research project of which this survey was a part, was on alternative fuels. Therefore, we basically included each engine technology or fuel type that currently is available and relevant, or might be of importance in the near future: gasoline, diesel, hybrid, LPG/CNG, biofuel, hydrogen, and electric. However, as the total number of alternatives should not get too large, different propulsion or fuel types were pooled into broader categories such as hybrid or biofuel. In order to allow for studying alternative-specific effects, it was essential that each fuel type was covered exactly once in each choice set (Hensher et al., 2005). Therefore, the fuel type behaves like a label of the alternatives and the (by design unlabeled) choice experiment is quasi-labeled.

With respect to the attributes "purchase price" and "engine power" we used a pivot design. Each respondent was asked beforehand to characterize the vehicle he or she intends to buy. This characterization referred to the car classification (full-size, compact, mid-size, van, sports car etc.)[8] as well as to upper and lower bounds

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

[7]Purchase price, fuel costs and engine power are standard explanatory variables in vehicle choice models (e.g., Horne et al., 2005; Ewing and Sarigöllü, 2000; Brownstone et al., 2000; McCarthy and Tay, 1998; McCarthy, 1996; Brownstone et al., 1996; Bunch et al., 1993; Manski and Sherman, 1980). CO_2 emissions and fuel availability are used in only a few surveys (Horne et al., 2005; Brownstone et al., 1996; Bunch et al., 1993).

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

for purchase price and engine power. The customized values of purchase price and engine power in the choice experiment were equal to 75%, 100% and 125% of the average of indicated bounds. The reason for doing so is the increase of relevancy of attribute levels and choice scenarios (e.g., Hoyos, 2010); the approach of pivoting or customization is common and well documented in the transportation literature (e.g., Axsen et al., 2009; Mau et al., 2008; Hensher et al., 2005; Horne et al., 2005; Greene and Hensher, 2003; Ewing and Sarigöllü, 2000, 1998; Bunch et al., 1993).

For fossil fuels there is indeed a constant correlation between fuel consumption and CO_2 emissions. By burning one liter of gasoline, for example, 2.32 kg of CO_2 are emitted.[9] In other words, decreasing the CO_2 emissions of a fossil-fuel-based vehicle automatically means a decrease in fuel consumption—and therefore in fuel costs. There is no such unambiguous correlation for the other propulsion technologies and fuel types. Power generation by burning coal, for example, is cheaper than power generation by using renewable energies—but emits substantially more CO_2. In trying to capture the pure effect of CO_2 emissions on choice decisions we included both fuel costs and emission performance as independent car attributes in our experimental design.

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

However, in order to avoid the most unrealistic scenarios, we allowed solely strictly positive emissions for fossil fuels (i.e. gasoline, diesel, CNG/LPG)[10] and

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

[10]Since, in the long term, there is no end-of-pipe technology that may address vehicle CO_2 emissions, this is reasonable. Only for non-fossil fuels (i.e. biofuel, hydrogen, electric) we included the attribute level "no emissions"—since their in-use emissions are effectively zero. Biofuels may

excluded the lowest level of service station network (i.e. 20%) for conventional-fueled alternatives. Still, there are some choice scenarios in the resulting design which may be considered as not very realistic, though theoretically possible.[11] But firstly, it should be noted that excluding the most unrealistic attribute levels for certain fuel types (as described above) also ensured that these scenarios appeared less frequently. For example, on average, alternative-fueled cars perform much better than conventional-fueled cars in terms of CO_2 emissions in the choice experiment. And secondly and mainly, according to Moore and Holbrook (1990), the realism of attribute-level combinations is of less practical importance as sometimes feared. Moore and Holbrook analyzed the effect of unrealistic stimuli on consumer judgements in terms of perceived realism and predictive power by three experiments in a car choice context. Their results provide evidence that the choice likelihoods are not affected by differences in scenario realism.

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

At this point, some remarks on the issue of choice complexity are appropriate. There is a growing literature addressing the effect of design dimensions on the consistency of stated choices (e.g., Hensher, 2006; Caussade et al., 2005; DeShazo and Fermo, 2002). Caussade et al. (2005), for instance, identify "number of attributes" and "number of alternatives" as the two most important design dimensions in terms of their impact on choice consistency. Notably, they find an U-shaped relation between the number of alternatives and the error variance (maximizing consistency by a number of four alternatives). This pattern is supported by findings from DeShazo and Fermo (2002) who report a quadratic relation. However, in their study the number of alternatives turns out to be one of the least influential design dimensions. Hensher (2006) investigated attribute consideration by respondents in choice experiments under varying information load. His results suggest that

be considered CO_2 neutral if they are the product of an entirely natural process of growth. However, emissions emerge in the course of the process of fuel production. Therefore, we also allowed positive CO_2 emissions for non-fossil fuels. Respondents were informed about this context at the beginning of the experiment.

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

Table 3.1: Attributes and attribute levels in the choice experiment

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

[a] average of the lower and upper bounds for the next car indicated by the respondent
[b] only applied to non-fossil fuel types (i.e. biofuel, hydrogen, and electric)
[c] not applied to conventional fuel types (i.e. gasoline and diesel)

choice complexity is not necessarily increasing with the amount of information respondents are confronted with in choice tasks. According to Hensher, it is not strictly a question of quantity, but rather of relevancy.[12]

The 7×6 choice set design used in this survey is relatively demanding for respondents.[13] However, it is arguable that the number of considered cars and attributes in real-world car choices is even bigger. In order to test whether the experimental design is overly burdensome for respondents, a pretest was conducted. After each pretest interview, the respondent was asked to comment the choice experiment and to indicate any possible problems related to this. The feedback was very positive and confirmed the interviewer's impression that the respondents answered the choice tasks very carefully. It was thus concluded that the used design is appropriate for this study's purpose.[14]

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

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

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

3.2.2 Model specification

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

$$U_{njt} = \beta_n' x_{njt} + \varepsilon_{njt} \tag{3.1}$$

with attributes of the alternative and demographics of the person x_{njt}, a related vector of coefficients β_n, and iid extreme value random term ε_{njt}. Unlike in standard logit, here β_n is allowed to vary over individuals with a specified density f.[15] This specification represents random taste variation in the population.

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

$$P_{n\mathbf{i}} = \int \prod_{t=1}^{T} \frac{e^{\beta' x_{ni_t t}}}{\sum_{j=1}^{J} e^{\beta' x_{njt}}} \, f(\beta) \, \mathrm{d}\beta, \tag{3.2}$$

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

The independent variables that enter our model (and the way in which they enter) are briefly discussed in the following. We try to keep the model simple, focussing basically on the car attributes that specified the alternatives in the choice sets. The different propulsion technologies and fuel types are included by alternative-specific constants, where diesel serves as baseline alternative. Since different people might prefer different fuels, we assume normal distributions for the related coefficients. Engine power also enters with normally distributed coefficient,

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

while the coefficients of service station availability and CO_2 emissions are assumed to be log-normally distributed. Unlike normal distribution, the log-normal one induces the same coefficient sign for the whole population. It is possible that some people dislike too much horsepower.[16] It is, however, not explainable why people should dislike a denser service station network or fewer emissions. Therefore, we do not allow for both directions of preferences for these variables.[17] Fuel costs per 100 km enter our model with log-normally distributed coefficient. Since the negative impact of fuel costs is unambiguous, we thereby restrict the coefficient to be non-positive for all individuals.[18] Purchase Price (in €1000) is the only attribute we consider as fixed parameter. We follow Revelt and Train (1998, 2000) with this specification, since it simplifies the derivation of the distribution of the willingness to pay. As it may be expected that individuals who intend to buy a relatively cheap car are more price-sensitive, we include an additional interaction term between the purchase price and a dummy variable that identifies respondents who indicated an upper price bound (UPB) that is below the sample median of €20,000 (representing 46% of the sample).[19]

In order to capture demographic differences in assessing CO_2 emissions, we include additional fixed-effects interaction terms between dummies covering information about gender, age or educational level, and the CO_2 emissions variable. In respect of age we differentiate between individuals under 45 years[20] and those 45 and older, and in respect of educational level between individuals who possess (at least) a higher education entrance qualification (HEEQ)[21] and those who do

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

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

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

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

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

[21]With HEEQ the general qualification for university entrance is meant. In Germany, the so

not. Thus, men aged 45 years or older without an HEEQ are the reference group (representing 22% of the sample). Our hypotheses are that women, younger, and more educated individuals are more concerned about the environment and, therefore, evaluate the CO_2 emissions of a car more negatively.[22] Table 3.2 gives the distribution of the sample demographics.

3.3 Empirical results and discussion

3.3.1 Testing for fatigue, learning, and lexicographic choices

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

Furthermore, the choice data was checked for lexicographic choices. It was found that 103 of the 598 respondents (17%) have chosen lexicographically; thereof,

called "Abitur" certificate can be received after 12 or 13 years at school (compared to other secondary school certificates after 10 or less years at school) and allows holders to attend university.

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

Table 3.2: Sample demographics and fleet of cars

Survey question	Sample (N=598)	Population
Gender		
Male	74.6	69.0
Female	25.4	31.0
Age		
Until 29	20.7	17.7
30-39	21.1	19.9
40-49	20.2	28.2
50-59	17.7	19.4
60 and more	20.2	14.8
Education		
Secondary modern school degree	17.1	24.0
High school degree	31.1	33.2
University of applied sciences entrance qualification	8.0	9.5
Higher education entrance qualification, university or college degree	43.5	31.3
(Yet) without school degree or others	0.3	2.0
Household's monthly net income		
Until €1,000	3.3	
€1,000-2,000	18.4	
€2,000-4,000	37.1	
€4,000 and more	22.6	
Not stated	18.6	
Number of cars in the household		
0	2.7	
1	41.1	
2	41.0	
3 and more	15.2	

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

40% used fuel costs, 39% fuel availability, 8% engine power, 7% price, and 6% CO_2 emissions as "sorting attribute". If the fuel type is also considered as possible "sorting attribute", then a total of 175 respondents (29%) were found to have chosen lexicographically; most respondents who have chosen consistently the same fuel type picked gasoline (33%) or diesel (26%). Compared to the total shares of lexicographic choices reported by Sælensminde (2006), the percentage in this sample is rather at the lower bound. It should however be noted that Sælensminde analyzed data from a rather "simple" choice experiment, including only two trip alternatives which were described using three attributes. Therefore, there is no indication that respondents increasingly used lexicographic choices here due to increased choice complexity.[23] It should further be noted that, as in this paper's choice experiment there were seven alternatives to choose from, the overall best values of three-level attributes appeared mostly twice or even three times in each choice set. For example, the lowest level of fuel costs (i.e. €5/100 km) appeared twice in 67% and three times in the remaining 33% of all choice sets. Likewise, the highest level of network density (i.e. 100%) appeared twice in 62% and three times in 34% of all choice sets. It seems thus likely that many of the lexicographic choices observed in this study represent actual preferences. To sum up, considering choices from all observed respondents for model estimation seems appropriate.

3.3.2 Parameter estimates for standard and mixed logit

The estimation results are given in Table 3.3. The second column provides the estimates of the standard logit model which helped to identify relevant variables for the mixed logit model, whose estimates are provided in the last three columns.[24] In

[23]According to Sælensminde (2006), lexicographic choices, which do not represent lexicographic preferences, may basically arise for two reasons: (1) simplification, as the choice task is too difficult, or (2) a study design using widely differing choice alternatives or attribute levels. Depending on the "sorting attribute" used by a respondent and the reason for his/her lexicographic choices, WTP estimates may be lower or higher than the real one.

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

the following, we will primarily refer to the latter one, but also consider differences between both specifications.

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

We find that the fuel type of the passenger car is a relevant attribute. On average, diesel is preferred by car buyers.[25] As expected, denser service station networks and lower fuel costs per 100 km increase choice probabilities. Furthermore, approximately 74% of individuals in our sample prefer more horsepower.[26]

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

Most notably, we find that the emissions performance of a car influences choice decisions. The CO_2 variable enters our model significantly, negatively signed. This might reasonably be expected. According to a recent study commissioned by the German Federal Ministry for the Environment and the Federal Environment Agency (BMU, 2008), environmental awareness of Germans is high. In this study,

change introduced in the estimation process (Hole, 2007).

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

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

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

Table 3.3: The estimated standard and mixed logit models

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

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

91% of the population rate environmental protection as important. Moreover, 75% blame the car industry for contributing strongly to pollution by not developing environmentally friendly cars. However, this does not automatically mean that people are willing to act on their own account in this regard. Our results suggest that people's environmental and climate concerns indeed motivate them to consider CO_2 emissions as a relevant attribute in car choices.[28] But the influence of this attribute varies in the sampled population, as indicated by the associated standard deviation.

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

3.3.3 Willingness-to-pay estimates

The insights that can be directly drawn from parameters in a nonlinear model are very limited. A useful way to illustrate the influence of CO_2 emissions and the observed differences in price sensitivity is to derive the associated willingness to pay (WTP). That is, the amount an individual is willing to pay in addition to the baseline price p for a marginal decrease of the baseline emissions e, without

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

Table 3.4: WTP (in €) for an emission reduction of 1 g of CO_2 per km

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

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

a change in utility. This is simply the ratio β_e/β_p of the emission (β_e) and the price (β_p) coefficients. As the price coefficient is fixed, this ratio follows the same distribution as the negative emission coefficient. In our case this implies that the WTP is log-normally distributed. Table 3.4 gives for each demographic group the median and mean of the WTP distribution for a one gram decrease in CO_2 emissions per km separately for the two price segments. The related standard errors are calculated with the help of Stata's `nlcom` command.

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

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

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

First of all, it is striking how big the difference in the amount of WTP is, depending on the stated UPB. As the price coefficient is almost three times as large in the low UPB case, the associated WTP is roughly a third of the amount as in the high UPB case. This finding makes sense: individuals who contemplate a rather narrow price range for their next car (be it due to income constraints or any other reason), are obviously more likely to consider the purchase price as decisive attribute than individuals who intend to buy a relatively expensive car; therefore, their WTP for improvements in other car attributes is lower. The reference group, for instance, is on average willing to pay about €24 less if we look at the low instead of the high UPB case.

Furthermore, there are differences in the WTP estimates depending on the individual's gender, age, and educational level. In particular, we find younger individuals to have a significantly higher WTP (indicated by the asterisks in Table 3.4). The fact that a group consists of individuals aged under 45 years more than doubles or triples the median WTP, compared to the reference group. This holds for each price segment. Likewise, it seems that women are willing to pay more than men, and individuals with an HEEQ more than those without. However, the observed differences in WTP depending on gender and educational level are of weak statistical significance or insignificant.

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

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

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

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

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

[32] Findings of Viscusi and Zeckhauser (2006) are interesting in this regard. In 2004, they surveyed over 250 Harvard students, thus a group of relatively well-educated individuals. On average, the students estimate the climate-change-induced temperature increase in Boston consistently with the Intergovernmental Panel on Climate Change (IPCC) estimate. In their paper, Viscusi and Zeckhauser provide a rough calculation that converts the students' willingness to pay higher gasoline taxes to curb climate change into an amount of $1500 per year.

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

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

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

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

Besides, the used survey method may also influence the results. Since stated choices by respondents lack the monetary commitment, an overestimation of the true willingness to pay is possible. This phenomenon is referred to as hypothetical

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

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

3.4 Summary and conclusion

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

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

Chapter 4

Do Environmental Benefits Matter? Evidence from a Choice Experiment among House Owners in Germany

4.1 Introduction

In the course of efforts to address climate change and its negative impacts, the building sector has drawn the attention of policymakers. This sector is a major emitter of the greenhouse gas carbon dioxide (CO_2) due to the high energy demand for electricity and heating, mainly in OECD and non-OECD European countries (IEA, 2011). In Germany, for example, approximately 30% of the total energy produced is consumed in residential buildings. Together, space heating (74%) and water heating (11%) in residential buildings account for approximately one fourth of the end energy consumption (BMVBS, 2007).

Given the European Union Greenhouse Gas Emissions Trading System (EU ETS), decentralized heat generation is of particular relevance for future climate policy. Unlike electricity and district heating, emissions arising from decentralized heat generation are not covered by the EU ETS. Therefore, measures to save heat energy in residential buildings are likely to result in effective CO_2 abatement and not just in a shift of emissions. For example, buying a more energy-efficient heating system, shifting from a fossil-fueled to a non-fossil-fueled heating system, and improving the thermal insulation properties of exterior walls, roof, top ceiling, cellar ceiling or windows are reducing the CO_2 emissions of a building, *ceteris paribus*.

In Germany, regulations addressing thermal insulation of buildings have existed for more than five decades; it all started with the DIN 4108 standard in its formulation of 1952. Currently, the Energy Savings Ordinance (ESO/EnEV) and the Renewable Energies Heat Act (REHA/EEWärmeG) are in force. ESO basically regulates the annual primary energy requirement and energy efficiency for heating, warm water and ventilation systems, as well as the transmission loss of the building envelope (EnEV, 2007, 2009). It applies to new buildings being constructed and existing buildings being reconstructed, retrofitted, or refurbished, that are regularly heated or cooled. According to ESO, for example, oil- and gas-fired furnaces installed prior to October 1978 had to be removed by the end of 2008. Moreover, since January 2009, every owner who wants to sell or let his/her residential building has to make an energy pass available to prospective buyers and tenants. This energy pass contains information on the energy performance of the building and is intended to help interested parties to estimate the heating expenditure, before the sale or lease contract is concluded. ESO hereby follows the EU's Directive on the energy performance of buildings (European Commission, 2003), which has recently been recasted (European Commission, 2010c). Since 2009, new buildings being constructed have to partly cover their heat requirement by renewable energies, as prescribed by REHA (EEWärmeG, 2009). REHA thus aims to raise the share of renewables in Germany's heating energy consumption to 14% by 2020. If solely, for example, a solar thermal system is intended to be installed, at least 15% of the heating energy would have to be covered by this system. Heat pumps and wood-burning heating systems would have to provide at least half of the heating energy. Alternatively, house owners can comply with the required standards by using several renewable energy sources, local and district heating coming from cogeneration or waste heat recovery, as well as by overfulfilling the insulation standard defined by ESO, or a combination of these measures. In addition to these mandatory requirements, there exist several public funding programmes to promote house owners' investments in energy efficiency and renewable energies.

Besides technical improvements, household behavior is also relevant for residential energy use (e.g., Lindén et al., 2006; Poortinga et al., 2003). However, this paper focuses on technologies. Associated with high acquisition costs, the used heating equipment and the installed insulation system determine the energy use in buildings for years and even decades. Between 1989 and 2006 less than 30% of

Germany's old buildings (i.e. residential buildings which were completed between 1900 and 1979) had been energy-efficiently refurbished (BMVBS, 2007). Given an annual refurbishment rate of approximately 1 to 2%, there is still considerable energy-saving potential. In order to design cost-effective policies that make an impact on residential energy use and related CO_2 emissions, it is important to know house owners' preferences on heating and insulation technologies and to learn more about their decisions.

In this paper, we present the results of a choice experiment concerning energy retrofits for existing houses in Germany. The sample consists solely of owner-occupiers of single-family detached houses, semidetached houses and row houses.[1] In the experiment, participating house owners could either choose a modern heating system or an improved thermal insulation for their house. Unlike previous studies, we explicitly included both cost and environmental benefits of energy-saving measures. Based on the choice data, we estimate a standard and a mixed logit model. Moreover, we derive willingness-to-pay (WTP) estimates for CO_2 savings.

The remaining paper is structured as follows: Section 4.2 gives a brief overview of existing literature on preferences for energy-saving measures in residential buildings and WTP for climate policy. The data and the methods used are described in detail in Section 4.3. In Section 4.4 the results of our econometric analysis are presented and discussed. The final section summarizes and concludes.

4.2 Literature review

Unlike this paper, previous studies on preferences for energy-saving measures in residential buildings did not focus explicitly on environmental benefits of such measures (e.g., Banfi et al., 2008; Grösche and Vance, 2009; Kwak et al., 2010; Sadler, 2003). However, their results suggest that not only cost benefits play a role in household decisions, but also other criteria. Sadler (2003) conducted two choice experiments among more than 600 owners of single-family detached houses across Canada. One experiment concerned home renovations, the other heating systems. Her results show that respondents preferred energy-efficient renovations

[1]It should be noted that the considered house types comprise 60% of Germany's total living space and almost 50% of Germany's residential units (IWU, 2011).

compared to those without energy retrofits beyond included and observed cost and comfort attributes. Likewise, more efficient heating systems (e.g., high-efficiency gas furnaces and heat pumps) were preferred in the heating experiment. Interestingly, she further found differences in the implicit discount rate used for home renovations (21%) and heating systems (9%). Banfi et al. (2008) studied the WTP for energy-saving measures in Switzerland's residential buildings. They conducted a choice experiment among 163 apartment tenants and 142 house owners, who had recently moved. In the experiment, respondents could choose between their actual situation and a hypothetical alternative, which differed in the energy-efficiency levels of windows and façade, the presence of a ventilation system and the price (monthly rent for apartments, purchase price for houses). The obtained WTP estimates for the considered energy-saving measures were relatively high; they even exceeded related real-world capital costs, as shown by the authors. However, they include all kinds of benefits that potentially arise to respondents: cost-savings, increases in comfort, and environmental benefits. Kwak et al. (2010) recently conducted a similar study among 509 households from Korean metropolitan areas. They also found substantial WTP amounts for several heating energy-saving measures (i.e. increasing the number of window glasses and their variety, increasing the thickness of the façade, establishing a ventilation system). Grösche and Vance (2009) used revealed preference data from a German sample of 2530 single-family house owners and analyzed retrofit choices between 1995 and 2004. The surveyed retrofit measures were roof insulation, façade insulation, windows replacement, heating-equipment replacement, and their combinations. Based on engineering calculations of the respective energy savings, the authors estimated the WTP of households per kWh saved in the building's primary energy demand. By comparing the WTP estimates with the associated investment costs, they identified considerable incentives for free-ridership on public subsidization.

Further evidence for the potential importance of environmental motives in decisions can also be drawn from the abundant literature on other measures to lower household energy consumption, such as washing and shower habits or use of lighting equipment (e.g., Ek and Söderholm, 2010; Poortinga et al., 2003; Sardianou, 2007). Using a conjoint analysis, Poortinga et al. (2003) examined to what extent the strategy (technical improvements vs. behavioral changes), the domain (home vs. transport) and the amount (small vs. large) of energy savings influence preferences for related measures. 455 Dutch households indicated the acceptability of 23 different energy-saving measures on a 5-point Likert-scale. The measures considered ranged from “switching off lights in unused rooms” and “shorter showers” to “energy-efficient heating system” and “house insulation”. The results show that respondents particularly preferred technical improvements and home energy-saving measures, while the amount of energy savings played seemingly no role for the acceptability. Recently, Ek and Söderholm (2010) analyzed the stated willingness of 536 Swedish households to increase (behavioral) efforts to save electricity within the areas “laundry”, “lighting”, “heating” and “hot water”. Their findings suggest that environmental concern is an important motivating factor for households to lower electricity use.

In recent years, several studies have been conducted to obtain WTP measures for carbon abatements, carbon offsets, or climate change policy in general (e.g., Achtnicht, 2012; Berrens et al., 2004; Brouwer et al., 2008; Hersch and Viscusi, 2006; MacKerron et al., 2009; Solomon and Johnson, 2009; Viscusi and Zeckhauser, 2006). Using different stated preference methods and samples, the results of these studies are varying. Berrens et al. (2004) used higher energy and gasoline prices as payment mechanism in their contingent valuation (CV) study of U.S. households and found an annual mean WTP of approximately \$192 for GHG emissions reduction under the Kyoto Protocol.[2] Viscusi and Zeckhauser (2006) surveyed Harvard students and found a median WTP of \$0.50 per gallon of gasoline and 3% of income to avoid global warming. The authors provided a rough calculation that converts the students' willingness to pay to curb climate change into an amount of \$1500 and \$4500 per year, respectively. According to Hersch and Viscusi (2006) who used data from a 1999 Eurobarometer survey, Europeans aged 15–64 are on average willing to pay €0.023 more per liter of gasoline to protect the environment.[3] Also focusing on car fuel prices, Solomon and Johnson (2009) conducted a CV study in Michigan, Minnesota, and Wisconsin to obtain the WTP for biomass or “cellulosic” ethanol. The observed additional WTP per gallon was translated by the authors into a mean total WTP of \$556 per capita per year. Unlike the mentioned studies, Brouwer et al. (2008) and MacKerron et

[2]The reported \$192 were obtained by using their most conservative estimator. The annual mean WTP increased to \$816 if only households with a positive WTP were considered.

[3]The WTP amount rose to €0.115, conditional on having a positive WTP.

al. (2009) considered carbon offsets in an aviation context. Brouwer et al. (2008) surveyed more than 400 air travel passengers in their CV study and found an average WTP of approximately €25 per metric ton of CO_2 equivalent. In addition to a CV question, MacKerron et al. (2009) used a choice experiment among UK adults aged 18–34 with a higher education qualification. The obtained mean WTP was £24 per metric ton of CO_2 from the CV question and £12.47 from the choice experiment (for the offset itself, plus another £11.14 for the offset certification). Achtnicht (2012) used data from a Germany-wide conducted choice experiment concerning car choices and derived car buyers' median WTP per gram of CO_2 per kilometer. The reported values vary between €13 and €127, depending on age, sex, educational level, and intended purchase price. Johnson and Nemet (2010) provide a more comprehensive survey of existing estimates of WTP for climate policy. They found the estimates to range from $22 to $437 per household annually, with a median of $135 (in 2008 U.S. dollars). However, the authors also emphasize the difficulties of comparing existing estimates, because the surveyed studies vary in their elicitation method, policy object under valuation, payment mechanism, explanatory variables, type of WTP measure, as well as size and nature of the sample.

The contribution of this paper is twofold. First, the paper adds to the existing literature on preferences on energy-saving measures in residential buildings by quantifying the impact of associated environmental benefits in household decisions. For this purpose, we conducted a choice experiment in an energy-saving context and explicitly included CO_2 savings as an attribute. Unlike previous studies, we are thus able to model trade-offs between profitability and environmental factors. Second, by deriving German house owners' average WTP for saved CO_2 emissions, the paper contributes to the ongoing research efforts to elicit values for non-market (environmental) goods. Our results can be compared with other WTP measures, which were mostly gained in transportation contexts by also using stated preference approaches.

4.3 Data and methods

4.3.1 Choice experiment

In order to investigate preferences on energy-saving measures and its attributes we conducted a choice experiment among house owners in Germany. In particular, we were interested in the role that environmental benefits play compared to other benefits. Moreover, possible differences in valuing single attributes, depending on whether the given measure is a heating system or an insulation, were of particular interest to us. Though choice sets are hypothetical and choices are only stated, choice experiments are an appropriate method to study these issues. The researcher has full information about non-chosen alternatives, can vary attribute levels independently, is able to elicit WTP measures for non-market goods and, therefore, overcome possible drawbacks of revealed preference data (Louviere et al., 2000). Choice experiments have been employed in numerous and various empirical studies, some of which in an energy-saving context (e.g., Banfi et al., 2008; Kwak et al., 2010; Sadler, 2003).

In our choice experiment, interviewees were provided with two hypothetical measures of modernization regarding their heating supply or heating usage respectively, from which they could choose. Specifically, they could either choose a modern heating system or an improved thermal insulation for their house. We thereby did not specify the concrete energy source (i.e. gas, oil, coal, wood, other biomass, solar-, air-, water- or geothermal-heat) or the part of the house for the insulation measure (façade/exterior wall, roof, top ceiling, cellar ceiling or windows). We rather asked interviewees to imagine the respective technology they would like to have for their home.[4]

The alternatives to choose from were described by the following seven attributes: acquisition costs; annual energy-saving potential; payback period; CO_2 savings; opinion of an independent energy adviser; public and/or private funding; and period of guarantee.[5] Table 4.1 describes the attributes and the related levels

[4]In a recent paper, Michelsen and Madlener (2011) studied German homeowners' motivation to opt for a certain type of heating system, using a principal component analysis. They identified six underlying dimensions: cost aspects; general attitude towards the heating system; government grant; reactions to external threats; comfort considerations; influence of peers.

[5]As noted by a referee, path dependence may have a significant impact on real-world market directions and individual choices (e.g., Arthur, 1989; David, 1985). Given the purpose of the

Table 4.1: Used attributes and related levels

Attributes	Heating system	Insulation
Acquisition costs (including, if any, public and/or private funding)	€10,000 €20,000 €30,000	€10,000 €20,000 €30,000 €40,000
Annual energy-saving potential at current energy prices (including fuel and electricity costs related to heating)	25% 50% 75% of current value, in €	25% 50% 75% of current value, in €
Payback period (number of years after which the modernization measure will pay off)	10 years 20 years 30 years	10 years 20 years 30 years
CO_2 savings	0% 25% 50% 75% 100%	25% 50% 75%
Opinion of an independent energy adviser	recommendable *blank*	recommendable *blank*
Public and/or private funding	Yes No	Yes No
Period of guarantee	2 years 5 years 10 years	2 years 5 years 10 years

in greater detail. It should be noted that the acquisition costs, the energy-saving potential and the payback period (i.e. the number of years after which the energy-saving measure will pay off) could not be added up to another in our experiment. While the energy-saving potential was calculated with current energy prices only, the payback period should also include a supposed energy price development.[6] Interviewees were informed about this context by the interviewer at the beginning of the experiment.

It should further be noted that the attribute levels of energy-saving potential had been customized to avoid unrealistic values. Interviewees were asked beforehand to state their annual heating costs. Then, the customized levels of the

study and its rather static perspective, it is however appropriate to focus choices on a limited list of comparable attributes in the choice experiment. The final design of the experiment results from discussions with experts from the field held within two dedicated workshops in September 2008 and March 2009.

[6]As the attribute levels are varied independently during the experiment, the supposed energy price development is not the same for each case or presented alternative.

energy-saving attribute were equal to 25%, 50%, and 75% of the stated heating costs. If interviewees did not know or did not state their fuel bill, annual costs of €14 per square meter have been assumed.[7] This corresponds with an annual heating energy consumption of 200 kWh per square meter, at a price of €0.07 per kWh.[8]

Long payback periods are a crucial barrier for carrying out modernization measures, following evidence from recent surveys in Germany (BMVBS, 2007; Stieß et al., 2010). According to BMVBS (2007), only 3% of owners and tenants are willing to accept payback periods of 12 or more years. Likewise, Stieß et al. (2010) identify a period of 15 years as acceptance limit for most house owners. As pointed out by Jakob (2007), the payback period of energy-saving measures is highly uncertain and depends on various factors. In particular, the assumed interest rate and time horizon determine the capital costs related to such measures, while energy prices and their development determine the marginal costs of heat generation. We explicitly included the payback period in our choice experiment to take these issues into account, but removed the related uncertainty.

By including both energy-saving potential and CO_2 savings, interviewees had to evaluate trade-offs among cost savings and environmental benefits. Though somewhat hypothetical, we are therefore able to quantify the effect, if any, of environmental benefits on choices of energy-saving measures. Previous studies on energy-saving measures, however, had a slightly different focus and are lacking this feature. As Banfi et al. (2008) state, their WTP estimates "includes comfort benefits and cost savings as well as the respondents' potential valuation of environmental benefits".

In order to capture the impact of a professional's recommendation on choices, we included the opinion of an independent energy adviser as attribute. In Germany, various professionals have the right to provide on-site energy advice, in general, and energy passes, in particular, for existing buildings (EnEV, 2009). Architects, engineers and physicists, among others, with focus on energy-saving building during their study or relevant professional experience, as well as skilled craftsmen with further training on energy-saving building can be called energy ad-

[7] 15.6% of the final regression sample did not state their heating costs.

[8] Both values are reasonable assumptions for Germany, given the average heating energy consumption of single-family detached, semidetached and row houses (BMVBS, 2007) and the average prices for natural gas and domestic heating oil in 2008 (BMWi, 2012).

viser, though there is no such official job description. Independent energy advice, for example, is available from the consumer advice center and publicly sponsored by the Federal Ministry of Economics and Technology.

In Germany, there exist several public funding programmes to encourage investments in energy-saving measures. For example, the KfW bank (Reconstruction Loan Corporation) offers grants and credits at reduced rates of interest for refurbishment measures designed to reduce home energy consumption. Private companies conceivably give discounts on their products and services, too. In the experiment we used funding just as a qualitative attribute, and let the acquisition costs already include possible grants or subsidies. We therefore avoid obtaining two different price elasticities, but are still able to study the effect of funding on choices per se.

Guarantee in this context means that for the given period of time the builder or contractor is obligated to remedy deficiencies free of charge. In case no period of limitation has been contractually agreed, it is regulated by the German Construction Contract Procedures (GCCP/VOB) that, for example, contractors are liable for defects of heating and insulation systems for at least two years. If within that period of limitation any defect actually has to be remedied, then another two-year period starts for this product or service. Some builders and contractors are providing longer periods of guarantee, mostly coupled with maintenance contracts. In case of insolvency or bankruptcy, all contractor's rights and obligations, including guarantees, are undertaken by insolvency insurance, if the contractor is member of the Chamber of Crafts (which is mandatory in Germany).

Given two alternatives, each described by seven attributes, each of which has two to five levels, the total number of possible combinations was far too big to let interviewees face all of them. Therefore, an orthogonal fractional factorial design was employed, using Sawtooth software. In the end, each interviewee was presented with 12 choice sets and asked to state which of the displayed alternatives seems more attractive to him/her and choose it.[9] Hensher et al. (2001) and Carlsson and

[9] After each choice interviewees had made, we asked them whether they would actually carry out such a modernization measure in their home if it already existed on the market. If we considered these answers too, we would virtually include a status-quo or no-choice alternative. Since our focus is on house owners' preferences for attributes and possible differences between heating and insulation alternatives, rather than forecasts or market shares, we go without it in this analysis.

Martinsson (2008) provide empirical evidence that, for example, a number of 12 choice sets is reasonable and does not significantly affect the results. Likewise, the used 7×2 choice set design is not too demanding for interviewees; larger matrices have been employed in previous studies (e.g., Brownstone et al., 1996; Goett et al., 2000).

4.3.2 Survey and sample

The data used in this paper is a subsample of a larger survey among German households, carried out in June 2009. In order to guarantee the quality and the representativity of the sample we charged the market research company GfK Group with carrying out the survey. It was conducted in two stages. After recruiting individuals who match to the requested subsamples with telephone interviews, the first stage, individuals were visited at their homes for face-to-face interviews using the computer (CAPI method), in the second stage. The interviews took about 50 to 60 minutes on average. The questionnaire consisted basically of five parts and contained questions about attitudes towards the environment (part 1), the household's energy use (part 2), housing conditions (part 3), and socioeconomic and demographic information (part 5). The choice experiment itself defined part 4 and is the main difference between the three gathered subsamples, each of which included more than 400 interviews.[10]

As we were interested in individuals who really can make decisions on their heating supply and heating usage independently, only owner-occupiers of single-family detached houses, semidetached houses and row houses[11], who do not use district heating, answered our choice experiment. Since in some German municipalities the use of district heating is mandatory, we excluded possibly affected house owners from the beginning. Moreover, the individuals had been explicitly asked, during the telephone screening, whether they are involved in household's energy-related decisions, like the choice of electricity supplier or heating technology. Only those who affirmed their involvement were finally recruited and interviewed. During the interview at stage two, individuals were further asked to state who

[10] Besides the choice experiment described in Subsection 4.3.1, analyzed in this paper, two further choice experiments were conducted within this survey; one concerning TV sets and another concerning green electricity.

[11] In the following we will refer to them briefly as house owners.

predominantly makes energy-related decisions in their households. Approximately 51% stated “myself”, 36% “me and my partner together”, and 13% “my partner”. Though studying choices that are relevant to the household as a whole, the choice experiment was answered by individuals. Obtained WTP estimates are therefore individuals’ WTP which can differ from households’ WTP, as discussed in Munro (2009).

The final regression sample includes 379 house owners with 4548 observed choices. Table 4.2 gives details on the demographic profile and the types of houses of the sample.

4.3.3 Model specification and estimation

Data from choice experiments can be analyzed econometrically with discrete choice models. Logit is the most common representative of this class of models; it has been applied in numerous empirical works on energy-saving measures (e.g., Banfi et al., 2008; Kwak et al., 2010; Sadler, 2003), and constitutes the basic model in this analysis, too. However, in order to address some of the limitations that standard logit models exhibit, we also use a mixed logit specification in this paper (e.g., Brownstone and Train, 1999; Goett et al., 2000; Revelt and Train, 1998, are providing relevant applications of mixed logit models).

Standard logit and the more general and flexible mixed logit model can both be derived from utility-maximizing behavior (Train, 2003). Meeting the requirements of repeated choices in the survey, the utility U_{njt} that person $n \in \{1, \ldots, N\}$ obtains from alternative $j \in \{1, \ldots, J\}$ in choice situation $t \in \{1, \ldots, T\}$ is modeled as a random variable

$$U_{njt} = \beta_n' x_{njt} + \varepsilon_{njt} \tag{4.1}$$

with attributes of the alternative and demographics of the person x_{njt}, a related vector of coefficients β_n, and iid extreme value random term ε_{njt}. Unlike standard logit, β_n is allowed to vary over individuals with a specified density f in a mixed logit specification. This specification represents random taste variation in the population. Since repeated choices by a person n were all made within one interview, we assume β_n to be constant over time. We thereby allow for correlation over time in the unobserved portion of utility of the mixed logit model.

However, the flexibility of mixed logit comes at a price. Unlike standard logit,

Table 4.2: Summary of the sample's demographics and houses

Survey question	Percent
Demographics	
Gender	
Male	61.0
Female	39.0
Age	
24-35	5.3
36-45	22.4
46-55	27.7
56-65	23.0
66 and more	21.6
Education	
Without school degree	0.3
Secondary modern school degree	33.0
High school degree	40.6
Academic high school degree	11.6
University or college degree	14.5
Household's monthly net income	
Less than €1,000	4.5
€1,000-1,499	10.0
€1,500-1,999	15.0
€2,000-2,499	20.3
€2,500-3,499	18.5
€3,500 and more	14.8
Not stated	16.9
Children $\leq$ 18 in household	28.5
Region	
Western Germany	81.8
Eastern Germany	18.2
Number of inhabitants	
1-4,999	31.4
5,000-19,999	28.5
20,000-99,999	25.9
100,000-499,999	8.4
500,000 and more	5.8
Houses	
House type	
Single-family detached house	74.7
Semidetached house	13.7
Row house	11.6
Year of completion	
Before 1948	22.4
1949-1978	32.7
1979-1986	12.9
1987-1990	6.9
1991-2000	14.8
2001-2009	10.3

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

$$P_{n\mathbf{i}} = \int \prod_{t=1}^{T} \frac{\exp(\beta' x_{ni_t t})}{\sum_{j=1}^{J} \exp(\beta' x_{njt})} \; f(\beta) \; \mathrm{d}\beta, \tag{4.2}$$

cannot be solved analytically.[12] It rather has to be approximated using simulation methods (Train, 2003). We use Halton draws with 500 replications for the maximum simulated likelihood estimation with Stata's `mixlogit` command (see Hole, 2007).

At this point, some remarks on our underlying assumptions of rationality and utility-maximizing behavior are appropriate. Of course, there is a huge amount of literature that provides evidence for reasonable doubt on these neoclassical economic assumptions about human behavior in many situations. In order to develop more realistic models of decision making than rational choice theory, the field of behavioral economics is concerned with anomalies and the interplay of psychology, sociology and economics since decades (Kahneman, 2003). In particular, Simon's theory of bounded rationality (Simon, 1959) and Kahneman and Tversky's prospect theory (Kahneman and Tversky, 1979) are famous and well-established concepts. However, by designing the choice experiment accordingly, we address common criticisms regarding the assumptions of rational choice theory. First, in the experiment individuals have full and perfect information on costs and benefits of their choices as all relevant attributes are included deterministically. And second, by presenting only two alternatives described by seven attributes the choice tasks are cognitively not too demanding. Therefore, assuming rational utility-maximizing individuals seems to be appropriate with respect to this hypothetical choice situation. Nonetheless, it is still possible that some individuals use non-compensatory decision rules to choose from the choice set, which could affect welfare estimates (e.g., Araña and León, 2009).[13] It should however be noted that discrete choice models can also be consistent with other forms of choice behavior than utility maximization, as they can be interpreted as (mathematically identical) latent-variable models (Train, 2003; Long and Freese, 2006).

[12] In standard logit f is a degenerate distribution. The choice probability $P_{n\mathbf{i}}$ then simplifies to the product of logit formulas under the integral sign in Equation (4.2).

[13] In his recent paper, Hoyos (2010) reviews the main challenges associated with environmental valuation using choice experiments that remained unaddressed so far.

Table 4.3: Variable definitions

Variable name	Definition
Acquisition costs	Acquisition costs in €1000
Acquisition costs × East	Acquisition costs in €1000 if house owner lives in Eastern Germany (without Berlin); zero otherwise
Energy-saving potential	Energy-saving potential in €/year (at current energy prices)
Payback period	Payback period in years (considering hypothetical future energy prices)
CO_2 savings × Heating	CO_2 savings in % if alternative is heating system; zero otherwise
CO_2 savings × Insulation	CO_2 savings in % if alternative is insulation; zero otherwise
Energy adviser	1 for "recommendable"; zero otherwise
Funding	1 for "yes"; 0 for "no"
Guarantee period	Period of guarantee in years
Heating system	1 for heating systems; zero otherwise
Age<46 × Heating	1 if interviewee is 45 years of age or younger (and alternative is heating system); zero otherwise
Education × Heating	1 if interviewee possess a higher education entrance qualification (and alternative is heating system); zero otherwise
New heating × Heating	1 if interviewee's current heating system has been installed after the year 2000 (and alternative is heating system); zero otherwise
Wood-burning × Heating	1 if interviewee's current heating system is wood-burning (and alternative is heating system); zero otherwise
Price expectations × Heating	1 if interviewee expects the price for his used heating fuel to increase strongly (and alternative is heating system); zero otherwise
State of insulation × Heating	1 if interviewee states that there is no need to improve the state of insulation at any part of the building (and alternative is heating system); zero otherwise

The independent variables that enter our models are briefly discussed in the following. Further details may be found in Table 4.3. Basically, we include the seven attributes that specified the alternatives in the choice experiment. In addition, a constant for the heating system alternative is included to capture the average effect of all unobserved factors; the insulation alternative thus serves as reference. After controlling for alternative-specific effects (i.e., whether the impact of the attributes varies across alternatives), we let two CO_2-savings variables enter the models—one for each alternative.[14] We further tested various demographic, socioeconomic, and other case-specific variables with a standard logit model. Those with a seemingly robust and significant influence on choices are included finally. These variables are: a house owner's age, educational level, region (Eastern vs. Western Germany), expectations for future fuel prices, and perceptions regarding the current state of home insulation, as well as the age and the fuel type of the currently installed heating system. While regional aspects have effect on the price sensitivity, the remaining variables seem to influence the preferences on energy-saving technologies, and enter the model as interactions with the alternative-specific constant (ASC). In so doing, we try to account for preference heterogeneity that can be explained by observed factors.

In the mixed logit model the ASC is specified with random coefficient. We therefore allow house owners' tastes regarding the energy-saving technologies to vary in the population—beyond observed factors. As there is no logically predefined sign for the ASC, we assume a normal distribution for the related coefficient. By including additional fixed-effects interaction terms between the ASC and the case-specific variables listed above, we allow the mean of the population distribution to vary deterministically (Andersen et al., 2009). The two CO_2-savings variables enter the mixed logit with log-normally distributed coefficients. In this wise we meet the assumption that nobody's utility increases with higher CO_2 emissions.[15]

Although it may be expected that price sensitivity varies among individuals

[14]There was also some indication for an alternative-specific effect for the energy-saving potential attribute. Energy-saving potential seems to matter slightly more for heating systems. However, the variation was rather small, and since the corresponding mixed logit specification failed to converge we include just the generic energy-saving variable.

[15]Unlike normal distribution, the log-normal one induces a positive coefficient sign for the whole population.

(beyond just regional aspects), both costs variables are specified with fixed coefficients. We follow Revelt and Train (1998, 2000) with this specification, since it simplifies the derivation of the distribution of the WTP.[16] Likewise, all remaining variables enter the mixed logit with fixed coefficients. We tested different random parameter specifications, but the simulated log-likelihood was not improved notably. Some of the tested specifications even failed to converge. As our focus lies on model fit rather than forecast, we go without additional random parameters and keep the model simple.

4.4 Empirical results and discussion

The estimation results are presented in Table 4.4. At first, we discuss the standard logit model; its estimated parameters and standard errors are given in column 2. It should be noted that we apply all 12 observed choices per interviewee for model estimation. In order to control whether, for example, fatigue by interviewees could have significantly affected choices and therefore model coefficients, we further estimated the model separately for the first and the last six choices only. Using a likelihood-ratio test, we compared the restricted model (i.e. all 12 choices) with the separately estimated models. The null hypothesis of equal coefficients across the first and the last six choices cannot be rejected at any common significance level ($\chi^2(16) = 17.52$). Hence, applying all 12 choices is reasonable.

As expected, energy-saving potential, recommendation of an independent energy adviser, funding, and period of guarantee enter the model positively signed, while the estimated coefficients of acquisition costs and payback period are negatively signed. All those coefficients differ significantly from zero at the 1% significance level. We further find a significant difference in price sensitivity between Eastern and Western Germany. It seems that Eastern German house owners' choices are more affected by the costs attribute, indicated by the negatively signed coefficient. We expect that existing differences in the levels of income between both German regions are mainly causing this phenomenon. These differences may

[16] The assumptions made about the distribution of price or costs variables are crucial with respect to the WTP distribution. By using fixed coefficients, we neglect possible heterogeneity in price sensitivity, but make sure that the distribution of WTP has finite moments. In their very recent paper, Daly et al. (2011) provide an in-depth discussion on this issue and, moreover, identify a helpful criterion to determine whether WTP distributions have finite moments.

Table 4.4: The estimated standard and mixed logit models

	Standard logit	Mixed logit		
Variable	Mean	Mean	Median	SD
Acquisition costs	−0.0401***	−0.0568***		
	(0.00241)	(0.00310)		
Acquisition costs × East	−0.0257***	−0.0187***		
	(0.00552)	(0.00707)		
Energy-saving potential	0.000494***	0.000625***		
	(6.08e − 05)	(7.23e − 05)		
Payback period	−0.0186***	−0.0235***		
	(0.00233)	(0.00278)		
CO_2 savings × Heating	0.00668***	0.0114***	0.00500***	0.0232**
	(0.000743)	(0.00168)	(0.00120)	(0.00929)
CO_2 savings × Insulation	0.00213	0.0432	0.000543	3.432
	(0.00161)	(0.0287)	(0.000612)	(7.813)
Energy adviser	0.201***	0.268***		
	(0.0330)	(0.0394)		
Funding	0.153***	0.198***		
	(0.0330)	(0.0389)		
Guarantee period	0.0217***	0.0256***		
	(0.00578)	(0.00686)		
Heating system	−0.380***	−0.278*		0.841***
	(0.109)	(0.143)		(0.100)
New heating × Heating	−0.288***	−0.148		
	(0.0730)	(0.155)		
Age<46 × Heating	0.276***	0.203		
	(0.0750)	(0.150)		
Education × Heating	−0.251***	−0.306*		
	(0.0759)	(0.158)		
Wood-burning × Heating	−0.269***	−0.186		
	(0.104)	(0.221)		
Price expectations × Heating	0.197***	0.289**		
	(0.0683)	(0.142)		
State of insulation × Heating	0.580***	0.431***		
	(0.0805)	(0.164)		
Observed choices	4548		4548	
Persons	379		379	
Log likelihood	−2688.92		−2420.59	
Pseudo R2	0.147		0.232	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

actually be found in our sample. While 17% of surveyed Western Germans stated a household monthly net income of €3500 or more, only 4% of Eastern Germans did so.[17] Likewise, the percentage of low-income households (i.e., monthly net income below €1000) is bigger in the Eastern-German subsample (10%) than in the Western-German (4%). However, in preliminary analysis we used the income itself as explanatory variable and found no effects on price sensitivity. Since 17% of the sample did not make any statement about the household's monthly net income, we excluded it from further analysis.

As already mentioned in Subsection 4.3.3, we find the impact of CO_2 savings to vary across alternatives. Though positively signed for both alternatives, CO_2 savings only enter the utility of heating systems significantly. A Wald test rejects the hypothesis of equal coefficients ($\chi^2 = 6.44$). This finding is remarkable. Although both heating and insulation systems equally affect the energy efficiency and, hence, the CO_2 emissions of residential buildings, environmental benefits of related energy-saving measures are not considered equally by house owners. Perhaps house owners associate the negative environmental impacts of burning fuel for heating more directly and strongly with the heating system itself. However, a rational explanation for this behavior is missing so far.

Not surprisingly, we find that the current state of the building envelope and the used heating system have an effect on house owners' choices. If the used heating system was installed after the year 2000, or is wood-burning, choosing the heating alternative is less likely. This suggests that house owners who use a rather new heating, and/or a rather cheap fuel, are satisfied with their current heating equipment and thus see no need for action. Likewise, choosing the heating alternative is more likely if house owners expect the price for their used heating fuel to increase strongly, or if there is no need to improve the state of insulation at any part of the building, in their view.

In addition, we find age and education to influence house owners' preferences on energy-saving measures. Interviewees 45 years of age or younger, who could arguably be assumed to be less afraid of new technologies and state-of-the-art equipment, are more likely to choose the heating alternative. On the other hand,

[17] Within the survey interviewees were asked to state the household's monthly net income. Predefined ranges were: below €1000; between €1000 and €1499; between €1500 and €1999; between €2000 and €2499; between €2500 and €3499; and €3500 or more.

interviewees who possess a higher education entrance qualification (HEEQ) are more likely to choose the insulation alternative. The ASC itself enters the standard logit model significantly, and negatively signed. That is, factors that are not included in the model tend to increase the choice probability for the insulation alternative on average. Additional benefits of insulation, such as maintaining a cool home during summer and increasing noise protection, possibly lead to this result.

Now we turn to the mixed logit model, with normally and log-normally distributed coefficients for the ASC and the CO_2-savings variables, respectively. Columns 3–5 of Table 4.4 show the estimated parameters and standard errors.[18] The mixed logit specification improves the fit significantly compared to the standard logit model (likelihood-ratio test: $\chi^2(3) = 536.66$). Moreover, the significant standard deviation of the ASC coefficient indicates unobserved taste variation regarding heating systems in the population. However, the impact of case-specific variables which are included to capture observed preference heterogeneity regarding heating systems decreases. Though all coefficients have the same sign as in the standard logit, only education, price expectations and state of insulation enter the mixed logit significantly.[19]

The fixed coefficients of acquisition costs, energy-saving potential, payback period, energy adviser, funding, and guarantee period all keep their sign and significance level. Their increase in magnitude compared to the standard logit is expected and due to the different scale of utility (Brownstone and Train, 1999). Like in the standard logit, the impact of CO_2 savings varies across alternatives. Again, the estimates suggest that house owners consider CO_2 savings only in terms of heating systems as relevant attribute. Moreover, the mixed logit provides evidence for taste variation in the population, as the standard deviation of the heating related CO_2 coefficient enters significantly.

However, the insights that can be directly drawn from parameters in a nonlinear

[18] Note that Stata actually reports the estimated mean and standard deviation of the natural logarithm of log-normally distributed coefficients. The median, mean and standard deviation of the coefficient itself, as well as the related standard errors that are presented in Table 4.4 has been computed using Stata's `nlcom` command (see Hole, 2007).

[19] Note that the estimated parameters for the fixed-effects interaction terms between the ASC and the case-specific variables imply shifts in the mean of the population distribution of the ASC coefficient (Andersen et al., 2009).

Table 4.5: The estimated WTP measures for saved CO_2 (in €)

	Mean	Median	SD
WTP of Western Germans	200.3***	88.0***	409.2**
(based on acquisition costs)	(30.8)	(21.6)	(164.4)
WTP of Eastern Germans	150.6***	66.2***	307.8**
(based on acquisition costs)	(25.6)	(16.8)	(125.9)
WTP	18.2***	8.0***	37.1**
(based on energy-savings per year)	(3.4)	(2.1)	(15.5)

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

model are very limited. A useful way to quantify and interpret the impact of CO_2 savings, or any other attribute, is to look at the ratios of estimated parameters. If the denominator is the coefficient of a monetary variable, the ratio represents the marginal WTP.

Based on the mixed logit model, we derive the average WTP for an increase of one percentage point in CO_2 savings for the heating system alternative. As CO_2 savings do not significantly enter the utility function of the insulation alternative, no meaningful WTP could be obtained from that. Rows 1–4 of Table 4.5 present the WTP based on the acquisition costs, separated into Eastern[20] and Western German house owners, while the bottom two rows gives the WTP based on the energy-saving potential. As both monetary variables have fixed coefficients, the respective WTP follows the same distribution as the CO_2-savings coefficient (i.e. log-normal distribution; see Figures 4.1–4.3 for illustration). In the following discussion we will refer to the median WTP, which divides the cumulative distribution function in half.[21]

Western German house owners' average median WTP is €88. This means that for each percentage point a heating system saves on CO_2 emissions additionally, its acquisition costs could rise by approximately €88, without any change in utility and thus choice probability (given that all other attributes are unchanged). The

[20]Note that the sum of both costs coefficients gives the actual acquisition costs coefficient for Eastern German house owners.

[21]Note that in a (right-skewed) log-normal distribution the standard deviation has a significant positive effect on the mean. Since in our models the estimated standard deviations for the WTP measures are relatively high (indicating very heterogeneous preferences and resulting in a high skewness of distributions), the much less outlier-sensitive median seems to be the appropriate measure of central tendency here.

Figure 4.1: WTP of Western Germans based on acquisition costs

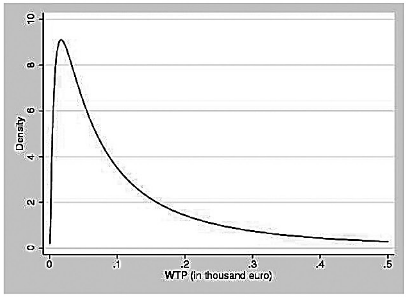


Figure 4.2: WTP of Eastern Germans based on acquisition costs

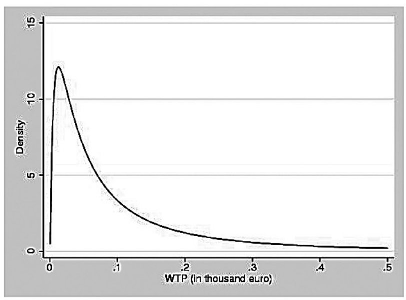
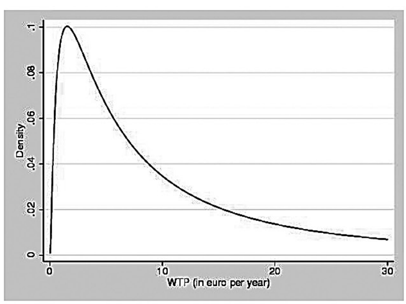


Figure 4.3: WTP based on energy-savings per year



median WTP of Eastern German house owners is smaller due to the larger costs coefficient. On average, they are willing to pay €66.2 for the same increase in CO_2 savings. Based on the energy-saving potential, the average median WTP can be translated into €8 per year. However, it is important to note that the given WTP measures are point estimates which are measured with uncertainty (e.g., Hensher and Greene, 2003). We also have to take into account the standard errors. For instance, the 95% confidence interval on the median WTP based on energy-savings ranges from €3.9 and €12.1 per year.

The obtained WTP measures are substantial. Of course, it is not straightforward to translate them into a WTP per metric ton of CO_2. Given the fact that we could not observe each household's heating energy consumption, we do not know what their total emissions actually are. The CO_2 emissions that arise from heating a residential building depend on various factors. Among others, the heating system and fuel, the state of insulation of the building envelope, the ratio of surface of a building to its volume, and the heated living area per member of household are crucial. Therefore, an approximation of each household's emissions is difficult and would require a specific analysis of each individual case. However, this goes beyond the scope of this paper and cannot be performed on the basis of the present data. Nonetheless, we may provide a rough calculation by assuming that an average house emits approximately 6.5 metric tons of CO_2 per year.[22] Based on this figure and assuming unchanged heating behavior,[23] the average median WTP based on energy-savings could be translated into a WTP of €123.1 per metric ton CO_2 (with 95% confidence interval between €59.3 to €186.6).

Our results are lying in between those of former studies. Nonetheless, WTP estimates obtained from stated preference methods have to be treated with some caution. Since stated choices by interviewees lack the monetary commitment, over-

[22]In Germany exist approximately 17.3 million residential buildings which directly accounted for 113 million metric tons of CO_2 in 2005 (BMVBS, 2007). It should be noted that those figures do also include blocks of flats, but not indirect emissions arising from the generation of electricity or district heating.

[23]As noted by a referee, in practice it is very difficult to assess ex-ante the actual energy and CO_2 savings associated with building refurbishments and retrofits. In particular, rebound effects could offset some of the predicted technological potentials (see, e.g., Sorrell and Dimitropoulos, 2008, for more on this issue). In this study, however, all values presented to interviewees are meant to apply *ceteris paribus*. Whether individuals took into account their potential behavioral changes or other related uncertainties when making choices was not observed.

estimating the true WTP is possible. This phenomenon is referred to as hypothetical bias. Murphy et al. (2005) conducted a meta-analysis to assess the magnitude of the hypothetical bias and reported the median ratio of hypothetical to actual value to be only 1.35, with choice-based methods being important in reducing hypothetical bias. In a choice experiment, however, the scaling of the price/cost vector may possibly have an impact on the estimated WTP. For instance, Carlsson and Martinsson (2008) found the marginal WTP to be consistently higher in an otherwise completely identical version of a choice experiment, with levels of the cost attribute being doubled. On the other hand, Hanley et al. (2005) also investigated the effects of changing price vectors in choice experiments and found no significant impact on estimates of WTP. By including two monetary attributes in our experiment, we are somewhat able to control whether those effects might be a serious issue in this study. The average WTP for saving one extra euro per year is €11.02 (€8.29 for Eastern German house owners), which seems to be reasonable values, given the long-term character of the considered energy-saving measures. This result rather suggests that hypothetical bias and the used scale of the cost vector do not affect the presented estimates.

4.5 Summary and conclusion

Residential buildings strongly contribute to global CO_2 emissions due to the high energy demand for electricity and heating, particularly in industrialized countries. Within the EU, decentralized heat generation is of particular relevance for future climate policy, as its emissions are not covered by the EU ETS. We conducted a choice experiment concerning energy retrofits for existing houses in Germany. In the experiment, the approximately 400 sampled house owners could either choose a modern heating system or an improved thermal insulation for their home. We used standard and mixed logit specifications to analyze the choice data. We found environmental benefits to have a significant impact on choices of heating systems. However, they played no role in terms of insulation choices. Based on the estimated mixed logit model, we further obtained WTP measures for CO_2 savings.

The (residential) building sector is already highly regulated in Germany, as discussed above. Nonetheless, it remains an open question whether the regulations in force are appropriate. The crucial criterion that those regulations should meet is cost efficiency (i.e. to achieve an aim at the lowest possible cost). Standards as prescribed by ESO and REHA are unlikely to meet cost efficiency, since standards usually ignore differences in individual marginal abatement costs (e.g., Kolstad, 2000). Considering people's preferences generally helps to design policy instruments that make good economic sense. In particular, it allows to value benefits of environmental and climate policy.

In the experimental situation studied here, we observed individual choice behavior that may improve the social welfare: house owners considered negative environmental externalities associated with their residential energy use, at least in terms of their heating system choices. Given this observation and the relatively high WTP for CO_2 savings, we can conclude that people are aware of their responsibility and willing to contribute to climate protection. Therefore, private households seem to be an appropriate and promising unit to address future climate and energy policy. However, there are a lot of uncertainties and intransparencies which hinder investments in energy-efficient technologies in the real world, but which were abstracted in the experiment. In reality, people do not know for sure how energy prices will develop in the long run, what the concrete energy and CO_2 savings of new technologies will be, when investments will pay off, or how long they will live in their current home. Further, getting informed about existing energy-saving measures may be associated with high costs of searching. The status-quo bias (e.g., Kahneman et al., 1991; Venkatachalam, 2008) may be an additional source of inertia in choosing energy-saving measures. As a consequence, under-investments are likely to occur. In general, in order to overcome existing market barriers, future policies should try to reduce consumers' uncertainties as far as possible, for example, by addressing the problems of information asymmetry and imperfect information (e.g., Howarth and Andersson, 1993).

Given the existing empirical evidence on WTP for climate policy and its varying results, it remains the task for future research to figure out what the determining influences are. Besides (expectable) varying preferences across different countries, the respective circumstances seem to play a crucial role. Apparently, it makes a difference whether people are asked for their willingness to pay higher prices for gasoline, airline tickets, or energy-efficient heating systems. Likewise, it may matter whether choice-related environmental impacts are presented as absolute or relative emissions or emission savings of CO_2. As a consequence, there is no unique carbon price. Similar framing effects have been found in other contexts (e.g., Tversky and Kahneman, 1981). Moreover, the specific elicitation method might be influential too. However, results of this study particularly suggest that CO_2 savings were affecting heating choices but not insulation choices—though using the very same elicitation method. Whether this is due to a lack of knowledge, psychological reasons, or just complex preferences on behalf of the surveyed people needs to be clarified in the future.

Chapter 5

Factors Influencing German House Owners' Preferences on Energy Retrofits

5.1 Introduction

Driven by the high energy demand for electricity, heating, and cooling, the building sector is a major consumer of fossil fuels and a major emitter of greenhouse gases (IEA, 2011). This holds particularly true for industrialized countries such as Germany, where, for example, almost one third of total energy supply is consumed in residential buildings, primarily for space and water heating. From a purely engineering perspective, the potential to reduce both Germany's fossil fuel use and greenhouse gas emissions by replacing old heating equipment and improving thermal insulation of the existing building stock is considerable. Between 1989 and 2006 less than 30% of all possible energy-efficient renovations were implemented in Germany's residential buildings built between 1900 and 1979 (BMVBS, 2007). And in spite of the increasing importance of renewable energy sources, almost every second residential heating system in Germany is fueled by natural gas, while approximately another three in ten use fuel oil (BMVBS, 2007). The German government seeks to exploit this potential in order to achieve its climate protection goals and to secure future energy supply. In addition to regulations that specify energy efficiency requirements for existing buildings being renovated or reconstructed, such as the Energy Savings Ordinance (EnEV), there are public funding programs in place that provide grants and low-interest loans for energy retrofitting activities. However, the political success in terms of raising the retrofit rate has been rather limited so far. This indicates that economic, technical, and behavioral factors influencing retrofit decisions are still not well understood and not properly addressed by current policy design.

In this paper, we analyze data from a 2009 survey of German house owners both descriptively and econometrically. The aim is to learn more about reasons and motivations that encourage house owners to carry out building energy retrofits as well as on barriers against such investments. The survey data include responses to a choice experiment involving energy retrofits for existing houses. We analyze them by using both standard and mixed logit regression of choice outcome on experimental attributes as well as individual and building characteristics. Based on the estimated mixed logit (error component) model, we simulate the incentive effects of different policy options, such as public subsidies for such measures and energy tax increases.

This paper, therefore, contributes to the existing literature on preferences on energy-saving measures in residential buildings. An early study by Cameron (1985) using individual household data from the U.S. focused on energy retrofits such as insulation and storm windows. Through simulations based on a fitted nested logit model, she found the demand for retrofits to be responsive to retrofit costs, relative energy prices, and income. More recently, some studies provided empirical evidence for Switzerland (Alberini et al., 2011; Banfi et al., 2008; Jakob, 2007, 2006). Jakob (2007) undertook a comprehensive analysis of drivers and barriers to retrofit decisions of single-family house owners using survey data. He found that energy-efficient renovations are driven to a large extent by technical (e.g., lifetime of façade or roof) and occasional factors (e.g., building or roof space extensions), rather than income, age, or education. Banfi et al. (2008) conducted a choice experiment with Swiss apartment tenants and house owners in order to study the willingness-to-pay (WTP) for energy-saving measures. In the experiment, respondents could choose between their actual situation and a hypothetical alternative differing in the level of insulation of windows and façade, the presence of a ventilation system, and the price (monthly rent for apartments, purchase price for houses). The obtained WTP estimates are relatively high, but do not differentiate between the various kinds of benefits of the considered energy-saving measures (i.e. cost savings, increases in comfort, and environmental benefits). However, in contrast to our study presented here, Banfi et al. (2008) did not include any socioeconomic variables in their final binary logit model, while the multinomial logit model used by Jakob (2007) lacks detailed information on the renovation alternatives themselves. The study that is most closely related to ours is that by Alberini et al. (2011), who surveyed Swiss owner-occupiers of single-family, semidetached, and row houses that had not been renovated since 1996. The choice sets used in their choice experiment contained two unlabeled energy retrofit alternatives and the status quo. They found those respondents who expect significant increases in oil prices and those who consider climate change as important reason for doing retrofits to be less likely to opt for the status-quo alternative. Socioeconomic variables, however, had no significant effect on respondents' choices.

Other studies concerning preferences for retrofit measures are available for Canada (Sadler, 2003), the Netherlands (Poortinga et al., 2003), South Korea (Kwak et al., 2010), and Sweden (Nair et al., 2010). And there are also a few German studies on this topic, mainly concerned with WTP (Achtnicht, 2011; Grösche and Vance, 2009). Using both standard and mixed logit specifications, Grösche and Vance (2009) analyzed revealed preference data from a sample of single-family house owners, and estimated the households' WTP per kWh saved. However, the costs and energy savings associated with the respective retrofit measure (i.e. roof insulation, façade insulation, windows replacement, heating equipment replacement, and combinations thereof) had not been directly observed, but rather had to be estimated by the authors. Therefore, engineering calculations as well as information on regional wages and material costs were employed. Achtnicht (2011) was the first to explicitly include environmental benefits of building energy retrofits in terms of CO_2 savings in a choice experiment study. Based on a fitted mixed logit model, he obtained considerable WTP estimates of German house owners for reducing CO_2 emissions. In this paper, we use data from the same survey, but focus on key drivers and barriers for the adoption of energy retrofits. Note that, in addition to the studies involving thermal insulation measures, there is also a related strand of literature that solely focuses on preferences on residential heating systems; see Michelsen and Madlener (2012) for an overview.

The remainder of the paper is structured as follows: Section 5.2 describes the survey data (5.2.1) and gives a brief theoretical background on the discrete choice models used for the analysis (5.2.2). The empirical results are presented in Section 5.3, with the findings from the descriptive statistical analysis discussed in Subsection 5.3.1, the parameter estimates in Subsection 5.3.2, and the simulation results in Subsection 5.3.3. The final Section 5.4 summarizes and concludes.

5.2 Data and methods

5.2.1 Survey design

The data set analyzed in this paper consists of survey responses of more than 400 owner-occupiers of single-family detached, semidetached, and row houses in Germany;[1] it represents a subsample of a representative survey of German households undertaken in June 2009. The survey was carried out by the market research company GfK in two stages: after recruiting individuals with telephone interviews, they were visited at their homes for computer-assisted face-to-face interviews (CAPI method). During the telephone screening, the individuals had been explicitly asked whether they are involved in the household's energy-related decisions, such as the choice of electricity supplier or heating technology. Only those who affirmed such an involvement were finally recruited and interviewed. A summary of the sample statistics is given in Table 5.1. The interviews took about fifty to sixty minutes on average, and made use of a structured questionnaire. This contained mostly closed questions about attitudes towards the environment, the household's energy use, housing conditions, and socioeconomic and demographic information.

The centerpiece of the questionnaire was a choice experiment involving building energy retrofits. Respondents could either choose a modern heating system or an improved thermal insulation for their house. Note that neither the concrete energy source for the heating measure nor the part of the house for the insulation measure were specified in the experiment. Instead, respondents were asked to imagine the technology option they would like to have for their home. A fractional factorial design was employed, using the Sawtooth software, so that respondents faced 12 choice sets, each containing two alternatives. Both alternatives were described by seven attributes: acquisition costs; annual energy-saving potential; payback period; CO_2 savings; opinion of an independent energy adviser; public

[1]In the following, we will refer to them briefly as house owners or respondents. Note that the considered house types account for 59% of the total residential living space and 48% of the residential units in Germany (IWU, 2011).

and/or private funding; and period of guarantee[2] (Table 5.2). The experiment was designed such that acquisition costs, energy-saving potential, and payback period could not be added up to another. While the energy-saving potential was customized and calculated with current energy prices only, the payback period also included a supposed energy price development.[3] For more details on the design of this choice experiment see Achtnicht (2011).

In the choice experiment, the basic task for respondents was to opt for their preferred energy retrofit measure. After each choice, the respondents were also asked whether they would actually carry out the chosen measure in their home or not. Importantly, unlike Achtnicht (2011), we consider these subsequent answers in our analysis, and thereby include a status-quo (or no-choice) alternative. This approach ensures better congruence with consumer theory and real-world choices (e.g., Hoyos, 2010; Hanley et al., 2001; Carson et al., 1994), and allows for calculating marginal effects of explanatory variables on the probability of undertaking energy retrofits.

5.2.2 Model specifications

To analyze the outcome of the choices econometrically, the use of discrete choice models is required. Such models owe their theoretical grounding in microeconomics especially to McFadden (1974) and his *random utility maximization* approach. In this framework, a utility U_{nj} provided by an alternative j to a person n is assumed to be

$$U_{nj} = V_{nj} + \varepsilon_{nj}, \tag{5.1}$$

where $V_{nj} = V(x_{nj})$ is a deterministic (observed) utility component, depending on attributes of the alternative and demographics of the person x_{nj}, and ε_{nj} is a (unobserved) stochastic component. According to the economic theory of utility-maximizing behavior, person n chooses that alternative from the alternative set $\{1, \ldots, J\}$ which provides him with the greatest utility. Since utility is modeled as

[2]Guarantee in this context means that for the given period of time the builder or contractor is obligated to remedy deficiencies free of charge. In the absence of a time limitation stipulated in the contractual agreement, it is regulated by the German Construction Contract Procedures (GCCP/VOB) that, for example, contractors are liable for defects of heating and insulation systems for at least two years.

[3]Respondents were informed about this context by the interviewer at the beginning of the experiment.

Table 5.1: Summary of sample statistics

Survey question	Percent (N=408)
Gender	
Male	60.8
Female	39.2
Age	
24–35	5.4
36–45	22.0
46–55	28.9
56–65	22.5
66 and more	21.2
Education	
No school degree	0.3
Secondary modern school degree (“Hauptschulabschluss”)	34.0
Intermediate school degree (“Realschulabschluss”)	39.2
Academic high or technical secondary school degree (“Abitur” or “Fachabitur”)	11.8
University or college degree	14.5
Not stated	0.3
Household’s monthly net income	
Less than €1,000	4.7
€1000–1499	10.3
€1500–1999	15.0
€2000–2499	19.4
€2500–3499	18.9
€3500 and more	15.0
Not stated	16.9
Children not older than 18 in household	28.9
Region	
Western Germany	82.6
Eastern Germany	17.4
Number of inhabitants	
1–4999	30.4
5000–19,999	26.7
20,000–99,999	27.5
100,000–499,999	8.8
500,000 and more	6.6
House type	
Single-family detached house	74.0
Semidetached house	14.2
Row house	11.8
Year of completion	
Before 1948	22.6
1949–1978	32.8
1979–1986	13.7
1987–1990	7.1
1991–2000	14.2
2001–2009	9.6

Table 5.2: Attributes and attribute levels in the choice experiment

Attribute	Measure	Levels
Acquisition costs (including, if any, public and/or private funding)	Heating system Insulation	€10,000, €20,000, €30,000 €10,000, €20,000, €30,000, €40,000
Annual energy-saving potential at current energy prices (including fuel and electricity costs related to heating)	Heating system Insulation	25%, 50%, 75% of reference[a] (in €) 25%, 50%, 75% of reference[a] (in €)
Payback period (number of years after which the measure will pay off)	Heating system Insulation	10 years, 20 years, 30 years 10 years, 20 years, 30 years
CO_2 savings	Heating system Insulation	0%, 25%, 50%, 75%, 100% 25%, 50%, 75%
Opinion of an independent energy adviser	Heating system Insulation	recommendable, *blank* recommendable, *blank*
Public and/or private funding	Heating system Insulation	Yes, No Yes, No
Period of guarantee	Heating system Insulation	2 years, 5 years, 10 years 2 years, 5 years, 10 years

[a] Current annual heating energy costs indicated by the respondent; if respondents did not know or did not state their fuel bill (15.6% of final regression sample), annual costs of €14 per square meter have been reasonably assumed.

a random variable, however, only choice probabilities can be estimated. Depending on the assumptions made about the distribution of the random variables ε_{nj} ($n = 1, \ldots, N; j = 1, \ldots, J$), different discrete choice models are defined.

In this paper, we use both a standard logit and a mixed logit model for the analysis. In standard logit models, the ε_{nj} are independent and identically distributed with type I extreme value distribution. As we further assume V to be linear in unknown parameters β, the probability that person n chooses alternative i then takes the following closed form (e.g., Train, 2003):

$$P_{ni} = \frac{\exp(\beta' x_{ni})}{\sum_{j=1}^{J} \exp(\beta' x_{nj})}. \tag{5.2}$$

Note that in our case there are three alternatives per choice set ($J = 3$): heating measure ($j = 1$), insulation measure ($j = 2$), and status quo or no measure ($j = 3$). The status quo is used as the base alternative; its deterministic utility V_{n3} is therefore normalized to zero. The standard logit model is fitted by maximum likelihood estimation using Stata's `asclogit` command.

In our mixed logit specification, we include an additional error component

$\mu_n d_j$, where μ_n is a normally distributed random term with zero mean, and d_j a dummy variable that identifies the two retrofit measures (i.e. $d_j = 1$ if $j < 3$; 0 otherwise). Thereby, we allow the heating and insulation alternative to be correlated in unobserved factors. This relaxes the IIA assumption of standard logit, and thus might represent a more realistic substitution pattern, in particular in the presence of the status-quo alternative (e.g., Hess and Rose, 2009; Campbell et al., 2008; Scarpa et al., 2005). Under these assumptions the choice probability can be written as the integral of standard logit probabilities over all values of μ, weighted by the density of μ (e.g., Brownstone and Train, 1999), i.e.

$$P_{ni} = \int \frac{\exp(\beta' x_{ni} + \mu d_i)}{\sum_{j=1}^{J} \exp(\beta' x_{nj} + \mu d_j)} \ \phi(\mu|0, \sigma) \ \mathrm{d}\mu, \tag{5.3}$$

where β and σ are the parameters to be estimated. As this integral cannot be solved analytically, it has to be approximated through simulation during the estimation process. We follow the suggestion by Hole (2007) and use Halton draws with 500 replications for the maximum simulated likelihood estimation using Stata's `mixlogit` command.

5.3 Results and discussion

5.3.1 Descriptive results

Before turning to the estimation results, let us first discuss drivers and barriers to energy retrofit measures, as they were identified by respondents in this survey. Respondents were provided with lists of possible reasons why they would or would not consider certain measures for their house, where multiple answers were allowed. The four most frequently stated drivers for investing in energy retrofits were high energy costs (65%), due renovations (46%), increases in comfort (37%), and environmental and climate protection (29%). On the other hand, the absence of need for heating system (65%) or building envelope renovations (62%), the lack of financial resources (59%), and uncertainty about the payback period (51%) constitute important barriers. When asked for their response to high heating energy costs, respondents indicated that they mainly reduce the room temperature (70%) or heating duration (69%). Investing in new heating equipment and improved

Table 5.3: General reasons for energy retrofit measures

Reason	Percent (N=408)
High energy costs	65.0
Renovation is due in any case	46.1
Increasing comfort in my home	37.3
Environmental and climate protection	28.7
Subsidies for such measures	27.5
Increasing my home's market value	25.7
Higher independence from energy or fuel supplier	25.0
Grant of low interest rate credits for such measures	20.3
Expected future legal requirements	16.7
Current legal requirements	14.2
Attraction of modern technology	7.4
Positive image of such measures	4.2
Other reasons	7.1
Not stated	4.7

thermal insulation is far less common. See Tables 5.3–5.5 for more details.

Overall, the descriptive results suggest that German house owners are willing to install a new heating system or building envelope insulation if the following requirements can be met: (1) one must be able to afford it financially; (2) it must be (perceived as) profitable in terms of energy cost savings and payback period; and (3) there must be a favorable opportunity, such as a heating system to be replaced or a building envelope due for renovation. Otherwise, (simple) behavioral changes in heat energy consumption remain the only response to increasing energy expenses. In order to gain a deeper understanding of what drives people to invest in building energy retrofits, we analyze the experimental choice data econometrically in the next section.

5.3.2 Parameter estimation results

By applying both a standard logit and a mixed logit model to the choice data, we identify further factors that influence house owners' decisions. In order to capture (observed) taste heterogeneity we control for a rich set of individual and building characteristics. The final variable specification was determined with the aid of a standard logit model. The estimation results are summarized in Table 5.6.[4] Note that interaction terms regarding different energy-saving measures have

[4]Although we use repeated choice observations per respondent, the reported standard errors of the standard logit model are not adjusted for clustering. This is due to the fact that the fully specified model did not converge when accounting for correlated observations, and might under-

Table 5.4: Personal barriers against certain energy retrofit measures

Barrier	Applies	Does not apply	Not stated
A renovation of the heating system is not necessary.	66.4	29.9	3.7
A renovation of the building envelope is not necessary.	61.5	35.3	3.2
I am/we are lacking the financial resources.	58.6	31.6	9.8
I am not sure whether such measures will pay off.	50.5	46.8	2.7
My/our house is already energy-optimized.	36.5	57.4	6.1
Adequate credits are not available.	35.3	48.0	16.7
The funding structure is too complex.	33.8	50.5	15.7
Such long-term investments will not pay off at my age.	30.6	67.2	2.2
I am not familiar with the new technology.	28.2	63.0	8.8
My/our house is lacking space to store certain fuels.	28.2	70.1	1.7
I am apprehensive of too much dirt and stress.	24.5	69.6	5.9
I am lacking the information.	22.3	71.3	6.4
I am not sure how much longer I will live in this house.	21.8	74.8	3.4
I am lacking the time.	21.6	71.1	7.4
My/our house is lacking space to install the equipment for certain heating systems.	18.1	78.4	3.4
I am apprehensive of losses of comfort due to newly required insulation standards (e.g. moldiness or restrictions for ventilating rooms).	13.0	80.4	6.6
My spouse/domestic partner opposes.	9.3	79.9	10.8
Structural or technical conditions are against a refurbishment (e.g. listed building).	8.3	87.8	3.9

All information in percent (N=408)

Table 5.5: Alternatives to reduce heating energy costs

Alternative	I already do/did that	I would consider that	That's out of the question	Not stated
Reduction of room temperature in several rooms / all over the house	69.6	16.7	13.2	0.5
Reduction of heating duration in several rooms / all over the house	68.6	20.1	10.8	0.5
Increased use of secondary heating system (e.g. fireplace)	32.6	31.1	31.4	4.9
Investment in improved thermal insulation	25.5	42.7	28.2	3.9
Acquisition of more efficient heating system	17.4	41.7	36.3	4.7
Switch to another energy or fuel supplier	15.9	44.6	34.1	5.4
Acquisition of heating system using a cheaper energy source	12.0	45.8	36.2	5.9

All information in percent (N=408)

to be interpreted with reference to the status quo, which is the base alternative and which was chosen in 61.6% of the cases (compared to 22.3% for heating and 16.1% for insulation).

Let us first discuss the estimated standard logit model and then comment on differences between this and the additionally estimated mixed logit model. The attributes used in the experiment all enter the choice model significantly with expected signs. We find that higher acquisition costs and longer payback periods have a negative effect on choice probabilities, whereas greater energy-saving potential, recommendations made by independent energy advisers, funding, and longer guarantee periods exert a positive influence. In terms of environmental benefits, we find that CO_2 savings enter the model significantly and positively signed for heating systems, but play no role when it comes to insulation (compared to the status quo). This is in line with Achtnicht (2011) who analyzed the same data set, but did not take into account the status-quo alternative. The alternative-specific constants (ASCs) for heating and insulation capture the average effect of all unobserved factors. Their positive signs indicate that non-included factors on average increase the retrofit measure's likelihood of being chosen.

We also find significant income effects on choices. Low-income households are less likely to invest in energy retrofits. Unfortunately, 17% of respondents did not answer the survey question on the household's monthly net income. In order not to lose too many observations, we identify those respondents with a dummy variable and let this interact with the ASCs. Those who did not state their income are also less likely to invest. This finding may suggest that low-income households in particular did not indicate their income, which is partly supported by responses to other closely related questions (e.g., in terms of employment) and by comparing the sample income shares with official income data from 2009.[5]

Eastern Germans (excluding citizens of Berlin) seem to be more price-sensitive than western Germans.[6] High acquisition costs thus constitute an even higher

state the standard errors. However, when including only generic variables (i.e. the attributes of the alternatives) in the model, analyses gave similar results in terms of statistical significance, both if adjusting for clustering and if using only one choice observation per respondent.

[5]Note, however, that only house owners were surveyed who are arguably older and richer than the representative sample on which the official income statistics are based.

[6]Interestingly, Brosig-Koch et al. (2011) recently found that twenty years after reunification there are still significant differences in social behavior between eastern and western Germans. In their solidarity experiment, eastern German students were willing to hand over smaller amounts

barrier for eastern Germans. Having controlled for price sensitivity and income, however, eastern Germans are more likely to change their status quo. This is indicated by the positive and significant interaction terms between the "East" dummy and the ASCs. This result is somewhat surprising, given that, at least in terms of apartment buildings, houses in the east (and the south) of Germany are more energy-efficient as their counterparts in the northwest.[7] On the other hand, taking all residential buildings together, the building stock in eastern Germany is on average older than that in western Germany (Destatis, 2008). Hence, it remains unclear whether this finding reflects some kind of backlog demand in terms of building retrofits or a general willingness to further invest in energy-efficiency improvements due to already experienced benefits.[8]

The respondent's age enters the model significantly. The older the house owner, the lower the likelihood of retrofit activities. We also control for both formal education and particular climate change knowledge. The literature provides evidence that not only formal education (specified by levels, degrees, or number of years), but also informal education can be influential when it comes to environment-related decisions (e.g., Torgler et al., 2009; Torgler and García-Valiñas, 2007; Carlsson and Johansson-Stenman, 2000; Danielson et al., 1995). In this study, we use the highest school degree obtained to measure a respondent's formal education, and identify those with an academic high school, technical secondary school, college, or university degree with a dummy variable. In order to determine a respondent's climate change knowledge we asked for the most important drivers of climate change. Thereby, respondents were provided with a list of six possible options, including the "don't know" option, and multiple answers were allowed.[9] The associated dummy variable takes the value 1 if both greenhouse gas emissions and rainforest deforestation, but not the ozone hole, were cited as reasons for climate change (24.3%).

of money to potential losers than other students.

[7]Results from the energy-efficiency index by ista/IWH, which is based on energy consumption data from almost three million apartments in 312,000 buildings, not including single-family, semidetached, and row houses (http://www.iwh-halle.de/projects/2010/ista/d/download.asp).

[8]Nair et al. (2010) provide some evidence for the Swedish case that house owners are more likely to invest in retrofit measures if they replaced a building envelope component in the recent past.

[9]The answering options were "changes in solar activity" (15.2%), "increased emissions of greenhouse gases" (77.0%), "deforestation of the rainforest" (71.3%), "the hole in the ozone layer" (58.6%), "other reason" (14.7%), and "don't know" (2.0%).

We find that better educated house owners and those with good knowledge about causes of climate change are more likely to select the insulation alternative. In terms of heating systems no statistically significant differences could be observed.

Besides these demographic and socioeconomic variables, we also include information on the building and its heating system in the model. The results match a priori expectations. Owners of houses that were built after 1990 (24%), or owners who saw no need to improve the thermal insulation (24%), are less likely to invest in energy retrofits. The retrofit of the heating system is even less likely if it is relatively new (33% installed it after the year 2000). If, however, the heating system is oil-fired (42.1%), then a heating retrofit becomes more attractive. This finding is arguably driven by the peak in the oil price in summer 2008, less than one year before the survey was conducted. In general, we find that fuel price expectations play an important role in investing in energy-saving measures. House owners who expect the price of their heating fuel to increase strongly in the next ten years (40.4%) are more willing to change the energy-related status quo of their homes.

Next, we turn to the estimated mixed logit model in order to see how it differs from the estimated standard logit model. First and foremost, we find the error component specification to perform better than the standard logit one; a likelihood-ratio test reveals that the model fit is improved significantly ($\chi^2(1) = 1716.79$). The relatively large increase in the log likelihood, however, is mainly due to the fact that here, unlike in the standard logit specification, we account for repeated choices per respondent. The error component itself enters the choice model significantly, indicating correlation in the unobserved portion of utility between the two retrofit measures. This leads to increased substitution between the heating and the insulation measure. This means that, for instance, improvements in the heating alternative would attract disproportionately more house owners who previously would have selected the insulation alternative than those who opted for the status quo. In terms of the observed variables, we obtain consistent results here, although the statistical significance of some individual-specific variables is reduced. In addition, it should be noted that the general increase in magnitude of estimated parameters compared to the standard logit model is expected due to the different scale of utility (Brownstone and Train, 1999).

Overall, the econometric results do support the descriptive findings and put them on a firmer basis. Evidently, house owners who are able to afford it financially (e.g., costs, income), for whom it is profitable (e.g., energy-saving potential, payback period, age), and for whom there is a favorable opportunity (e.g., house age, heating age) are more likely to undertake retrofit activities. In addition, we find that place of residence, education, and specific climate change knowledge also influence retrofit decisions in a significant manner.

5.3.3 Simulation results

The computation of (average) marginal effects is usually a convenient way to summarize regression results and to illustrate the policy relevance of variables. However, a common problem with data from choice experiments is that the observations are based on hypothetical alternatives rather than real-world choice sets. Averages of experimental attribute levels thus do not reflect any meaningful reference point. Nonetheless, it is interesting to see how a small change in a regressor affects the predicted choice probabilities. Therefore, we define a baseline scenario where we use specific values for the experimental attributes, but leave all other variables at their sample values. Starting from this, we compute the effect of a one-unit change in a regressor for each case, holding all other variables equal, and then average the individual effects. For dummy variables, we compute the effect of a discrete change from zero to one. To take account of the correlation in unobserved factors between both retrofit measures, and thereby relax the IIA property of the standard logit model, we use the mixed logit error component specification here. Table 5.7 presents the results of this simulation in detail.

In our baseline scenario, we consider a hypothetical situation in which both heating and insulation alternatives are equal in cost (€20,000), achieve the same energy-cost (50% of current heating costs)[10] and CO_2 savings (50%), and have the same payback (15 years) and guarantee periods (2 years). Also, we assume that neither funding from private or public sources nor expert recommendations from independent energy advisers are available. Based on the estimated mixed logit model, the status-quo alternative would have by far the highest probability of being chosen in such a situation (58.9%), followed by insulation (27.5%) and heating measures (13.6%). The result that, on average, insulation measures are preferred

[10]In the final regression sample, 50% of current annual heating costs are distributed as follows: Mean = 0.71; Standard Deviation = 0.32; Minimum = 0.10; Maximum = 2.00 (all values are reported in €1000/year).

Table 5.6: The estimated models

	Standard logit		Mixed logit	
	Estimate	Std. err.	Estimate	Std. err.
Variables				
Acquisition costs (in €1000)	−0.0540***	(0.0030)	−0.0696***	(0.0036)
Acquisition costs (in €1000) × East (dummy)	−0.0226***	(0.0075)	−0.0290***	(0.0091)
Energy-saving potential (in €1000/year)	0.4297***	(0.0638)	0.6501***	(0.0911)
Payback period (in years)	−0.0211***	(0.0033)	−0.0249***	(0.0037)
CO_2 savings (in %) × Heating (ASC)	0.0066***	(0.0009)	0.0091***	(0.0010)
CO_2 savings (in %) × Insulation (ASC)	−0.0006	(0.0021)	0.0001	(0.0024)
Energy adviser (dummy; 1 for "recommendable")	0.1926***	(0.0513)	0.2296***	(0.0555)
Funding (dummy; 1 for "yes")	0.2509***	(0.0515)	0.2972***	(0.0558)
Guarantee period (in years)	0.0251***	(0.0081)	0.0296***	(0.0091)
Heating system (ASC relative to status quo)	0.5658**	(0.2397)	1.5369*	(0.8934)
Insulation system (ASC relative to status quo)	0.5845**	(0.2854)	1.7286*	(0.9103)
East (dummy) × Heating (ASC)	0.7446***	(0.1676)	1.0789**	(0.4780)
East (dummy) × Insulation (ASC)	0.4875**	(0.2089)	0.7398	(0.5021)
Income below €2000 (dummy) × Heating (ASC)	−0.6169***	(0.0100)	−1.2890***	(0.4085)
Income below €2000 (dummy) × Insulation (ASC)	−0.5128***	(0.1079)	−1.1515***	(0.4105)
Income missing (dummy) × Heating (ASC)	−0.3141***	(0.1116)	−0.8270*	(0.4729)
Income missing (dummy) × Insulation (ASC)	−0.8179***	(0.1374)	−1.2829***	(0.4800)
Age (in years) × Heating (ASC)	−0.0209***	(0.0034)	−0.0410***	(0.0142)
Age (in years) × Insulation (ASC)	−0.0078**	(0.0038)	−0.0271*	(0.0143)
Education (dummy) × Heating (ASC)	−0.0102	(0.0912)	0.0627	(0.3872)
Education (dummy) × Insulation (ASC)	0.1890*	(0.1018)	0.2436	(0.3904)
Climate change knowledge (dummy) × Heating (ASC)	0.1083	(0.0911)	0.1835	(0.3844)
Climate change knowledge (dummy) × Insulation (ASC)	0.2917***	(0.1000)	0.5099	(0.3866)
House built after 1990 (dummy) × Heating (ASC)	−0.2335**	(0.0984)	−0.5461	(0.4235)
House built after 1990 (dummy) × Insulation (ASC)	−0.3620***	(0.1148)	−0.7731*	(0.4289)
State of insulation (dummy) × Heating (ASC)	−0.2007**	(0.0955)	−0.7685*	(0.4070)
State of insulation (dummy) × Insulation (ASC)	−0.9213***	(0.1217)	−1.5597***	(0.4155)
Heating installed after 2000 (dummy) × Heating (ASC)	−0.2253**	(0.0902)	−0.3781	(0.3699)
Heating installed after 2000 (dummy) × Insulation (ASC)	0.2821***	(0.0976)	0.2395	(0.3718)
Oil-fired heating (dummy) × Heating (ASC)	0.2372***	(0.0816)	0.3513	(0.3453)
Oil-fired heating (dummy) × Insulation (ASC)	−0.0427	(0.0924)	−0.0389	(0.3486)
Price expectations (dummy) × Heating (ASC)	0.3310***	(0.0793)	0.4944	(0.3387)
Price expectations (dummy) × Insulation (ASC)	0.1632*	(0.0901)	0.3705	(0.3420)
Error components				
Retrofit measure			2.8505***	(0.1717)
Persons	379		379	
Observed choices	4548		4548	
Log likelihood	−3768.1		−2909.8	
McFadden's Pseudo R^2	0.246		0.418	

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

compared to heating measures could be due to ancillary benefits of insulation, such as maintaining a cool home during summer and increased noise protection (see Jakob, 2006, for a discussion on the role of co-benefits of thermal insulation measures in retrofit decisions).

In the scenarios 1–5, we consider how outcome probabilities respond to one-unit improvements in selected attributes of both energy-saving measures. Although the status quo remains the dominant choice of house owners in each scenario, statistically significant changes can be observed. These changes can be interpreted as the incentive effects of different policy options, such as public subsidies and energy tax increases. It should be noted, however, that the magnitude of the effects depends on the point of evaluation as well as the scale of the variable of interest. Since the energy-saving potential is measured in €1000 per year, for example, we consider an increase of only 0.1 units (i.e. €100) in scenario 2. In scenario 1, we see that a €1000 reduction in acquisition costs raises the likelihood of energy retrofits by 0.8 percentage points compared to the baseline. But this, of course, predicts only the isolated, *ceteris paribus* effect of such a cost reduction. In reality, lower costs imply shorter payback periods that may also be the result of some sort of funding, which further make energy retrofits more likely (see scenarios 3 and 5). Similar considerations apply to higher energy-cost savings, which, taken by themselves, raise the likelihood of energy retrofits by 0.7 percentage points (scenario 2). Scenario 4 reveals the notable effect that the opinion of an independent energy adviser has upon a house owner's decision-making. Compared to the baseline scenario, the choice probability for the status-quo alternative decreases by 2.6 percentage points if we assume that both energy-saving measures are recommended by an expert.

5.4 Summary and conclusion

In this paper, we identified key drivers and barriers for the adoption of building energy retrofits in Germany, which is promoted by public policy as an important measure to address the future challenges of climate change and energy security. We analyzed data from a 2009 survey of more than 400 owner-occupiers of single-family detached, semidetached, and row houses in Germany, that was conducted as a computer-assisted personal interview (CAPI). In the survey, respondents were

Table 5.7: The simulated average choice probabilities and effects

Scenario	Definition	Heating	Insulation	Status quo
Baseline	Hypothetical values for heating and insulation attributes: costs = 20, energy savings = 50% of reference, payback period = 15, CO_2 savings = 50, energy adviser = 0, funding = 0, guarantee period = 2; sample values for all other variables	13.6	27.5	58.9
1	Same as baseline, but with costs − 1	+0.3	+0.6	−0.8
2	Same as baseline, but with energy savings + 0.1	+0.2	+0.5	−0.7
3	Same as baseline, but with payback period − 1	+0.1	+0.2	−0.3
4	Same as baseline, but with energy adviser = 1	+0.9	+1.7	−2.6
5	Same as baseline, but with funding = 1	+1.1	+2.2	−3.3

All estimates are statistically significant at the $p < 0.01$ level.

asked directly for reasons for and against retrofitting their homes, but also faced a choice experiment involving different energy retrofit measures. Overall, both the descriptive and econometric results show that house owners who are able to afford it financially, for whom it is (or who perceive it as) profitable in terms of energy cost savings and payback period, and for whom there is a favorable opportunity, such as a heating system that needs replacement or a building envelope that is due for renovation, are more likely to undertake energy retrofit activities.

The latter point seems to be of particular importance in order to explain the persistent low retrofit rate of around 1% in Germany. Our results suggest that most house owners wait until building components are approaching the end of their useful life, before considering options for renovation or replacement (Jakob, 2007, came to a similar conclusion for the Swiss case). Once such an opportunity occurs, they assess whether or not the additional costs for energy efficiency improvements are affordable and profitable. This behavior can be viewed as rational from the house owner's perspective.

Given this, the crucial question now is how to stimulate building energy retrofits, and thereby reduce the energy consumption and CO_2 emissions of existing buildings, in an effective and cost-efficient way. German regulations in force prescribe certain energy-efficiency standards for buildings being renovated or reconstructed. But standards usually fail to meet the cost-efficiency criteria (e.g., Kolstad, 2000; Hahn and Stavins, 1991), and lack a dynamic incentive for house owners to undertake (cost-efficient) measures beyond the existing energy efficiency standard.

We used the estimated model to simulate the incentive effects of other conceivable policy options. Public subsidies or other forms of financial support lower the costs of energy retrofits for individual house owners and thus make them more likely to be chosen. However, free-rider problems generally jeopardize the efficiency of funding measures (see Grösche and Vance, 2009, for some German evidence). On the other hand, an energy tax increase makes energy retrofits also more beneficial for house owners, but raises issues of distributional justice that must be addressed.

Professional energy advice seems to be a promising option in helping to achieve the aforementioned goals of effectiveness and cost efficiency. The incentive effect of expert recommendations that we found in our stated preference setting was notable in magnitude. Also, from a theoretical economic perspective, it is preferable to have decisions that are based on reliable and accurate information. Imperfect information and transaction costs constitute important barriers to investments in energy-efficient technologies in the real world (e.g., Howarth and Andersson, 1993), but were abstracted in the choice experiment analyzed here. Increased use of energy advisory services may help to alleviate the problem of imperfect information on the part of consumers. It seems, therefore, recommendable to support independent energy advice by public funding.[11,12] However, an important task for future research will be to confirm its effectiveness and to examine potential free rider issues using real-world field data.

[11]Such programs exist, for example, in the federal state of Baden-Wuerttemberg. There, the Ministry of Environment cooperates with different partners from the fields of crafts, architecture, and engineering within the project “EnergieSparCheck” in order to provide house owners with information on the energy requirement of their homes and potential energy-saving measures.

[12]Research on the role of energy audits in the residential household sector is still very rare. Anderson and Newell (2004) found a high responsiveness of U.S. manufacturers to government-sponsored energy audits in terms of energy-efficient technology adoption.

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Appendix A

Questionnaire of the Car Buyers Survey

Screeningfragen

Scr 1. Feststellung ob Gesprächspartner Einzelperson oder Paar/Gruppe

- ☐ Einzelperson
- ☐ Paar oder Gruppe

Scr 2. Leben Sie ...

- ☐ im selben Haushalt?
- ☐ in verschiedenen Haushalten?

Scr 3. Haben Sie selbst oder Ihr Haushalt die Absicht, in nächster Zeit ein neues oder gebrauchtes Auto zu kaufen?

- ☐ Ja
- ☐ Nein

Scr 4. Können Sie sich einen solchen Kauf im Laufe der nächsten Jahre grundsätzlich vorstellen?

- ☐ Ja
- ☐ Nein

Scr 5. Falls Paar/Gruppe aus dem selben Haushalt: Fragen, wer von den vor Ort anwesenden Personen (überwiegend) die Pkw-Kaufentscheidung trifft. Entscheider ist ...

- ☐ anwesend
- ☐ nicht anwesend

Interviewerhinweis: Bitte entscheiden Sie auf Basis der zu den Screeningfragen gegebenen Antworten, ob dieses Interview durchgeführt werden soll.

Aktuelle(r) Pkw und nächster Pkw-Kauf

1. Wie viele Pkw gibt es momentan in Ihrem Haushalt?

- ☐ Kein Pkw vorhanden — Programmierhinweis: Weiter mit Frage 6
- ☐ 1 Pkw
- ☐ 2 Pkw
- ☐ 3 Pkw
- ☐ 4 und mehr Pkw

1a. Bitte nennen Sie uns Marke und Modell dieses Pkws.

Programmierhinweis: Für jeden Pkw abfragen.

Marke ____________________ (z.B. VW, Opel etc.)
Modell/Typ ____________________ (z.B. Golf 4 1.6 / 323i / A6 2.7 etc.)

2. Haben Sie in Ihrem Haushalt in der Vergangenheit auch schon andere als die oben genannte(n) Marke(n) besessen?

- ☐ Ja
- ☐ Nein, immer dieselbe Marke
- ☐ Trifft nicht zu, da erstes Auto — Programmierhinweis: Weiter mit Frage 4

3. Hatten alle Ihre bisherigen Pkw im Haushalt die gleiche Antriebsart? (Ottomotor/Dieselmotor, etc.)

- ☐ Ja, Antriebsart war immer dieselbe
- ☐ Nein, unterschiedliche Antriebsarten
- ☐ weiß nicht

4. Handelt es sich bei Ihrem nächsten Fahrzeugkauf voraussichtlich um eine Ersatzanschaffung oder um ein zusätzliches Auto?

- ☐ Ersatz für ...
  Programmierhinweis: Alle in Frage 1a genannten Pkw einblenden
- ☐ Zusätzliches Fahrzeug — Programmierhinweis: Weiter mit Frage 6

5a. Ordnen Sie bitte Ihr aktuelles Fahrzeug (das möglicherweise ersetzt werden soll) in die entsprechende Größenklasse ein.

- □ Kleine Klasse (z.B. Toyota Yaris, VW Polo, Fiat Punto, Opel Corsa, Nissan Micra, Peugeot 207)
- □ Untere Mittelklasse (z.B. VW Golf, Opel Astra, Audi A3, Ford Focus, Kia Cee'd, Renault Mégane)
- □ Mittelklasse (z.B. Mercedes C-Klasse, Skoda Octavia, VW Passat, BMW 3er, Volvo V50, Audi A4)
- □ Obere Mittel-/Oberklasse (z.B. Audi A6/A8, BMW 5er/7er, Saab 9-5, Mercedes E-/S-Klasse)
- □ Van/Großraumlimousine (z.B. VW Touran/T5, Renault Scenic, Ford C-/S-Max, Citroen C8)
- □ Geländewagen (z.B. Toyota RAV4, Mercedes G/ML, BMW X3, Honda CR-V, Hyundai Santa Fe)
- □ Sportwagen/Coupé/Cabrio (z.B. Porsche 911, Mazda MX-5, Alfa Romeo Spider)

5b. Wer ist der Halter dieses Fahrzeugs?

- □ ich selbst
- □ andere Person, die in meinem Haushalt lebt
- □ andere Person, die nicht in meinem Haushalt lebt
- □ es ist ein Geschäfts-/Firmenwagen

5c. Als dieser Pkw seinerzeit angeschafft/gekauft wurde, handelte es sich um einen …

- □ Neuwagen / Wagen mit Tageszulassung
- □ Jahreswagen / Vorführwagen
- □ 1 – 3 Jahre alten Gebrauchtwagen
- □ 4 – 7 Jahre alten Gebrauchtwagen
- □ mehr als 7 Jahre alten Gebrauchtwagen

5d. Wie viel PS hat dieses Fahrzeug?

_____ PS

5e. Antriebsart:

- □ Benzin (Otto-/Wankelmotor)
- □ Diesel
- □ Sonstiges, und zwar ____________________

5f. Wie hoch ist bei Ihrem derzeitigen Pkw die Kfz-Steuer?

_____ Euro/Jahr
- ☐ weiß nicht
- ☐ keine Angabe

6a. Stellen Sie sich nun bitte eine mögliche Pkw-Kaufsituation vor. Denken Sie dabei bitte an das Fahrzeug, das Sie voraussichtlich als nächstes anschaffen werden. Größenklasse des nächsten Pkws:

- ☐ Kleine Klasse (z.B. Toyota Yaris, VW Polo, Fiat Punto, Opel Corsa, Nissan Micra, Peugeot 207)
- ☐ Untere Mittelklasse (z.B. VW Golf, Opel Astra, Audi A3, Ford Focus, Kia Cee'd, Renault Mégane)
- ☐ Mittelklasse (z.B. Mercedes C-Klasse, Skoda Octavia, VW Passat, BMW 3er, Volvo V50, Audi A4)
- ☐ Obere Mittel-/Oberklasse (z.B. Audi A6/A8, BMW 5er/7er, Saab 9-5, Mercedes E-/S-Klasse)
- ☐ Van/Großraumlimousine (z.B. VW Touran/T5, Renault Scenic, Ford C-/S-Max, Citroen C8)
- ☐ Geländewagen (z.B. Toyota RAV4, Mercedes G/ML, BMW X3, Honda CR-V, Hyundai Santa Fe)
- ☐ Sportwagen/Coupé/Cabrio (z.B. Porsche 911, Mazda MX-5, Alfa Romeo Spider)

6b. Art des nächsten Pkw-Kaufs:

- ☐ private Kaufentscheidung
- ☐ frei wählbarer Firmen-Pkw
- ☐ Sonstiges, und zwar ____________________

6c. Beim nächsten Pkw handelt es sich voraussichtlich um einen ...

- ☐ Neuwagen / Wagen mit Tageszulassung
- ☐ Jahreswagen / Vorführwagen
- ☐ 1 – 3 Jahre alten Gebrauchtwagen
- ☐ 4 – 7 Jahre alten Gebrauchtwagen
- ☐ mehr als 7 Jahre alten Gebrauchtwagen

6d. Die voraussichtliche Höhe des Kaufpreises liegt ...

zwischen __________ Euro und __________ Euro

6e. Die voraussichtliche Motorleistung des Fahrzeugs liegt ...

zwischen _____ PS und _____ PS

6f. Wie viele Kilometer werden voraussichtlich mit diesem Fahrzeug pro Jahr zurückgelegt?

durchschnittlich etwa __________ km pro Jahr

6g. Die Reichweite (gefahrene Kilometer pro Tankfüllung) des Fahrzeugs sollte mindestens sein ...

_____ km pro Tankfüllung

6h. Wie hoch dürfte bei Ihrem zukünftigen Pkw die Kfz-Steuer höchstens sein?

_____ Euro pro Jahr

Discrete Choice Experiment

7. Auf den folgenden 6 Seiten werden jeweils 7 verschiedene Pkw der von Ihnen gewählten Größenklasse gezeigt. Diese Autos unterscheiden sich hinsichtlich bestimmter Eigenschaften.

Sagen Sie uns bitte jeweils, welches der aufgelisteten Fahrzeuge Ihnen insgesamt so attraktiv erscheint, dass Sie es als Neu- oder Gebrauchtwagen kaufen würden.

Es kann im Einzelfall durchaus sein, dass es Fahrzeuge mit den angegebenen Eigenschaften momentan noch nicht oder inzwischen nicht mehr zu kaufen gibt. Das sollte Sie nicht stören; stellen Sie sich einfach vor, es gäbe solche Fahrzeuge.

Nehmen Sie bei Ihrer Wahlentscheidung bitte an, dass:

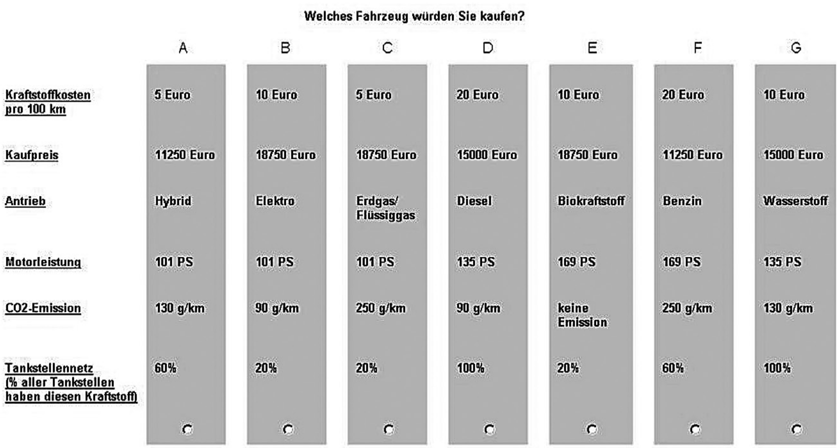
1. die angebotenen Pkw bezüglich nicht genannter Eigenschaften (z.B. Sicherheit, Zuverlässigkeit) gleich sind

2. Strom, Biokraftstoff oder Wasserstoff als Energiequellen für Pkw (derzeit noch) mit Energieträgern erzeugt werden, die CO_2 ausstoßen. Deshalb können auch bei diesen Alternativen CO_2-Emissionen aufgeführt sein, obwohl diese Fahrzeuge bei der Nutzung keine Emissionen verursachen.

Attribute	Ausprägungen
Antrieb	Benzin, Diesel, Hybrid, Erdgas/Flüssiggas, Biokraftstoff, Wasserstoff, Elektro
Kaufpreis	75, 100, 125% des Mittelwerts aus Frage 6d (in €)
Motorleistung	75, 100, 125% des Mittelwerts aus Frage 6e (in PS)
Kraftstoffkosten pro 100 km	5, 10, 20 €
CO_2-Emission	keine Emission[a], 90, 130, 170, 250 g/km
Tankstellennetz (% aller Tankstellen haben diesen Kraftstoff)	20[b], 60, 100%

[a] nur bei folgenden Antriebsarten erlaubt: Biokraftstoff, Wasserstoff und Elektro
[b] nicht erlaubt bei Benzin und Diesel

Figure A.1: Example choice set of the DCE concerning alternative-fuel vehicles



Welches Fahrzeug würden Sie kaufen?

	A	B	C	D	E	F	G
Kraftstoffkosten pro 100 km	5 Euro	10 Euro	5 Euro	20 Euro	10 Euro	20 Euro	10 Euro
Kaufpreis	11250 Euro	18750 Euro	18750 Euro	15000 Euro	18750 Euro	11250 Euro	15000 Euro
Antrieb	Hybrid	Elektro	Erdgas/ Flüssiggas	Diesel	Biokraftstoff	Benzin	Wasserstoff
Motorleistung	101 PS	101 PS	101 PS	135 PS	169 PS	169 PS	135 PS
CO2-Emission	130 g/km	90 g/km	250 g/km	90 g/km	keine Emission	250 g/km	130 g/km
Tankstellennetz (% aller Tankstellen haben diesen Kraftstoff)	60%	20%	20%	100%	20%	60%	100%

Kriterien beim Pkw-Kauf

8a. Wählen Sie bitte aus den im Folgenden genannten Kriterien diejenigen aus, die für Sie persönlich beim Pkw-Kauf maßgeblich sind.

Programmierhinweis: Kriterien randomisiert abfragen

- ☐ Marke
- ☐ Image
- ☐ Umweltfreundlichkeit
- ☐ Design
- ☐ Sicherheit

- ☐ Qualität / Zuverlässigkeit
- ☐ Platzangebot / Kofferraumgröße
- ☐ Serienausstattung
- ☐ Motorleistung / Höchstgeschwindigkeit / Beschleunigung
- ☐ Kaufpreis
- ☐ Verbrauch / Kraftstoffkosten pro 100 km
- ☐ CO_2-Emission
- ☐ Händlernetz / Service
- ☐ Wiederverkaufswert
- ☐ Unterhaltskosten (Versicherungen, Inspektionen, . . .)
- ☐ Sportlichkeit
- ☐ Komfort
- ☐ Kfz-Steuer
- ☐ Tankstellennetz / Tankstellendichte
- ☐ Antrieb

8b. Wählen Sie bitte aus den von Ihnen genannten Kriterien die 5 Wichtigsten aus. Programmierhinweis: Einblenden der in 8a ausgewählten Kriterien

8c. Bitte ordnen Sie nun die von Ihnen gewählten Kriterien gemäß ihrer Wichtigkeit für den Pkw-Kauf. Vergeben Sie hierfür bitte Ränge von 1 bis 5, wobei

- der Rang 1 das wichtigste Kriterium und

- der Rang 5 das am wenigsten wichtigste Kriterium bezeichnet.

Programmierhinweis: Einblenden der in 8b ausgewählten Kriterien

9. Welche Antriebs-/Kraftstoffarten bevorzugen Sie? Bitte sortieren Sie die nachfolgend genannten Antriebe hinsichtlich ihrer Wichtigkeit für Sie persönlich. Vergeben Sie hierfür bitte Ränge von 1 bis 7, wobei

- der Rang 1 den wichtigsten Antrieb und

- der Rang 7 den am wenigsten wichtigsten Antrieb bezeichnet.

Programmierhinweis: Antriebe randomisiert abfragen

- ☐ Benzin
- ☐ Diesel
- ☐ Hybridantrieb
- ☐ Erdgas / Flüssiggas
- ☐ Biokraftstoff
- ☐ Wasserstoff
- ☐ Elektroantrieb

Konsum- und Mobilitätsverhalten

10. Im Folgenden werden einige Tätigkeiten aufgelistet. Bitte geben Sie bei jeder Aktivität an, welches Verkehrsmittel Sie in der Regel dazu nutzen? (Mehrfachantworten möglich, aber maximal 3 Antworten je Zeile)

	zu Fuß	Fahrrad	Moped, Mofa/ Motorrad	Auto als Fahrer	Auto als Mitfahrer	Bus	Straßenbahn, S-Bahn/ U-Bahn	Eisenbahn	Flugzeug	Sonstiges
zur Arbeit/ Ausbildung/ Schule	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
für dienstliche / geschäftliche Erledigungen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
zum Einkaufen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
für private Erledigungen (Arzt, Bank, ...)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Holen/Bringen von Personen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
für Freizeitaktivitäten	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Urlaubsreise	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

11. Bitte beurteilen Sie jede der folgenden Aussagen und kreuzen Sie jeweils an, welche Antwort am ehesten für Sie zutrifft.

	Trifft nicht zu	Trifft teilweise zu	Trifft zu
Beim Einkaufen achte ich in der Regel darauf, ob die Produkte umweltverträglich sind.	☐	☐	☐
Ich würde höhere Strompreise in Kauf nehmen, wenn ich wüsste, dass zur Stromerzeugung alternative Energien eingesetzt werden.	☐	☐	☐
Für kurze Strecken nutze ich öfter das Fahrrad.	☐	☐	☐
Ein ÖPNV mit besseren Taktzeiten sowie höherem Komfort wäre für mich eine Alternative zum Verkehrsmittel Pkw.	☐	☐	☐

Allgemeine demographische Informationen

12. Abschließend benötigen wir noch einige Angaben zu Ihrer Person und zu Ihrem Haushalt, damit wir die Angaben für verschiedene Alters- und Personengruppen auswerten können.

In welchem Jahr sind Sie geboren?

19__

13. Bitte geben Sie Ihr Geschlecht an:

- ☐ männlich
- ☐ weiblich

14. Pkw-Führerscheinbesitz

- ☐ Ja, seit _____ (Jahr)
- ☐ Nein

15. Wie oft können Sie über ein Auto verfügen?

- ☐ jederzeit
- ☐ gelegentlich
- ☐ ausnahmsweise
- ☐ gar nicht

16. Welchen Bildungsabschluss haben Sie? Nennen Sie bitte den höchsten.

- ☐ (Noch) keinen
- ☐ Haupt- (Volks-)schulabschluss
- ☐ Realschulabschluss (Mittlere Reife)
- ☐ Abschluss der polytechnischen Oberschule
- ☐ Fachhochschulreife
- ☐ Abitur (Gymnasium oder EOS)
- ☐ Hochschulabschluss (Fach-/Hochschule, Universität)

17. Wie würden Sie Ihre berufliche Situation beschreiben? Sind Sie …

- ☐ Vollzeit-erwerbstätig (35h/Woche und mehr)
- ☐ Teilzeit-erwerbstätig (15 – 34h/Woche)
- ☐ Teilzeit- oder stundenweise erwerbstätig (unter 15h/Woche)
- ☐ zurzeit arbeitslos Programmierhinweis: Weiter mit Frage 19
- ☐ Auszubildende(r), Lehrling, Umschüler(in) Programmierhinweis: Weiter mit Frage 19
- ☐ Wehr-, Zivildienstleistender Programmierhinweis: Weiter mit Frage 19
- ☐ Schüler(in), Student(in) Programmierhinweis: Weiter mit Frage 19
- ☐ Hausfrau/-mann Programmierhinweis: Weiter mit Frage 19
- ☐ Rentner(in), Pensionär(in), im Vorruhestand Programmierhinweis: Weiter mit Frage 19

18. Was ist Ihre Stellung im Beruf? Sind Sie …

- ☐ Arbeiter(in)
- ☐ Angestellte(r) mit einfacher Tätigkeit (z.B. Verkäufer(in), Stenotypist(in))
- ☐ Angestellte(r) mit qualifizierter Tätigkeit (z.B. Sachbearbeiter(in), Buchhalter(in), technische(r) Zeichner(in))
- ☐ Angestellte(r) mit Leitungsfunktion (z.B. Direktor(in), Geschäftsführer(in), Vorstand größerer Betriebe und Verbände)
- ☐ Beamte(r)
- ☐ Landwirt(in)
- ☐ Andere(r) Selbstständige(r)
- ☐ Mithelfende(r) Familienangehörige(r)

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

_____

20. Wie viele Personen in Ihrem Haushalt haben einen Pkw- Führerschein?

_____

21. Wie viele Personen in Ihrem Haushalt sind <u>unter</u> 18 Jahren?

_____

22. Wie viele Einwohner hat die Gemeinde/Stadt, in der Sie wohnen?

- ☐ Unter 1.000 Einwohner
- ☐ 1.000 – 5.000 Einwohner
- ☐ 5.000 – 20.000 Einwohner
- ☐ 20.000 – 50.000 Einwohner
- ☐ 50.000 – 100.000 Einwohner
- ☐ Mehr als 100.000 Einwohner   Programmierhinweis: Weiter mit Frage 24

23. Liegt die Stadt/Gemeinde, in der Sie wohnen, im ländlichen Raum oder im Einzugsgebiet/Umland einer Großstadt?

- ☐ Ländlicher Raum
- ☐ Einzugsgebiet/Umland einer Großstadt

24. Bitte geben Sie Ihre Postleitzahl oder Ihren Wohnort an.

Postleitzahl _______ Wohnort ___________________

25. Wie hoch ist ungefähr das monatliche Nettoeinkommen Ihres Haushalts?

Alle Ihre Angaben werden streng vertraulich behandelt.

- ☐ Bis zu 1.000 Euro
- ☐ Zwischen 1.000 und 2.000 Euro
- ☐ Zwischen 2.000 und 4.000 Euro
- ☐ Über 4.000 Euro
- ☐ keine Angabe

Interviewerhinweis: Falls das ein Gruppeninterview war, bestimmen Sie bitte den Grad der Einflussnahme der Begleitpersonen auf die Antworten.

Appendix B

Questionnaire of the House Owners Survey

Screeningfragen

Scr 1. Sind Sie an Entscheidungen in Ihrem Haushalt über Angelegenheiten in Zusammenhang mit Energie (Strom, Gas/Öl, Heizung) bzw. Energieverbrauch (z.B. Energie verbrauchende Geräte) beteiligt?

- ☐ Ja
- ☐ Nein — Programmierhinweis: Ende des Interviews

Scr 2. Welche der beiden Aussagen trifft auf Ihren Haushalt hinsichtlich der Stromnutzung zu?

- ☐ Ich/wir erhalte(n) die Stromabrechnung direkt vom Energieversorger
- ☐ Ich/wir zahle(n) die Stromkosten über die Nebenkosten, d.h., an den Vermieter oder an die Hausverwaltung — Programmierhinweis: Ende des Interviews

Scr 3. Beziehen Sie Nah- oder Fernwärme?

- ☐ Ja — Programmierhinweis: Ende des Interviews
- ☐ Nein
- ☐ keine Angabe — Programmierhinweis: Ende des Interviews

Scr 4. Sind sie bereit, uns jetzt zu einem ca. 60-minütigen Gespräch zur Verfügung zu stehen? Alle Angaben, die Sie hier machen, unterliegen selbstverständlich dem Datenschutz und werden nie in Verbindung mit Ihrem Namen ausgewertet.

- ☐ Befragter bereit für Interview
- ☐ Späterer Zeitpunkt passt besser
- ☐ Interview verweigert — Programmierhinweis: Ende des Interviews

Scr 5. Arbeiten Sie selbst oder Angehörige Ihres Haushalts in einer der folgenden Berufsgruppen?

- ☐ Werbung — Programmierhinweis: Ende des Interviews
- ☐ Presse, Rundfunk, Fernsehen — Programmierhinweis: Ende des Interviews
- ☐ Energieversorgung — Programmierhinweis: Ende des Interviews
- ☐ Marktforschung — Programmierhinweis: Ende des Interviews
- ☐ Nichts davon, andere Berufsgruppe

Einleitende Fragen

R 2a. Was, glauben Sie, sind die zwei wichtigsten Probleme, dem sich unser Land heute gegenübersieht (zwei Nennungen möglich)?

Programmierhinweis: Statements randomisiert abfragen

- ☐ Arbeitsmarkt
- ☐ Familienpolitik
- ☐ Wirtschafts- und Finanzpolitik
- ☐ Umwelt- und Klimaschutz
- ☐ Rentenpolitik
- ☐ Innere Sicherheit (z.B. Terrorismus)
- ☐ Gesundheitspolitik
- ☐ Integration von Ausländern und Migranten
- ☐ Bildungspolitik
- ☐ Energiepolitik
- ☐ Sonstiges, bitte nennen ____________________
- ☐ keine Angabe

R 1a. Wer entscheidet in Ihrem Haushalt über Angelegenheiten in Zusammenhang mit Energie (Strom, Gas/Öl, Heizung) bzw. Energieverbrauch (z.B. Energie verbrauchende Geräte) <u>in erster Linie</u>?

- ☐ Das entscheide ich
- ☐ Das entscheidet mein Partner/meine Partnerin
- ☐ Das wird bei uns partnerschaftlich entschieden
- ☐ Bei uns läuft das ganz anders, nämlich ____________________
- ☐ keine Angabe

R 1b. Möchten Sie bei technischen Dingen im Allgemeinen genau Bescheid wissen, wie sie funktionieren, oder reicht es Ihnen, dass sie funktionieren?

- ☐ Ich möchte genau Bescheid wissen
- ☐ Hauptsache es funktioniert
- ☐ keine Angabe

Umwelteinstellungen und Umweltverhalten

R 2b. Was sind Ihrer Meinung nach die wichtigsten Ursachen für den Klimawandel? Mehrfachnennungen erlaubt. Interviewerhinweis: Wort Ursachen betonen

- ☐ Veränderte Sonnenaktivität
- ☐ Erhöhter Ausstoß von Treibhausgasen
- ☐ Abholzung der Regenwälder
- ☐ Ozonloch
- ☐ andere Ursache
- ☐ weiß nicht
- ☐ keine Angabe

R 2c. Bitte kreuzen Sie für jede der folgenden Aussagen an, ob Sie eher zustimmen, neutral sind oder eher nicht zustimmen.

	Stimme eher zu	Neutral	Stimme eher nicht zu	Keine Angabe
Für den Klimawandel ist vor allem der Mensch verantwortlich	☐	☐	☐	☐
Im Zuge des Klimawandels verschlechtert sich die Lebensqualität der Bevölkerung hierzulande	☐	☐	☐	☐
Der Klimawandel bedroht die Lebensgrundlagen der Menschheit	☐	☐	☐	☐
Es gibt keine ernsthaften negativen Folgen des Klimawandels	☐	☐	☐	☐

R 2d. Bitte kreuzen Sie für jede der folgenden Aussagen an, ob Sie eher zustimmen, neutral sind oder eher nicht zustimmen.

	Stimme eher zu	Neutral	Stimme eher nicht zu	Keine Angabe
Wir Bürger und Bürgerinnen können durch unser Kaufverhalten wesentlich zum Schutz der Umwelt beitragen	☐	☐	☐	☐
Ich bin bereit, etwas für den Schutz der Umwelt zu tun, solange ich keine Abstriche bei meinem Lebensstandard machen muss	☐	☐	☐	☐
Umweltschutz sollte durch verbindliche staatliche Regeln für alle gestaltet werden, z.B. Öko-Steuern und Verbote	☐	☐	☐	☐
Wissenschaft und Technik werden viele Umweltprobleme lösen, ohne dass wir unsere Lebensweise ändern müssen	☐	☐	☐	☐

R 2e. Auf der folgenden Liste haben wir verschiedene Aussagen zum Kauf von Produkten bereitgestellt. Bitte kreuzen Sie für jede dieser Aussagen an, ob Sie eher zustimmen oder eher nicht zustimmen.

	Stimme eher zu	Stimme eher nicht zu	Keine Angabe
Ich achte beim Kauf von Haushaltsgeräten auf einen niedrigen Energieverbrauch	☐	☐	☐
Ich achte darauf, dass Geräte und Produkte, die ich kaufe, möglichst langlebig sind	☐	☐	☐
Ich kaufe gezielt Produkte (z.B. Wein, Obst und Gemüse) aus meiner Region	☐	☐	☐
Ich kaufe gezielt Produkte, die bei ihrer Herstellung und Nutzung die Umwelt nur gering belasten	☐	☐	☐
Ich boykottiere Produkte von Firmen, die sich nachweislich Umwelt schädigend verhalten	☐	☐	☐
Ich bevorzuge Produkte aus fairem Handel	☐	☐	☐
Ich lasse häufiger das Auto stehen und fahre mit öffentlichen Verkehrmitteln oder mit dem Fahrrad	☐	☐	☐
Ich verzichte aus Umweltgründen auf Flugreisen	☐	☐	☐

R 2f. Wären Sie bereit, für Produkte des täglichen Bedarfs, die bei vergleichbarer Leistung nachweislich umwelt- bzw. klimaverträglicher sind als Konkurrenzprodukte, einen Aufpreis zu zahlen?

☐ Ja, ich würde einen Aufpreis akzeptieren
☐ Nein, ich würde keinen Aufpreis akzeptieren
☐ keine Angabe

R 2g. Für wie umweltbewusst halten Sie sich:

☐ Sehr umweltbewusst
☐ Umweltbewusst
☐ Wenig umweltbewusst
☐ Nicht umweltbewusst
☐ keine Angabe

Strom- und Wärmenutzung

R 4a. Wissen Sie, wie viele Kilowatt-Stunden (kWh) Strom Ihr Haushalt im vergangenen Jahr verbraucht hat?

ca. _____ kWh
☐ weiß ich nicht, kann ich keine Aussage dazu machen

R 4b. Wissen Sie, wie viele Cents Sie im vergangenen Jahr für 1 Kilowatt-Stunde Strom bezahlt haben?

ca. _____ Cents pro Kilowatt-Stunde

☐ weiß ich nicht, kann ich keine Aussage dazu machen

R 4c. Wie hoch waren Ihre Kosten des Strombezugs für den Gesamthaushalt im vergangenen Jahr?

_____ Euro
☐ weiß ich nicht, kann ich keine Aussage dazu machen

R 4d. Glauben Sie, dass Ihr Haushalt ... Strom konsumiert als ein Durchschnittshaushalt der gleichen Größe in Deutschland?

☐ viel mehr
☐ mehr
☐ gleich viel
☐ weniger
☐ viel weniger
☐ keine Angabe

R 4e. Wie schätzen Sie den Preis von Ökostrom gegenüber konventionellem Strom ein? (Glauben Sie, dass Ökostrom ... als konventioneller Strom ist?)

☐ viel teurer (mehr als 10%)
☐ etwas teurer (bis zu 10%)
☐ gleich teuer
☐ etwas billiger (bis zu 10%)
☐ viel billiger (mehr als 10%)
☐ keine Angabe

R 4f. Welche Preisentwicklung erwarten Sie für Strom in den nächsten 10 Jahren?

☐ Preis steigt stark an
☐ Preis steigt leicht an
☐ Preis bleibt in etwa auf dem aktuellen Niveau
☐ Preis sinkt leicht ab
☐ Preis sinkt stark ab
☐ weiß nicht
☐ keine Angabe

Wohnverhältnisse und Einstellung zur Energieeffizienz

R 5a. Wählen Sie bitte aus den im Folgenden genannten Kriterien diejenigen aus, die für Sie persönlich bei der Wahl einer Wohnung/eines Hauses maßgeblich sind.

- ☐ Lage, Infrastruktur
- ☐ Anzahl der Zimmer, Raumanordnung
- ☐ Größe der Wohnfläche
- ☐ Höhe der Kaltmiete / Kaufpreis
- ☐ Energieverbrauch / energetischer Zustand des Hauses
- ☐ Sicherheit des Wohnumfelds
- ☐ Klima- und Umweltfreundlichkeit
- ☐ Ausstattung der Wohnung / des Hauses
- ☐ Verhältnis zu den Nachbarn
- ☐ Freiflächen wie Balkon, Terrasse oder Garten
- ☐ Gesamteindruck des Hauses, Image
- ☐ Art der Wärmeversorgung/Energieversorgung
- ☐ Andere
- ☐ keine Angabe

R 5b. Wählen Sie bitte aus den von Ihnen genannten Kriterien die drei Wichtigsten aus.

Bitte beschreiben Sie im Folgenden Ihre aktuelle Wohnsituation.
R 5ca. Wie groß ist die Wohnfläche?

ca. _____ qm
- ☐ keine Angabe

R 5cb. Anzahl der Zimmer:

_____
- ☐ keine Angabe

R 5d. Wie groß ist Ihre beheizte Wohnfläche?

ca. _____ qm
- ☐ keine Angabe

R 5e. Wie groß ist die Anzahl der beheizten Zimmer:

______
- ☐ keine Angabe

R 5fa. Wohnen Sie . . . ?

- ☐ zur Miete, und zwar in einem/einer . . .
- ☐ in Eigentum, und zwar in einem/einer . . .

R 5fb. Wohnen Sie . . . ?
zur Miete, und zwar in einem/einer . . .

- ☐ Einfamilienhaus Programmierhinweis: Weiter mit Frage R 5h
- ☐ Doppelhaushälfte Programmierhinweis: Weiter mit Frage R 5h
- ☐ Reihenhaus Programmierhinweis: Weiter mit Frage R 5h
- ☐ Mehrfamilienhaus Programmierhinweis: Weiter mit Frage R 5h
- ☐ Hochhaus Programmierhinweis: Weiter mit Frage R 5h
- ☐ Sonstiges Programmierhinweis: Weiter mit Frage R 5h
- ☐ keine Angabe Programmierhinweis: Weiter mit Frage R 5h

R 5fc. Wohnen Sie . . . ?
in Eigentum, und zwar in einem/einer . . .

- ☐ Einfamilienhaus
- ☐ Doppelhaushälfte
- ☐ Reihenhaus
- ☐ Mehrfamilienhaus Programmierhinweis: Weiter mit Frage R 5h
- ☐ Hochhaus Programmierhinweis: Weiter mit Frage R 5h
- ☐ Sonstiges Programmierhinweis: Weiter mit Frage R 5h
- ☐ keine Angabe Programmierhinweis: Weiter mit Frage R 5h

R 5g. Wann wurde das Gebäude erbaut?

- ☐ vor 1948
- ☐ 1949 bis 1978
- ☐ 1979 bis 1986
- ☐ 1987 bis 1990
- ☐ 1991 bis 2000
- ☐ 2001 bis 2009
- ☐ keine Angabe

R 5h. Laut der Energieeinsparungsverordnung (EnEV) sind seit dem 1. Januar 2009 alle Hauseigentümer und Hauseigentümerinnen in Deutschland verpflichtet, bei Vermietung oder Verkauf ihres Gebäudes den so genannten Energieausweis vorzulegen. Dieser Energieausweis enthält Informationen über die Energieeffizienz eines Wohngebäudes. Er soll insbesondere Mietern und Käufern helfen, den Energieverbrauch eines Gebäudes vor einem möglichen Vertragsabschluss einzuschätzen.

Haben Sie von diesem Energieausweis für Gebäude bereits gehört?

- ☐ Ja
- ☐ Nein
- ☐ keine Angabe

R 5i. Was halten Sie von diesem Energieausweis?

- ☐ Ich halte ihn für sinnvoll. Ein Energieausweis erhöht die Transparenz für Mieter und Käufer.
- ☐ Ich halte ihn nicht für sinnvoll. Ein Energieausweis erhöht den bürokratischen Aufwand und somit die Kosten für Vermieter und Verkäufer.
- ☐ Mir ist dieser Energieausweis eigentlich egal.
- ☐ keine Angabe

R 5j. Planen Sie bzw. können Sie sich vorstellen innerhalb der nächsten 5 Jahre umzuziehen?

- ☐ Ja
- ☐ Nein — Programmierhinweis: Weiter mit Frage R 4g
- ☐ keine Angabe — Programmierhinweis: Weiter mit Frage R 4g

R 5k. Wie wird Ihr nächstes Wohnverhältnis vermutlich aussehen?

- ☐ Zur Miete in einer Wohnung
- ☐ Zur Miete in einem Haus
- ☐ Kauf einer Wohnung
- ☐ Kauf eines Hauses
- ☐ Bau eines Hauses — Programmierhinweis: Weiter mit Frage R 5n
- ☐ keine Angabe

R 5l. Werden Sie sich bei Ihrer nächsten Wohnungssuche/Haussuche den oben genannten Energieausweis vom Vermieter/Verkäufer zeigen lassen?

- ☐ Ja
- ☐ Nein
- ☐ weiß noch nicht
- ☐ keine Angabe

R 5m. Wären Sie bereit für eine Wohnung/ein Haus mit einer höheren Energieeffizienz (und damit niedrigeren Energiekosten) auch eine höhere monatliche Kaltmiete/einen höheren Kaufpreis zu zahlen?

- ☐ Ja, solange ich mir die Wohnung/das Haus noch leisten kann. Programmierhinweis: Weiter mit Frage R 4g
- ☐ Ja, aber nur solange die Warmmiete insgesamt nicht steigt / wenn die innerhalb der Nutzungsdauer des Hauses insgesamt gesparten Energiekosten auch die Kaufpreiserhöhung decken. Programmierhinweis: Weiter mit Frage R 4g
- ☐ Nein, eine Mieterhöhung/einen erhöhten Kaufpreis aufgrund einer verbesserten Energieeffizienz würde ich nicht akzeptieren. Programmierhinweis: Weiter mit Frage R 4g
- ☐ keine Angabe Programmierhinweis: Weiter mit Frage R 4g

R 5n. Werden Sie sich bei Ihrem Bauvorhaben von einem Energieberater beraten lassen?

- ☐ Ja, wahrscheinlich
- ☐ Nein, wahrscheinlich nicht
- ☐ weiß noch nicht
- ☐ keine Angabe

R 4g. Welche Art von Heizsystem nutzen Sie hauptsächlich zur Beheizung Ihrer Wohnung?

- ☐ konventionelle Zentralheizung, und zwar betrieben mit . . .
  ☐ Öl ☐ Gas ☐ Holz(pellet) ☐ Kohle
- ☐ Zentralheizung mit Niedertemperaturkessel, und zwar betrieben mit . . .
  ☐ Öl ☐ Gas
- ☐ Zentralheizung mit Brennwertkessel, und zwar betrieben mit . . .
  ☐ Öl ☐ Gas ☐ Holz(pellet)
- ☐ Wärmepumpen-Heizung, und zwar folgenden Typ . . .
  ☐ Erdwärme ☐ Wasser ☐ Luft
- ☐ Fernwärme/Nahwärme
- ☐ Elektroheizung, und zwar folgenden Typ . . .
  ☐ Direktheizung ☐ mit Teilzeitspeicher ☐ mit Vollzeit-/Pufferspeicher

- ☐ Einzelöfen, und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Holz(pellet) ☐ Kohle
- ☐ Mikro-Blockheizkraftwerk (Mikro-BHKW), und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Erneuerbare Energieträger (z.B. Rapsöl, Biodiesel)
- ☐ Keine Beheizung
- ☐ weiß nicht
- ☐ keine Angabe

R 4h. Wann wurde dieses Heizsystem eingebaut?

Programmierhinweis: Frage nur stellen wenn R 5fc = a,b oder c

_____

- ☐ keine Angabe

R 4i. Wie hoch sind die jährlichen Brennstoffkosten/Stromkosten bezogen auf dieses Heizsystem?

ca. _____ Euro/Jahr

- ☐ weiß nicht
- ☐ keine Angabe

R 4j. Welche Preisentwicklung erwarten Sie für den Energieträger dieses Heizsystems in den nächsten 10 Jahren?

- ☐ Preis steigt stark an
- ☐ Preis steigt leicht an
- ☐ Preis bleibt in etwa auf dem aktuellen Niveau
- ☐ Preis sinkt leicht ab
- ☐ Preis sinkt stark ab
- ☐ weiß nicht
- ☐ keine Angabe

R 4k. Welches weitere Heizsystem gibt es in Ihrer Wohnung?

- ☐ Elektroheizung
- ☐ Einzelofen, und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Holz(pellet) ☐ Kohle
- ☐ Solarthermische Anlage
- ☐ Keines — Programmierhinweis: Weiter mit Frage R 4m
- ☐ keine Angabe

R 4i. Wie hoch sind die jährlichen Brennstoffkosten/Stromkosten bezogen auf dieses Heizsystem?

ca. _____ Euro/Jahr
- ☐ weiß nicht
- ☐ keine Angabe

R 4m. Wie erfolgt bei Ihnen die Bereitstellung von Warmwasser?

- ☐ ausschließlich gekoppelt mit primärem Heizsystem
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)
- ☐ durch elektrische Warmwasserbereitstellung (Durchlauferhitzer, Boiler)
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)
- ☐ mithilfe einer solarthermischen Anlage
- ☐ weiß nicht
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)
- ☐ keine Angabe
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)

R 4n. Ist Ihre solarthermische Anlage mit ihrem Primären Heizsystem oder mit der Warmwasserbereitstellung gekoppelt?

- ☐ gekoppelt mit primärem Heizsystem
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)
- ☐ gekoppelt mit elektrischer Warmwasserbereitstellung
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)
- ☐ weiß nicht
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)
- ☐ keine Angabe
  Programmierhinweis: Weiter mit nächstem Block (Wärme, Strom oder TV)

Fragebogenblock Wärme

W 1. Welchen Energiestandard erfüllt Ihr Haus?

- ☐ Nullenergiehaus oder Plusenergiehaus
- ☐ Passivhaus
- ☐ Niedrigenergiehaus
- ☐ KfW-40
- ☐ KfW-60
- ☐ _____-Liter-Haus

☐ Keinen der genannten — Programmierhinweis: Weiter mit Frage W 3
☐ keine Angabe — Programmierhinweis: Weiter mit Frage W 3

W 2. Seit wann erfüllt Ihr Haus diesen Energiestandard?

Jahr _____ — Programmierhinweis: Weiter mit Frage W 17
☐ keine Angabe — Programmierhinweis: Weiter mit Frage W 17

W 3. Ist die Fassade Ihres Hauses wärmegedämmt?

☐ Ja
☐ Nein — Programmierhinweis: Weiter mit Frage W 6
☐ keine Angabe — Programmierhinweis: Weiter mit Frage W 6

W 4. Handelt es sich um eine Innen- oder Außendämmung?

☐ Innen
☐ Außen
☐ keine Angabe

W 5. Wann wurde die Dämm-Maßnahme durchgeführt?

Jahr _____
☐ keine Angabe

W 6. Ist das Dach Ihres Hauses wärmegedämmt?

☐ Ja
☐ Nein — Programmierhinweis: Weiter mit Frage W 8
☐ keine Angabe — Programmierhinweis: Weiter mit Frage W 8

W 7. Wann wurde die Dämm-Maßnahme durchgeführt?

Jahr _____
☐ keine Angabe

W 8. Ist die oberste Geschossdecke Ihres Hauses wärmegedämmt?

☐ Ja
☐ Nein — Programmierhinweis: Weiter mit Frage W 10

☐ keine Angabe Programmierhinweis: Weiter mit Frage W 10

W 9. Wann wurde die Dämm-Maßnahme durchgeführt?

Jahr _____
☐ keine Angabe

W 10. Nutzen Sie Ihr Dachgeschoss als Wohnraum?

☐ Ja
☐ Nein
☐ keine Angabe

W 11. Haben Sie Wärmeschutzverglasung?

☐ Ja
☐ Nein Programmierhinweis: Weiter mit Frage W 13
☐ keine Angabe Programmierhinweis: Weiter mit Frage W 13

W 12. Seit wann sind die derzeitigen Wärmeschutzfenster eingebaut?

Jahr _____ Programmierhinweis: Weiter mit Frage W 14
☐ keine Angabe

W 13. Wann wurden Ihre Fenster eingebaut?

Jahr _____
☐ keine Angabe

W 14. Haben Sie einen Keller?

☐ Ja
☐ Nein Programmierhinweis: Weiter mit Frage W 17
☐ keine Angabe Programmierhinweis: Weiter mit Frage W 17

W 15. Ist die Kellerdecke gedämmt?

☐ Ja
☐ Nein
☐ keine Angabe

W 16. Seit wann?

Jahr _____
☐ keine Angabe

W 17. In Zeiten hoher Energiepreise und knapper werdenden Ressourcen spielen die Themen Energieverbrauch, Energieeffizienz und erneuerbare Energien eine immer größere Rolle in der politischen und öffentlichen Diskussion. Als Hauseigentümer(in) haben auch Sie sich wahrscheinlich schon Gedanken zu Ihrem Energieverbrauch bzw. Ihren Energiekosten gemacht. Im privaten Haushaltsbereich fällt der Großteil der verbrauchten Energie für die Erzeugung von Raumwärme und die Bereitstellung von Warmwasser an. Möglichkeiten, Heizenergiekosten zu sparen, gibt es viele: Sie reichen von Verhaltensänderungen bis hin zu umfassenden energetischen Modernisierungsmaßnahmen wie die Verbesserung der Wärmedämmung oder die Erneuerung der Heizungsanlage. Wir möchten gerne von Ihnen wissen, wie Sie persönlich auf hohe Energiekosten reagieren würden bzw. in der Vergangenheit schon reagiert haben, und aus welchen Gründen für Sie energetische Modernisierungsmaßnahmen überhaupt in Frage kämen.

Welche Alternativen würden Sie generell in Betracht ziehen, wenn Sie Ihre Heizenergiekosten senken möchten?

	Mache ich schon / Habe ich schon gemacht	Würde ich in Betracht ziehen	Kommt für mich nicht in Frage	Keine Angabe
Reduktion der Raumtemperatur im Haus bzw. in einzelnen Zimmern	☐	☐	☐	☐
Reduktion der Heizdauer im Haus bzw. in einzelnen Zimmern	☐	☐	☐	☐
Wechsel des Energieträger- bzw. Brennstoff-Lieferanten	☐	☐	☐	☐
Vermehrte Nutzung eines sekundären Heizsystems (z.B. Kamin)	☐	☐	☐	☐
Investition in eine verbesserte Wärmedämmung	☐	☐	☐	☐
Anschaffung eines effizienteren Heizungssystems	☐	☐	☐	☐
Anschaffung eines Heizungssystems, das einen günstigeren Energieträger verwendet	☐	☐	☐	☐

W 18. Aus welchen Gründen kämen für Sie energetische Modernisierungsmaßnahmen an Ihrem Haus (d.h. eine Erneuerung der Heizung und/oder die Verbesserung der Wärmedämmung) überhaupt in Frage? Bitte beantworten Sie die Frage unabhängig davon, ob Sie eine Maßnahme konkret planen, diese in ferner Zukunft liegt oder ob Sie Maßnahmen bereits umgesetzt haben. (Mehrfachnennungen erlaubt)

- ☐ Hohe Energiekosten
- ☐ Sanierung sowieso fällig
- ☐ Finanzielle Subventionen für derartige Maßnahmen
- ☐ Gewährung günstiger Kredite für derartige Maßnahmen
- ☐ Größere Unabhängigkeit von Energielieferanten
- ☐ Schutz der Umwelt bzw. des Klimas
- ☐ Positives Image einer derartigen Maßnahme
- ☐ Reiz moderner Technologien
- ☐ Steigerung des Marktwerts meines Hauses
- ☐ Steigerung der Behaglichkeit im Haus
- ☐ Aktuelle gesetzliche Auflagen
- ☐ Künftig erwartete gesetzliche Auflagen
- ☐ Aus anderen Gründen
- ☐ keine Angabe

W 19. Welche persönlichen Barrieren sprechen für Sie im Moment gegen bestimmte energetische Modernisierungsmaßnahmen?

	Trifft zu	Trifft nicht zu	Keine Angabe
Mein/Unser Haus ist bereits energetisch optimiert	☐	☐	☐
Eine Sanierung der Gebäudehülle ist nicht notwendig	☐	☐	☐
Eine Sanierung der Heizungsanlage ist nicht notwendig	☐	☐	☐
Die finanziellen Möglichkeiten fehlen mir/uns	☐	☐	☐
Bauliche bzw. technische Gründe sprechen gegen eine Sanierung (z.B. Denkmalschutz)	☐	☐	☐
Ich befürchte zu viel Dreck und Stress	☐	☐	☐
Mir fehlen die Informationen	☐	☐	☐
Ich bin mit der neuen Technik nicht vertraut	☐	☐	☐
Mir fehlt die Zeit	☐	☐	☐
Langfristige Investitionen rechnen sich in meinem Alter nicht mehr	☐	☐	☐
Ich bin mir nicht sicher, ob sich die Maßnahmen wirklich rechnen	☐	☐	☐
Ich bin mir nicht sicher, wie lange ich noch in diesem Haus wohnen werde	☐	☐	☐
In meinem/unserem Haus ist für die Anlagentechnik bestimmter Heizsysteme nicht genügend Platz vorhanden	☐	☐	☐
In meinem/unserem Haus ist für die Lagerung bestimmter Brennstoffe nicht genügend Platz vorhanden	☐	☐	☐
Die Förderstrukturen sind zu komplex	☐	☐	☐
Es sind keine zufriedenstellenden Kredite verfügbar	☐	☐	☐
Mein Partner ist dagegen	☐	☐	☐
Ich befürchte Komfortverluste durch neue Dämmstandards (z.B. Schimmelbildung oder Einschränkungen beim Lüften)	☐	☐	☐

W DCE. Im Folgenden werden Ihnen jeweils zwei hypothetische Modernisierungsmaßnahmen zur Auswahl gestellt, die Ihre Wärmeversorgung bzw. Wärmenutzung verändern. Ganz konkret haben Sie die Wahl zwischen einer moderneren Heizungsanlage und einer besseren Wärmedämmung. Dabei wird weder der konkrete Energieträger der Heizung (also Gas, Öl, Kohle, Holz, sonstige Biomasse, Solar-, Luft-, Wasser- oder Erdwärme) noch der Gebäudeteil der Dämmmaßnahme (also Fassade/Außenwand, Dach, oberste Geschossdecke, Kellerdecke oder Fenster) genauer spezifiziert. Das überlassen wir Ihnen: Stellen Sie sich bitte einfach die jeweilige Alternative/Technologie vor, die Sie sich für Ihr Haus wünschen würden.

Sagen Sie uns bitte jeweils, welche der gezeigten Alternativen Ihnen attraktiver erscheint und wählen Sie diese aus. Im Anschluss an jede Wahl werden Sie gefragt, ob Sie die gewählte Modernisierungsmaßnahme – wenn es sie denn gäbe – auch in der Realität an ihrem Haus durchführen würden oder nicht.

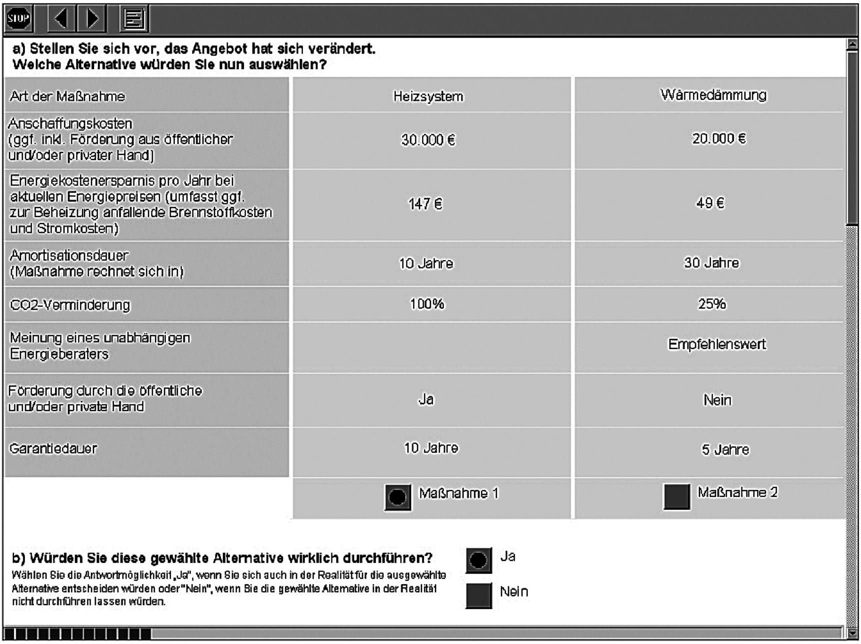
Interviewerhinweis: Die folgende ergänzende Erklärung wird vorgelesen, während der Proband den ersten Conjoint-Screen bereits sieht.

Die zur Auswahl gestellten Alternativen werden durch sieben Eigenschaften beschrieben. Unter diesen Eigenschaften befinden sich u.a. die Anschaffungskosten, die Energiekostenersparnis und die Amortisationsdauer (d.h. die Anzahl der Jahre nachdem sich eine Modernisierungsmaßnahme rechnet). Bitte beachten Sie, dass sich diese drei Eigenschaften nicht miteinander verrechnen lassen! Während die Energiekostenersparnis sich auf aktuelle Energiepreise bezieht, berücksichtigt die Amortisationsdauer darüber hinaus wahrscheinliche Energiepreisentwicklungen.

Es kann im Einzelfall durchaus sein, dass es Heizungen oder Dämmungen mit den angegebenen Eigenschaften momentan noch nicht gibt. Das sollte Sie nicht stören; stellen Sie sich einfach vor, es gäbe sie.

Attribute	Maßnahmen	Ausprägungen
Anschaffungskosten (ggf. inkl. Förderung aus öffentlicher und/oder privater Hand)	Heizsystem Wärmedämmung	10.000, 20.000, 30.000 € 10.000, 20.000, 30.000, 40.000 €
Energiekostenersparnis pro Jahr bei aktuellen Energiepreisen (umfasst ggf. zur Beheizung anfallende Brennstoff- und Stromkosten)	Heizsystem Wärmedämmung	25, 50, 75% des akt. Werts (in €) 25, 50, 75% des akt. Werts (in €)
Amortisationsdauer (Maßnahme rechnet sich in)	Heizsystem Wärmedämmung	10, 20, 30 Jahre 10, 20, 30 Jahre
CO_2-Verminderung	Heizsystem Wärmedämmung	0, 25, 50, 75, 100% 25, 50, 75%
Meinung eines unabhängigen Energieberaters	Heizsystem Wärmedämmung	Empfehlenswert, *blank* Empfehlenswert, *blank*
Förderung durch die öffentliche und/oder private Hand	Heizsystem Wärmedämmung	Ja, Nein Ja, Nein
Garantiedauer	Heizsystem Wärmedämmung	2, 5, 10 Jahre 2, 5, 10 Jahre

Figure B.1: Example choice set of the DCE concerning building energy retrofits



a) Stellen Sie sich vor, das Angebot hat sich verändert.
Welche Alternative würden Sie nun auswählen?

Art der Maßnahme	Heizsystem	Wärmedämmung
Anschaffungskosten (ggf. inkl. Förderung aus öffentlicher und/oder privater Hand)	30.000 €	20.000 €
Energiekostenersparnis pro Jahr bei aktuellen Energiepreisen (umfasst ggf. zur Beheizung anfallende Brennstoffkosten und Stromkosten)	147 €	49 €
Amortisationsdauer (Maßnahme rechnet sich in)	10 Jahre	30 Jahre
CO2-Verminderung	100%	25%
Meinung eines unabhängigen Energieberaters		Empfehlenswert
Förderung durch die öffentliche und/oder private Hand	Ja	Nein
Garantiedauer	10 Jahre	5 Jahre
	Maßnahme 1	Maßnahme 2

b) Würden Sie diese gewählte Alternative wirklich durchführen?
Wählen Sie die Antwortmöglichkeit „Ja", wenn Sie sich auch in der Realität für die ausgewählte Alternative entscheiden würden oder "Nein", wenn Sie die gewählte Alternative in der Realität nicht durchführen lassen würden.

Ja
Nein

W 20. Bei welchem Teil Ihres Hauses würden Sie den aktuellen Dämmzustand am ehesten verbessern wollen?

- ☐ Gebäudefassade — Programmierhinweis: Weiter mit Frage W 22
- ☐ Dach — Programmierhinweis: Weiter mit Frage W 22
- ☐ Oberste Geschossdecke — Programmierhinweis: Weiter mit Frage W 22
- ☐ Fenster und Haustür — Programmierhinweis: Weiter mit Frage W 22
- ☐ Kellerdecke — Programmierhinweis: Weiter mit Frage W 22
- ☐ Bei keinem
- ☐ keine Angabe — Programmierhinweis: Weiter mit Frage W 22

W 21. Bei welchem Teil Ihres Hauses wird zukünftig am ehesten eine Sanierung fällig sein?

- ☐ Gebäudefassade
- ☐ Dach

- ☐ Oberste Geschossdecke
- ☐ Fenster und Haustür
- ☐ Kellerdecke
- ☐ keine Angabe

W 22. Wenn Sie Ihr bestehendes Heizsystem in der Zukunft sanieren müssten, oder aber modernisieren bzw. ergänzen wollen, für welche Alternative würden Sie sich entscheiden?

Interviewerhinweis: Mehrfachnennungen möglich, wenn Systeme kombinierbar

- ☐ konventionelle Zentralheizung, und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Holz(pellet) ☐ Kohle ☐ egal
- ☐ Zentralheizung mit Niedertemperaturkessel, und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ egal
- ☐ Zentralheizung mit Brennwertkessel, und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Holz(pellet) ☐ egal
- ☐ Wärmepumpen-Heizung, und zwar folgenden Typ ...
  - ☐ Erdwärme ☐ Wasser ☐ Luft ☐ egal
- ☐ Fernwärme/Nahwärme
- ☐ Elektroheizung, und zwar folgenden Typ ...
  - ☐ Direktheizung ☐ mit Teilzeitspeicher ☐ mit Vollzeit-/Pufferspeicher ☐ egal
- ☐ Einzelöfen, und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Holz(pellet) ☐ Kohle ☐ egal
- ☐ Mikro-Blockheizkraftwerk (Mikro-BHKW), und zwar betrieben mit ...
  - ☐ Öl ☐ Gas ☐ Erneuerbare Energieträger (z.B. Rapsöl, Biodiesel) ☐ egal
- ☐ Solarthermische Anlage
- ☐ weiß nicht
- ☐ keine Angabe

W 23. Welche Attribute verbinden Sie mit den folgenden Energieträgern? Bitte kreuzen Sie Zutreffendes an.

	Öl	Gas	Kohle	Biomasse (z.B. Holz)	Solar	Erd-, Luft-, oder Wasserwärme	keine Angabe
sauber	☐	☐	☐	☐	☐	☐	☐
klima- bzw. umweltfreundlich	☐	☐	☐	☐	☐	☐	☐
zukunftssicher	☐	☐	☐	☐	☐	☐	☐
knapp	☐	☐	☐	☐	☐	☐	☐
teuer	☐	☐	☐	☐	☐	☐	☐
preisstabil	☐	☐	☐	☐	☐	☐	☐
gemütlich, behaglich	☐	☐	☐	☐	☐	☐	☐
zuverlässig	☐	☐	☐	☐	☐	☐	☐

Allgemeine demographische Informationen

Abschließend benötigen wir noch einige Angaben zu Ihrer Person und zu Ihrem Haushalt, damit wir die Angaben für verschiedene Alters- und Personengruppen auswerten können.

R 6k. Wie viele Personen leben in Ihrem Haushalt, sie selbst eingeschlossen?

_____ Personen
- ☐ keine Angabe

R 6l. Wie viele Personen in Ihrem Haushalt sind ...

... unter 6 Jahre? _____
... 6 bis 14 Jahre? _____
... 15 bis 18 Jahre? _____
- ☐ keine Angabe

R 6a. In welchem Jahr sind Sie geboren?

_____
- ☐ keine Angabe

R 6b. Wie ist Ihr Familienstand?

- ☐ ledig
- ☐ verheiratet
- ☐ verwitwet
- ☐ geschieden
- ☐ keine Angabe

R 6c. Welchen Bildungsabschluss haben Sie? Nennen Sie bitte den höchsten.

- ☐ (Noch) keinen
- ☐ Haupt- (Volks-)schulabschluss
- ☐ Realschulabschluss (Mittlere Reife)
- ☐ Abschluss der polytechnischen Oberschule
- ☐ Fachhochschulreife
- ☐ Abitur (Gymnasium oder EOS)
- ☐ Hochschulabschluss (Fach-/Hochschule, Universität)
- ☐ keine Angabe

R 6d. Wie ist Ihr aktuelles Beschäftigungsverhältnis?

- ☐ Vollzeit-erwerbstätig (35h/Woche und mehr)
- ☐ Teilzeit-erwerbstätig (weniger als 35h/Woche)
- ☐ Zurzeit arbeitslos
  Programmierhinweis: Weiter mit Frage R 6f, Frage R 6e = 0 setzen
- ☐ Auszubildende(r), Lehrling, Umschüler(in)
- ☐ Wehr-, Zivildienstleistender
- ☐ Schüler(in), Student(in)
- ☐ Hausfrau/-mann
  Programmierhinweis: Weiter mit Frage R 6f, Frage R 6e = 0 setzen
- ☐ Rentner(in), Pensionär(in), im Vorruhestand
  Programmierhinweis: Weiter mit Frage R 6f, Frage R 6e = 0 setzen
- ☐ keine Angabe

R 6e. Wie viele Stunden pro Woche arbeiten Sie in bezahlter Arbeit?

_____ Stunden
- ☐ keine Angabe

R 6f. Wie viele Stunden pro Woche verwenden Sie für unbezahlte Arbeit (Haus- und Familienarbeit)?

_____ Stunden
- ☐ keine Angabe

R 6g. Leben Sie mit einem Partner/einer Partnerin zusammen?

- ☐ Ja
- ☐ Nein — Programmierhinweis: Weiter mit Frage R 6j
- ☐ keine Angabe — Programmierhinweis: Weiter mit Frage R 6j

R 6h. Wie viele Stunden pro Woche verwendet Ihr Partner/Ihre Partnerin für bezahlte Arbeit?

_____ Stunden
- ☐ keine Angabe

R 6i. Wie viele Stunden pro Woche verwendet Ihr Partner/Ihre Partnerin für unbezahlte Arbeit (Haus- und Familienarbeit)?

_____ Stunden
☐ keine Angabe

R 6j. Wie alt ist die haushaltsführende Person?

_____ Jahre
☐ keine Angabe

R 6m. Wie hoch ist ungefähr das monatliche Nettoeinkommen Ihres Haushalts? Alle Ihre Angaben werden streng vertraulich behandelt.

☐ Unter 1.000 Euro
☐ Zwischen 1.000 und 1.499 Euro
☐ Zwischen 1.500 und 1.999 Euro
☐ Zwischen 2.000 und 2.499 Euro
☐ Zwischen 2.500 und 3.499 Euro
☐ Über 3.500 Euro
☐ keine Angabe

R 6n. Welches dieser folgenden Lebensereignisse haben Sie in den letzten 12 Monaten selbst erlebt bzw. vor mehr als 1 Jahr aber nicht mehr als 5 Jahren selbst erlebt?

	In den letzten 12 Monaten	In den letzten 5 Jahren	Nicht erlebt	Keine Angabe
Umzug in eine neue Wohnung / in ein neues Haus	☐	☐	☐	☐
Beginn des Ruhestandes / Pensionierung	☐	☐	☐	☐
Geburt des 1. Kindes	☐	☐	☐	☐
Geburt eines weiteren Kindes	☐	☐	☐	☐
Geburt des 1. Enkelkindes	☐	☐	☐	☐
Auszug des letzten Kindes aus Wohnung / Haus	☐	☐	☐	☐
Hochzeit	☐	☐	☐	☐
Scheidung / Trennung	☐	☐	☐	☐

R 6o. Feststellung des Bundeslandes

☐ Baden-Württemberg
☐ Bayern
☐ Berlin
☐ Bremen
☐ Brandenburg
☐ Hamburg
☐ Hessen

- ☐ Mecklenburg-Vorpommern
- ☐ Niedersachsen
- ☐ Nordrhein-Westfalen
- ☐ Rheinland-Pfalz
- ☐ Sachsen
- ☐ Sachsen-Anhalt
- ☐ Saarland
- ☐ Schleswig-Holstein
- ☐ Thüringen

R 6p. Feststellung Anzahl der Einwohner des Ortes

- ☐ bis 4.999
- ☐ 5.000 – 19.999
- ☐ 20.000 – 99.999
- ☐ 100.000 – 499.999
- ☐ 500.000 Einwohner und mehr

R 6q. Feststellung Geschlecht des befragten Teilnehmers

- ☐ männlich
- ☐ weiblich

Photo`s:
Image ”A symbolic CO_2 Molecule, responsible for global warming and pollution” Copyright Spectral-Design, 2013
Image ”Detail of petrol pump, yellow green and red colors” Copyright Willy Deganello, 2013
Image ”Electric car charging to energy column on green meadow” Copyright Giordano Aita, 2013
Image ”Schematic construction of facade insulation” Copyright Wilm Ihlenfeld, 2013
Image ”Solar water heating system on the roof” Copyright Pavel Vakhrushev, 2013

One of the major challenges that our world faces today and in the future is human-induced climate change. The primary cause of global warming, leading to climate change, is the burning of fossil fuels for energy and transport, which increases the concentration of greenhouse gases in the atmosphere. Energy efficiency and renewable energy sources are considered by many as a silver bullet to avoid the worst climate change scenarios. However, the support for and success of any effort to improve energy efficiency and expand renewable energies strongly depends on preferences and choices of consumers.

In four distinct but related essays, this doctoral thesis examines consumer preferences for alternative-fuel vehicles and building energy retrofits, using data from two surveys conducted in Germany. It provides empirical evidence on the impact of fuel availability on demand for alternative-fuel vehicles in the German context. It makes important contributions to the growing, but heterogeneous literature that seeks to elicit willingness to pay for climate protection. Finally, it attempts to explain the persistent low retrofit rate in Germany and makes suggestions on how to stimulate energy retrofits in an effective and cost-efficient way.

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