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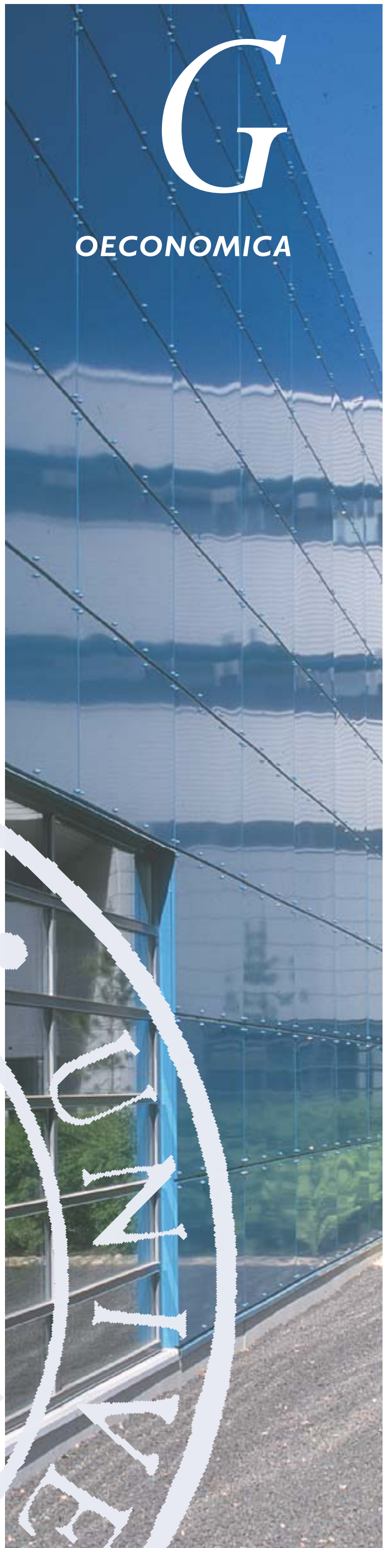

Enni Ruokamo

HOUSEHOLD PREFERENCES FOR ENERGY GOODS AND SERVICES

A CHOICE EXPERIMENT APPLICATION

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
DEPARTMENT OF ECONOMICS, ACCOUNTING AND FINANCE

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A choice experiment application

Academic dissertation to be presented with the assent of The Doctoral Training Committee of Human Sciences, University of Oulu for public defence in the Arina auditorium (TA105), Linnanmaa, on 22 March 2019, at 12 noon

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Abstract

This thesis includes three studies on household preferences for energy goods and services. The first study examines determinants of households' heating system choices using a choice experiment. The choice sets include six main heating alternatives (district heating, ground heat pump, exhaust air heat pump, solid wood boiler, wood pellet boiler, and electric storage heating) that are described by five attributes (supplementary heating systems, investment costs, operating costs, comfort of use and environmental friendliness). The results imply that hybrid heating appears to be accepted among households. The results also reveal differing preferences for the main heating alternatives and show that they are affected by demographic characteristics. The studied attributes also play a significant role when heating systems are being chosen.

The second study is a methodological one that extends the analysis of the first study. The second study explores the effect of perceived choice complexity on the randomness of choices in choice experiments. The study investigates how different self-evaluated factors of choice complexity affect mean scale and scale variance. The findings suggest that perceived choice complexity has a systematic impact on the parameters of econometric models of choice. However, differences exist between alternative self-evaluated complexity-related covariates. The results indicate that individuals who report that answering the choice tasks is more difficult have less deterministic choices. Perceptions of the realism of home heating choice options also affect scale and scale variance.

The third study utilizes the choice experiment to analyze households' willingness to participate in demand side flexibility. The study examines whether individuals are willing to time their electricity usage and heating; whether they are interested in dynamic pricing contracts such as real-time pricing, two-rate tariffs, or power-based tariffs; and how emissions reductions affect their choices. The results indicate that households' sensitivity to restrictions in electricity usage is much stronger than their sensitivity to restrictions in heating. Households also require compensation to choose real-time pricing over fixed fees. The findings suggest that room may exist for new dynamic electricity distribution contracts, such as power-based tariffs, in the market. Other value-creating elements besides monetary compensation also exist that could incentivize households to offer demand side flexibility because households value power system level reductions in CO2 emissions.

Keywords: choice experiment, choice modeling, complexity, consumer, demand response, demand side management, direct load control, dynamic pricing, electricity, emissions reduction, energy, Finland, flexibility, home heating system, household, hybrid heating, preference heterogeneity, preferences, scale, willingness to pay

Ruokamo, Enni, Kotitalouksien preferenssit energiahyödykkeisiin ja -palveluihin. Valintakoesovellus
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Tiivistelmä

Tämä väitöskirja koostuu kolmesta tutkimuksesta, joissa tarkastellaan kotitalouksien preferenssejä energiahyödykkeitä ja -palveluita kohtaan. Ensimmäinen tutkimus keskittyy kotitalouksien lämmitysjärjestelmävalintoihin ja niitä määrittäviin tekijöihin. Tämä tutkimus on tehty valintakoemenetelmällä, jonka valintatilanteet sisältävät kuusi eri päälämmitysjärjestelmävaihtoehtoa (kaukolämpö, maalämpöpumppu, puulämmitys, pellettilämmitys, varaava sähkölämmitys ja poistoilmalämpöpumppu). Päälämmitysjärjestelmiä kuvataan viiden ominaisuuden avulla, jotka ovat tukilämmitysjärjestelmä, investointikustannukset, käyttökustannukset, käyttömukavuus ja ympäristöystävällisyys. Tulosten mukaan kotitalouksien preferenssit päälämmitysjärjestelmävaihtoehtoja kohtaan ovat vaihtelevia. Valintaan vaikuttavat sekä tarkastellut ominaisuudet että kotitalouden demografiset tekijät. Tulokset myös paljastavat, että kotitaloudet suhtautuvat myönteisesti hybridilämmitykseen.

Toinen tutkimus on menetelmällinen, missä hyödynnetään ensimmäisen tutkimuksen aineistoa. Tämä tutkimus keskittyy yksilöiden kokeman vastaamisen vaikeuden vaikutuksiin valintakoemenetelmässä. Vastaamisen epätarkkuus tunnistetaan valintakoemenetelmässä skaalan ja skaalavarianssin avulla. Tutkimus tarkastelee, kuinka itsearvioidut vastaamisen vaikeutta mittaavat tekijät vaikuttavat keskimääräiseen skaalaan ja skaalavarianssiin valintojen ekonometrisissa malleissa. Tulosten mukaan koettu vastaamisen vaikeus vaikuttaa systemaattisesti ekonometrisen valintamallin parametreihin. Vastaamisen vaikeutta mittaavien tekijöiden välillä on kuitenkin eroja. Tuloksien perusteella vastaajat, jotka kokevat valintatilanteisiin vastaamisen keskimääräistä vaikeampana, tekevät satunnaisempia valintoja. Myös valintatilanteiden koettu realistisuus vaikuttaa skaalaan ja skaalavarianssiin.

Kolmannessa tutkimuksessa arvioidaan kotitalouksien halukkuutta osallistua energian kysyntäjoustoon valintakoemenetelmällä. Tämä tutkimus selvittää ovatko kotitaloudet halukkaitta siirtämään sähkönkulutusta ja lämmitystä, ja kuinka kiinnostuneita he ovat dynaamisista sähkön hinnoittelusopimuksista kuten pörssisähkösopimuksesta, yösähkösopimuksesta tai tehoperusteisesta sopimuksesta. Lisäksi tutkitaan vaikuttavatko järjestelmätason päästövähennykset kotitalouksien valintoihin. Tulosten perusteella kotitaloudet suhtautuvat sähkönkulutuksen rajoituksiin selvästi negatiivisemmin kuin lämmityksen rajoituksiin. Kotitaloudet myös vaativat rahallista korvausta valitakseen pörssisähkösopimuksen kiinteähintaisen sopimuksen sijaan. Tulosten mukaan markkinoilla voisi olla tilaa uudenlaisille sopimustyypeille, kuten tehoperusteiselle vaihtoehdolle. Tulokset osoittavat, että kotitaloudet arvostavat järjestelmätason hiilidioksidipäästövähennyksiä. Täten rahallisen korvauksen lisäksi on olemassa myös muita arvoa luovia tekijöitä lisätä kotitalouksien osallistumista kysyntäjoustoon.

Asiasanat: dynaaminen hinnoittelu, energia, energiapalvelut, etäohjaus, hybridilämmitys, kotitalous, kuluttaja, kysyntäjousto, lämmitysjärjestelmä, maksuhalukkuus, preferenssien heterogeenisyys, preferenssit, päästövähennys, skaala, Suomi, sähkö, sähkösopimus, valintakoemenetelmä, valintojen mallinnus

To my son Reino

Acknowledgments

Something very important related to completing this thesis is captured in the aphorism by Albert Einstein “Anyone who has never made a mistake has never tried anything new.” Indeed, this journey was not always the easiest nor without mistakes, but I am very happy that I had the courage to start the adventure.

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Oulu, January 2019 Enni Ruokamo

Abbreviations

ASC	alternative specific constant
CE	choice experiment
CL	conditional logit
EV1	extreme value one
G-MXL	generalized mixed logit
HCM	hybrid choice model
HHHS	hybrid home heating system
IIA	independence of irrelevant alternatives
IID	identically and independently distributed
LC	latent class
MNL	multinomial logit
MXL	mixed logit
PBT	power-based tariff
RES	renewable energy resources
RTP	real-time pricing
SP	stated preference
TT	two-rate tariff
WTP	willingness to pay

Original publications

This thesis is based on the four introductory chapters and the following three essays, which are referred to throughout the text by their Roman numerals.

I Ruokamo, E. (2016). Household preferences of hybrid home heating systems – A choice experiment application. *Energy Policy, 95*, 224-237.

II Ruokamo, E., Czajkowski, M., Hanley, N., Juutinen, A., & Svento, R. Linking perceived choice complexity with scale heterogeneity in discrete choice experiments: home heating in Finland. (Unpublished manuscript)

III Ruokamo, E., Kopsakangas-Savolainen, M., Meriläinen, T., & Svento, R. Towards flexible energy demand – Household preferences for dynamic contracts, services and emissions reductions. (Unpublished manuscript)

Author contributions:

The research idea for essay I was developed by Enni Ruokamo and the research ideas for essays II and III were jointly developed with the coauthors. Enni Ruokamo was responsible for planning and conducting the two surveys used in essays I, II, and III, and Teemu Meriläinen contributed to the conduction of the survey used in essay III. Enni Ruokamo executed the statistical analyses for essays I, II, and III, and Mikolaj Czajkowksi contributed to the statistical analysis of essay II. Enni Ruokamo was the corresponding author of essays I, II, and III. The coauthors contributed to editing essays II and III.

Contents

1 Introduction

1.1 Background and motivation

Increasing concern over climate change has pushed energy markets all over the world to a massive transformation into decarbonized energy systems. This transformation is closely linked to technological development, market restructuring[1], a decreasing stock of fossil fuels, and rapid deployment of renewable energy. Generally, decarbonizing the energy sector will require significant changes from all market participants, including energy companies, customers, and policymakers. Achieving the goals of reducing emissions and ensuring a secure and competitive energy supply is a challenge. Different solutions are called for—increasing the share of renewable energy sources (RES) in the power system and enhancing energy efficiency at all stages of the energy chain from generation to final consumption are essential.

The transformation into a decarbonized energy system and new energy technologies requires a significant activation of end users. Households' energy consumption accounts for a large share of total energy consumption in developed countries and, in turn, plays a considerable role in mitigating global climate change (Nejat, Jomehzadeh, Taheri, Gohari, & Abd. Majid, 2015)[2]. Moreover, energy policy plays a significant role in controlling energy consumption. The European Union has made a notable effort in activating households by stipulating provisions in many policy documents, such as the Electricity Directive (2009/72/EC) and the Energy Efficiency Directive (2012/27/EU). The aim is to utilize the potential of the residential sector in terms of both energy efficiency and demand side flexibility.

A large portfolio of solutions exists that can be used to empower consumers. These solutions include smart metering systems (Pepermans, 2014), demand response programs and dynamic pricing (Faruqui & Sergici, 2010), direct load control services (Stenner, Frederiks, Hobman, & Cook, 2017), nonprice energy conservation programs (Allcott, 2011b), energy efficiency investments (Trotta, 2018), microgeneration technologies (Claudy, Michelsen, & O'Driscoll, 2011;

[1] The deregulation of the energy markets in the 1990s created competition in generation and retail in many countries. This development enabled consumers to freely choose their electricity supplier and electricity contract type.

[2] For instance, the share of residential energy consumption is around 25 percent in the European Union (Eurostat, 2016).

Islam & Meade, 2013), and other enabling technologies such as in-home energy displays (Faruqui, Sergici, & Sharif, 2010; Jessoe & Rapson, 2014).

Despite the broad range of solutions and their benefits for the end user, research surveys and field experiments show that broad uptake is still missing for many of these solutions (Bertoldi, Zancanella, & Kiss, 2016; Stenner et al., 2017). Many explanations exist for this finding. Consumers traditionally exhibit low price elasticity for electricity (Allcott, 2011a; Ito, 2014). There are also barriers related to technology standards, availability of services, and monetary incentives (Nolan & O'Malley, 2015). Moreover, energy (and investment) literacy may explain differences at the individual level (Blasch, Filippini, & Kumar, 2017; Blasch, Boogen, Filippini, & Kumar, 2017). Consumers may also be disengaged and uninterested in energy issues or are unaware of all of the opportunities available to them (Ellabban & Abu-Rub, 2016; Kowalska-Pyzalska, 2018). For consumers to change their habits and behavior can also be very challenging[3].

Investigating consumer preferences is essential because successful activation of consumers requires a diverse offering of energy-related products and services that meet the needs of this heterogeneous set of individuals. A broad spectrum of the literature examines the factors that may influence consumers' energy-related preferences and behavior (see reviewing studies from Kowalska-Pyzalska (2018) and Hobman, Frederiks, Stenner and Meikle (2016)). From an individual perspective, the adoption of different energy technologies and programs is driven by several exogenous and endogenous factors. Exogenous factors include, for example, technological characteristics, costs, and the regulatory framework, whereas endogenous factors cover aspects from individuals' knowledge and attitudes to energy consumption behavior and habits.

Previous studies often lack the perspective that different energy solutions and technologies are used in parallel. For example, if we consider demand response programs, direct load control is likely accompanied by smart meters and dynamic pricing. Moreover, if we think about energy efficiency investments, electric heating is often supported by air source heat pumps. This thesis contributes to the existing literature by studying the complementary nature of i) different heating technologies and ii) demand side flexibility characteristics. There are only a few studies (Michelsen & Madlener, 2013; Scarpa & Willis, 2010) on consumers' home heating mode choices that simultaneously consider the effects of primary and

[3] Cognitive biases and behavioral anomalies related to residential energy consumption (Wilson & Dowlatabadi, 2007) are beyond the scope of this thesis.

supplementary heating systems on decision-making processes. Moreover, little is known about consumers' willingness to participate in demand response such that it simultaneously accounts for the effects of alternative pricing schemes, direct load control, financial rewards, and environmental benefits associated with demand side flexibility.

1.2 Energy efficiency and residential heating sector

Heating and cooling account for approximately 70 percent of the European Union's residential energy use and have been estimated as remaining the most significant demand drivers in the long run (European Commission, 2018). Moreover, even higher shares of residential heating consumption are recorded in cold climate conditions. For example, in Finland, more than 80 percent of households' annual energy consumption is spent on heating the household space and water (Official Statistics of Finland, 2016). Hence, the residential heating sector exhibits considerable energy efficiency and savings potential that has also been highlighted in many energy policies worldwide (Nejat et al., 2015).

Many suggestions have been made on how to increase energy efficiency in the residential heating sector. One crucial suggestion considers heating system upgrades. Efficiency improvements can consider both new technologies that replace the old capital stock and that improve the efficiency of the present capital stock. A good example of the former is a ground source heat pump that replaces an oil boiler. Other suggestions include, for instance, renovations, energy retrofits, and installations in new houses.

Broad literature exists on energy efficiency that states that efficiency improvements help reduce emissions and mitigate climate change in a cost-effective manner (Tajudeen, Wossink, & Banerjee, 2018; Ürge-Vorsatz, Cabeza, Serrano, Barreneche, & Petrichenko, 2015). In contrast, several studies (Brännlund, Ghalwash, & Nordström, 2007; Druckman, Chitnis, Sorrell, & Jackson, 2011) acknowledge that most of the potential energy savings and emissions reductions resulting from energy efficiency improvements have been mitigated by different behavioral responses that are commonly called rebound effects. Although these effects are neither anticipated nor intended, they may reduce the size of the achieved energy savings and emissions reductions. The rebound effect also exists in the case of space heating investments. There may be a direct rebound effect, such as consumers with an efficient ground-source heat pump may increase the ambient room temperature through lower cost of use. Indirect rebound occurs when the lower cost of use increases the household consumption of other goods and services, such as energy savings used for travel. Even though the rebound effect exists, this effect has been found to be relatively small in the case of home heating investments (Haas & Biermayr, 2000; Hediger, Farsi, & Weber, 2018).

Generally, energy efficiency measures change over time because of technological advances. Although relying primarily on one heating system traditionally has been common, households are increasingly using a combination of complementary heating technologies. A hybrid home heating system (HHHS) is an energy efficient alternative to a traditional heating system, such as oil, gas, or direct electric heating. A HHHS combines more than one form of energy to heat space and household water and uses a supplementary heating system alongside the main heating system. A HHHS may utilize many sources of renewable energy to generate heat, such as solar, solid wood, wood pellet, and ground heat, as well as outside and exhaust air. In general, hybrid heating provides flexibility and efficiency to its users. HHHSs can offer additional protection from unpredictable fuel cost increases because the heating systems' operations do not rely on only one technology or fuel source. Moreover, HHHSs are easily adjustable because adding and switching supplementary heating alternatives to a central heating system is possible. HHHSs can also be operated through automatized control systems and, hence, automatically use the most efficient fuel source.

Previous studies have mainly focused on technological, motivational, and socio-demographic factors that influence the adoption of various heating technologies (Braun, 2010; Decker & Menrad, 2015; Dubin & McFadden, 1984; Michelsen & Madlener, 2012; Michelsen & Madlener, 2013; Sahari, 2017; Vaage, 2000). However, the literature lacks a thorough investigation of hybrid heating solutions. Most studies focus on individual heating alternatives, whereas the hybrid nature of space heating has been given little or no attention. This thesis addresses this knowledge gap. These analyses are needed because knowledge of household preferences facilitates the promotion of HHHSs.

1.3 Demand side flexibility

A key focus of the development of future energy systems is on smart grids and demand response solutions. A smart grid is a modern electric power grid infrastructure in which generation, transmission, distribution, and consumers are physically connected through communication systems[4] with markets, utilities, and services (Ellabban & Abu-Rub, 2016). Generally, smart grids and demand response play an important role in shaping an electricity system that consists of increasing amounts of RES. Demand response helps balance fluctuations in the generation of RES and, thus, facilitates higher penetration of this intermittent production into the power system (Huuki, Karhinen, Kopsakangas-Savolainen, & Svento, 2017). Demand response can also reduce peak loads and flatten the residual load (Müller & Möst, 2018). Consequently, the need for generation capacity may decrease, power plant utilization may increase, and network reinforcements may decline (Strbac, 2008).

Demand response helps the operation of the electricity grid by enabling consumers to reduce or shift their electricity usage during peak periods in response to price signals or other incentives. Therefore, consumers are presented with time-dependent price (or other) signals that more accurately convey the actual electricity generation cost at each moment. Available electricity pricing schemes vary from fixed to fully dynamic rates with retail prices changing within short time intervals. According to Dütschke and Paetz (2013), dynamic pricing can be categorized as time-varying and load-based programs. In time-varying programs, the rate depends on the point in time when electricity is demanded, whereas the rate in load-based programs is determined by the household's current power load level. Real-time pricing (RTP) is the most dynamic program and has significant potential to increase flexibility. RTP reflects the scarcity in the power system, and prices typically vary from hour to hour. Several studies have shown that dynamic pricing affects households' consumption behavior (Allcott, 2011a; Faruqui & Sergici, 2013). Nevertheless, RTP has proven to be a very unattractive contract alternative among households. Most residential customers are still on traditional fixed-rate tariffs in which the price remains stable over time. For instance, only seven percent of households in Finland had an RTP contract in 2016 (Energy Authority, 2017). According to Joskow (2012), current knowledge of household behavior is not comprehensive enough to achieve universal deployment of dynamic pricing.

[4] An important part of the communication system is a smart meter which is a device installed at the consumer's premises that measures real-time electricity consumption and allows two-way communication with the distribution system operator and other possible operators (Pepermans, 2014). Smart meters enable demand response and help to raise the awareness of consumers through delivery of actual consumption data. Finland has adopted smart electricity metering on a large scale with a 100 percent coverage among customers (Annala, 2015).

Moreover, predicting the degree to which dynamic prices affect demand flexibility is difficult (Allcott, 2011a).

On top of different pricing schemes, realizing the full potential of demand side flexibility also requires automated and/or third-party load control energy services for households (Annala, 2015; Dütschke & Paetz, 2013; Kobus, Klaassen, Mugge, & Schoormans, 2015). The clear advantage of a direct load control service is that an individual household does not need to be particularly active, although control measures can create some discomfort for the household. Despite offering a range of potential benefits (such as financial incentives) and ongoing technological advances of load control devices, widespread consumer uptake and usage of direct load control remains low (Stenner et al., 2017). Furthermore, having many households interested in signing up for load control services creates new business opportunities in the market. For a flexibility operator, that is, an aggregator (Campaigne & Oren, 2016), this means that the operator can utilize the fragmented demand flexibility of individual households and design products that can be sold, for example, in the balancing market.

Thus, to enhance the attractiveness of dynamic contracts and direct load control services, household preferences should be better understood and the incentives designed appropriately. This thesis simultaneously studies consumer preferences for different dynamic contract and service alternatives. This study is one of the first to provide information on household preferences for dynamic power-based tariffs (PBTs) and to determine a household's willingness to pay (WTP) for emissions reductions at the power system level that result from increased demand flexibility.

1.4 Aims of the thesis

The purpose of this thesis is to study the household preferences of energy-related goods and services. More specifically, this thesis analyzes the determinants of choice for innovative home heating systems and demand side flexibility. The Choice Experiment method (CE) (Hensher, Rose, & Greene, 2015; Johnston et al., 2017) is used to examine consumer preferences for the characteristics of both heating systems and demand side flexibility.

This thesis consists of three essays. The first essay (I) focuses on the determinants of households' heating mode choices. More precisely, the essay studies homeowners' preferences for hybrid home heating alternatives and provides general information on households' attitudes and perceptions toward these alternatives. The target population of the essay was randomly selected from a group of homeowners living in recently built detached houses in Finland. This essay examines the type of heating mode choices that households make when they are presented with varying scenarios that cover today's heating technologies. Moreover, because households differ in what they perceive to be important heating attributes, this essay investigates the role of the attributes when households choose one type of heating system over another. In particular, the essay focuses on the hybrid character of the heating mode. To account for preference heterogeneity among households, households' different socio-demographic characteristics are also used to explain their heating system choices.

The second essay (II) extends the analysis of essay I to consider whether the perceived complexity in the heating CE further affects the results. The essay is a methodological paper that investigates whether higher levels of perceived choice complexity in the CE lead to a decrease in choice accuracy, that is, an increase in choice randomness. This essay makes novel use of respondents' self-evaluated factors concerning choice complexity and tests their effects on the estimated randomness in respondents' choices.

The third essay (III) examines households' preferences for demand side flexibility. The target population of this essay is comprised of randomly selected Finnish homeowners. The essay investigates homeowners' willingness to participate in the direct load control of electricity consumption and space heating, whether they are interested in dynamic contracts such as RTP, two-rate tariffs (TTs) or PBTs, and how different amounts of potential system-level emissions reductions affect their participation in flexibility. The essay also determines homeowners' WTP for these flexibility characteristics. In addition, the essay gives information on homeowners' opinions on energy conservation, energy production, and electricity pricing that is linked to demand side flexibility.

The remaining sections of this thesis are organized as follows. Section 2 describes the methodology of this thesis. Section 3 provides summaries of the three essays. Policy and methodological implications, future research topics, and concluding remarks are presented in Section 4. The essays are found in the section on Original Publications.

2 Methodology

2.1 Choice experiment

This thesis uses the stated preference (SP) methodology, more precisely CE, to analyze individual preferences for energy goods and services[5]. SP methods use surveys to estimate measures of economic value and can assess both use and nonuse values[6] (Johnston et al., 2017).

CE originates from marketing research (Green & Srinivasan, 1978; McFadden, 1986) and emerged in the 1990s in environmental applications (Adamowicz, Louviere, & Williams, 1994; Adamowicz, Boxall, Williams, & Louviere, 1998; Boxall, Adamowicz, Swait, Williams, & Louviere, 1996). In CE, individuals are asked to choose from a set of choice alternatives described with bundles of attributes. The CE makes it possible to determine how individuals construct their preferences for energy goods and services by identifying the characteristics i.e. attributes that are significant for an individual's choice, the ranking of these attributes, and the marginal WTP for a change in a specific attribute. The CE also allows assessing preferences for hypothetical yet realistic energy goods and services. Eventually, the CE results can be utilized for demand estimation, identification of consumer segments and to inform the design of energy goods and services to match consumer needs.

Good survey design and implementation are crucial to maximizing the validity and reliability of the CE results. According to Johnston et al. (2017), it is essential to i) design a survey instrument that clearly presents the status quo and other choice alternatives, ii) select a random sample of the potentially affected population, and iii) choose a survey mode with the desired properties. Regarding the first, the design of attributes and attribute levels for the CE is vital (Hensher et al., 2015). Generally, goods and services can be characterized by a combination of various attributes, and the choice among these is the key issue for the researcher. In CE studies, the amount of examined alternatives and attributes are somewhat limited because individuals cannot consider choice scenarios that are too complex (Swait & Adamowicz, 2001a; Swait & Adamowicz, 2001b). Moreover, attributes should be relevant to respondents, and their levels should be measurable in a meaningful manner. The

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[5] Another common SP approach is the contingent valuation (CV) in which the respondents are asked directly to report their WTP for a specified good (Alberini & Kahn, 2006).
[6] For a detailed description of use and nonuse values, readers are referred to Perman et al. (2011).

attributes used in this thesis are carefully designed to describe the investigated energy goods and services in a realistic and understandable manner.

Two ways exist to present the choice tasks to respondents: generic and labeled. In the labeled CE, the choice alternatives are given a descriptive meaning. The experiments that use generic alternatives do not convey any information to the decision maker other than “alternative 1, 2, or 3,” for example. This thesis utilizes both approaches. Using the labeled approach is reasonable in essays I and II because the aim is to estimate heating mode-specific parameter estimates. In essay III, however, the objective is to study trade-offs between flexibility characteristics; therefore, the generic approach is more suitable.

After alternatives and attributes for the CE have been identified, the experimental design consideration takes place. Several different design options are available under the so-called fractional factorial design (Ngene, 2018). Fractional factorial design selects choice tasks in a structured manner from all possible choice task combinations. A well-known fractional factorial design is the orthogonal design, which aims to minimize the correlation between the attribute levels in the choice tasks. Orthogonal designs, however, have limitations and generate such choice tasks, which do not provide much information (Hensher, 1994; Huber & Zwerina, 1996). As a response to these problems, efficient designs have been developed. Instead of merely looking at the correlation between the attribute levels, efficient designs are those that maximize the information from each choice task (Carlsson & Martinsson, 2003; Huber & Zwerina, 1996)[7]. Efficient designs outperform orthogonal ones but require prior parameter values and, therefore, strongly depend on the accuracy of these priors. Bayesian efficient designs relax the accuracy of the prior parameter estimates (Bliemer, Rose, & Hess, 2008; Sándor & Wedel, 2001). A Bayesian efficient design is more robust to the misspecification of priors and optimizes the expected efficiency of the design over a range of prior parameter values (Ngene, 2018). In this thesis, the Bayesian framework is used to generate designs for the CEs.

Survey pretesting is central to developing a questionnaire and choice scenarios that are understandable and credible to respondents. Both qualitative and quantitative pretesting are recommended (Bateman et al., 2002; Johnston et al., 2017). The CEs of this thesis are carefully designed and tested, and were developed with experts and pretested through qualitative one-to-one interviews and

[7] Efficiency means that the design aims to enable an estimation of the parameters with standard errors that are as low as possible.

quantitative pilot studies. The pilots were also conducted within the target population for the main study. Pretests using nonrepresentative groups are not guaranteed to provide accurate information on the survey's performance within the target population (Johnston et al., 2017).

Survey mode and sampling are closely linked with sample frame and representativeness. The literature shows that the survey mode (mail or web) may not significantly influence the study results (Lindhjem & Navrud, 2011); however, sampling remains crucial. Johnston et al. (2017) state that high-quality surveys use random sampling from representative target sample frames (e.g., general population). This thesis uses random sampling from the target populations by utilizing addresses obtained from the civil registry (i.e., Population Information System of Finland).

After collecting the survey responses, the data are analyzed[8]. Sections 2.2 and 2.3 present the theoretical framework and econometric specifications used in this thesis. Section 2.4 discusses some methodological limitations related to this thesis.

2.2 Theoretical framework

The CE technique is grounded in neoclassical microeconomic theory. Thurstone (1927) originally proposed modeling dominance judgments in paired comparisons in terms of psychological stimuli. Later, Marschak (1959) interpreted this stimulus as a utility and provided a derivation from utility maximization. Such models are called random utility models (RUMs). Generally, the CE technique attempts to identify the utility that individuals have for attributes of energy-related goods and services by studying the trade-offs between these attributes when individuals make choice decisions. The theory of value (Lancaster, 1966) combined with the RUM states that individuals make choices based on the presence of good characteristics and some degree of randomness.

The subsequent derivation of RUMs follows Train (2009). Assume now that an individual *n* faces a choice among *J* alternatives. The individual obtains a certain level of utility from each alternative. We denote this utility obtained from alternative j as $U_{nj}, j = 1, \ldots, J$. The utility maximizing individual chooses the alternative that provides the greatest utility. Therefore, *n* chooses alternative *i* if and only if $U_{ni} > U_{nj} \; \forall \; j \neq i$.

[8] The surveys used in this thesis are available from the author on request.

Consider now the researcher who does not directly observe the utility. The researcher can observe some attributes of the alternatives faced by the individual, labeled x_{nj}, and some characteristics of the individual, labeled s_n, and can specify a function that catches these observed factors of the individual's utility. This function, called a representative utility function, is denoted as $V_{ni} = V(x_{ni}, s_n)$. Because the researcher cannot observe all utility factors, $V_{ni} \neq U_{ni}$. The utility to individual *n* from choosing alternative *j* is given by

$$U_{nj} = V_{nj} + \varepsilon_{nj}, \tag{1}$$

where the random component ε_{nj} captures the factors not included in V_{nj}.

The probability that individual *n* chooses alternative *i* is

$$\begin{aligned} P_{ni} &= \Pr\left(U_{ni} > U_{nj} \; \forall \, j \neq i\right) \\ &= \Pr\left(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj} \; \forall \, j \neq i\right) \\ &= \Pr\left(\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj} \; \forall \, j \neq i\right). \end{aligned} \tag{2}$$

The probability P_{ni} is a cumulative distribution given that the difference for each random term $\varepsilon_{nj} - \varepsilon_{ni}$ is lower than the observed quantity $V_{ni} - V_{nj}$. Therefore, for any individual with characteristic s who faces a set of alternatives, the probability of choosing i equals the probability that the difference between the unobserved utility of alternatives j and i is less than the difference between the representative utility of alternatives *i* and *j* (Louviere, Hensher, & Swait, 2000).

2.3 Econometric specification

The structure of V_{nj} depends on the model specification. McFadden (1974) linked the theoretical RUM to the statistical discrete choice model, with a specification of the Multinomial Logit (MNL) model (or Conditional Logit (CL) model).

Assume now that individual *n* can choose among *J (j=1,…, J)* alternatives in each *t (t=1,…, T)* choice task. In the traditional MNL model, the utility of individual *n* choosing alternative *j* in the choice task *t* is represented in the following general form

$$U_{njt} = \beta' x_{njt} + \varepsilon_{njt}, \tag{3}$$

where x_{njt} is a vector of nonmonetary and monetary attributes, β is a vector of estimated parameters, and ε_{njt} is an idiosyncratic error term. Note that x_{njt} can also include an alternative specific constant (ASC) for the status quo (or multiple ASCs in the labeled CE) that allows for intrinsic preferences for the choice alternative. The idiosyncratic error is assumed to be independently and identically distributed (IID) and extreme value one (EV1) type (also called the Gumbel distributed) (McFadden, 1974). The variance of the error is $var(\varepsilon_{njt}) = \pi^2/6$, and the density of the error term is

$$f(\varepsilon_{njt}) = e^{-\varepsilon_{njt}} e^{-e^{-\varepsilon_{njt}}}. \quad (4)$$

Under the IID and EV1 assumptions for the error term, the choice probability can be expressed in a closed-form solution. In the MNL model, the conditional probability of choice j in choice situation t for individual n is

$$P_{njt} = \frac{\exp(\beta' x_{njt})}{\sum_{k=1}^{J} \exp(\beta' x_{nkt})}. \quad (5)$$

A common objective of discrete choice models is to obtain WTP measures. In simple linear models, the marginal WTP values are calculated as the ratio of two parameter estimates (holding all else constant) in the following manner

$$WTP = \frac{\beta_k}{-\beta_{€}}, \quad (6)$$

where β_k and $\beta_{€}$ are the parameters for the nonmonetary and monetary attributes, respectively. The negative sign in front of the monetary parameter is necessary if the monetary attribute is cost-related.

The MNL model is limited in the sense that it makes strong assumptions regarding individuals' choice behavior. The MNL model generates homogeneous average taste parameter estimates and imposes restrictive independence of the irrelevant alternatives (IIA) property. The IIA states that the ratio of two alternatives is constant regardless of the other alternatives included in the choice set (Hensher et al., 2015; Luce, 1959). Consequently, many models have been developed to allow for preference heterogeneity and that relax the IIA assumption.

2.3.1 Models with observed and unobserved preference heterogeneity

Two of the most popular alternatives to model preference heterogeneity are the Mixed Logit (MXL) model (Ben-Akiva et al., 1997; McFadden & Train, 2000;

Revelt & Train, 1998) and the Latent Class (LC) model (Kamakura & Russell, 1989). These models also avoid the IIA property[9].

The MXL model is the most flexible specification and can approximate any random utility model (McFadden & Train, 2000). In the MXL model, utility is expressed as

$$U_{njt} = \beta_n' x_{njt} + \varepsilon_{njt}, \tag{7}$$

where the taste parameters β_n are now respondent-specific. The model assumes that each individual also has some random taste parameters in β_n and that they follow distributions specified by a researcher such that $\beta_n \sim f(\beta + \Delta' s_n, \Gamma_n)$, with population mean β and variance-covariance matrix Γ_n. It is possible to have the means of the taste parameters to be influenced by observable individual specific characteristics s_n and the associated coefficient vector Δ.

Because β_n is now unknown, the unconditional probability for choice j in all T choice tasks is

$$P_{nj} = \int_{\beta_n} \left(\prod_{t=1}^{T} \frac{\exp\left(\beta'_n x_{njt}\right)}{\sum_{k=1}^{J} \exp\left(\beta'_n x_{nkt}\right)} \right) f(\beta_n) d\beta_n. \tag{8}$$

The choice probabilities are obtained by integrating over all possible values of β_n. Several distributions can be used for random parameters, such as normal, lognormal, gamma, uniform, and triangular. The lognormal distribution is useful when the coefficient is known to have the same sign for every individual, such as a cost coefficient that is known to be negative for everyone.

The probabilities in (8) are approximated through simulation. The probability is

$$\widetilde{P_{nj}} = \frac{1}{D} \sum_{d=1}^{D} \prod_{t=1}^{T} \frac{\exp\left(\beta'_d x_{nj}\right)}{\sum_{k=1}^{J} \exp\left(\beta'_d x_{nk}\right)}, \tag{9}$$

where D is the number of draws and $\widetilde{P_{nj}}$ is an unbiased estimator of P_{nj}. To obtain the simulated log-likelihood, the simulated probabilities are inserted into the log-likelihood function as follows

$$SLL = \sum_{n=1}^{N} \sum_{j=1}^{J} y_{nj} \ln \widetilde{P_{nj}}, \tag{10}$$

[9] Other models that avoid IIA and/or allow for unobserved preference heterogeneity are the Nested Logit model (McFadden, 1978), the Generalized Extreme Value model (McFadden, 1978), and the Multinomial Probit model (Thurstone, 1927).

where $y_{nj} = 1$ if n chooses j and zero otherwise (Train, 2009).

A good approximation usually needs a fairly large number of random draws D. Therefore, with large samples and large models, significant computation is needed, which can be very time-consuming (Train, 2009). This issue can be mitigated by using intelligent rather than standard random draws, such as Halton draws (Bhat, 2001) or Sobol draws (Czajkowski & Budziński, 2017).

Models with scale heterogeneity

So far, we have assumed that the variance of the error term is the same for all individuals. The supposition that unobserved factors have greater variance for some individuals than others leads to the following specification

$$U_{njt} = \beta_n' x_{njt} + \varepsilon_{njt}/\sigma \,, \tag{11}$$

where σ is the scale parameter. If we normalize the scale parameter σ to one (which is equivalent to multiplying Equation (11) by σ), we obtain

$$U_{njt} = \sigma \beta_n' x_{njt} + \varepsilon_{njt}. \tag{12}$$

Now, σ proportionally scales up or down the vector of preference parameters. Heterogeneity in scale can correspond to a certain type of heterogeneity in the utility weights. Note that because the utility function is ordinal[10], the specification in Equation (12) represents the same preferences as in Equation (7).

To allow the scale to differ systematically for some individuals, we can specify the MXL model as

$$U_{njt} = \sigma(\exp(\theta' h_n))\beta_n' x_{njt} + \varepsilon_{njt}. \tag{13}$$

Here, we have a Heteroskedastic MXL (H-MXL) model (Czajkowski, Giergiczny, & Greene, 2014) in which the effective scale is a function of h_n, a set of scale-related covariates of individual n, and the corresponding coefficient vector of covariates of scale θ.

Note that both parameters σ and β cannot be identified in the H-MXL model. To identify both, we need to allow the scale parameter to be individual-specific by making it a random variable following a certain distribution. The resulting model is the Generalized Mixed Logit (G-MXL) model (Fiebig, Keane, Louviere, & Wasi,

[10] The utilities obtained from discrete choices are measured on an ordinal scale, indicating only differences in the utility matter and not the absolute values of utility (Hensher, Rose, & Greene, 2015).

2010; Greene & Hensher, 2010). In the G-MXL model, the random utility expression is

$$U_{njt} = \sigma_n \beta_n' x_{njt} + \varepsilon_{njt} = [\sigma_n \beta + \gamma \eta_n + (1-\gamma)\sigma_n \eta_n]' x_{njt} + \varepsilon_{njt}. \qquad (14)$$

Here, β again represents the population means, whereas η represents individual specific deviations from these means. Now, we also have an individual specific scale parameter σ_n (unlike in the H-MXL model). In Equation (14), γ is a weighting parameter that indicates how the variance in residual preference heterogeneity varies with scale. If $\gamma = 1$, we obtain the G-MXL-I model, where $\beta_n = \sigma_n \beta + \eta_n$. If $\gamma = 0$, we obtain the G-MXL-II model, where $\beta_n = \sigma_n(\beta + \eta_n)$. These are the two extreme cases of scaling residual taste heterogeneity.

Czajkowski, Hanley and LaRiviere (2016) introduced how to account for the systematic differences in both the mean scale and its variance. Now, we develop the mean of the random scale parameter and its variance functions of covariates of scale such that $\sigma_n \sim LN(1 + \theta' h_n, \tau + \iota' h_n)$. This further implies that the scale parameter is of the form

$$\sigma_n = \exp(\bar{\sigma} + \theta' h_n + \tau \exp(\iota' h_n) \varepsilon_{0n}), \qquad (15)$$

where $\varepsilon_{0n} \sim N(0,1)$. Note that $\bar{\sigma}$ denotes the population mean of scale, and τ is the coefficient of the scale heterogeneity in the sample. For identification, we need to normalize σ_n by setting the mean scale $\bar{\sigma} = -\tau^2/2$. Again, h_n is a set of scale-related covariates of individual *n* (that may overlap with s_n), and θ is the corresponding coefficient vector of covariates of the mean scale, whereas ι is the corresponding coefficient vector of covariates of the scale variance.

Models in willingness to pay space

Often, economic investigations focus on WTP estimations, but so far, the utility specifications have been in the preference space. Thus, we reparametrize the utility to the WTP space, where the utility parameters can immediately be interpreted as marginal WTP values (Scarpa & Willis, 2010; Train & Weeks, 2005). In the WTP space, the utility takes the following generic form

$$U_{njt} = \sigma(\alpha_n m_{njt} + \beta_n' x_{njt}) + \varepsilon_{njt} = \sigma \alpha_n (m_{njt} + \beta'_n x_{njt}/\alpha_n) + \varepsilon_{njt}$$
$$= \lambda_n (m_{njt} + \upsilon'_n x_{njt}) + \varepsilon_{njt}. \qquad (16)$$

Here, m_{nj} is a monetary vector, x_{nj} is a vector of nonmonetary attributes, and α_n and β_n are corresponding vectors of estimated parameters. When we manipulate the original equation in (16), we obtain $\upsilon_n = \beta_n / \alpha_n$, which is a vector of marginal WTP for each of the nonmonetary attributes. The scale parameter σ does not directly impact the WTPs but remains in λ_n, that is, in the monetary coefficient. The λ_n can be linked with scale-covariates[11] as follows: $\lambda_n = \exp(\theta' h_n)\alpha_n$ (Faccioli, Kuhfuss, & Czajkowski, 2018).

The WTP space specification enables convenient distributions for WTP because it avoids the need to consider the distribution of inverse coefficients (Daly, Hess, & Train, 2012). The estimated coefficients are interpretable in the money space, as are the estimated standard errors that need not be derived using simulation or closed form approximations (e.g., via the Delta method). According to the Train and Weeks (2005) models in WTP space may provide more reasonable distributions of WTP with fewer individuals having large WTPs than models in the preference space.

2.4 Methodological limitations

Some methodological and econometric limitations exist related to this thesis that need to be discussed.

Some biases are specific to surveys. The generalizability of the CE results depends on the sample representativeness that is linked with the nonresponse bias and the sampling bias. The nonresponse bias is a phenomenon through which the group of individuals responding to a survey has different responses than the group of individuals not responding. Sampling bias results in a nonrandom sample of a target population and is caused by errors made in the sampling phase. It is noteworthy that unrepresentative samples can provide information on preference and welfare patterns that are likely present in the target population (Johnston et al., 2017). However, respondent and target population characteristics should be documented to make possible the assessment of representativeness. In essay III, the nonresponse bias is likely present given a low response rate. Hence, summary statistics on the respondent demographics are provided and compared with known population demographics from a reliable source.

One of the major criticisms of CEs is that the choices are made in hypothetical markets (Fifer, Rose, & Greaves, 2014). Hypothetical bias means that individuals make different choices in a hypothetical setting than in real-life situations. The

[11] Again, h_n is a set of scale-related covariates of individual n, and θ is the corresponding coefficient vector.

hypothetical bias is thought to occur because respondents face no real consequences for their actions; that is, incentive compatibility is lacking (Harrison, 2006). Hypothetical bias is also a reflection of consequences arising from the hypothetical question. It raises a question whether individuals are answering strategically in the CE. Moreover, individuals may anchor on their current choice[12]. Although some studies suggest that hypothetical bias is an issue in CEs (Lusk & Schroeder, 2004), the literature does not provide conclusive evidence-based support for the existence of hypothetical bias (Carlsson & Martinsson, 2001; Fifer et al., 2014). Thus, hypothetical bias is a fruitful topic for future research (see Section 4.3).

Another important limitation is related to choice heuristics. Choice heuristics usually arise from individuals applying simplified decision rules to reduce the cognitive burden in the survey (DeShazo & Fermo, 2002; Kahneman & Tversky, 1979)[13]. The accumulating empirical evidence suggests that individuals may exclude choice alternatives and attributes, pay different degrees of attention to attributes, or impose thresholds to attributes in the CE (Campbell, Hutchinson, & Scarpa, 2008; Campbell, Hensher, & Scarpa, 2012; Doherty, Campbell, Hynes, & van Rensburg, 2013; Hensher, 2010; Scarpa, Zanoli, Bruschi, & Naspetti, 2013). Furthermore, some individuals may also always choose the status quo (or nonstatus quo) alternative in the experiment (Oehlmann, Meyerhoff, Mariel, & Weller, 2017; Scarpa, Ferrini, & Willis, 2005). Individuals may also lack experience with the investigated topic that may lead to errors in choice behavior (LaRiviere et al., 2014). Johnston et al. (2017) instruct that these response anomalies should already be addressed during survey design and pretesting. If these effects are found to persist, they should be investigated as part of the data analysis. In essay I, the exclusion of choice alternatives is taken into account in the choice analysis.

Follow-up or supporting questions can be useful in helping researchers understand the validity of the responses (e.g., protest responses) and choice consistency (e.g., labeling effect, attribute non-attendance, or choice randomness). This information may then be used to make ex post adjustments to econometric specifications to enhance the validity of the CE (Johnston et al., 2017). However, understanding that consideration must be given to whether these variables are endogenous to valuation responses is important if this information is used as covariates in the choice models (Czajkowski, Vossler, Budziński, Wiśniewska, & Zawojska, 2017; Dekker, Hess, Brouwer, & Hofkes, 2016). This topic relates to all

[12] This issue is likely present in the heating system CE.

[13] Choice heuristics are also present in revealed preference choices in real markets.

of the essays. Protest responses have been identified based on follow-up information in essay III. Moreover, information from supporting questions has been used as part of the data analysis in essays I and II.

Limitations also exist related to econometric specifications. The G-MXL model (used in essay II) has been criticized by asking whether separately identifying both unobserved preference and scale heterogeneity is possible (Hess & Rose, 2012; Hess & Train, 2017). As described by Hess and Train (2017), scale heterogeneity is a form of correlation among utility coefficients by which the coefficients of all included variables are larger in magnitude for some individuals than others. However, if all parameters change in parallel, the scale likely changed and not the marginal utilities of all attributes. Although we cannot disentangle scale and preference heterogeneity in any framework, the G-MXL provides us with a separate parameter that captures simultaneous changes in all preference parameters that may be interpreted as scale. However, the use of the G-MXL model requires considerable effort to test alternative specifications and ensure convergence to a global maximum. Scaling all of the utility coefficients (including the ASC) is also important to allow for scale heterogeneity (see also Hess & Train, 2017).

3 Summary

3.1 Essay I: Household preferences of hybrid home heating systems – A choice experiment application

The residential heating sector and the technologies used are changing (Vihola & Heljo, 2012). Although relying primarily on one heating system has traditionally been common, households are now beginning to utilize a combination of complementary heating technologies as a result of technological advances. This emerging trend warrants our study of innovative hybrid home heating systems (HHHS) and of household views of these technologies. Such analyses are needed because knowledge of household preferences facilitates the promotion of HHHSs. Note that this study is one of the few to investigate the determinants of households' adoption of HHHSs that simultaneously accounts for the effect of both main and supplementary heating systems in decision making.

We use CE to analyze individuals' preferences for the characteristics of HHHSs. Heating system scenarios are designed to represent the most relevant main and supplementary heating alternatives of today in Finland. The labeled choice sets have six main heating system alternatives: district heat, solid wood, wood pellet, electric storage heating, ground heat pump, and exhaust air heat pump. These alternatives are further described using five attributes: supplementary heating systems, investment costs, operating costs, comfort of use, and environmental friendliness.

The final survey occurred in August 2014 and was executed through a mailed questionnaire. Two thousand Finns were selected from the civil registry's (Population Information System of Finland) database. This sample was randomly drawn from a group of homeowners whose new detached houses were finished between January 2012 and May 2014. We received a total of 432 completed questionnaires, resulting in a response rate of 21.6 percent.

The following results are based on the MXL model estimations. The results indicate that heat pump technologies (i.e., ground heat pumps and exhaust air heat pumps) have become prominent in the residential heating market. The ground heat pump is the most popular main heating system, whereas district heating is the second most popular alternative. Several possible reasons exist for the popularity of heat pump technologies and district heating. Our results indicate that both comfort of use and environmental friendliness factors are important when choosing these systems. However, the results show that district heating is relatively sensitive to increases in operating costs, whereas ground heat pumps are relatively sensitive to increases in investment costs.

Solid wood-fired heating is found to be a relatively popular main heating alternative. The least favored main heating alternatives are the wood pellet boiler and electric storage heater. Our results suggest that wood pellet choices are strongly affected by the label rather than by the attributes. Thus, wood pellet heating systems likely present more intangible factors than other heating systems. Regarding electric storage heating systems, high annual operating costs associated with this alternative likely render this system less popular.

A discussion of respondent preferences for supplementary heating systems is pivotal in this essay. We investigate solar panel and solar water heater combinations, outside air heat pumps, and water-circulating fireplaces. The results show that the respondents favorably view combined solar panel and solar water heater systems and outside air heat pumps. The water-circulating fireplace is the least-favored supplementary heating alternative. Interestingly, the results reveal persisting views and habits regarding suitable supplementary heating alternatives for electric storage heating. Only outside air heat pumps positively affect electric storage heating choices, whereas the other main heating alternatives are supported by at least two of the examined supplementary heating alternatives.

When considering the remaining attributes, increasing investment and operating costs reduce the probability of corresponding heating system selection, as expected. The comfort of use variable emerges as a highly significant factor that affects the heating system choices, especially when comfort of use levels decline from good to satisfactory. The respondents also consider environmental aspects when making decisions, even though ecological differences between heating alternatives are quite minor in the case of HHHSs.

Socio-demographic variables serve as important determinants of household heating system decisions. We find that the living environment is often correlated with heating system decisions. More specifically, solid wood and ground heat systems are more popular in rural areas. The results also show that older individuals are more willing to adopt electric storage heating systems and that a higher level of education decreases the probability of exhaust air heat pump and solid wood heating selections. Not surprisingly, the solid wood heating selection is positively affected by forest ownership, and the ground heating (associated with relatively high investment costs) selection is correlated with higher income levels.

3.2 Essay II: Linking perceived choice complexity with preference heterogeneity in discrete choice experiments: home heating in Finland

Decision making in CEs involves respondents in comparing options described in terms of attributes and attribute levels and making trade-offs between these attributes. According to random utility theory, individuals make choices between options based on the utility they obtain from the attributes used to describe these options but with a degree of randomness (Thurstone, 1927). The random component of utility can be interpreted either as partly random choices from the perspective of the individual making that decision or the random part can result from the inability of the economist to measure everything that determines choices. Randomness from either perspective seems likely related to the complexity of the choice process.

Choosing a specific heating system is a complex and difficult decision for homeowners (Decker & Menrad, 2015). Difficulties arise from the fact that an investment in a heating system is made only occasionally (for example, made only once every 20 years) and is a significant expenditure for most households. More importantly, a wide array of heating technologies with different characteristics (e.g., price factors, comfort of use aspects, and ecological and technical issues of the heating systems) exist that one can consider carefully before purchasing. We include multiple heating technologies and attributes in our CE design. As a result, the choice tasks are rather complex.

It is reasonable to speculate that some individuals find the choice tasks in our survey more difficult than others. We can hypothesize that a higher level of perceived complexity leads to a decrease in choice accuracy, i.e., an increase in choice randomness. This hypothesis can be tested provided that one has measures of choice set complexity as perceived by the respondent.

This study explores the link between perceived choice complexity and choice randomness. We make novel use of respondents' self-evaluated factors concerning choice complexity and test their effects on the estimated randomness in the choices made. To our knowledge, this way of explaining choice consistency using self-evaluated complexity covariates has not been done in CE studies.

The results are obtained using the G-MXL model. We find that individuals who report that answering the choice tasks is difficult have less deterministic choices; that is, the mean scale decreases as perceived difficulty increases. Furthermore, if respondents report that unrealistic choice alternatives made answering more complicated, they seem to have a lower mean scale. We also allow for the variance of the individual scale to differ across respondents. The results suggest that respondents who find choice tasks unrealistic (and, hence, more complicated) have lower scale variance and, thus, are more similar to each other in terms of their randomness.

Regarding welfare analysis, our results indicate that explicitly accounting for perceived choice complexity does not seem to affect preference parameters to a significant degree in this dataset. This finding indicates that, at least in this dataset, the bias resulting from failing to account for choice complexity may be small for welfare estimates.

3.3 Essay III: Towards flexible energy demand – Household preferences for dynamic contracts, services and emissions reductions

Whereas demand side flexibility is increasingly studied (Broberg & Persson, 2016; Dütschke & Paetz, 2013; Richter & Pollitt, 2018), according to our knowledge, no studies exist on a household's willingness to participate in a demand response that simultaneously considers the effects of alternative pricing schemes, direct load control, required compensations, and potential emissions reductions. This study is also one of the first to provide information on household preferences for power-based distribution tariffs and to determine consumers' WTP for power system level emissions reduction that results from the demand response.

The CE of this study covers several important aspects of demand side flexibility. In each choice task, the respondent is provided with three choice alternatives. One of the alternatives corresponds to the benchmark situation, that is, the status quo, without flexibility characteristics, whereas the two other alternatives present possible scenarios with flexibility characteristics. The choice alternatives are described by six attributes: electricity distribution contract, electricity sales contract, remote load control of heating, remote load control of electricity use, potential system-level emissions reductions, and annual monetary savings (i.e., reduction in annual energy bill).

The final survey took place in October 2016 and was executed by sending a mail invitation with instructions on how to respond to the Internet survey. The survey was targeted at Finnish homeowners, of whom four thousand were randomly drawn from the civil registry's (i.e., Population Information System of

Finland) database. We received 380 responses to the final survey, resulting in a response rate of 9.5%.

The results are based on the MXL model in the WTP space, which accounts for correlation between the random parameters. The results show that respondents require, on average, a 78€ [±14€] reduction in their annual electricity bill to choose RTP over fixed price. This finding indicates that uncertainty in the monthly energy bill is linked to considerable discomfort. This finding may also reflect the degree to which individuals are, on average, willing to adjust their electricity consumption in response to changes in electricity spot price. Regarding electricity distribution contracts, the two-rate tariff is associated with close to a significant 33€ [±21€] compensation requirement. The WTP for PBT is not significantly different from zero, suggesting that respondents may be indifferent between fixed-rate and power-based tariffs. Therefore, some room likely exists in the market for new dynamic distribution fees.

The results reveal that respondents' sensitivity to restrictions in electricity usage is greater than comparable restrictions in heating. Considerable differences also exist in their perceptions of load control in the morning and the evening. The greatest disutility is attached to constraints imposed on both heating and electricity load controls in the evening. The required annual compensation from electricity load control is 199€ [±26€] in the evening and 54€ [±17€] in the morning. One possible explanation for this finding is that everyday household tasks (e.g., doing laundry and dishes) are usually done in the evening. The required compensations for accepting load control in heating are 80€ [±21€] and 58€ [±17€], respectively. These values indicate that many households accept in principle the load control in heating, at least within tight bounds. The load control in heating offers flexibility by sacrificing only a little comfort of living.

The results show that as emissions reductions and annual savings increase, the probability of choosing respective alternatives increases among the respondents. Respondents are willing to pay on average 79€ [±27€] annually for a 10% emissions reduction and 133€ [±15€] for a 30% emissions reduction. This finding demonstrates that, on top of monetary savings, another value-creating element also exists that increases demand side flexibility.

To investigate preference heterogeneity, we introduce interactions between the status quo and other covariates. Doing so enables us to examine the respondent characteristics that affect the choice between inflexible and flexible alternatives. From sociodemographic covariates, the choice probability of the status quo is higher among low-educated households and people who are younger than 60 years old. This finding suggests that highly educated and older households are more willing to participate in flexibility than low-educated and younger households. From other characteristics, we find that a positive perception of an RTP contract (i.e., the respondent has RTP or has considered such a contract) is associated with a higher probability of choosing flexibility alternatives. This finding indicates that understanding the potential benefits of dynamic pricing is likely linked to a stronger willingness to participate in demand side flexibility. We also test several other intuitively relevant factors that are not found to be significant. The findings imply that respondents' gender or income do not explain their choices. In addition, respondent's living environment and dwelling characteristics (such as heating system) do not have explanatory power.

4 Discussion and conclusion

4.1 Policy implications

A number of policy implications can be derived from essay I when we consider what policymakers should do to encourage individuals to invest in energy efficiency. The findings indicate that policies supporting the adoption of supplementary heating systems could be effective because households appear to view them favorably, although many of these systems have yet to reach their market potential. In particular, solar-based heating could be a main policy target because it is the most favored supplementary heating alternative. Furthermore, taxation and subsidy planners should consider the fact that the investigated main heating systems differ considerably in terms of the direct and cross marginal effects of investment and operating costs. Policies that target operating costs may appear more effective because households are more sensitive to changes in operating costs than to changes in investment costs. However, because investment cost subsidization is likely simpler than operating cost subsidization and/or taxation, our findings suggest that investment cost subsidies for heat pump technologies and district heating are likely effective.

The empirical analysis also illustrates the importance of careful marketing and policy targeting because socio-demographic characteristics clearly affect household heating system decisions. Moreover, not all combinations of main and supplementary heating systems are equally likely to be chosen. Additionally, the environmental features of heating systems should be leveraged in policy planning and marketing strategies because households appear to consider them. Policymakers should cite environmental factors when implementing different policies and when promoting heating systems. Furthermore, well-designed regulations and guidelines of Finnish building authorities seem positively linked to household heating system decisions. However, a need remains for informative and objective heating system consultation because many households claim that inadequate valid information is available on HHHSs. While some households are becoming more familiar with these technologies, the development of information provisions is of vital importance.

Whereas essay I focuses on heating investments, essay III concentrates on demand response solutions. The findings show that households are willing to participate in smart load control services but, at the same time, require compensation for the associated discomfort. The findings imply that the load control of heating is likely low hanging fruit because the required compensations are moderate and distinctly lower relative to the respective compensations for the load control of electricity usage[14]. Regardless of the potential interest in direct load control services and smart meter infrastructure, the market penetration of smart home technologies has been rather low in practice. Arguably, the lack of reasonably priced automated home technologies explains the slow adoption of demand response programs (Nolan & O'Malley, 2015). Given that demand side flexibility brings clear system-level benefits, such as a higher utilization rate of existing capacity and more efficient use of variable renewable energy (Huuki et al., 2017), considering whether the costs of these technologies should be covered by energy companies or whether society should cover part of the costs is important.

When observing different dynamic pricing alternatives, the RTP has not gained considerable market share even though they have been available for residential customers for some years. The findings imply that risk aversion and difficulties in understanding the contracts may explain the low participation in RTP (see also, Hobman et al., 2016). This implication indicates that energy companies should make dynamic contracts even simpler and more customer friendly. Price-related risks can be at least partly reduced by utilizing smart automated home technology, which manages price information and load. From the electricity distribution perspective, the findings suggest that homeowners perceive the share of the distribution price in the total electricity bill to be too high. This perception may be realized as a willingness to accept new types of distribution contracts, such as PBTs. Furthermore, the findings show that emissions reductions are highly valued among households and may activate households to participate in demand side flexibility. Nevertheless, only a limited amount of electricity contracts are available on the market that provide real incentives to change consumption patterns based on environmental information (such as real-time emissions; see Karhinen, Huuki, & Ruokamo, 2018). Hence, energy companies should further develop their offerings to meet their customers' needs.

[14] Space heating also corresponds to a considerable share (around 70%) of the total residential energy consumption (Official Statistics of Finland, 2016) and, hence, has the highest potential for demand side flexibility.

4.2 Methodological implications

Speculating that some individuals may find CEs more difficult than others is reasonable. Essay II explores whether a failure to acknowledge choice complexity in the CE modeling processes induces biases in preference parameters and the associated welfare analysis. The findings imply that choice complexity is a multidimensional phenomenon and is likely present in CEs. However, the bias resulting from failing to account for choice complexity in the choice model may be small for welfare estimates (at least in this dataset). Hence, the recommendation is to mitigate the choice complexity in the design phase and assure through careful pretesting that the CE is well-understood by respondents. Moreover, the modeling techniques that aim to account for choice complexity should be developed in a way that individual-level differences are better considered. Furthermore, to differentiate the choice complexity from choice uncertainty, separate assessments should be conducted. Also, making the complexity assessment after each choice task would be important.

An efficient and unbiased estimation of WTP is among the primary goals of CEs. As Johnston et al. (2017) state, achievement of this goal can be threatened by unsuitable and inappropriate model specifications and incorrect assumptions. These specifications and assumptions include, for example, imposing a fixed coefficient for the monetary attribute or assumptions yielding WTP distributions, which do not have finite moments (Daly et al., 2012). Essay III demonstrates that modeling WTP estimates is sensitive for the model specification. More precisely, not accounting for the correlation between random parameters may significantly affect the WTP estimates. Thus, careful consideration must be given to whether models without correlations yield reliable WTP estimates.

4.3 Future research

The topics of this thesis open important new paths for future research. One possible research topic is to investigate household preferences of hybrid heating in countries other than Finland. Market share analysis and simulating the uptake of heating systems under different policy stimuli and cost structure changes would also be interesting topics for future research. In addition, studying household preferences in a context where new heating technologies replace the old capital stock needs more attention. Generally, determining the potential of hybrid heating and investigating in detail the barriers that slow the adoption of these solutions are important.

Moreover, future research areas consist of investigating household preferences for demand side flexibility in broader contexts and real-life experiments. It should be also noted that the financial incentives for consumers to participate in demand response are very often inadequate. Hence, studying consumer preferences for flexibility operators (i.e., aggregators or virtual power plants) is important because these new market players may combine several households and enter markets with higher potential financial benefits.

From the methodological viewpoint, investigating how households' actual heating system choices are reflected in their hypothetical choices would be interesting. The heating data allow us to investigate whether the set of considered labeled heating alternatives in the choice task (i.e., consideration set) is explained by respondents' actual heating system choices. We also have information on how satisfied respondents have been with their heating systems. In turn, we can further explain their consideration sets using this self-reported satisfaction. These analyses would shed light on a hypothetical bias, a condition whereby individuals answering surveys respond in a manner other than they would if faced with similar choices in real markets.

In addition, modeling the link between choice consistency and choice complexity can be further developed. Although we treat the self-reported complexity covariates as error-free measures in essay II, these covariates are likely latent. A possible topic for future work is to use the fairly new Hybrid Choice Models (HCMs) (also known as integrated choice and latent variable models) to further investigate the link between perceived choice complexity and choice consistency (Czajkowski et al., 2017; Hess & Stathopoulos, 2013; Walker & Ben-Akiva, 2002). HCM controls for the endogeneity of perceptions (and attitudes) in a manner that differs from simply including them as explanatory variables in traditional choice models. These latent variables differ from socio-demographic variables because the former cannot be observed directly[15].

[15] Attitudes and perceptions are latent variables that are typically measured on a Likert scale. These responses are then used as indicators for underlying latent attitudes (Walker & Ben-Akiva, 2002). Moreover, attitudes and perceptions may once again be explained by socio-demographic characteristics (Daly, Hess, Patruni, Potoglou, & Rohr, 2012).

4.4 Concluding remarks

Energy consumption, energy efficiency investments and pro-environmental actions involve individual decision making and behavior. However, the literature shows that individuals do not always choose the welfare-maximizing outcome (Frederiks, Stenner, & Hobman, 2015; Kahneman, 2003). Pollitt and Shaorshadze (2011) discuss the role of behavioral economics [16] in energy policy and state that policymakers should intervene and attempt to induce welfare-maximizing outcomes. Such an intervention could be done, for instance, through setting appropriate choice sets, proper framing, and providing appropriate default options. The power of default is present in both individuals' heating system choices and participation in demand side flexibility. Finnish building guidelines set the default heating alternatives to cover efficient heating solutions (i.e., individuals are guided to choose other than oil or direct electric heating). The findings of this thesis and the market observations support the fact that individuals are increasingly choosing the efficient alternative. In contrast, the default related to demand response solutions is still the inflexible alternative (i.e., fixed-rate pricing and no remote load control) that is clearly reflected in the results of this thesis and the real markets.

Consumers' unwillingness to participate in demand response may also be explained by the fact that information search is costly and understanding dynamic pricing contracts or smart home technologies is difficult. On top of this, the underlying product—electricity—is homogenous and the input is not consumed directly[17]. Further, because electricity comprises only a modest share of household budgets, for households not to invest the time and effort in changing their electricity consumption behavior may be rational. These points highlight the need for easily accessible and understandable contracts and services.

Although this thesis uses data from Finland, the findings can be used as guidelines for applying policies in other countries. Finland's residential heating sector can serve as an example for other countries as more energy efficient structures are developed. Proper legislation, clear guidelines, high-quality building supervision, and information sharing serve as key elements to achieving a greener residential heating sector. The residential heating sector is likely moving toward utilizing combinations of different heating alternatives. As buildings' energy performance increases in importance, flexible hybrid heating can provide notable

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[16] In contrast to traditional neoclassical economics, which assumes rational, utility maximizing behavior from individuals, behavioral economics accounts for irrational aspects of decision making.
[17] Electricity provides services for individuals; that is, it allows us to do laundry or watch television.

energy efficiency gains. Flexible HHHSs are suitable solutions for smart homes with integrated heating, electricity, and ventilation systems. In turn, HHHSs also complement demand side flexibility solutions.

Overall, flexibility and energy efficiency are key elements in the transformation into a decarbonized energy sector. This thesis demonstrates that marketing strategies and policies targeting the residential sector must be designed to identify essential determinants of energy good and service adoption and to account for taste variations among consumers. Motivating consumers seems to require a combination of technological, monetary, and environmental incentives.

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