Department of Economics

Essays on Households' Technology Choices and Long-Term Energy Use

Anna Sahari

Aalto University

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Essays on Households' Technology Choices and Long-Term Energy Use

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Abstract

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Abstract

This thesis consists of three essays on households' choice of heating technology at the moment of building a new detached house. The analyses make use of Finnish administrative registry data to study how sensitive these investments are to electricity prices and how socio-demographic characteristics of households are related to technology choices. The data link each new house to the house owner as well as local electricity prices. Identification of price impacts is based on cross-sectional variation in the price of electricity distribution.

The first essay focuses on the binary choice between central heating or direct electric heating. The latter technology fixes electricity as the source of heat whereas central heating can accommodate different energy sources. The results show that the choice of electric heating technology is sensitive to electricity prices, implying that consumers do account for future operating costs at the investment stage. The elasticity of technology choice with respect to distribution costs of electricity is estimated to be -0.63 at the average price level.

The second essay estimates households' willingness to pay higher investment costs in order to obtain reductions in the lifetime costs of heating. This essay introduces additional data on investment costs and the heat consumption of houses, and evaluates sensitivity to total annual heating costs. The results show that there is considerable heterogeneity in the valuation of future energy costs across builders, and this variance is not captured if random coefficients are used to account for heterogeneity. The estimated WTP-values are consistent with reasonable discount rates averaging 8 to 10 percent.

The third essay considers the full range of technologies available, and links household characteristics to technology choices. The findings indicate a strong importance of upfront costs and annual costs for the investment decision. Increasing electricity prices induce substitution from electric heating into wood heating and ground heat. Consequently, the CO_2-emissions from heating energy production are reduced. The results suggest that some households are constrained in their ability to pay high investment costs associated with more efficient technologies. Furthermore, previous experience of house ownership is an important determinant of the technology choice, implying there may be information asymmetries between the households.

Keywords elasticity, electricity, households, discrete choice, energy

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Tiivistelmä

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Väitöskirjan nimi
Esseitä kotitalouksien investoinneista energiaa kuluttavaan teknologiaan

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☐ **Monografia** ☐ **Artikkeliväitöskirja** ☒ **Esseeväitöskirja**

Tiivistelmä
Tämä väitöskirja koostuu kolmesta esseestä, jotka käsittelevät lämmitysjärjestelmän valintaa uusissa omakotitaloissa. Tutkimuksessa selvitetään kuinka herkkiä investointipäätökset ovat sähkön hinnoille, sekä kuinka kotitalouksien ominaisuudet liittyvät lämmitysteknologian valintaan. Analyysissä hyödynnetään suomalaista rekisteriaineistoa, joka yhdistää uuden rakennuksen talon omistajan tietoihin sekä paikallisiin sähkön hintoihin.

Ensimmäinen essee tarkastelee valintaa suoran sähkölämmityksen ja vesikiertoisen lämmityksen välillä. Ekonometrisen analyysin tulokset osoittavat, että sähkön siirtohinta vaikuttaa merkittävästi suoran sähkölämmityksen valintatodennäköisyyteen. Kuluttajat siis osaavat huomoida tulevaisuuden lämmityskustannukset tehdessään investointipäätöksiä. Suoran sähkölämmityksen kysyntäjousto sähkön siirtohinnan suhteen on -0.63 siirtohintojen keskitasolla.

Toisessa esseessä estimoidaan kotitalouksien halukkuus maksaa korkeampia investointikustannuksia säästääkseen vuosittaisissa lämmityskuluissa yli ajan. Rekisteriaineistoa täydennetään arvioilla lämmitysjärjestelmien investointikustannuksista sekä uusien talojen odotetusta lämmönkulutuksesta. Tulosten mukaan maksuhalukkuus vaihtelee huomattavsti yli kotitalouksien, ja tämän tunnistaminen vaatii kotitalouskohtaisia havaintoja; vaihtelu ei nouse esille simulaatiohin perustuvassa tilastollisessa analyysissä (random coefficients logit). Maksuhalukkuudesta johdettu investointikohtainen korkotaso on keskimäärin 8-10 prosenttia.

Kolmannessa esseessä tarkastellan teknologiavalinnan yhteyttä kotitalouden havaittuihin ominaisuuksiin. Tulosten mukaan sekä investointikustannukset että vuosittaiset lämmityskustannukset ovat merkittäviä investointipäätöksen tekijöitä. Sähkön hintojen nousu siirtää kysyntää sähkölämmityksestä etenkin maalämpöön ja puulämmitykseen, minkä seurauksena lämmitysenergian tuotannosta aiheutuvat CO_2-päästöt vähenevät. Tulokset viittaavat siihen, että osa kotitalouksista ei voi investoida haluamaansa järjestelmään korkeiden investointikustannsten takia. Lisäksi aiempi kokemus talon omistamisesta vaikuttaa vahvasti investointipäätökseen, mikä voi olla osoitus epäsymmetrisestä informaatiosta talon rakentajien kesken.

Avainsanat sähkö, kysyntäjousto, kotitaloudet, energia

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Helsinki, February 28, 2017,

Anna Sahari

Contents

List of Essays

This thesis consists of an introduction and the following essays.

1. Households' Technology Choices and Long-Run Energy Price Sensitivity. *Unpublished manuscript.*

2. Household Heterogeneity in Willingness to Pay for Energy Cost Reductions. *Unpublished manuscript.*

3. Determinants of Households' Heating Technology Investments. *Unpublished manuscript.*

Introduction

Energy production and consumption result in pollution externalities which contribute to global climate change. To mitigate climate change, and to reduce reliance on imported energy, the European Union has set ambitious targets for reducing energy use. According to the EU 2030 energy strategy, the Union is to use 27% less energy by 2030 compared to a business-as-usual scenario.

Households' energy consumption forms a large share of total energy use in developed countries; according to Eurostat, residential energy accounts for 25 percent of total energy consumption in the EU. Consumers' decisions about which appliances to purchase, what type of car to drive and how to insulate their home shape the stock of energy-using durable goods and determine the overall level of household energy demand. Several policy measures target these investment decisions. These include fuel economy standards in the US, bans on incandescent light bulbs both in the US and EU, mandatory energy efficiency labels for appliances and buildings in the EU, and targets for increasing the amount of smart electricity meters in the EU.

Such policy measures bring about several questions relevant to academic researchers. What are the market failures which the policies aim to correct? If such failures exist, are they large enough to warrant the market interventions? That is, do the current policies pass a cost-benefit test? What would be an optimal policy measure? Answering these questions requires empirical research on consumers' investment into energy-using durable goods and on the consumption of energy by households.

This dissertation aims to advance knowledge on the existence and magnitude of investment inefficiencies. The analysis relies on high-quality administrative registry data on an important investment: the choice of heating technology in new residential detached houses. The main contribution of the dissertation stems from two features of the data: the detailed information on the households making the investment decisions, and the measure of electricity prices which explicitly differentiates between the short-term and long-term prices. Observing these prices separately alleviates the problem of measurement error related to long-term price expectations. The comprehensive set of observable household characteristics allows evaluating how the possible investment inefficiency is distributed across individuals.

There are several reasons that could lead to an investment level that is not privately or socially optimal. Consumers may lack information on the energy consumption of products, and thus be unaware of the potential savings from purchasing more efficient goods. This can be studied by seeing how increased information changes observed or stated purchase behaviour (Allcott and Taubinsky, 2015; Newell and Siikamäki, 2014). There could be financial constraints that prevent investment. Especially in buildings, energy efficiency improvements typically require large up-front costs, while the savings accrue slowly over a long period of time in the form of reduced energy consumption. If households lack funds to invest and cannot secure a loan, investment levels could end up being too low. Such credit constraints are likely to exist to some extent, but empirical evidence is scarce due to lack of data (Palmer, Walls and Gerarden, 2012).

Finally, the level of investment could be too low if consumers are inattentive to the costs of using a durable good. In this case, the investment cost that is paid immediately will gain too much weight in decision making, even though lifetime operating costs often form a larger share of the total costs of a durable good. Such inattention could result from several types of biases, classified by Allcott, Mullainathan and Taubinsky (2014) into: salience bias, biased beliefs, endogenous inattention and present bias. An extensive literature has formed around investigating whether inattention to operating costs prevails. Though different empirical approaches are employed, the question all these studies fundamentally aim to answer is the following: are consumers willing to pay €1 in immediate investment costs to obtain savings of €1 in present value lifetime operating costs. If the willingness to pay is less than €1, consumers undervalue lifetime operating costs, and investments into energy efficiency will not be at the optimal level.

1 Consumers' investment decisions: theoretical framework

To illustrate the factors relevant to long-term investments, consider the choice situation faced by a consumer purchasing an energy-using durable good. There are J options available, and each option has purchase price P_j and an efficiency factor e_j. Denote the other attributes of the product by A_j. The consumer's expected energy consumption level is m. For simplicity, assume that the different options of the good have the same energy price p. The consumer's utility from purchasing option j is a function of prices, product attributes and the level of consumption:

$$u_j = \beta(P_j + \sum_{t=0}^{T} \delta^t p_t e_j m) + A_j + \epsilon_j$$

where δ is the discount factor and the energy price is indexed by time t to account for differences in expected future price levels. The consumer will choose option j if

$$u_j > u_k, \forall j \neq k$$

This is the underlying choice problem in consumers' purchase of durable goods. If consumer-level data is not available, the individual choice problem can be aggregated up to derive a specification estimable on market-level data (as in Allcott and Wozny, 2014). If individual-level observations are available, a discrete choice model can be estimated to provide estimates of the parameters of the utility function (for example Hausman, 1979; Newell and Siikamäki, 2014).

2 Empirical challenges

There are certain aspects of the utility specification defined above which will pose challenges to empirical work. To see this, rewrite the utility function in more detail to explicitly incorporate individual-level factors, denoted by i:

$$u_j = \beta_i(P_j + \sum_{t=0}^{T} \delta_i^t p_t e_j m_i) + A_{ij} + \epsilon_j$$

The valuation that consumers place on costs, β_i will vary across individuals. If individual-level data is available, this can be accounted for by making the coefficient a function of observable characteristics. Alternatively, simulation techniques can be used to estimate parameters of the distribution of β. The level of utilisation m_i will also vary, due to differences in the use of products. Again, this can be accounted for if sufficient data is available.

The individual-specific variation in discount factors can be more problematic. Consumers' discount rates will vary because people have different personal time preferences and because the financial discount rate they apply to the investment is likely to depend on individual-specific factors, such as income and credit risk. Also the lifetime of the investment T could be individual-specific. If the consumer does not hold the product for its whole lifetime, it can typically be sold (this is the case at least for cars and home improvements). If markets correctly price the goods, the initial investment will be capitalised into the resale price, and consumers can rely on recovering the full value of their investment. However, if markets fail in pricing, or if consumers expect markets to fail, the relevant lifetime to each consumer will be the time they personally expect to use the good.

Disentangling the impacts of lifetimes from discount rates can be challenging. Identifying personal discount rates requires experiments (for example Harrison, Lau and Williams, 2002), observations from a setting with explicit intertemporal monetary tradeoffs (Simon, Warner and Pleeter, 2015) or dynamic structural estimation (for example Yao, Mela, Chiang and Chen, 2012). Information related to durable good purchases typically does not allow using these methods so that the correct personal discount rate could be assigned to each individual in the data. An exception is the study of Newell and Siikamäki (2014), where the authors separately elicited personal discount rates via an experiment, and used this information to evaluate the results of the choice experiment concerning water heaters. They found that personal discount rates varied widely across experiment participants, and that using these discount rates produced higher willingness to pay for energy cost savings than if a common discount rate was assumed.

The result that assuming homogeneity across consumers biases valuation of future fuel costs downwards has been shown analytically and using simulation by Bento, Li and Roth (2012). Acknowledging consumer heterogeneity is also important in policy evaluation and design. For example, Grigolon, Reynaert and Verboven (2014) show using data on European car markets that introducing heterogeneity changes the results and policy implications drawn from the analysis. Allcott, Mullainathan and Taubinsky (2014) analyse optimal policy analytically and through simulation examples, and conclude that optimal policy design requires targeting those consumers who are most subject to biases. The welfare effects of policy, and the importance of consumer heterogeneity, is further studied in Allcott and Taubinsky (2015) by using data from randomised experiments.

The longevity of durable good investments poses another challenge in addition to consumers' perceptions of time. Namely, the total cost of the investment will depend on future energy price levels, which are unknown. Information on consumers' price expectations is rarely available, and therefore researchers must rely on current prices when forming expected lifetime costs. There is evidence on gasoline price expectations showing that indeed consumers expect the future price to equal today's price (Anderson, Kellogg and Sallee, 2013). This alleviates the concern that current prices would give very biased measures of expected future costs. However, the validity of the assumption of stable prices is still likely to be context-specific and will depend on the fuel and market considered.

A final issue related to investment decisions is the timing of investment; it may be endogenous to developments in energy prices and energy efficiency. This is especially true for purchases which are not absolutely necessary, such as upgrading an air conditioning unit or washing machine. Given that the price of energy efficiency has declined rapidly over time (see Rapson, 2014, for illustrations), it is possible that some consumers choose to delay investment in order to get more efficiency at lower cost. This type of sensitivity to prices and energy consumption is not captured if dynamics of the investment decision are not explicitly modelled. Rapson (2014) provides evidence on the importance of this issue by estimating a dynamic structural model of demand for air conditioners. He finds air conditioner purchase to be very sensitive to past developments in energy efficiency, suggesting that consumers are aware of the importance of future operating costs at the time of purchase.

3 Contribution of the dissertation

This dissertation consists of three essays which all analyse household investment into durable energy-using goods. The investment considered is the heating system in detached residential houses, and this choice is studied at the time of building a new house. The data on new buildings and the households acting as builders are drawn from Finnish administrative registries. The full data include an annual 90% random sample of all new residential detached houses built in Finland during 2000-2011.[1] The houses

[1] Statistics Finland does not grant access to full samples of individual-level data.

are linked to the owner and the owner's spouse using the personal identity number. Individual-level variables are drawn from Statistics Finland registries, and these include variables such as income, education, family size, profession and age. The base data include 109 289 observations of new houses and the households who own them.[2]

The house data are supplemented with information on electricity prices, provided by the Energy Authority. This authority maintains a record of all contracts offered by retailers on the deregulated retail market. In addition, the Energy Authority records distribution fees set by local distribution system operators. Distribution of electricity in the low-voltage grid is a regulated activity monitored by the Energy Authority. The electricity and distribution prices are matched to each house based on the location defined by the postal code.

The quality of the data allows alleviating some of the challenges presented above. First, because all Finnish houses must be equipped with a heating system, it is not possible for households to delay investment. The timing is determined by factors such as availability of lots and funding, which are exogenous to energy prices or developments in energy efficiency of specific heating technologies.

Second, the range of options available is limited and the technologies are well-established. Heating technologies are not differentiated products, hence unobservable product characteristics are less of a concern in estimation.

Third, the extensive set of observable household characteristics allows incorporating consumer heterogeneity explicitly into the models. Investment behaviour can be analysed with respect to several important sociodemographic variables, which can give insight into the existence and magnitude of possible investment inefficiencies.

Finally, the information on electricity prices is exceptional in that it differentiates between the short-term and long-term price of electricity. The retail price is a short-term price. Households are free to choose their electricity retailer and can switch from one provider to another in search of lower prices. The reference price for the retail market is the Nordic spot price of electricity, which depends on market conditions and, to a large extent, on weather conditions. In contrast, the distribution fee is not a

[2]This data represents a 12 percent increase to the stock of detached houses. The stock of heating technologies, however, is also shaped by renovations to old houses. These retrofits are not registered systematically as new houses are, hence the data are not collectively available.

market price. It is compensation paid to the local grid operator for the service of distributing electricity. Distribution prices are based on costs of maintaining and operating the grid, and the cross-sectional variation in prices thus results from differences in grid characteristics. These include things such as length and type of cables, connections to the grid and the number of power cuts due to storms. These underlying cost determinants are stable, and therefore distribution prices change very little over time. This persistence makes distribution prices a relevant measure of long-term prices, and this is precisely the price which consumers should be sensitive to when making long-term investments.

4 Overview of the essays

The first essay studies the impact of electricity price on the choice of installing direct electric heating. The alternative to this technology is central heating, which can incorporate different sources of energy. Focusing on this binary choice is justified by the irreversibility of installing electric heating; in practice it is prohibitively costly to change the main source of heat if direct electric heating is installed. This setting thus captures an inherent structure of the investment decision. In terms of estimation it means that the usually restrictive assumption of logit models, proportional substitution across alternatives, actually applies. A binary setting also allows extensive robustness checks in the form of a linear probability model. Identification of price impacts is based on the cross-sectional variation in electricity prices. The extensive set of control variables includes house characteristics, household characteristics, annual time effects, regional effects and an indicator for building an urban versus a rural setting. A binary discrete choice model is estimated on the heating choice and results are used to produce estimates of the elasticity of demand for electric heating with respect to electricity price. This measures consumers' long run sensitivity to electricity price, as adjusting the level of electricity consumption typically happens through investing into more efficient energy-using durables. The elasticity is estimated to vary from -0.41 to -1.18 within the observed price range. The results are highly statistically significant and larger than those found in previous research.

The second essay estimates households' valuation of future heating costs. The measure of valuation is the willingness to pay higher investment costs in order to obtain reductions in the lifetime costs of the heating system. This essay introduces additional data on investment costs and the heat consumption of houses, and evaluates sensitivity to total annual heating costs, as opposed to electricity prices separately. The willingness to pay is estimated as a function of household characteristics in order to evaluate to what extent this measure varies across households, and to discover which variables have the highest impact on the valuation. The analysis is based on a discrete choice model, and the options considered are the three technologies which use electricity as the fuel: direct electric heating, water central electric heating and ground source heat pumps. The coefficients of the model are reparametrised to directly represent willingness to pay-values. The results show that the valuation of future heating costs varies significantly across builders. This variance is not captured if random coefficients are used to account for heterogeneity. The estimated willingness to pay ranges from €5 to €20 with a mean of €10. This implies that, on average, households are willing to pay 10 Euros more in investment costs to obtain savings of 1 Euro each year over the lifetime of the system. The level of willingness to pay is impacted especially by previous experience of house ownership, the presence of children and family size. Household income drives the extreme values obtained; the highest willingness to pay is estimated for households with exceptionally high income. In light of expected lifetimes of heating systems, these values of willingness to pay are consistent with discount rates of 7 to 10 percent on average.

The third essay considers the full range of technologies and fuels available, and relates household characteristics and electricity prices to investment choices in order to uncover the most relevant determinants of technology choice. The results are used to analyse the potential existence of investment inefficiencies, and the substitution across technologies in response to increases in electricity prices. The findings indicate a strong importance of upfront investment costs and fuel costs for the investment decision. Increasing electricity prices induce substitution from electric heating especially into wood heating and ground heat. The choice probability of wood heating increases notably at the highest level of electricity prices, and this effect is especially strong in rural areas where firewood is easily accessible. This substitution decreases the demand of electricity for heating purposes, and the results imply an elasticity of -0.35 for electricity demand. Consequently, also the CO2 emissions from electricity production are reduced, however the large shift into wood means that actual emissions do not decrease. Though households seem to be well aware of the importance of lifetime costs, the evidence suggests that some households may be constrained in their ability to pay high investment costs associated with more efficient technologies. In addition, previous experience of house ownership is an important determinant of the technology choice, suggesting there may be information asymmetries between the households.

5 Conclusions

This dissertation contributes to the literature on household behaviour with respect to long-term investments related to energy use. The analysis relies on extensive data which combine detailed information on individuals with accurate measures of long-term energy prices. The high quality of the data allows addressing two important issues: household heterogeneity and expectations of long-term energy price levels.

The results of this dissertation can be summarised as follows. First, the evidence drawn from observations on heating technology investments speaks for high sensitivity to energy prices at the investment stage. The results of the first and third essay especially show that households substitute away from electric heating as electricity prices increase. This effect is only visible for the distribution price of electricity; the retail price does not show up as a significant determinant of technology choice. This indicates that consumers understand the different nature of these prices and are able to base decisions on the relevant price measure.

Second, though on average the valuation of operating costs is high, this measure varies notably across households. The second essay illustrates that ignoring this variation will produce a biased estimate of the level of willingness to pay. Furthermore, capturing this variance requires explicitly incorporating household characteristics into the estimation.

Third, the results of the second and third essays on the impact of household characteristics on technology choice indicate the presence of certain investment inefficiencies. Households at the lower end of the observed income distribution are less likely to install a system with high investment costs and are estimated to have lower valuation of future operating costs. This significant impact of income, while controlling for education and the amount of debt, implies that credit constraints may be an issue for some households. Education has a large impact on the choice of heating technology, with highly educated home owners being more likely to choose the technology characterised by high upfront investment and lowest operating costs. This indicates that there may be biases related to understanding the importance of operating costs. Finally, households whose current dwelling is a detached house are estimated to prefer technologies which are prevalent in the existing stock of detached houses. This speaks for the importance of own experience in technology choice.

Overall, these findings imply that consumers are price sensitive, meaning that instruments such as energy taxes do have an effect on consumers' investment behaviour. The observed electricity price increases have induced substitution predominantly into technologies which rely on renewable energy sources. However, given that the evidence suggests the presence of investment inefficiencies, the introduction of new, energy-efficient technologies which are characterised by high investment costs and low lifetime energy expenses could be further accelerated by well-targeted policy measures.

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Households' Technology Choices and Long-Run Energy Price Sensitivity

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Abstract

This paper studies the impact of energy price on households' investment into energy-using capital. The analysis is based on detailed and extensive individual-level registry data on Finnish households' choice of heating technology at the moment of building a new house. Identification of price impacts is based on local, exogenous variation in costs of electricity. These costs include the retail price of electricity and the price of electricity distribution, matched to each house at the postal code level. The regulated distribution prices are strongly persistent at the local level, providing a good approximation for long-term energy costs. A discrete choice model is estimated on the heating choice and results are used to produce estimates of the elasticity of demand for electric heating with respect to the electricity price. This measures consumers' long run sensitivity to electricity price, as adjusting the level of electricity consumption happens through investing into more efficient energy-using durables. The elasticity is estimated to vary from -0.41 to -1.18 within the observed price range. The results are highly statistically significant and larger than those found in previous research. This high sensitivity to price speaks for forward-looking consumers as opposed to myopia.

Keywords: *Elasticity, Electricity, Discrete choice*

JEL codes: *D12, Q41*

1 Introduction

Aggregate energy demand is derived from the energy-consuming capital stock of firms and consumers. In the short run the stock is fixed, limiting the possibilities for adapting to higher energy prices. Adjustment to persistent changes in energy price levels happens over the long run, through investment into new technology (Atkeson and Kehoe, 1999; Linn, 2008).

Empirically evaluating the long-term price elasticity therefore requires looking into the investment decisions that determine the capital structure. This paper accomplishes exactly this task by analysing Finnish households' choice of heating technology at the moment of building a new house. The analysis is based on an exceptional dataset which combines individual-level registry data on individuals and the investments with local electricity price data. The price data explicitly differentiate the short-term and long-term price faced by consumers. The results indicate that households are highly sensitive to use costs at the investment stage. The elasticity of demand for electric heating technology with respect to electricity price is estimated to range from -0.41 to -1.18 depending on the electricity cost level.

This research is related to a strand of literature originating with the works by Hausman (1979) and Dubin and McFadden (1984). The issue of energy price sensitivity has again become topical, as concerns over climate change have brought energy use to the forefront of policy in the European Union and elsewhere. Reductions in consumption have been sought and encouraged especially through increased energy efficiency. This has raised the issue of the so-called "efficiency gap" (Allcott and Greenstone, 2012), which refers to underinvestment into energy efficiency due to consumers not fully accounting for lifetime costs at the point of purchasing energy-using durable goods. In the context of long-run price sensitivity, this type of myopia would imply low levels of price elasticity of demand.

Empirical work has sought to uncover consumers' energy price sensitivity by using observations on purchase of durables: heating and cooling devices, cars and appliances. The conclusions from these studies are mixed. For example, in the context of vehicles, Allcott and Wozny (2014) find evidence of undervaluation of fuel costs, while Busse, Knittel and Zettelmeyer (2013) and Sallee, West and Fan (2015) do not. Rapson (2014) studies air conditioner purchase, explicitly modelling the timing of investment and price expectations, and estimates the elasticity with respect to electricity price to be -0.30. The result is only weakly statistically significant, however, and relies on several sets of assumptions, which is indicative of the difficulties in estimating long-term effects. Jacobsen (2015) uses aggregate US data, and finds no significant relationship between state-level electricity prices and the share of energy efficient appliances, concluding that consumers do not respond to electricity prices when purchasing these goods.

Despite different empirical set-ups, all research in this field relies on the assumption that consumers use current energy prices as a measure for future energy prices. Another central issue is consumer heterogeneity. It is well known that heterogeneity plays a key role in energy use and, consequently, in the valuation of energy efficiency (Allcott and Greenstone, 2012; Bento, Li and Roth, 2012). Yet extensive consumer-level data is rarely available. For example, the research on fuel efficiency exploits at most millions of observations on car purchases, but information on the consumers buying the cars is not included (as in Allcott and Wozny, 2014, or Sallee, West and Fan, 2015) or can be used only at an aggregate level (Busse, Knittel and Zettelmeyer, 2013; Grigolon, Reynaert and Verboven, 2015). When household-level data is available, it often originates from surveys, which may suffer from limited sample size and issues related to the accuracy of reporting.

In this study, the data and the choice situation studied are such that many of the difficulties present in the evaluation of long-term investments can be overcome. First, the data are drawn from national administrative records, allowing for a large sample size and accurately measured variables. The data include detailed information on the house owners, making it possible to control for household heterogeneity in several observable characteristics.

Second, this study exploits persistent, regional electricity price variation which is exogenous to the households. Price sensitivity is measured with respect to the distribution cost of electricity, which comprises on average half of the total unit cost of electricity faced by consumers. The distribution prices, as opposed to the retail prices of electricity, are very stable at the local distribution grid level. This is because distribution is a regulated activity, where pricing is monitored and is based on costs of operating and maintaining the grid. Consumers must buy distribution from their local grid operator. These properties make the distribution price a long-term price, and justify the assumption that consumers use the current price level as an indicator for expected prices. The presence of both time and cross-sectional variation in prices allows using different fixed effect-specifications as controls in estimation.

Third, the heating technology investment does not incorporate an element of timing. Due to the Finnish climate, each new house must be equipped with a heating system at the point of building; home owners do not time their heating system purchase with developments in energy efficiency. The number of possible main heat sources is limited and the technologies are well-established. This allows using a simple, standard discrete choice model in estimation. Moreover, new builds are not subject to any other policy measures than national building standards. For example, no investment subsidies have been in place.

Fourth, the heating technology investment has notable economic consequences for the household, as heating costs form a large share of the annual living costs in a detached house. It is also a fixed characteristic of the building, and will impact resale value.[1] Hence, it is not likely that rational inattention would be present in this setting. Sallee (2014) discusses rational inattention in the context of energy efficiency, and demonstrates how it may be rational for consumers not to be fully informed about energy efficiency, as this is rarely the attribute which will be pivotal in product choice. Therefore, it does not pay off to incur the costs of acquiring information and searching for the most efficient appliance. This may be one reason why price sensitivity estimates based on appliance purchase are small (for example Jacobsen, 2015). Furthermore, appliances such as dishwashers or fridges tend to be differentiated products, where characteristics other than energy efficiency can be very important to consumers. These include things such as aesthetics, ease of use or noisiness, which can be difficult to control for when estimating appliance choice.[2] This does not apply to the same extent to heating systems, as they are primarily technical devices which are hidden from view and not actively operated on a daily basis.

I obtain results using a standard binary logit model of choice between

[1] Recent empirical studies have shown that consumers do place value on such energy-related fixed characteristics of buildings; for example, buildings with higher energy performance ratings sell with a premium compared to lower rated buildings (Brounen and Kok 2011), as do homes with district heating when compared to electrically heated homes (Harjunen and Liski 2014).

[2] In the vehicle fuel efficiency literature, this problem of unobservable product characteristics is dealt with by using fixed effects at a detailed product level.

two distinct technologies: electric heating and central heating. This divide is justified by an inherent difference between these technologies: electric heating using cables or electric radiators is an irreversible investment. In contrast, central heating systems separate the generation of heat from its distribution around the building. This separation allows changing the source of heat later without major revisions to building structures. The most common central heating technology in new houses is a ground source heat pump, which makes use of geothermal heat stored in the ground. The pump operates with electricity, but the electricity consumption only amounts to approximately one third of the total heating energy consumption of the house.

The high value of price sensitivity estimated in this study speaks for forward-looking consumers as opposed to myopia. This implies that consumers respond to price signals, and instruments such as taxes can be used to encourage investment into energy efficiency. Indeed, counterfactual scenarios based on the model indicate that the increases in electricity costs over the sample period have accounted for an 8 percent decrease in the amount of electrically heated homes.

2 Empirical strategy

The heating system investment is modelled as a binary choice between electric heating and central heating. This is a fundamental decision that the household must make at the building stage. It will impact the value of the house through expected future costs of use, as well as through the option value of changing the source of heat at a later point in time. If electric heating is installed, this option is not available. Switching to another heat source would require retrofitting the house with a heat distribution system. Though possible, this is a very expensive operation. Therefore, installing electric heating fixes electricity as the heating fuel, and ties the annual heating costs to the future development of electricity prices.

Conversely, central heating can accommodate several different sources of heat. These include ground source heat pumps, district heat, wood or oil, which all have lower unit costs than electric heating. Electricity may also be used; in this case electricity is used for heating water which then circulates around the house. In this case, it is possible to benefit from time-of-day pricing, by stocking up on heat during the night when prices are lower.[3]

The household thus has to choose whether to fix electricity as the source of heat, or install a more flexible system. Denote by $U_{ij} = V_{ij} + \epsilon_{ij}$ the utility for household i from system j. Indexing electric heating by E and central heating by C, the probability of choosing electric heating is

$$\begin{aligned} \Pr(U_{iE} > U_{iC}) &= \Pr(V_{iE} + \epsilon_{iE} > V_{iC} + \epsilon_{iC}) \\ &= \Pr(V_{iE} - V_{iC} < \epsilon_{iC} - \epsilon_{iE}) \end{aligned}$$

If the random terms are assumed to be distributed i.i.d. extreme value type I, the difference of these terms is distributed logistic (see for example Train 2009 and the references therein). In this case the choice probability has a closed-form solution: $P_{ij} = e^{u_{ij}} / \sum e^{u_{in}}$. In the heating choice context, central heating can be viewed as an outside option to electric heating, and its utility is normalised to zero. In this case the choice probability becomes

$$P_{ij} = \frac{1}{(1 + e^{-u_{ij}})}$$

This can be estimated by maximum likelihood.

The assumption of independently distributed error terms is a restrictive one and implies that consumers substitute between the options in fixed proportions (the *independence from irrelevant alternatives* (IIA) property). In the case of heating choices this property means that as households substitute away from electric heating, the shares of other technologies will be increased by the same proportion and identically across all technologies. This is likely not to hold true in reality. However, in this analysis the focus is on examining the binary choice of electric heating versus any other heating system. Hence, the IIA actually does hold in this grouping of technologies; the share of all other technologies must increase proportionally to the decline in electric heating. This is a further reason for focusing the analysis on the choice of electric heating versus central heating. The analysis captures a relevant aspect of the capital investment, but restrictive assumptions need not be imposed. In addition, results can be obtained also by using regular OLS estimation, and this method will be used in robustness checks.

The utility from electric heating will depend on investment costs I_i, expected lifetime heating costs H_i and heating system characteristics x:

$$U_i = \beta(I_i + H_i) + \sum_m \mu_m x_m + \epsilon_i \tag{1}$$

[3]Residential use of gas is extremely rare in Finland; gas stoves can be found in some older apartment buildings which have been equipped with gas piping.

The expected lifetime heating cost is $H_i = \sum_{t=0}^{T} \delta_i^t p^t K_i$, where $\delta_i = 1/(1 + r_i)$ is the discount factor, p^t is the expected electricity price in time t and K_i is the expected amount of heating energy purchased annually. This is a function of house size, measured in square meters, and the heat consumption of the building, measured in kWh needed per square meter annually.

All this information is not available, hence the utility function will include variables recorded in the data that are correlated with the different components of heating costs. The following specification will be used in estimation:

$$u_i = \beta^{el} p^{el} + \beta^{d} p^{d} + \sum_k \gamma_k z_{ik} + \sum_g \alpha_g w_{ig} + A + T + R + L + \varepsilon_{ij} \tag{2}$$

The electricity cost is composed of the price of electricity and the price of distribution: $p^e = p^{el} + p^d$. It is assumed here that households use current prices as a measure for future operating costs.[4] This assumption may be questionable regarding the retail cost of electricity, but less so for the distribution price. Since these prices are regulated and depend on local characteristics, it is reasonable to assume that today's price level is a good indicator for the future price level, in real terms. The electricity cost components are estimated separately, to allow for a differing impact of the retail (short-term) price and distribution (long-term) price.

The house characteristics z_{ik} include k variables related to the amount of heating energy to purchase. These variable are house size, an indicator for building material, an indicator for building method, and a measure of climate conditions in the form of heating degree days. House size and insulation determine the amount of heating energy needed. House size is observed, but the insulation level is not. Building standards set a maximum allowable level for heat consumption, but some households may opt for build a house with better insulation than is required. To proxy for this, an indicator for stone as building material is included. Stone houses tend to consume less heating energy per unit than wooden houses, due to the material's characteristics. The indicator for building method takes value one if the house is made from elements. As a building method, using prefabricated elements may indicate that the house is a standard build. Also house location will impact the heat need, as northern parts of Finland are on average much colder than southern and coastal areas. Local cli-

[4] This is a common assumption made in empirical studies where consumers' expectations of future fuel costs must be formed. Anderson et. al (2013) provide evidence that consumers expect fuel prices to rise at the rate of inflation, hence remain constant in real terms.

mate conditions are controlled for by heating degree days, which measure the annual difference between indoor and outdoor temperature. Heating degree days are defined at the municipal level.

Household characteristics relevant to the heating choice are represented by w_{ig} in the utility specification. These variables include net income, age, education, family size, an indicator for the presence of children under 3 years of age, and an indicator for whether the household owns a house at the time of building. Of these variables income, age and education are likely to be correlated with the discount rate and the lifetime the household uses when evaluating the total costs of the heating investment (for references and discussion on personal discount rates and individual characteristics see for example Frederick, Loewenstein and O'Donoghue 2002; Simon, Warner and Pleeter 2015; and Newell and Siikamäki 2015). Family size and the presence of young children may influence how the household values aspects such as ease of maintenance, which is a component of the perceived costs of the heating system. Familiarity with the technology may influence heating choice. A majority of the existing detached housing stock is heated by electricity. Hence, if a builder is a house owner at the moment of building a new house, it is highly likely that she will have experience of living in an electrically heated home. In addition, house owners may be more aware of the importance of heating costs than households who have previously lived in apartments.

The fixed effects include an alternative-specific constant A, annual time effects T, regional effects R and a building location indicator L. The alternative-specific constant captures other attributes of electric heating besides price. Annual time effects T account for factors which will impact all house builders uniformly, such as improvements in insulation levels over time due to stricter building standards. Time effects will also capture any changes over time in the levels of investment costs.

Regional effects R control for climate conditions and other broader regional characteristics which can influence both distribution prices and heating choices. For example, eastern Finland tends to have very different snow conditions than the western coast. The number of power cuts due to snowfall will influence both the costs of distribution companies and possibly the heating choices of households. In addition, regional effects control for factors such as differences in the level of building costs; costs are notably higher in regions which include growing, urban areas. There are 19 administrative regions in Finland, of which the island of Åland is not included here due to missing electricity price information.

The building location indicator L takes value one if a town plan is in force at the building site. The existence of a town plan is an indicator for location type; urban sites tend to have town plans in force, whereas general master plans usually prevail in more rural areas. This controls especially for the availability of firewood as a substitute fuel, and for the indirect effect of building restrictions. In urban, densely populated areas firewood is less likely to be easily available, and this can impact choice of heating. Furthermore, town plans can place restrictions on building characteristics, typically by limiting the materials and designs used in the façade of the building. This can indirectly influence heating choice, for example through an impact on building costs.

The list of included controls is extensive, as in the non-linear case omitted variables can be problematic even if they are not directly correlated with the variable of interest (Greene, 2008). Therefore, it is important to include all those variables which can be argued to influence choice of heating. Moreover, as described by Bento, Li and Roth (2012) in the context of vehicle fuel efficiency, consumers sort into different durable goods based on their price sensitivity. In the case of heating, price sensitive consumers are more likely to build smaller houses and possibly insulate them more than is required. If this heterogeneity in price sensitivity is not accounted for, it will bias the coefficient on fuel price towards zero.

Though the data is detailed in terms of house and household characteristics, nevertheless some important variables are not observed and must be excluded from the estimation. The unit prices of other fuels are not available at a detailed enough level to be included in the analysis. However, the main substitute for electric heating, ground heat, uses electricity to operate the pump and hence has the same fuel cost as electric heating. The prices for electric water central heating are slightly lower than those for electric heating, but these two prices are extremely highly correlated and typically have the same development over time; the only difference is in the level of the price. The price of light fuel oil is only available at an aggregate national level. The importance of this price is not likely to be large. The amount of oil heating installed is very small, indicating that builders no longer view this as a relevant technology. The price of wood for heating depends heavily on how far it is transported from and on the exact type; whether wood is used in the form of chips, pellets of different sized logs. It is not possible to define a relevant price for wood for each household without knowing these details. It is common for houses heated with wood to have access to own firewood on the lot or close by. In these cases, the household does not directly face the market price of heating wood.

Secondary heat sources, such as fireplaces, are not recorded in the data. In addition to insulation, these will impact the amount of energy purchased for heating. Overall, improper measurement of the heat need of the house will impact the estimated sensitivity to electricity price. The possible bias should be in the direction of finding a positive correlation between electricity price and choice of electric heating. For houses with small consumption of heating energy, electric heating may well be the optimal choice due to the combination of low investment costs and operating costs. Treating these houses as standard in the data will give the illusion of households that are not sensitive to electricity prices.

An important missing variable is the investment cost for electric heating and its substitutes. Builders' choices will be influenced by the up-front costs of heating systems even though the lifetime operating costs constitute most of the total cost. If there were large changes in the investment cost for the different technologies over the sample period, the impacts of these changes could confuse the estimation of the effect of electricity costs. Information on the average cost of installing electric heating and its main substitute ground heat is provided by The Building Information Foundation, which is the main objective source of information for home builders. Their statistics reveal that there have been only minor changes in the investment costs for different heating systems, and largely these changes are attributable to the overall increases in building material costs and labour expenses. These types of cost changes will impact all technologies in the same way. The investment cost difference between electric heating and ground heat is so large that small changes to costs are in practice insignificant; the cost of ground heat is on average 3.6 times the cost of electric heating.

3 Data

The data are based on an annual 90 percent random sample of all new detached houses built from 2000 to 2011.[5] This amounts to 132 002 houses. As the analysis is to be based on houses built by private persons, houses in

[5]Statistics Finland does not grant access to full samples of individual-level data.

other ownership categories are dropped. This leaves 113 937 houses in the base data, with the annual amount of houses ranging from 6920 to 10 744. Electricity prices are only available from 2006 onwards, which limits the estimation sample to include years 2006-2011. Furthermore, houses with access to district heat are excluded from the estimation sample. This restriction must be imposed because many municipalities have had in place an obligation for new houses to join the district heat network.[6]

The information on building characteristics comes from the Population Register Centre of Finland which keeps a record of all building permits. Construction of new homes is closely monitored: all building activity requires a permit from the local authorities, and once a permit is granted, building must commence within three years or the permit will expire. Reporting to the authorities has three stages: an initial request for a building permit, a notification once building has started and finally a notice of the completion of the project. The variables in the data are based on information filed with the request for a building permit, but only those houses are included in the data for which the building process has actually started.

The building permit formula contains details of the main heating system, the size and material of the house, the exact location and the identity of the house owner. The heating system is reported in two stages by choosing from given options. First, the technology is chosen to be water central, air central, electric heating or stove heating.[7] Second, the fuel is identified as district heat, oil, electricity, gas, wood, ground heat, coal, peat or other.

The evolution of heating shares in the estimation sample is depicted in Figure 1. Electric heating has been the most common source of heat until 2011 when ground heat takes over. This is clearly the main substitute for electric heating; the shares of other heating modes grow only modestly over time.

The strong increase in the amount of ground heat installed in new houses is illustrative of the overall development in the popularity of ground heat pumps. The first installations of this technology were made already in the 1970's, but it took twenty years for it to become established as a ver-

[6]The overall share of district heat in the data is 13 percent, but where district heat is available, it is the most common heat source chosen by 80 percent of households.

[7]Also the option "no heating" is possible. This was reported for one house in the whole sample.

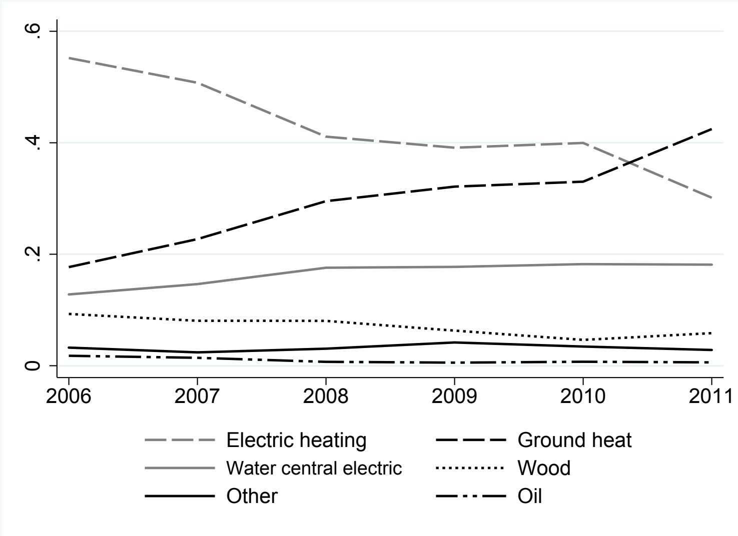

Figure 1. Heating technology shares in new houses.

Notes: Heating shares based on an annual 90% random sample of all new detached residential homes built by private persons in Finland.

itable alternative to other main heat sources. According to statistics of the Finnish Heat Pump Association, the numbers of annually installed ground heat pumps began rapidly increasing at the end of the 1990's, and during 2000-2007 the total number of ground heat pumps more than doubled. The installation rate has remained very high at over 10 000 ground heat pumps installed annually during 2011-2014. Most of the installations take place in old houses, where ground heat replaces oil heating.

The buildings are matched to the owners using the personal identity number. To construct household-level data, the building is matched to both owners in case there are two, or to the owner and the owner's spouse (married or cohabiting) in case only one owner is reported. These socio-demographic variables are recorded by Statistics Finland and include measures such as age, education, number and age of children, income, debt, occupation and ownership status of the current dwelling.

Table 1 shows descriptive statistics of selected variables in the sample used for estimation. The numbers are calculated separately for electrically heated homes and those with central heating. On average, home builders are families with children and higher income and education than the overall population average. Higher education refers to the building owner having education at or above the level of a Bachelor's degree.[8] A

[8]In 2010, the average household income was approximately 36 400 Euros, and

Table 1. Summary statistics of selected variables.

	Electric heating	Other technologies
Disposable household income (€)	46 455	50 309
Age of building owner	37	36
Share of owners with higher education	0.31	0.43
Share of households with young children	0.38	0.44
Family size	3.3	3.4
Share of houses in rural location	0.19	0.20
House size (m^2)	169	203
Share of stone houses	0.05	0.11
Share of element houses	0.50	0.48
Number of observations	12 927	18 556

Notes: The table shows summary statistics of builder and house characteristics, grouped by the chosen heating technology. The sample includes years 2006-2011 and only those houses with no access to district heat. All monetary values in 2010 euros. Higher education refers to the house owner having education at least at the level of a Bachelor's degree. The share of households with young children refers to the presence of at least one child under 3 years of age.

typical house is built from wood and has a total area of approximately 200 square meters, with electrically heated homes being notably smaller than homes with central heating.

Local electricity and distribution prices are matched to each observation using the postal code. These prices are provided by the Energy Authority, which maintains a monthly record of all the contracts offered by electricity retailers in Finland. In addition, The Energy Authority records distribution prices and acts as the regulatory authority in monitoring these prices. Distribution prices are available from 2003 onwards and retail prices from 2006 onwards. Given the importance of the electricity price variation in the analysis, this part of the data is described in more detail below and in Appendix A.

3.1 Electricity prices

The total electricity cost faced by the consumer is the sum of the retail price of electricity and the distribution fee: $p^{total} = p^{el} + p^{d}$. On average, distribution costs constitute around 40 percent of the total cost of electricity. Both cost components include a fixed monthly fee and a unit cost defined in c/kWh. Block price contracts are not offered on the Finnish

the share of Bachelor-level education was 13 percent in the population aged 25-69.

electricity market. In the price data supplied by the Energy Authority, the fixed fee in each contract has been averaged over the expected load to arrive at prices defined solely in c/kWh. Prices are defined for different customer types corresponding to different load profiles. For example customers living in apartment buildings are offered different prices from customers living in detached houses with electric heating.[9] The electricity price used in the analysis refers to the price for customers in detached houses with electric heating.

Distribution prices

The distribution of electricity is a regulated activity and this service is always provided by the local distribution system operator (DSO). The DSOs are responsible for building and maintaining the distribution grid, as well as reading the meters at end-use points. Over the time period 2006-2011, there were 87 distribution companies, and hence 87 distinct price areas. The companies vary widely in size and administration; there are small distributors which manage the grid within the area of a single municipality, and very large distributors which manage grids over large areas spanning several municipalities. Some distributors are wholly municipality owned (either by a single municipality or jointly by neighbouring municipalities), while others may have a mixture of different shareholder types.

The differences across DSOs are illustrated in Table 2, which shows summary statistics on technical characteristics of DSOs during 2006-2011. Data on DSOs is public, and it is published annually by the Energy Authority. It can be seen that there is large variation in the length of the grid, in the number of connections to the grid, and in the share of the grid running underground. The number of power cuts also varies widely. This number refers to the average number of times a customers faces a disruption in the distribution service during a year. Power cuts are common in areas where distribution cables run through forests and can be damaged during storms.

These differences in DSO characteristics translate into differences in distribution prices. Pricing is regulated by the Energy Authority, and DSOs are allowed to cover costs and earn a reasonable return on capital.

[9] There are in total four customer types for households, corresponding to different annual expected loads: apartments (2000 kWh), detached houses (5000 kWh), detached houses with electric heating (18 000 kWh) and detached houses with central electric heating (20 000 kWh).

Table 2. DSO technical characteristics, 2006-2011.

	Average	Std.Dev.	Min	Max
Grid length (km)	4329	10 512	26	70 980
Ground cables (%)	44	26	2	100
No. of connections	19 736	48 204	74	368 397
No. of power cuts	6.4	7.8	0	54
No. of transformers	1498	3620	7	23 580

Notes: The table presents technical characteristics of distribution system operators during 2006-2011. The figures are published by the Energy Authority, which uses this and additional information to monitor pricing of distribution by company. The number of DSOs observed annually declines from 87 to 81 during this time period, due to small distributors merging with a neighbouring, bigger company.

Appendix A provides evidence on how prices relate to DSO characteristics. Overall, lower prices are associated with densely populated areas and larger amounts of transmitted energy. Areas facing many power cuts tend to have higher prices.

The range of distribution prices observed is illustrated in Table 3 and Figure 2. The prices refer to the price for customers living in detached, electrically heated houses. This is the price that is used in the empirical analysis. The prices include taxes, since this is the total price faced by consumers. Table 3 illustrates the development in prices over time, in terms of average price levels and the range of prices observed. This table includes all available price data, to show the longer term trend over time. These summary statistics are calculated from the prices linked to new houses, the number of observations thus refers to the number of new houses observed each year.

On average, distribution prices remained very stable, and even slightly decreased, from 2003 to 2007. From 2007 onward the average price level and the range of prices observed starts to increase. This is at least partly due to taxation. At the beginning of 2008 the tax on consumers was raised from 0.73 c/kWh to 0.87 c/kWh. Another, much larger tax increase came into force at the beginning of 2011, when the tax rate almost doubled, going from 0.87 c/kWh to 1.69 c/kWh. This caused a notable jump in the overall level of distribution prices.

The difference between the minimum and maximum price is annually around 2 c/kWh. In the time period used in estimation, 2006-2011, the price ranged from approximately 3 c/kWh to 6.4 c/kWh. In terms of heat-

Table 3. Summary statistics of distribution prices by year.

	Mean	Std.Dev	Min	Max	Range	Observations
2003	4.03	0.28	3.15	5.91	2.76	7852
2004	4.03	0.29	3.04	5.05	2.01	8394
2005	3.98	0.30	2.95	4.87	1.92	8789
2006	3.91	0.33	2.91	4.99	2.08	8603
2007	3.87	0.35	2.94	5.20	2.26	8191
2008	3.98	0.37	3.00	5.20	2.20	6719
2009	4.18	0.47	3.01	5.79	2.78	5546
2010	4.42	0.50	3.04	5.68	2.64	7207
2011	5.37	0.52	3.93	6.77	2.87	6118

Notes: The table presents summary statistics for distribution prices. All prices in 2010 euros. Prices include taxes. The number of observations refers to the amount of new houses observed in the data.

ing costs for an average house, a difference of 3 c/kWh amounts to an annual difference in heating costs of 510 euros. Over the lifetime of the system, this is approximately €7700.[10] Using the overall average distribution price of 4.2 c/kWh, the lifetime costs of electric heating, resulting from distribution only, would be €10 780. Including the retail price raises the total use costs for electric heating to well above €20 000 over a lifetime of 25 years. Given that installation costs for electric heating range on average from 4000 to 5000 Euros, this illustrates how the operating costs form most of the total costs of electric heating.[11]

Figure 2 shows the histogram of distribution prices in the sample used in estimation. The y-axis presents the fraction of prices in each bin. It can be seen that though the highest price are close to 7 c/kWh, these are rare in the data. Over 80 percent of prices are below 5 c/kWh.

The differences in the cost structure of grids in different types of areas fix the price level and make it a persistent characteristic of each distribution area. This stability in prices is illustrated by high autocorrelation both in the distributor-specific prices and in the annual ranking of distributors with respect to price. The values for these autocorrelations are presented in Table 4.

[10]This calculation assumes a house size of 170 m^2, a heat consumption of 100 kWh/m^2, a 5 percent discount rate and a lifetime of 25 years.

[11]According to The Building Information Foundation, the average investment cost for electric heating in 2010 was around €4500, whereas the corresponding value for ground heat was approximately €16 000.

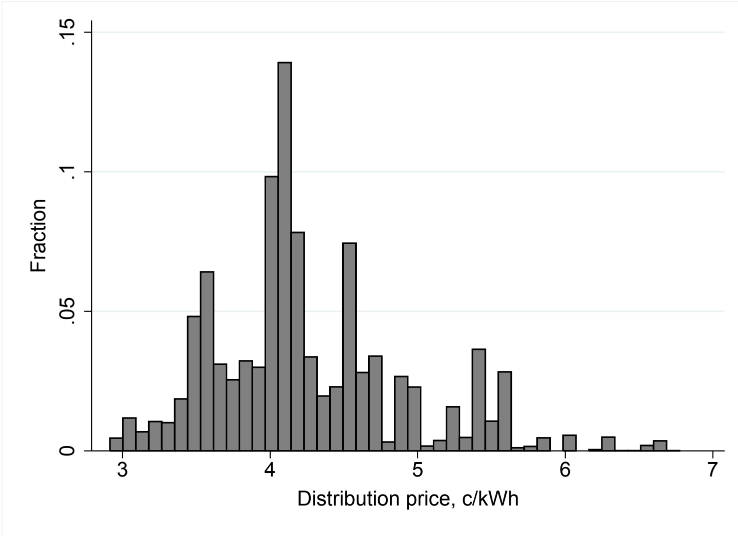

Figure 2. Histogram of distribution prices.

Notes: The histogram describes the distribution prices observed in the data used in estimation. Years included: 2006-2011, prices in 2010 euros. The y-axis shows the fraction of prices in each bin.

Table 4. Autocorrelations for distributors.

	Autocorrelation of price	Autocorrelation of rank
First lag	0.92	0.96
Second lag	0.82	0.90

Notes: The table reports autocorrelation in the distribution price and in the annual ranking of distributors according to price. Prices are defined as annual averages by distributor, and they include taxes. Autocorrelations calculated for the whole time period distribution prices are available: 2003-2014.

Retail prices

The Finnish retail market was opened to competition in 1997, and since then small-scale end users have been able to choose which retailer to contract with. There are over 70 retailers in the market, and approximately half of these offer contracts to customers in any location. The remaining retailers are local, and only serve customers within the local distribution grid.

Contrary to distribution prices, it is not possible to know which retail price is the actual price faced by the households in the data. Therefore, each observation is assigned the lowest price of a standard contract offered by the default supplier. This supplier is defined by the law as that retailer which has a dominant market position within the distribution grid. Thus, if a a consumer has made no effort to actively seek a retailer in the retail market, they will be buying from the local default supplier. A retailer may be the default supplier in more than one grid area; there are 66 obligatory suppliers and over 80 distribution areas.

Standard contracts offer prices which change rarely, typically only once or twice per year. So-called market-based contracts, where the price changes quarterly, monthly, or even hourly, were very rare during the sample period. They only constituted about 5 percent of all contracts offered on the market. Excluding these explicit market-based contracts, retailers in Finland have not transmitted the strong seasonality of electricity prices to customers, but have changed prices gradually to account for the long term increase in the electricity price level (see Lehto, 2010, for analysis on the determinants of retail prices).

Despite a deregulated market, there is notable variation in retail prices. The price distributions for selected years are illustrated in Figure 3. The variance of prices increases over time, and there is a strong increasing time trend in the mean price. The lowest range of prices is typically offered by the retailers who do not participate in the national market and only serve customers within the local grid area. Consumers can avoid the highest prices by switching from the local supplier to any nationwide retailer. This is, however, a rare event; according to the Nordic Energy Regulators, the share of customers who switched suppliers was 4.4 percent in 2008 and 7.6 percent in 2011 (Nordic Market Report, 2012).

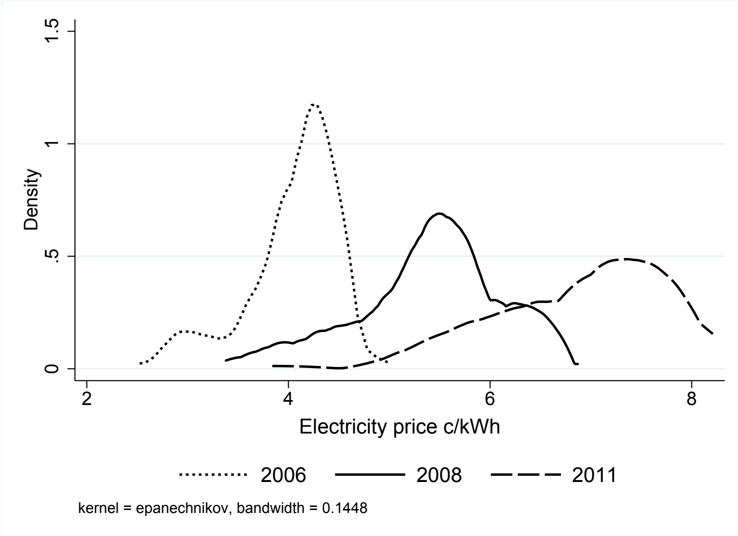

Figure 3. Annual density of retail price.

Notes: Annual density of the retail price of electricity for selected years. The price depicted is the lowest price offered by each retailer to customers in detached houses with electric heating. Prices converted to 2010 euros.

4 Cost of electricity and heating shares at the municipal level

To provide preliminary evidence on the relationship between heating technology shares and electricity costs, the main variables of interest are examined at the municipal level. Distribution areas do not exactly match municipality borders. Given that there are approximately 80 distributors and over 300 municipalities, typically one DSO is responsible for the grid in several adjoining municipalities' areas. In addition, some municipalities are located at the boundary of two or several distribution areas. In the original price data, there are 42 municipalities which have more than one distribution price assigned to it. This is 16 percent of the total amount of municipalities. Therefore, when aggregating prices to the municipal level, for these municipalities the average price consists of the average over all observed prices in the area. In the individual-level data, the correct distribution price can be assigned to each house, as the location of houses is defined by postal code.

Figure 4 illustrates municipal distribution price levels across the country. Each municipality is coloured according to the average distribution price for 2006-2011. It can be seen that price levels are not systematically defined by geography; for example the cheapest prices are found both in

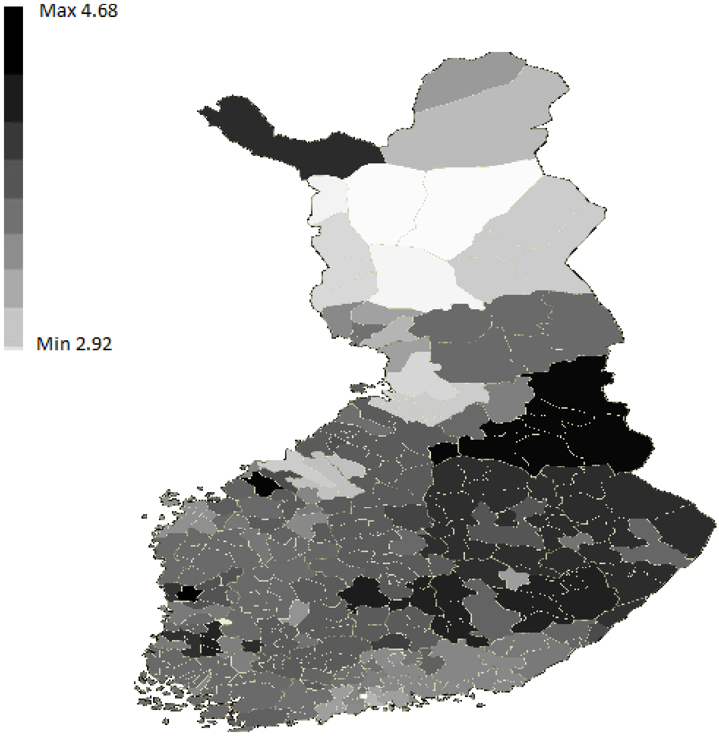

Figure 4. Average distribution prices at municipality level.

Notes: The figure illustrates the level of distribution prices across Finland. Each municipality is coloured according to the average distribution price in that area during 2006-2011. Distribution areas typically encompass several municipalities, and distribution area borders do not match municipality borders exactly. Therefore 42 municipalities are such that the average price level is a combination of two or more distribution system operators' prices.

the population-dense southern parts of the country and in the northern municipalities of Lapland.

The aggregate data of houses and builders is formed by taking annual averages over observations of new houses at the municipal level. This aggregate data contains 320 municipalities observed over the time period for which regional prices are available, that is 2006-2011. There are 336 municipalities in the data in total, but electricity prices are not observed for 16 municipalities. This is due to two factors. First, electricity price data is not recorded for the municipalities located on the island of Åland. Second, there are changes to postal codes over time. If a house is built in an area for which the postal code has been abolished, no price data can be linked to this house. The municipalities with missing price information

Table 5. Correlations at the municipal level.

	Retail	Distribution	House size	Income	Education	Age
Share of electric heating	-0.18	-0.21	-0.34	-0.25	-0.16	0.13

Notes: The table presents pairwise correlations between the municipal share of electric heating and average municipal electricity price levels and builder characteristics. The correlations are calculated from a panel of municipalities during 2006-2011 with 1850 observations, formed by aggregating the household-level data to municipal averages.

are small, with typically less than 10 houses built per year. Note also that not all municipalities are observed annually, as there may be no new houses built in a certain year.

In this municipality-level data, 20 percent of the observations are such that more than one distribution price is observed annually within one municipality. This means that the area is located at the intersection of one or more distribution areas. In these cases, the municipal annual average price is a weighted average of the prices observed, where the weight is determined by the number of builders facing each observed price.

Table 5 reports correlations between the municipal share of electric heating, electricity prices and average builder characteristics. Electricity prices are negatively associated with the share of electric heating, but the correlations are not very strong. Of builder demographics, higher income and education correlate negatively with the share of electric heating, as does house size.

Results from OLS regressions of the municipal share of electric heating on the local electricity and distribution prices are reported in Table 6. The first column shows that, conditional on time trends, electricity prices do not seem to be related to the amount of electric heating. The retail price even has a positive coefficient.

To see if this relationship holds under a more detailed examination, further controls are added. These include municipality characteristics, region fixed effects and municipality-level builder characteristics. Municipality characteristics include the share of houses with access to district heat and the share of houses built in an area where a town plan is in force.[12] The prevalence of town plan areas and the availability of district heat can be correlated with distribution pricing as they describe local

[12] Access to district heat is not directly reported in the data. A house is inferred as having access to district heat if another house in the same neighbourhood has installed district heat. A neighbourhood is defined by street name and postal code.

characteristics which are indicative of grid structures. This is illustrated by the change in coefficient estimates when these controls are added; both price coefficients are now negative, though not statistically significant. Controlling for regional level factors further increases the magnitude and the significance of the distribution price coefficient, while the effect is the opposite for the retail price.

Finally, aggregate builder characteristics are added. Though these should not directly be correlated with distribution prices, at the aggregate level it is possible that household characteristics are indicative of municipal factors which could be associated with pricing. There could thus be an indirect correlation between household characteristics and distribution prices. Controlling for builder characteristics increases the magnitude of the coefficient on the distribution price, while the coefficient on the retail price is in practice zero.

These results assert the view that distribution prices are a fixed local characteristic. In contrast, the zero result on retail prices indicates that the local price level conveys no information relevant to long-term decision making. Furthermore, the weak correlations between distribution prices and shares of electric heating, conditional on time trends, alleviate the concern that there would be unintentional sorting into different distribution price areas based on unobservable characteristics of households.[13]

The magnitude of the distribution price coefficient implies that a 1 cent increase in the price of distribution is associated with a decrease of 7 percentage points in the municipal share of electric heating. Given that the average share of electric heating is 0.41, this is a reduction of 17 percent. It should be noted that an increase of 1 cent is very large, for example at the regional level the annual range of distribution prices is usually less than this.

Analyses based on aggregate data similar to this one have been used to infer the causal effect of energy prices on investment choices (for example Jacobsen, 2015; Busse, Knittel and Zettelmeyer, 2013; Klier and Linn, 2010). However, there are reasons why in this context the coefficient on distribution cost may not measure the true impact of long-term price levels on demand of electric heating. For one, the municipal values are in many cases based on very few observations. In 65 percent of the

[13] For example, if households with strong preferences for new technology and dislike for electric heating sort into locations which have characteristics that also induce higher distribution prices, this would produce a negative correlation between distribution prices and the share of electric heating.

data, the municipal averages are calculated from at most 20 observations. Thus, they may be very inaccurate measures of the relevant quantities. Second, at the aggregate level the exogeneity of the distribution price is not self-evident. The regression residual may contain omitted local characteristics which are correlated both with heating shares and distribution prices, causing bias in the coefficient on distribution prices. Finally, the price level is not measured precisely for those municipalities located at the border of several distribution areas. For these reasons, it is preferable to use individual-level data to assess the influence of electricity costs on choice of heating.

5 Results

5.1 Electricity prices and the choice of electric heating

Table 7 presents parameter estimates for electricity cost components from different specifications of the binary discrete choice model. Standard errors are included in parentheses. A more detailed description of the results, including coefficient values on other variables can be found in Appendix C.

The impact of the distribution price is consistently negative and highly statistically significant across specifications. The negative coefficient indicates a negative impact of distribution costs on the utility from electric heating, which will reduce the probability of choosing this heating technology. Controlling for house and household heterogeneity increases both the magnitude and the precision of the estimated coefficient. This illustrates the importance of including consumer characteristics.

The specification in column 4 includes an interaction of the distribution price with the town plan indicator. The coefficient implies that the impact of distribution prices is higher in areas where town plans are in force. Interactions with other house and household characteristics did not prove to be statistically significant, and are not presented here.[14] Household heterogeneity in attention to heating costs is analysed in detail in Sahari (2016a).

[14]Interactions were examined with respect to house size, income, education, age, the presence of children and the ownership status of the current dwelling. Both discrete choice models and linear probability models were used to assess the importance of interaction effects.

Table 6. Relationship between electric heating and electricity prices.

Dependent variable: municipal share of electric heating.

	1	2	3	4
Electricity price	0.024**	-0.020*	0.015	0.002
	(0.011)	(0.011)	(0.013)	(0.011)
Distribution price	0.008	-0.017	-0.048***	-0.069***
	(0.013)	(0.013)	(0.016)	(0.015)
Controls				
Town plan		0.044*	0.071**	0.123***
District heat availability		-0.450***	0.497***	-0.367***
Area (10m^2)				-0.003***
Net income (1000 €)				-0.001
Education				0.004***
Age				-0.027
Year fixed effects	Yes	Yes	Yes	Yes
Regiona fixed effects	No	No	Yes	Yes
R2	0.08	0.15	0.20	0.33
Obs	1850	1850	1850	1812

Notes: The table reports results from a regression of the share of electric heating on electricity prices and controls by OLS. All values are annual municipal averages. Heteroskedasticity-robust standard errors reported in parentheses for the coefficients on price variables. The variable 'town plan' refers to the share of houses built on sites where a town plan is in force. District heat availability measures the share of new houses with access to district heat. Area refers to total building size, net income includes all earnings net of taxes. Education measures the share of builders with at least a Bachelor-level education. Age is the average age of building owners. Significance levels: *** 1%, ** 5%, * 10%.

The impact of the retail electricity price, though negative, is not statistically significant. This result was already indicated in the aggregate level examination of electricity costs and the share of electric heating. Given the freedom to choose a retailer, the local electricity price may or may not be a relevant determinant of heating costs, depending on which retailer the household plans to contract with. It may also be an imperfect indicator of future price developments, as retail prices are based on market conditions which may be volatile. This is in contrast to the distribution price, which is not the price of a commodity but rather a compensation for the service of distributing electricity, and the level of this compensation is controlled by regulation. It is therefore not evident how consumers form expectations of retail price levels; it may be that expectations are based on longer term trends of prices, or on averages over specific regions or time periods. This issue is left for future research.

Appendix D presents results from several robustness checks. Section D.1 presents logit estimations with alternative definitions for the electricity prices and fixed effects. These include: adding interactions of time and year to the fixed effects, defining the distribution price as an average over three preceding years, using the lowest retail price available to each household, and estimating the effect of the distribution price from all available price data, which includes years 2003-2011. None of these changes to the model specification change the estimated impact of distribution price on the choice of electric heating.

Section D.2 investigates the relationship between electricity prices and house characteristics other than heating. It may be possible that electricity prices influence for example the choice of house size, as both these variables are important determinants of annual living costs. The estimations indicate that distribution prices are not a determinant of other house characteristics, however the results on the retail price vary. Therefore, the section also presents results of the heating choice estimation when house size is excluded from the set of controls. The effect of the distribution price on the choice of electric heating is now less precisely estimated, but the result does not significantly differ from the results reported here.

Section D.3 presents results from estimation by a linear probability model. In this case, local effects can be controlled for in more detail by using fixed effects at the level of municipalities, which is not possible in the logit model. The marginal effects obtained from the linear probability model match the effects obtained from the logit model. The inclusion of municipality-level fixed effects does not change the estimated impact of distribution price.

Table 8 presents marginal effects for electricity cost components, based on the estimated parameters from specification 4. The effects are calculated as an average over individual effects and at the means of variables. The marginal effect of the retail price is not significantly different from zero, as implied by the parameter estimate. The marginal effects for distribution price indicate that an increase of 1 c/kWh in distribution costs will reduce the probability of choosing electric heating by around 6 percentage points. In relation to the overall share of electric heating in the data, 0.41, this is a reduction of 15 percent. When calculated by location, the average marginal effect of the distribution price is -0.042 in areas without a town plan and -0.079 in areas with a town plan.

5.2 Elasticity of electric heating demand with respect to electricity costs

To illustrate the sensitivity of aggregate electric heating demand to electricity costs, the estimates from specification 4 are used to generate predicted shares of electric heating, using the range of distribution prices observed in the data. Figure 5 plots the distribution prices and the quantity of electric heating in the estimation sample. The 95% confidence interval of the prediction is represented by the shaded region. As the distribution price rises from 3 c/kWh to 7 c/kWh, the share of electric heating declines from 0.49 to 0.24. This implies that the aggregate demand for electric heating in new houses is clearly sensitive to long-term electricity prices.

The elasticity for the aggregate amount of electric heating is obtained by calculating the predicted aggregate share of electric heating for 10 000 draws of the distribution price coefficient, at a given distribution price. Then price is increased by 1 percent and the predicted market share of electric heating is again calculated 10 000 times, based on the same draws. These values are then used to calculate the elasticity of aggregate electric heating demand with respect to distribution price. Table 9 reports the results for elasticities calculated at three different price levels, where 4 c/kWh is approximately the mean price observed in the sample. At this price level, the elasticity is -0.63. The elasticity increases with the price level, going up to -1.18 at the price of 6 c/kWh. This is close to the current distribution price level; the average distribution price was 5.6 c/kWh in 2014.

Table 7. Results on electricity prices from binary logit estimation of heating choice.

Dependent variable: choice of electric heating				
	1	2	3	4
Electricity price	-0.033	-0.035	-0.047	-0.047
	(0.030)	(0.032)	(0.032)	(0.032)
Distribution price	-0.207***	-0.283***	-0.310***	-0.216***
	(0.035)	(0.038)	(0.038)	(0.045)
Interaction effect with distribution price				
Town plan = 1				-0.163***
				(0.040)
Controls				
Year fixed effects	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Town plan indicator		Yes	Yes	Yes
Building characteristics		Yes	Yes	Yes
Household characteristics			Yes	Yes
Average LL	-0.65	-0.60	-0.59	-0.59
Number of observations: 31 483				

Notes: The table presents results from a binary logit estimation of heating choice, the dependent variable being the choice of electric heating. Standard errors calculated by the delta method. All monetary variables measured in 2010 values. The town plan indicator equals one if the house is built in a location where a town plan is in force. Building characteristics include: total house size, building material (=1 if stone), building method (=1 if elements) and heating degree days at municipal level. Household characteristics include: all income net of taxes, education of building owner (=1 if at least Bachelor-level), age of building owner, presence of young children (=1 if at least one child under 3 years), family size, current dwelling status (=1 if house owner). Significance levels: *** 1%, ** 5%, * 10%.

Table 8. Impact of electricity costs on choice probability.

	Average marginal effect	Marginal effect at means
Electricity price	-0.009	-0.011
	(0.007)	(0.008)
Distribution price	-0.064***	-0.074***
	(0.008)	(0.009)

Notes: Marginal effects from a binary logit model of choice of electric heating. The dependent variable is the choice of electric heating. The marginal effects are based on specification 4 in Table 7, including time, region and municipality type fixed effects, house characteristics and household characteristics. The number of observations is 31 483. Significance levels: *** 1%, ** 5%, * 10%.

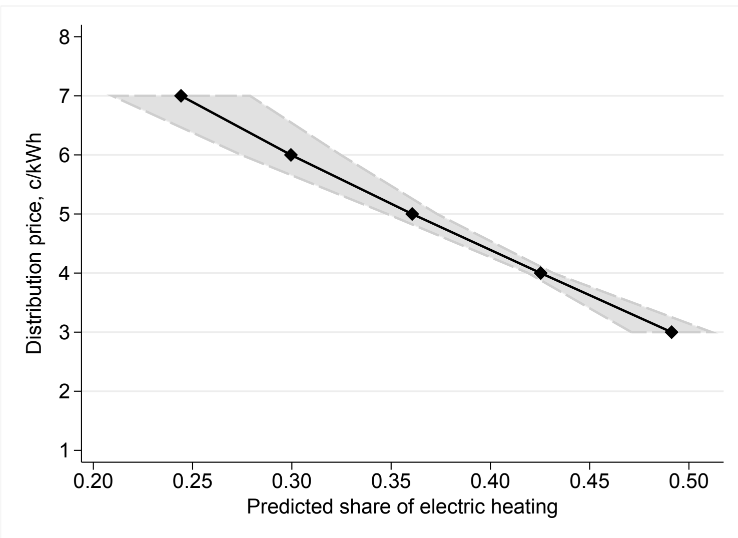

Figure 5. Distribution price and the predicted amount of electric heating.

Notes: The figure illustrates the predicted amount of electric heating at different distribution price levels, based on a binary logit estimation of heating choice. The dependent variable is the choice of electric heating and estimation includes all observable house and household characteristics as well as region and year fixed effects (specification 4 in Table 7). Characteristics other than distribution price are kept at observed levels when calculating the prediction. The range of distribution prices used corresponds to the range observed in the sample used in estimation.

Table 9. Elasticity of electric heating demand with respect to distribution price.

	Mean	Std.Dev.	95 % Conf.Int.		p-value
			Lower	Upper	
3 c/kWh	-0.41	0.09	-0.59	-0.22	0.000
4 c/kWh	-0.63	0.15	-0.93	-0.33	0.000
6 c/kWh	-1.18	0.29	-1.75	-0.60	0.000

Notes: The table reports elasticity of electric heating demand with respect to distribution price. The elasticity measures are based on predicted market shares from a binary logit model of heating, reported in specification 4 of Table 7. The elasticity values are based on a bootstrap over 10 000 draws of the coefficients on distribution price.

These values can be contrasted with the results of other studies using appliance choice to estimate elasticity of household capital investment to electricity price. Dubin and McFadden (1984) use survey data on households' choice of space and water heating, and estimate a discrete choice model which takes into account the continuous consumption of electricity resulting from the choice of appliance. They find and elasticity of -0.47 for the choice of electric heating with respect to electricity price.[15] Rapson (2014) estimates the sensitivity of air conditioner purchase to developments in energy efficiency and fuel prices, and finds a weakly significant electricity price elasticity of -0.3 for room air conditioner units. The values obtained here are higher, and precisely estimated.

The elasticity of demand for the heating technology will translate into an elasticity of electricity demand for heating. Ultimately, the demanded megawatt hours of energy is the quantity of interest, as this determines the total costs of electric heating and the emissions resulting from the production of electricity. The final impacts on electricity demand and emissions will depend on which technologies consumers will switch to as prices increase. If heat pump technologies are the main substitute to electric heating, there will still be electricity demand for operating the pumps. However, households switching to wood will no longer demand electricity for heating purposes. Evaluating the impacts on energy demand and emissions will require assumptions on the heat consumption of houses and on the emission intensity of electricity production, as well as estimation of the substitution patterns between technologies. This analysis is carried out in Sahari (2016b).

[15] Vaage (2000) and Nesbakken (2001) use this approach on Norwegian data of heating choice, but do not report elasticities related to appliance choice.

5.3 Counterfactual scenario

During the sample period distribution prices have increased on average 40 percent. To what extent is this price increase responsible for the decline in the amount of electrically heated homes? The estimated high elasticity with respect to distribution price implies that electricity costs are likely to have impacted the observed development of heating shares.

This can be examined by calculating model predictions under different distribution price scenarios, keeping all other variables at their observed levels. At realised prices, the model predicts the share of electric heating to decline from 54 percent to 28 percent over the sample period. If distribution prices had remained at their 2006 levels, the model predicts the share of electric heating to decline to 39 percent. Over the whole time period, the predicted amount of electrically heated homes is 12 927 at observed prices, and 13 945 if prices are not allowed to increase from 2006 levels. That is, if prices had remained stable during 2006-2011, the amount of electrically heated homes would be 8 percent higher.

This is illustrated in Figure 6, which plots the share of electric heating under the two price developments. There is practically no difference in the prediction for 2006-2008, as distribution prices remained very stable during this time. However, large price increases do make a difference, as illustrated by the difference in quantities for 2011 when the large tax increase came into force.

The magnitude of the impact of the tax can be assessed in more detail by comparing the model prediction at 2010 prices to 2011 prices. At realised prices, the model predicts 1324 electrically heated homes for 2011. Using the price level of 2010, the prediction is 1631 electrically heated homes. This difference in quantity amounts to a reduction of 19 percent, and it is attributable to the change in distribution prices from 2010 to 2011. It is not an accurate impact of the tax; calculating this would require knowing what prices would have been in 2011 if the tax increase had not taken place. However, it does give indication that notable price changes have large impacts on households' investment behaviour

6 Summary and conclusion

Observations on energy price levels and investment into energy-intensive capital indicate that persistent differences in energy prices lead to dif-

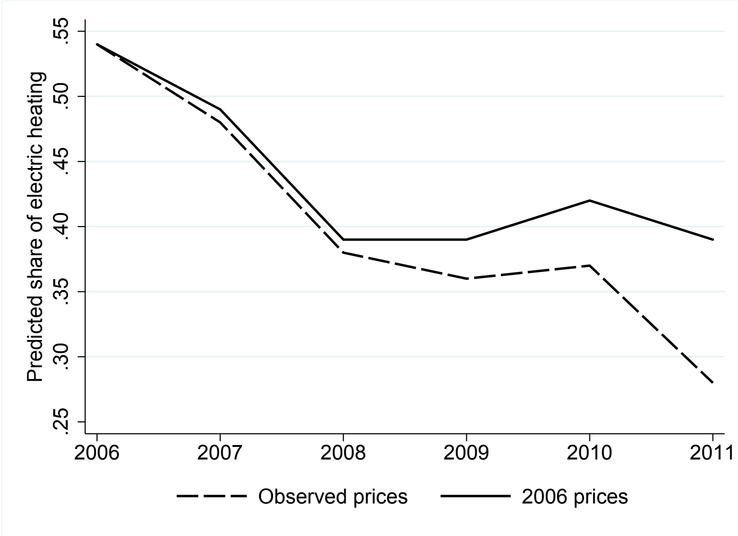

Figure 6. Predicted development of electric heating share.

Notes: The figure shows the predicted amount of electric heating based on a binary logit model of choice of electric heating (specification 4 in Table 7). The predictions are calculated for observed price levels and keeping prices at their 2006 values.

ferences in the composition of the capital stock. That is, in the long run capital adjusts to energy price levels although in the short run energy use is rather inelastic. This paper studies the question using data on home builders' choice of heating technology. Due to the long lifetime of heating systems, this choice reflects households' long run sensitivity to energy prices.

The focus of this study is on the impact of electricity costs on the choice of electric heating. The heating choice is modelled as a binary choice between direct electric heating and central heating systems, and detailed information on household and house characteristics are used to control for heterogeneity in the sensitivity to price.

The data allow estimating the impact of short-term prices and long-term prices separately. The long-term price is represented by the local distribution fee for electricity. These prices are regulated and based on local grid characteristics, hence there is notable cross-sectional variation in prices, yet the price levels are very persistent locally. Consumers must purchase distribution from the local grid operator, whereas the retail market for electricity is deregulated and consumers are free to choose their electricity supplier.

The logit estimation produces highly significant parameter estimates, and the main variable of interest is consistently estimated as controls are added to estimation. The estimates are used to create predictions of the quantity of electric heating installed at different electricity cost levels. The elasticity of demand for electric heating with respect to use costs is estimated to vary from -0.41 to -1.18 within the observed range of distribution prices. The elasticity is -0.63 at the average price level.

The results imply that households are conscious of operating costs when making decisions on investment into energy-intensive durable goods. This is not surprising, since it is precisely at the investment stage that the household can influence its long-run level of electricity consumption. Once the appliance stock is fixed, it is difficult to strongly alter consumption without making notable changes in consumption habits, and this is reflected in the low short-run price elasticities of electricity demand.

Though the results here are not used to evaluate to what extent consumers incorporate expected future use cost of energy into their decision making, the high sensitivity to use cost at the investment stage speaks for forward-looking consumers as opposed to myopia. This implies that price instruments, such as taxes, can be influential in guiding households towards choosing energy-efficient durable goods.

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A Determinants of distribution prices

This appendix provides additional analysis on distribution prices. The data are a panel of distribution system operators over 2004-2014. These data have been gathered from files published by the Energy Authority, which include the price set by each DSO for each customer group and information on technical characteristics of DSOs.

Figure 7 shows the development of average distribution prices over time for two customer groups: K1, referring to customers in apartments with a low annual consumptions and L1, referring to customers in detached houses with electric heating. The prices are shown both with and without taxes. This figure illustrates two features of distribution prices. First, prices are on average extremely stable over time. The increase in prices over time is mostly due to taxation. The tax has changed twice during

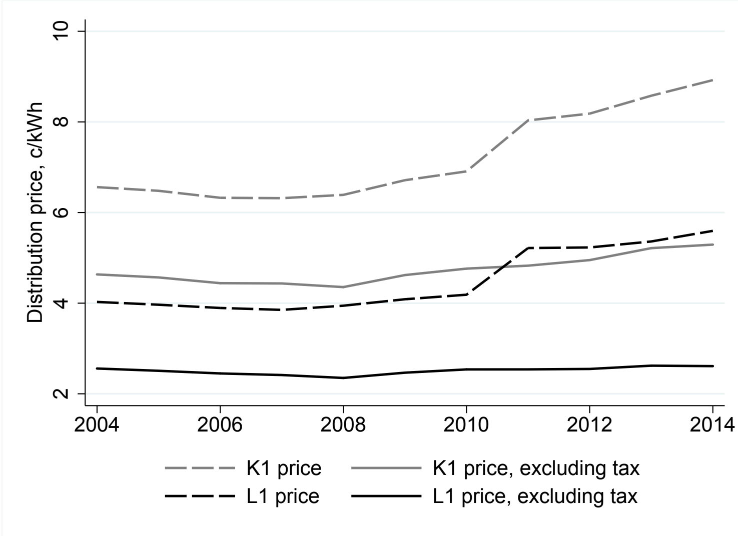

Figure 7. Average distribution prices over time.

Notes: The figure shows the average distribution price level for two customer groups: K1 with average annual consumption of 2000 kWh and L1 with average annual consumption of 18 000 kWh. The prices are shown including and excluding taxes.

this time period: in January 2008 when it was raised from 0.73 c/kWh to 0.87 c/kWh and in January 2011 when the tax level became 1.69 c/kWh. In addition to the electricity tax, VAT is levied on both distribution prices and electricity prices. This tax level was 22 percent until July 2010 when it was raised to 23 percent. On top of this, there is a security of supply payment, which has remained constant at 0.013 c/kWh.

Second, prices develop similarly over time in both customer groups, but K1 customers are charged a much higher price than L1 customers. It is natural for the unit price to be higher for those customers who have a much lower total consumption: the annual consumption of a detached house with electric heating can be 3 to 4 times higher than the annual consumption coming from appliance use only. On average, K1 prices are 2 times higher than L1 prices.

Table 10 shows results of an OLS regression of distribution prices on DSO characteristics, separately for K1 prices and L1 prices. The prices exclude taxes. The results indicate that prices tend to be lower in densely populated grid areas. The amount of energy supplied is measured separately for the low voltage distribution grid (0.4 kv) and medium voltage grid (1-70 kv) to which industrial customers may also connect. These values are expressed in proportion to the median, as there is a very large variance in the GWh supplied. The coefficients imply that prices tend to be lower in areas with a large amount of small-scale customers (0.4 kv grid), but if the DSO also distributes energy at a higher voltage, this increases prices. The share of ground cables is not statistically significantly related to prices, however prices higher prices are associated with areas where customers experience more power cuts. This is measured as hours of disturbance annually, and the first lag is used in estimation. The number of transformers and the amount of personnel working in distribution activities are both measured in proportion to the median. The number of transformers is strongly positively correlated with grid length and the number of connections to the grid. Once these are controlled for, a higher number of transformers is associated with higher distribution prices. The coefficient on the personnel variable indicates that larger companies have lower prices, but this result is only significant for the L1 customer group and not very high in magnitude.

B Cross-sectional variation in electric heating and distribution prices

This appendix provides descriptives on the amount of electric heating across regions and on the distribution price within each region. Figure 8 shows the total amount of houses by region in the sample used in estimation. In addition, the total amount of electrically heated homes is presented. This figure illustrates two issues. First, although four regions stand out as having notably more new builds than others, it can be seen that new homes are built in all regions of the country. In all but two regions, over 100 houses are built each year. This indicates that the results of the estimation are not likely to be driven by a specific region, and that the observations on houses cover well the different electricity price areas.

Second, the amount of electrically heated homes is around one half of all new houses in each region. Despite a declining trend in electric heating over time, the number of electrically heated homes is above zero each year in all regions. This shows that there is variance in the dependent variable, on which to estimate the effect of electricity costs on heating choice.

The cross-sectional variation in observations and distribution prices is presented in Figure 9 for year 2008. The figure illustrates the variation used in estimating the impact of electricity prices; the horizontal line depicts the overall average price level, captured by time fixed effects, and

Table 10. Determinants of distribution prices

	OLS results		Summary statistics	
	K1 prices	L1 prices	Mean	Std.dev.
Connections per km	-0.126***	-0.046***	5.36	2.31
	(0.026)	(0.009)		
GWh, 0.4kv grid, (share of median)	-0.254***	-0.115***	2.76	5.44
	(0.074)	(0.017)		
GWh, 1-70kv grid, (share of median)	0.049*	0.038***	3.83	8.07
	(0.028)	(0.005)		
Ground cables (%)	-0.005*	0.000	44.34	26.50
	(0.002)	(0.001)		
Transformers (share of median)	0.114***	0.054***	3.76	9.10
	(0.024)	(0.006)		
Power cuts (h), 1. lag	0.026***	0.011***	2.98	5.53
	(0.007)	(0.003)		
Personnel (share of median)	0.037	-0.034***	1.74	2.63
	(0.028)	(0.013)		
R^2	0.50	0.44		
Number of observations: 848				

Notes: Results from an OLS regression of distribution prices on DSO characteristics. The last two columns show summary statistics on the variables used in estimation. Prices exclude taxes. Connections per kilometre refer to the number of connections to the grid per grid length. The amount of energy supplied in the 0.4kv grid and 1-70 kv grid is measured in GWh and expressed in proportion to the median. Ground cables measures the share of underground cables. Transformers refers to the number of low-voltage transformers, expressed in proportion to the median. Power cuts are defined as the total number of hours a customer has been cut off from the grid. The first lag of this variable is used. Personnel measures the number of people working in distribution operations, expressed in proportion to the median. Significance levels: *** 1%, ** 5%, * 10%.

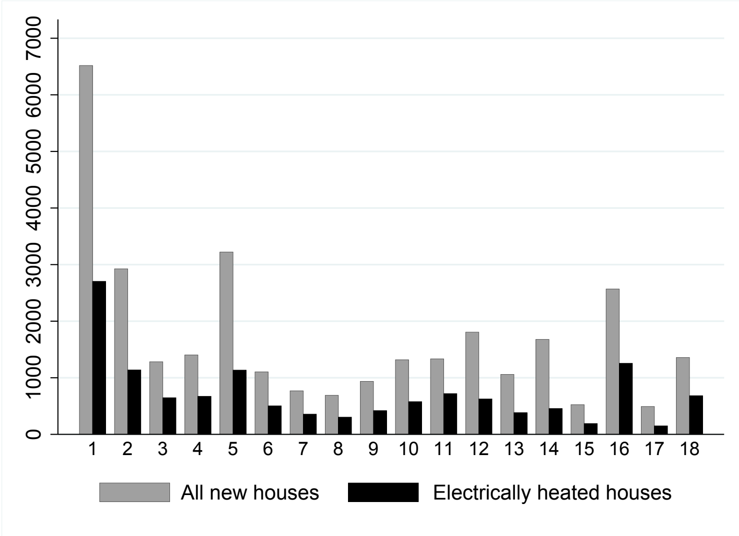

Figure 8. Total number of houses and electrically heated houses by region.

Notes: The total number of new houses and the number of electrically heated houses by region. Amounts calculated from the sample used in estimation, which includes years 2006-2011.

the regional average price level is indicated by a diamond. The range of prices observed within the given year for each region is shown by the dashed line. The bars present the total number of observations in each region.

There is notable variation in the observed price range within most regions. This variation results from new houses being built in different distribution system operators' areas, and it allows estimating the price impact while controlling for region fixed effects. The number of observations per region varies from around 100 to 1000, and the number of observations is not systematically related to region-level variance in prices; even regions with few new houses built per year have houses in several price areas.

C Full estimation results

Table 11 presents estimation results for all variables included in the estimation of heating choice. Note that the town plan indicator is grouped with the house characteristics, as this is essentially a feature of the building site.

Table 11. Results on electricity prices from binary logit estimation of heating choice

Dependent variable: choice of electric heating				
	1	2	3	4
Electricity price	-0.033	-0.035	-0.047	-0.047
	(0.030)	(0.032)	(0.032)	(0.032)
Distribution price	-0.207***	-0.283***	-0.310***	-0.256***
	(0.035)	(0.038)	(0.038)	(0.045)
Interaction with distribution price				
Town plan				-0.163***
				(0.040)
Observable heterogeneity: house				
Area ($10m^2$)		-0.128***	-0.121***	-0.121***
Material		-0.444***	-0.418***	-0.423***
Elements		-0.125***	-0.114***	-0.114***
HDD		-0.125	-0.190**	-0.191**
Town plan		0.630***	0.681***	1.368***
Observable heterogeneity: household				
Net income (10 000€)			-0.003***	-0.003***
Education			-0.227***	-0.226***
Age			0.010***	0.010***
Young children			-0.102***	-0.103***
Family size			0.033***	0.034***
House owner			0.221***	0.221***
Year fixed effects	Yes	Yes	Yes	Yes
Region fixed effects	Yes	Yes	Yes	Yes
Average LL	-0.65	-0.60	-0.59	-0.59
Number of observations: 31 483				

Notes: Results from a binary logit estimation of heating choice, the dependent variable being the choice of electric heating. Standard errors calculated by the delta method. All monetary variables measured in 2010 values. The town plan indicator equals one if the house is built in a location where a town plan is in force. Building characteristics include: total house size, building material (=1 if stone), building method (=1 if elements) and heating degree days at municipal level (HDD). Household characteristics include: all income net of taxes, education of building owner (=1 if at least Bachelor-level), age of building owner, presence of young children (=1 if children under 3 years), family size, current dwelling status (=1 if house owner). Significance levels: *** 1%, ** 5%, * 10%.

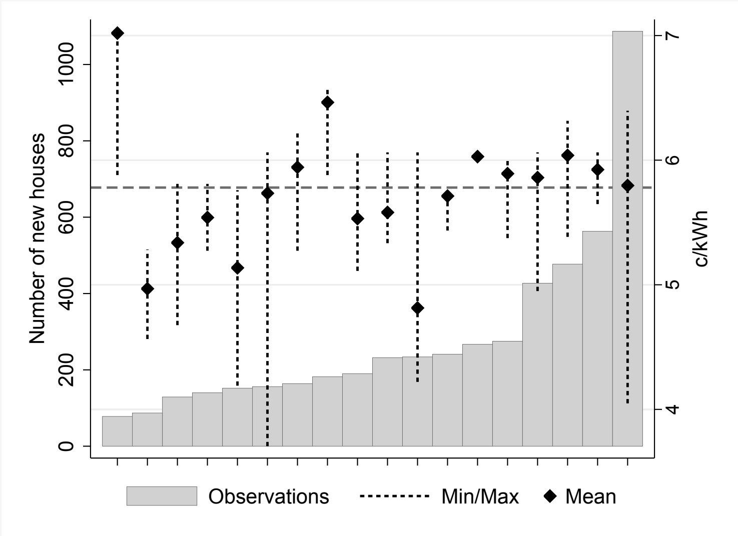

Figure 9. Range of distribution prices and number of observations by region, year 2008.

Notes: Number of new houses and observed range of distribution price by region for the year 2008. The diamonds indicate regional average prices, while the horizontal dashed line indicates the annual national average distribution price. Price levels depicted on the right-hand axis. The number of new houses is indicated by bars and read on the left-hand axis.

D Robustness checks

D.1 Alternative definitions for fixed effects and electricity prices

This appendix reports additional estimation results based on different specifications for fixed effects and electricity prices. All house and household characteristics are included as controls. The results are to be compared to specification number 3 presented in Table 7, where the coefficient on the distribution price was estimated to be -0.310 with a standard error of 0.038.

The first column in Table 12 shows results when the interaction of time and region are included in the fixed effects. The results are identical to the specification where only levels of year and region were included.

The second column shows results with the retail price of electricity defined to be the lowest price accessible to each household. That is, the retail price is the lowest average price available nationwide in a given year, unless the local default price is lower. In this case, the local price is assigned to the house. This removes some of the variation in retail prices, and hence the standard error on the retail price coefficient is now much larger. The coefficient on the distribution price is changed only slightly.

The third column shows results using the average distribution price from the previous three years as opposed to the price of the current year. That is, for observations in year 2006, the distribution price assigned to each house will be the average over the years 2003-2005 in that given distribution area. The point estimate of the distribution price coefficient is now more negative, however the standard error also increases since averaging removes some of the variation from the data.

The fourth column uses all available distribution price data. The estimation thus includes years 2003-2011. Two variables must now be dropped: the retail price of electricity and the education variable, as these are not recorded for the whole time period. The result on the distribution price does not significantly differ from the other specifications once more data is included.

To summarize the results from these checks, Figure 10 shows the estimated coefficients on distribution price along with the 95 percent confidence interval for the specifications presented in Table 12. For comparison, also the main result with all control variables (specification 3 in Table 7) is presented. It can be seen that the results are very similar in terms of coefficient values, and the confidence intervals overlap.

D.2 Electricity prices and house characteristics other than heating

This section presents descriptive analysis on the determinants of house characteristics observed in the data. These include house size, the building material and building method. Table 13 presents results of OLS regressions of these variables on house and household characteristics, as well as year and region fixed effects. The set of control variables is identical to the one used in technology choice estimation. House size is measured in 10 square meters. The building material and method are indicator variables, hence the coefficients measure the marginal effect on the probability that the house is built from stone, or that the house is built from elements. The share of stone houses is only 9 percent, which explains why most coefficients are very low in magnitude. The share of element houses is 48 percent.

Overall, the household characteristics which consistently have an impact on these building characteristics are income, education, age and whether

Table 12. Robustness checks on estimation of heating choice.

Dependent variable: choice of electric heating.

	1	2	3	4
Electricity price	-0.026	-0.040	-0.055*	
	(0.036)	(0.238)	(0.032)	
Distribution price	-0.310***	-0.315***	-0.335***	-0.330***
	(0.040)	(0.038)	(0.049)	(0.031)
Controls				
House characteristics	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes
Town plan indicator	Yes	Yes	Yes	Yes
Regional effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
Region x time	Yes			
Obs	31 483	31 483	31 483	56 714
Average LL	-0.59	-0.59	-0.59	-0.60
Average marginal effect	-0.063***	0.064***	-0.068***	-0.069***
	(0.008)	(0.008)	(0.010)	(0.006)

Notes: Results from robustness checks on choice of heating technology. The dependent variable is the the choice of electric heating. Standard errors calculated by the delta method. All monetary variables measured in 2010 values. The town plan indicator equals one if the house is built in a location where a town plan is in force. Building characteristics include: total house size, building material (=1 if stone), building method (=1 if elements) and heating degree days at municipal level. Household characteristics include: all income net of taxes, education of building owner (=1 if at least Bachelor-level), age of building owner, presence of young children (=1 if children under 3 years), family size, current dwelling status (=1 if house owner). In specification 2, the lowest available retail electricity price is assigned to each household, as opposed to the local default price. In specification 3, the distribution price refers to the average local price over previous three years. In specification 4, all available distribution price data is used. Estimation includes years 2003-2011. The retail price must now be dropped. Significance levels: *** 1%, ** 5%, * 10%.

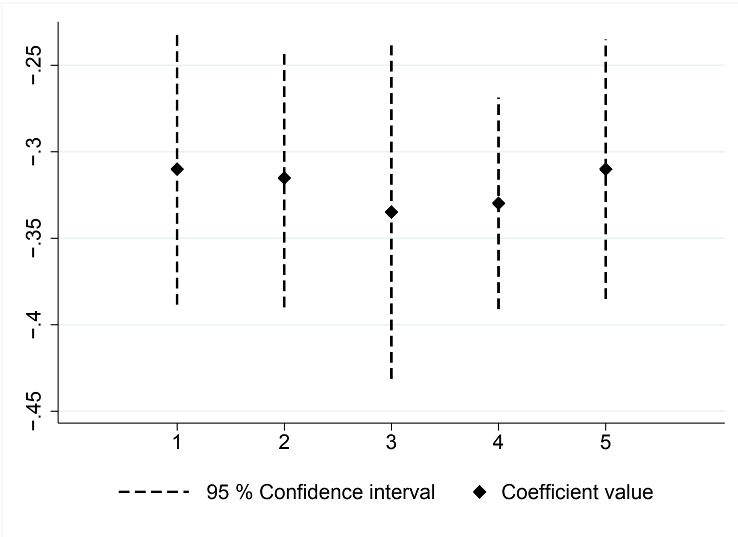

Figure 10. Coefficient estimates and confidence intervals from robustness checks.

Notes: Coefficient estimates and confidence intervals for the electricity distribution price variable. Estimates based on a binary logit model of heating choice, the dependent variable being the choice of electric heating. All models include house and household characteristics. Specification 1 refers to a model with fixed effects at the level of region-by-year, in addition to region and year effects in levels. Specification 2 refers to a model with the retail price of electricity for each household defined as the lowest available price as opposed to the local default price. Specification 3 refers to a model where the distribution price is the average local price over three preceding years. Specification 4 refers to a model estimated on all available distribution price data, including years 2003-2011. Specification 5 is the point of comparison: the model includes all observable heterogeneity and fixed at the level of region and year, estimated on data from 2006-2011.

the household currently resides in an owner-occupied detached house. Location is important, as indicated by the significant effect of the town plan indicator for all building choices. The house characteristics are also strongly correlated with each other: the results indicate that stone houses are considerably larger than houses built from wood, and much less likely to be built from elements.

The distribution price of electricity is estimated to be negatively correlated with house size and choice of stone as the building material. However, these effects disappear if fixed effects are introduced at a more detailed level of municipalities. Nevertheless, this result, as well as the correlations between house characteristics, emphasizes the importance of including observable heterogeneity in the estimation of technology choice.

Table 14 illustrates how house characteristics impact the estimation of heating technology choice. When no house characteristics are included as controls, the retail price is estimated to have negative but weak effect on the choice of electric heating. As controls are added, this effect diminishes. Conversely, the impact of distribution price is strengthened both in magnitude and precision as controls are added. The strong inter-correlation of the house characteristics is illustrated by the changes to the coefficient estimates as more variables are added.

D.3 Estimation by a linear probability model

This appendix provides estimation results using a linear probability model instead of a discrete choice model. Due to the nonlinearity of the discrete choice model, issues such as omitted variables can be more problematic in this set-up than in the standard linear regression model. Moreover, the use of fixed effects can give rise to the 'incidental parameters'-problem. This refers to the asymptotic properties of fixed effects in a panel where the time dimension typically is short. In this case the coefficient estimates for fixed effects can be inconsistent, and because of the nonlinearity of the model, this inconsistency will impact all other coefficients in the model. It has been shown that this inconsistency can bias coefficient estimates upwards (see Greene, 2008, and the references therein).

To check for upward bias in the results of the binary choice model, the same utility specification is estimated by ordinary least squares, with the choice of electric heating as the dependent variable. The estimation results are used to predict heating choices, and these predictions are used in calculating elasticities as in section 5.2.

Table 13. Determinants of house characteristics

Dependent variable	Area ($10m^2$)	Material:stone	Element build
Electricity price	0.147*	0.005	0.002
Distribution price	-0.672***	-0.017***	0.007
Net income (€10 000)	0.044***	0.001***	0.001***
Age (10 years)	-0.015***	0.000***	-0.001***
Education	0.880***	0.014***	0.026***
Family size	0.942***	-0.003*	-0.001
Young children	-0.256	-0.007**	0.031***
Own house	0.640***	0.014**	0.039***
Town plan	-0.339***	0.034***	0.062***
HDD	-2.102***	-0.040***	0.016
Material:stone	5.381***		-0.288***
Element build	-1.142***	-0.084***	
Area		0.012***	-0.009***
Constant	26.783***	0.109**	0.590
R^2	0.21	0.15	0.07
Number of observations: 31 483			

Notes: The table presents results from OLS regressions where the dependent variable is house size, building material or the building method. The variable for building material takes value 1 if the house is built from stone. The variable for building method takes value 1 if the house is built from elements. Household characteristics include: all income net of taxes, education of building owner (=1 if at least Bachelor-level), age of building owner, presence of young children (=1 if children under 3 years), family size, current dwelling status (=1 if house owner). All specifications include annual time fixed effects and location fixed effects at regional level. Significance levels: *** 1%, ** 5%, * 10%.

Table 14. Robustness checks with respect to house characteristics

Dependent variable: choice of electric heating.

	1	2	3	4
Electricity price	-0.066**	-0.065**	-0.060*	-0.047
	(0.031)	(0.031)	(0.031)	(0.032)
Distribution price	-0.194***	-0.197***	-0.221***	-0.310***
	(0.037)	(0.037)	(0.037)	(0.038)
House characteristics				
Element built		0.095***	0.009	-0.114***
Material: stone			-0.092***	-0.418***
Area ($10m^2$)				-0.121***
Other controls				
Household characteristics	Yes	Yes	Yes	Yes
Town plan indicator	Yes	Yes	Yes	Yes
Regional effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
Average LL	-0.63	-0.63	-0.63	-0.59
Average marginal effects of electricity prices				
Electricity price	-0.014**	-0.014**	-0.013*	-0.010
Distribution price	-0.043***	-0.043***	-0.048***	-0.063***
Elasticity of electric heating demand w.r.t. distribution price				
	-0.42	-0.42	-0.44	-0.61

Notes: Results from robustness checks on choice of heating technology with respect to the inclusion of house characteristics in the set of control variables. The dependent variable is the the choice of electric heating. Standard errors calculated by the delta method. All monetary variables measured in 2010 values. The town plan indicator equals one if the house is built in a location where a town plan is in force. Household characteristics include: all income net of taxes, education of building owner (=1 if at least Bachelor-level), age of building owner, presence of young children (=1 if children under 3 years), family size, current dwelling status (=1 if house owner). Significance levels: *** 1%, ** 5%, * 10%.

The results are presented in Table 15. The first column shows results with fixed effects at the level of region and year. The coefficient on distribution price can be compared to the average marginal effect from the binary choice model. This effect, presented in Table 8 of section 5.1, is -0.063. The result of the linear probability model is identical to this. The second column shows results with fixed effects at the level of region, year and region-by-year. The coefficient on distribution price is not changed.

The third column shows results using fixed effects at the level of municipalities. This was not possible in the binary logit model, as the number of indicator variables proved too large. This more detailed fixed effect-specification results in a small reduction of the magnitude of the distribution price coefficient.

The elasticities based based on the predicted quantities from the different specifications are reported in the last row. The quantities are calculated from the share of electric heating predicted by the model, and the price elasticity is calculated at a distribution price level of 4 c/kWh. Overall, these elasticity measures are very similar across the specifications, and lower than the ones obtained from the logit model of choice. However, the OLS model is not well suited for producing predicted shares of heating, as it does not restrict the choice probability to lie between 0 and 1 as the logit model does. Therefore, it is more meaningful to compare the marginal effects from these different models. In this respect, the results from the linear probability models are very close to the ones obtained by a discrete choice model. This alleviates the possible concern for biases in the nonlinear model.

Table 15. Estimation of heating choice by ordinary least squares.

Dependent variable: choice of electric heating.

	1	2	3
Electricity price	-0.010	-0.005	-0.008
	(0.006)	(0.007)	(0.010)
Distribution price	-0.062***	-0.061***	-0.059***
	(0.008)	(0.008)	(0.012)
Controls			
House characteristics	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes
Regional effects	Yes	Yes	
Time effects	Yes	Yes	Yes
Region x time		Yes	
Municipality effects			Yes
Obs	31 483	31 483	31 483
R2	0.15	0.16	0.17
Predicted share of electric heating			
	0.42	0.42	0.42
Elasticity w.r.t. distribution price			
	-0.58	-0.57	-0.56

Notes: Results from estimation of heating choice by OLS. The dependent variable is the choice of electric heating. Heteroskedasticity-robust standard errors reported in parentheses. All monetary variables measured in 2010 values. Building characteristics include: total house size, building material (=1 if stone), building method (=1 if elements), heating degree days at municipal level and a town plan indicator (=1 if house built in a location with a plan in force). Household characteristics include: all income net of taxes, education of building owner (=1 if at least Bachelor-level), age of building owner, presence of young children (=1 if children under 3 years), family size, current dwelling status (=1 if house owner). Significance levels: *** 1%, ** 5%, * 10%. The elasticity is calculated at a distribution price of 4 c/kWh, using quantities calculated from the predicted share of electric heating.

Household Heterogeneity in Willingness to Pay for Energy Cost Reductions

Anna Sahari

Abstract

This study estimates households' willingness to pay higher investment costs in order to obtain reductions in lifetime energy costs of a durable good. This measure reveals how households value future operating costs. The analysis is based on extensive micro-level data on Finnish households' choice of heating technology at the moment of building a new house. The data are drawn from administrative records, and allow estimating the willingness to pay as a function of several observable household characteristics. The household-level data are supplemented by information on regional differences in climate and electricity prices, which induce variation in the heating costs faced by households building in different locations. The results are based on a discrete choice model of heating technology. The results indicate substantial heterogeneity in households' valuation of lifetime heating costs. On average, households are estimated to be willing to pay €10 more in investment cost to save €1 annually in heating costs over the lifetime of the investment. This implies discount rates averaging 7 to 10 percent when calculated at lifetimes commonly used in heating system comparisons.

Keywords: *Energy consumption, Intertemporal choice, Willingness to pay, Households, Discrete choice*

JEL codes: *D12, D91, Q41*

1 Introduction

It is well acknowledged that heterogeneity in consumer behaviour is an important factor in policy evaluation. Understanding the different dimensions of individuals' responses to incentives is a key issue in designing efficient policy measures, and in assessing whether such measures are needed to begin with.[1] In the context of energy efficiency, accounting for differences among consumers can be crucial in examining the existence and implications of the energy efficiency gap.[2] These differences include heterogeneity in the pattern and level of energy use, in driving habits, in attention to energy use as well as in the ability and willingness to evaluate the costs of longer term energy consumption.

Despite the importance of consumer characteristics, data limitations may hinder addressing these issues in research. Explicit incorporation of consumer heterogeneity requires individual-level data, which can be difficult to find. This type of data is often available from surveys. Recent examples related to residential energy efficiency include Davis (2012), Gillingham, Harding and Rapson (2012) and Lamos, Labandeira and Löschel (2016). Also experiments have been used to extract individual-specific valuations of energy efficiency (for example Allcott and Taubinsky, 2015; Newell and Siikamäki, 2014; Scarpa and Willis, 2010; Ward et al., 2011).

Another key feature of energy efficiency investments is the expected level of future energy prices. The profitability of these investments depends crucially on the development of energy prices, however it can be challenging to determine the relevant long-term price level to be used in analysis. Empirical research often must rely on the assumption that consumers use current fuel prices as expected prices, which may be questionable especially for volatile commodity prices such as oil.

[1] For example, Allcott, Knittel and Taubinsky (2015), Allcott, Mullainathan and Taubinsky (2014) and Allcott and Taubinsky (2015) all discuss optimal energy policy under misoptimising consumers, and note that this requires targeting the correct consumers; policy instruments based on average values could actually be welfare-reducing. In a different context, Chetty, Friedman, Leth-Petersen, Nielsen, and Olsen (2014) show using administrative individual-level data that retirement savings policies based on incentives only induce a small share of the population to change their savings behaviour, whereas automatic contributions to retirement accounts have the largest effect on passive individuals who form a majority of the population.

[2] The energy efficiency gap, or energy paradox (Allcott and Greenstone, 2012; Jaffe and Stavins, 1994) refers to underinvestment in seemingly profitable energy-saving measures, such as energy-efficient appliances, home improvements or renewable energy technology.

This study utilises detailed individual-level data to study household investment into energy-using durable goods. Specifically, the goal of this study is to shed light on how households' valuation of lifetime costs of a durable good vary with household characteristics. The value placed on lifetime costs is estimated as the willingness to pay higher investment costs in order to obtain annual savings in operating costs over the lifetime of the heating system. The durable good considered is the main heating system installed into new detached houses at the moment of building. The data are drawn from national administrative registries, and include observations on household characteristics in several dimensions. This enables a detailed analysis of the ways that household heterogeneity impacts investment behaviour.[3]

In addition to detailed information on households, the data include local electricity prices, explicitly differentiated between the short-term and long-term price level. This distinction is made possible by the design of the Finnish electricity market, which differentiates the retail price of electricity from the distribution price. The former price is determined on the deregulated retail market, whereas the latter is a compensation for the distribution service paid to the local grid operator. Distribution prices are regulated and based on the costs of operating and maintaining the local grid. This results in different, stable price levels across distribution areas. The strong persistence in local distribution prices makes them a relevant price measure for long-term electricity consumption.

This research contributes to a continuum of literature on households' energy-related behaviour, incited in the 1970's by the oil crisis. Estimating consumers' valuation of lifetime operating costs of durable goods dates back at least to Hausman (1979) and Dubin and McFadden (1984). Both these studies use observations of household investments to draw inferences on valuation of operating costs; Hausman (1979) estimated an implied discount rate of 25 percent based on air conditioner purchases, while Dubin and McFadden (1984) used choices of space and water heating. They introduced household heterogeneity by estimating the discount rate as a function of income, and found the implied discount rate to equal 20.5 percent at the mean income level.

More recent work has evaluated the WTP for energy savings in the con-

[3] In Finland, it is typical for detached residential houses to be built by the households themselves. It is the house owner who acts as the contractor and manages the project. Therefore, the issue of property developers making suboptimal decisions in terms of the habitants of the house is not present in this setting.

text of water heater choice (Newell and Siikamäki, 2014) and purchase of refrigerators (Ward et al., 2011) using choice experiments. Newell and Siikamäki found the WTP to average $0.8 for a $1 in lifetime cost savings, which implies undervaluation of operating costs relative to purchase price. They also elicited personal discount rates, which averaged 19 percent with a median of 11 percent. Ward et al. found contrary results, with experiment participants willing to pay on average $250-$350 for Energy Star-labelled fridges, with estimated annual cost savings of $14 from efficiency. Given that participants expected to own the appliance for 11 years, this implies valuation of energy efficiency beyond monetary savings only.

A number of papers have used a different approach to study the valuation of fuel economy in car markets. Busse, Knittel and Zettelmeyer (2013), Allcott and Wozny (2014) and Sallee, West and Fan (2015) all estimate a version of the 'attention weight' consumers place on lifetime fuel costs when purchasing a car. That is, they evaluate whether purchase price and present-value lifetime operating costs of the vehicle are equally valued in decision making. These studies exploit rich transaction data which allow accounting for unobservable product characteristics in several ways, however, consumer heterogeneity is not explicitly addressed.

The findings of these studies support modest to no undervaluation of fuel costs. The empirical specification in Allcott and Wozny (2014) and Sallee, West and Fan (2015) tests whether lifetime fuel costs are equally valued to purchase costs. This amounts to testing whether the coefficient on fuel costs equals one when the dependent variable is the purchase price of the vehicle. Allcott and Wozny (2014) find a value of 0.76, whereas Sallee et. al. (2015) report several specifications with all results very close to 1.

The approach in Busse et. al. (2013) is different, as they express fuel cost valuation in terms of the discount rate implied by observed price changes. They estimate the impact of fuel prices on purchase prices in equilibrium, and use assumptions on lifetimes, expected fuel prices and demand elasticities to find the discount rate that equates fuel price changes with purchase price changes. The authors report several discount rates corresponding to the different sets of assumptions. The range is wide from negative values to 20. However, most rates are reasonable at below 10 percent, and the authors conclude that the evidence does not support undervaluation.

Both these approaches require making the same assumptions. A lifetime for the investment must be assumed, and an expected energy price over this lifetime. If a discount rate is assumed, present-value operating costs can be calculated and an attention weight estimated. Alternatively, the usage costs can be expressed as an annual value, in which case the WTP can be estimated, and from this an implied discount rate can be inferred - given a lifetime.

All these relevant variables are likely to be viewed differently by different consumers. Lifetimes will depend on usage patterns, especially in the case of cars. Consumers may have different expectations for energy prices. The wide literature on personal discount rates indicates that time preferences vary over individuals.[4] This is likely to carry over to investment-specific discount rates, which will depend also on individual-specific views of the riskiness of the investment and on possible credit constraints. If common lifetimes and discount rates are assumed, these dimensions of heterogeneity are unaccounted for.

In the context of fuel efficiency, Bento, Li and Roth (2012) have shown using simulated data that ignoring consumer heterogeneity in fuel cost valuation will bias the estimates of fuel valuation downwards. This means that the discount rate implied by the valuation of future costs will be biased upwards. Using data on European car markets, Grigolon, Reynaert and Verboven (2014) exemplify that indeed introducing consumer heterogeneity into a model of vehicle choice changes the results as well as the policy implications. They use prior information on the distribution of mileage and allow for heterogeneity in valuation of other car attributes through random coefficients.

Similar results have been obtained by Newell and Siikamäki (2014 and 2015) in a choice experiment concerning energy efficiency labels and choice of water heaters. They document that individual discount rates, and consequently the WTP for energy efficiency, vary greatly with observable individual characteristics. They emphasize especially the large difference in discount rates associated with the level of education. Newell and Siikamäki (2014) note that assigning a common discount rate for all consumers can result in erroneous inferences on the optimality of households' energy-related behaviour.

In this study, consumer heterogeneity can be explicitly addressed by

[4]Frederick, Loewenstein and O'Donoghue (2002) provide an extensive review on the issue. Newell and Siikamäki (2015) discuss time preferences in the context of energy efficiency.

making the WTP a function of household characteristics. This is a clear advantage over the studies which must rely at best on aggregate information about consumers. Though random coefficients can be used to allow for individual-specific variation in fuel cost valuation, they do not provide information on the ways in which different characteristics impact the valuation. For this, observable characteristics are essential.

A second advantage of the data is the quality of the electricity price information. Any empirical analysis on investment into energy-consuming durables, whether they be cars, appliances or improved insulation, must assume some value for future energy prices. The common approach is to assume that consumers use the current price as the expected future price. Though there is some empirical evidence supporting this assumption (Anderson, Kellogg and Sallee, 2013), its validity is still likely to be very context-specific. This study can utilise the fact that electricity distribution prices in the Finnish market are defined at the level of local distribution grids, and these local prices are very stable. There are notable differences in the price levels across the country, due to the differences in geography and climate which impact the costs of providing the distribution service. This results in the local distribution price being a fixed characteristic of the area, and assigns this price as a natural measure of the long-term price level. The significance of the distribution price for the heating technology choice has been shown in Sahari (2016a) and Sahari (2016b).

Thus, the analysis exploits this price variation and models the choice of heating technology between those options which use electricity to generate heat. The heating choice is modelled as a standard logit model of choice, using the observable household characteristics to allow the WTP to vary across households. The estimated WTP ranges from €5 to €20, with an average of €10. These values result in mean implied discount rates ranging from 7 to 10 percent, given different assumptions on investment lifetimes.

2 Modelling the choice of heating system

2.1 General framework

Due to the Finnish climate, all houses must be equipped with a heating system. The investment decision is carried out at the building stage, and it incorporates the choice of heating technology and fuel. Heating technologies can be divided into two categories: central heating and electric heating. Electric heating refers to heating by electric radiators or cables in the floor. In a central heating system, the heat is first generated in a generating unit, and is then distributed around the house most often via water. In this system, the most common sources of heat are ground source heat pumps, electricity and wood. District heat is also prevalent in areas where it is available.[5]

Both heating technologies are a fixed characteristic of the house; lifetimes are very long, easily exceeding 30 years.[6] The main difference between electric heating and central heating systems is that central heating provides the option of changing fuels. For example, oil heating in old houses is often replaced by ground heat. In contrast, if the house has been fitted with direct electric heating, it would be extremely costly to later install a system for heat distribution.

Thus, the household must choose a heating system j out of J possible options. These options are limited and the same choice set is available to all households. The utility from system j for household i can be expressed as $U_{ij} = V_{ij} + \varepsilon_{ij}$ where ε_{ij} is a random term incorporating factors unobservable to the researcher. Using these random terms, the probability that household i chooses option j is formulated as:

$$\begin{aligned} \Pr(U_{ij} > U_{ik}, \forall j \neq k) &= \Pr(V_{ij} + \varepsilon_{ij} > V_{ik} + \varepsilon_{ik}, \forall j \neq k) \\ &= \Pr(\varepsilon_{ik} - \varepsilon_{ij} < V_{ij} - V_{ik}, \forall j \neq k) \end{aligned}$$

This probability can be expressed using the density of the random terms,

[5] Gas is very rarely used by households in Finland. Where gas networks are present, typically in old apartment buildings in larger cities, gas is used for cooking.

[6] The components of oil, wood, and electrical heating systems have very long lifetimes, though oil and wood furnaces need regular maintenance. Ground heat pumps include a compressor which must be renewed after approximately 15-20 years. The most expensive part of ground heat systems is the borehole which collects the geothermal heat. Once the hole is in place, it needs no maintenance or renewal.

$f(\varepsilon)$. Denote by $I(\cdot)$ an indicator function which equals 1 if the condition holds. The probability that option j is chosen is

$$\int_{\varepsilon} I(\varepsilon_{ik} - \varepsilon_{ij} < V_{ij} - V_{ik}, \forall j \neq k) f(\varepsilon_i) d\varepsilon_i$$

The discrete choice model is determined by the distributional assumption concerning the random terms in the specification of utility. If the random terms are assumed to be distributed i.i.d extreme value type I, the difference of these terms is distributed logistic, in which case the probability of choosing alternative j has the following form:

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_k e^{V_{ik}}}$$

The coefficients of the utility function are estimated by maximising the log likelihood function: $LL = \sum_{i=1}^{N} \sum_j y_{ij} P_{ij}$, where $y_{ij} = 1$ if alternative j is chosen.

Estimating the choice of heating system is based on a utility function defined as follows. The household wishes to produce the heat it needs at minimal cost, but it must also consider other characteristics of the heating system, such as reliability, maintenance and environmental aspects. Utility is defined to be an additively linear function of the characteristics of the heating system, that is, costs and other attributes. Utility for consumer i from heating system j is

$$u_{ij} = \beta_i (IC_{ij} + \sum_{t=0}^{T} \delta_i^t p_{tj} H_i) + \sum_k \alpha_{ik} x_{jk} + \varepsilon_{ij} \tag{1}$$

where IC_{ij} is investment cost, $\delta_i = 1/(1 + r_i)$ is the discount factor, p_{tj} is the expected fuel cost for option j in time t and H_i is the expected amount of heating energy purchased annually. Other attributes besides price are noted by x_{jk}.

Assuming that households use the current fuel price as their best estimate of future fuel prices, the present value heating costs over the lifetime of the system can be expressed as $\sum_{t=0}^{T} \delta_i^t p_j H_i = \Delta_i C_{ij}$. The multiplier $\Delta_i = \sum_{t=0}^{T} \delta_i^t$ incorporates the discount rate and the lifetime, and transforms the annual heating cost $C_{ij} = p_j H_i$ into lifetime operating costs.

The residual ε_{ij} is assumed to be distributed extreme value type I. This distribution has variance $\pi^2/6$. Assuming this variance implies that the model has been normalised for the scale of utility. That is, the variance has been set to $\pi^2/6$ by dividing utility by the scale parameter σ (Train, 2009). If heteroskedastic error terms are allowed, indicating individual-specific σ_i, this introduces correlation across the coefficients:

$$u_{ij} = (\beta_i/\sigma_i)IC_{ij} + (\beta_i/\sigma_i)\Delta_i C_{ij} + \sum_k (\alpha_{ik}/\sigma_i)x_{jk} + \kappa_{ij} \quad (2)$$

The willingness to pay for an attribute is defined as the ratio of two coefficients: the coefficient of the attribute divided by the coefficient used as the base. This is typically a coefficient on costs, which reflects the marginal utility of income. In the case of heating choice, the WTP is defined as the coefficient on annual heating costs divided by the coefficient on investment cost. This measures the change in investment cost necessary to keep the utility constant, given a change in heating costs. This can be seen by totally differentiating the utility function and setting the change in utility to zero (for simplicity, only the cost components are included here):

$$\begin{aligned} du_{ij} = \beta_i dIC_{ij} + \beta_i \Delta_i dC_{ij} &= 0 \\ \beta_i dIC_{ij} &= -\beta_i \Delta_i dC_{ij} \\ \frac{dIC_{ij}}{dC_{ij}} &= -\frac{\beta_i \Delta_i}{\beta_i} \end{aligned}$$

When the willingness to pay for an attribute is expressed as a ratio of two coefficients, the variation in scale can confound the variation in the WTP (Train and Weeks, 2005). Furthermore, when WTP measures are formed based on random coefficients, the resulting WTP can have an unrealistically wide distribution, due to it being a ratio of two random coefficients (Scarpa et al., 2008). To resolve this issue, it is possible to reparametrise the model so that the estimated coefficients directly measure WTP (Cameron and James, 1987, Cameron, 1988, Train and Weeks, 2005, Sonnier et al, 2007). This amounts to dividing all coefficients by the base coefficient. The coefficients on the other attributes can then be interpreted as measures of WTP. This also removes the issue of scale heterogeneity, as the transformed coefficients are independent of scale:

$$u_{ij} = IC_{ij} + \Delta_i C_{ij} + \sum (\alpha_{ik}/\beta_i)x_{jk} + \kappa_{ij} \quad (3)$$

The interpretation of the coefficient on heating costs depends on whether the costs are defined as an annual value or as a present discounted value over the lifetime of the system. Annual heating costs are $p_j H_i = C_{ij}$. In this case, the estimated coefficient on these costs amounts to the discount factor: $\Delta_i = \sum_{t=0}^{T} \delta_i^t$. This measures the willingness to pay an amount Δ_i more in upfront investment costs to save €1 annually over the lifetime of the investment. If a lifetime is assumed, an implied discount rate can be inferred from the value of the coefficient. This is the approach taken in Busse, Knittel and Zettelmeyer (2013) and will also be used in this study.

Alternatively, an assumption on the discount rate and lifetime could be made at the point of constructing the heating cost variable. In other words, the heating costs would be defined as the present value of lifetime heating costs: $\Delta_i C_{ij}$. The estimated coefficient on this variable should equal one, if purchase price and lifetime costs are equally valued. This is the attention weight estimated by Allcott and Wozny (2014).

2.2 Empirical strategy

In estimation, the coefficients are estimated as WTP values. That is, all coefficients are divided by the coefficient on investment costs (see Appendix D for details). The counterpart of Equation 3 is the following base specification:

$$u_{ij} = IC_{ij} + \gamma C_{ij} + A_j + A_j T_t + \sum_k \alpha_k A_j + \kappa_{ij} \tag{4}$$

where IC_{ij} is the investment cost, C_{ij} is the annual heating cost and A_j is a technology-specific constant, which represents attributes other than price. To control for time trends in factors impacting the valuation of these technologies, the constant is defined separately for the two time periods used in estimation, and this is carried out by interacting the constant with a time indicator T_t. The constant may also be interacted with household-specific characteristics k to allow for differences in valuation of technology-specific factors.

To incorporate household heterogeneity, two approaches are used. The first one introduces a random coefficient on the heating cost variable: $\gamma_i = \overline{\gamma} + \xi_i$. Estimation by simulation produces an estimate of the average $\overline{\gamma}$ and of the standard deviation of ξ. The second approach allows the coefficient on heating costs to be a function of observable household characteristics z_i: $\gamma_i = \overline{\gamma} + \sum_m \mu_m z_{mi}$. This introduces interaction terms into the specification:

$$u_{ij} = IC_{ij} + (\overline{\gamma} + \sum_m \mu_m z_{mi}) C_{ij} + A_j + A_j T_t + \sum_k k_i A_j + \kappa_{ij} \tag{5}$$

Estimation is performed on the subset of technologies using electricity as the fuel: electric heating, hydroelectric heating and ground heat.[7] This

[7] When the subset is fixed for all households, independent of the observed choice of heating, maximising the log-likelihood conditional on the subset provides consistent estimates of the parameter vector (McFadden 1978, Train 2009, see Appendix C for details).

restriction must be applied due to the lack of information on fuel costs for wood heating and oil. The estimation sample will include only those houses that did not have access to district heat. This is to account for the fact that many municipalities have in place a requirement for new houses to join the district heat network. It is impossible to distinguish whether district heat is chosen out of free will or due to municipal enforcement.

3 Data

3.1 Houses and builders

The data combine information from different national administrative registries. The information on houses originates from granted building permits. Those houses are included in the data for which the start of building has been recorded.[8] The information on individuals is drawn from Statistics Finland's registries. The full data include an annual 90 percent random sample of new residential detached and semi-detached houses matched to the house owners and their spouses, for the time period 2000-2011.[9] Houses are matched to owners based on the personal identity number. A full description of the data can be found in Sahari (2016a) and Sahari (2016b). This section will focus only on the subsample used in the WTP estimation.

This sample includes houses from 2010 and 2011. Earlier years must be dropped because investment cost estimates are valid only for this time period. Table 1 shows summary statistics of houses and households by heating technology. Of these, electric heating, hydroelectric heating and ground heat will be included in estimation. These technologies account for 90 percent of observations. The other technologies must be dropped due to lacking data on fuel costs.

The included options all use electricity for heating purposes, but the technologies are very distinct. Electric heating refers to directly heating the house with electric radiators or floor cables. This is a simple technology and cheap to install, but it cannot incorporate alternative heat sources.[10] Hydroelectric heating refers to a central heating system where

[8] All new builds require a permit which will expire if building does not commence within three years.

[9] Statistics Finland does not grant access to full samples of individual-level data.

[10] Houses with electric heating are often equipped with a fireplace or air source

electricity is first used to heat water which is then circulated around the house. This technology has two advantages in comparison to a direct electric heating system: first, the system can benefit from time-of-day pricing, by stocking up on heat during the night when prices are lower; and second, this system includes the option of later changing the heating fuel.

The main substitute for electric heating is ground heat. This technology exploits the stability of the temperature underground. A heat pump collects the heat from a borehole, and this energy is used to heat water which is then circulated through the house by radiators or floor heating. Ground heat pumps use electricity to operate the pump and as a back-up heat source, but their electricity consumption is only around one third of the amount that would be consumed if heating by electricity only. In terms of the purchased heating energy, ground heat pumps are the most efficient technology.

Wood is especially used as a source of heat in rural areas, where it is common to have firewood available on the lot the house is built on. Oil heating is practically non-existent in new houses, though its share in the total housing stock is still notable. The category "other" includes fuels such as peat and gas, which are extremely unusual in residential buildings, and other technologies not classified as main heat sources.

On average, home builders are families with children, and have earnings slightly above the whole population average. A typical house is built from wood and is located in a densely populated area. Such areas are identified by the type of plan in force at the building site; town plans tend to be used in urban and densely populated areas, whereas rural locations typically rely on less detailed master plans. The exception is houses with wood heating; only 21 percent of such houses are built in a town plan area. Average house size ranges from 157 square meters for houses with electric heating to 210 square meters for houses with ground heat.

3.2 Annual heating costs

Construction of expected annual heating costs is based on engineering estimates of heating energy consumption and on regional electricity prices. These are described briefly here, and in more detail in Appendix B.1.

The annual heating cost is defined as $C_{ij} = p_j(a_i)(\frac{kWh}{m^2})$, where p_j is the price of electricity for technology j, a_i is the size of house i measured in square meters and $\frac{kWh}{m^2}$ is the heat consumption per square meter. Of

heat pumps to complement the main heating technology.

Table 1. Summary statistics on builders and houses.

	Electric	Hydroelectric	Ground heat	Wood	Other	Oil
Area (m^2)	157	171	210	180	182	194
Wood houses, share	0.95	0.92	0.82	0.93	0.89	0.89
Town plan area, share	0.64	0.69	0.57	0.21	0.66	0.52
Age	39	37	37	38	37	42
High education, share	0.34	0.44	0.51	0.33	0.41	0.29
Net Income	45 183	47 425	52 789	41 638	46 470	43 231
Family size	3.28	3.39	3.45	3.26	3.22	3.34
Young children, share	0.37	0.44	0.46	0.35	0.41	0.38
Overall share	0.35	0.18	0.37	0.05	0.04	0.01

Notes: The table presents summary statistics of house and household characteristics by installed heating technology. The education variable refers to the share of home owners with at least a Bachelor-level education. Income is defined as all earnings and benefits net of taxes, in 2010 values. 'Young children' refers to the share of families with children under 3 years of age. 'Town plan' is an indicator for whether a town plan is in force at the building site as opposed to a less detailed master plan.

these cost components, house size and electricity prices are observed in the data. The expected heat consumption is based on an engineering model of a house built according to prevailing building standards.[11] This model defines a heat consumption based on the thermodynamic properties of the building structures and on outdoor temperature, which is defined at regional level. There are thus 19 different consumption values, one for each administrative region.

The variation induced by climatic conditions is illustrated in Figure 1. The vertical axes shows the annual heating cost for an average sized house with electric heating, built according to the building standards of 2010-2011. The total fuel cost of electricity is set to 11 c/kWh. The horizontal axis orders the regions in terms of climate from mildest to coldest. It can be seen that different climate conditions across the country produce notable differences in heating costs. In the warmest region on the west coast the annual heating cost is €1900, whereas it is €2600 in the north. This is an increase of 37 percent in heating costs, due only to differences in weather.[12]

[11]Building standards are defined in the National Building Code of Finland, and they set mandatory requirements for insulation levels and other aspects of the building.

[12]In terms of annual temperature, the regional climate differences range from values of 6 degrees Celsius on the south-western coast to around -1 degrees in

The efficiency of ground heat pumps is represented by the coefficient of performance. This coefficient describes the ratio at which the pump produces heat and reduces the amount of energy that must be bought in the form of electricity. In effect, to construct heating costs relevant to ground heat, the heat consumption of the house is divided by the coefficient of performance. This coefficient takes value 3. That is, for each unit of heating energy needed, one third must be bought as electricity and two thirds are provided by geothermal heat.[13]

Electricity costs are composed of the retail price of electricity and of the distribution fee: $p_j = p_j^r + p_j^d$. The subscript j refers to distinct prices set for customers with electric heating and hydroelectric heating. These prices are provided by the Energy Authority, which maintains a record of all retail contracts offered by retailers in Finland, and acts as the regulatory authority for distribution pricing.

Electricity prices are defined in cents per kilowatt hour. Block rate contracts are not used in Finland. Both retail and distribution contracts include a fixed monthly fee and price per consumption unit (kWh). To arrive at comparable prices defined only in cents per kilowatt hour, the Energy Authority averages the fixed fee over the expected consumption for each customer type.[14]

For the analysis, each household must be assigned a retail price for electric and hydroelectric heating. Ground heat is assigned the same price as electric heating, divided by the coefficient of performance of the heat pump. The Finnish retail market for electricity is deregulated, and households may buy electricity from any retailer which offers to sell to nationwide customers. Because it is not possible to observe which retailer the household is contracted with, it is assumed here that all households use the lowest price available nationwide as the relevant retail price level.

Distribution of electricity in the low-voltage distribution grid is a regu-

the north.

[13]This value is selected based on personal communication with Juha Jokisalo from Aalto University Department of Energy Technology and Jussi Hirvonen from the Finnish Heat Pump Association. The coefficient of performance used in the National Building Code during this time was 2.5. However, according to experts this value had been set as a lower bound, in order to be sure not to overestimate the benefits of ground heat. Actual, observed values were typically around 3.

[14]The customer types are: customers in apartments (expected annual load 2000 kWh), customers in detached houses with other than electric heating (5000 kWh), customers in detached houses with electric heating (18 000 kWh), and customers in detached houses with hydroelectric heating (20 0000 kWh).

lated activity, provided by the local distribution system operator. There were 87 distributors during the time period examined here. The distributors are allowed to cover costs and earn a reasonable profit on capital, and pricing is monitored annually by the Energy Authority. Thus, there are regional differences in the distributors' price levels due to the different structures of the distribution grids in different areas. This causes exogenous price variation in the electricity costs faced by households building in distinct locations. The local distribution fee is matched to each house using the postal code.

When all households are assigned the lowest national retail price, all variation in total electricity costs originates from the distribution price. This is precisely the variance that consumers are certain to face; the high end of retail prices can always be avoided by switching suppliers. The distribution price, however, is always defined by the local distribution system operator. Sahari (2016a) provides empirical evidence that this is the price that consumers are sensitive to. The variance in distribution prices is illustrated in Figure 2, which shows the distribution of annual heating costs for an average house with direct electric heating or hydroelectric heating using 2010 prices. The heat consumption of the house is defined to be 20 000 kWh annually and the retail price is set at 4.8 c/kWh for electric heating and at 4.52 c/kWh for hydroelectric heating. These were the lowest prices available nationwide for these customer types in 2010.

3.3 Investment costs

The data do not include the actual investment cost incurred by each builder. These must be approximated for each option by using additional data. This is a survey on house builders carried out annually by RTS Ltd. The survey respondents are drawn from the same population as the registry data: private households who are in the process of building a new detached house. Appendix B.2 provides a comparison of the two samples and more information on the survey data.

In 2010 and 2011, the survey asked respondents to state the approximate costs of their heating system. The reported costs are regressed on house and household characteristics that are available in both data, and the estimates are used to construct investment costs for the houses in the registry data. The estimation results are reported in Table 2. The costs of electric heating are defined as a function of house size and an indicator for high income. The income variable captures location and quality effects, as

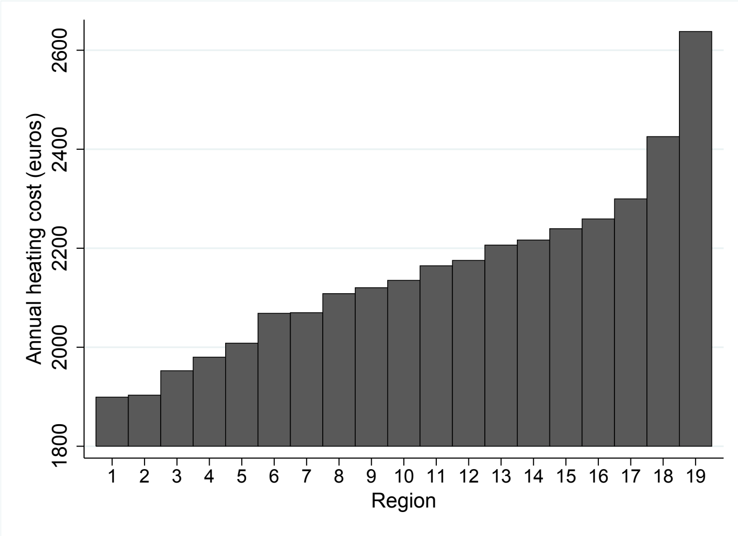

Figure 1. Annual heating costs of an average house by region.

Notes: The figure shows the annual heating cost for houses located in different regions. The heat consumption is that of a house built according to the building standards prevailing in 2010-2011. The heat consumption varies by region due to local climate differences. The heating cost is calculated at a total electricity cost of 11 c/kWh and assuming a house size of 180 square meters. The heat consumption varies from 96 kWh to 133 kWh per square meter.

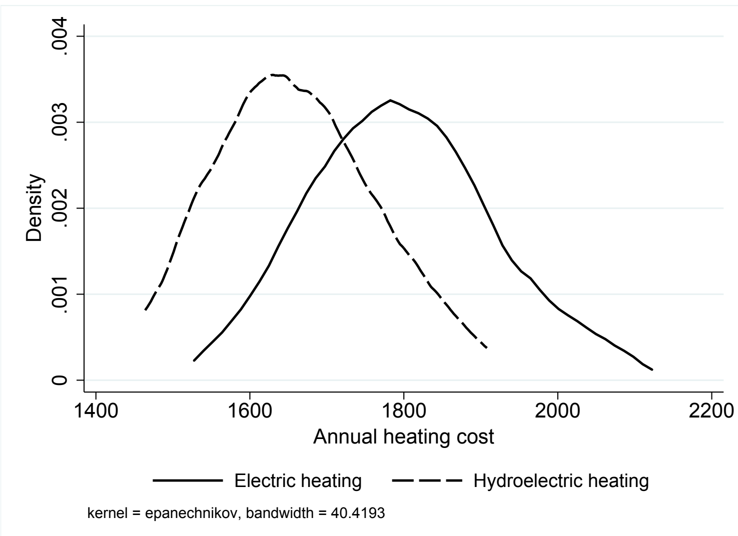

Figure 2. Cross-sectional variance in heating costs due to variance in distribution prices.

Notes: The figure shows the variation in annual heating costs resulting from cross-sectional differences in heating costs. The heating costs are calculated at a consumption of 20 000 kWh and retail prices set at 4.8 c/kWh for electric heating and 4.52 c/kWh for hydroelectric heating.

high income households tend to reside in regions where building costs are higher. Further cost determinants did not turn out to be significant, most likely due to the limited amount of observations. This also applies to hydroelectric heating, for which the costs are defined simply as a function of house size.

The information on ground heat richer, allowing for a more detailed definition of costs. For ground heat the impact of house size varies by location; the cost of one square meter is €8.5 more expensive in urban areas. Furthermore, high income households have higher investment costs. The costs also vary by climate, which is measured by heating degree days. This variable is defined at the level of municipality, and it is a function of the number of days when outside temperature is low enough to require heating. In colder regions, a deeper hole must be drilled in order to extract enough heat. This increases the investment costs, as the borehole is the most expensive component of a ground heat system. Despite this, the coefficient on heating degree days is negative. This likely reflects the fact that colder municipalities are located in the northern and eastern parts of the country, which tend to have a lower overall cost level.

Table 3 presents summary statistics of the constructed costs by the installed technology. Electric heating has the benefit of small investment costs, but operating costs are high. Moreover, this type of heating does not include the option of switching fuels at a later point in time. Hydroelectric heating in practice has the same operating costs as electric heating, but the investment cost is higher. Paying a higher investment cost in this case can be justified by the option value of later on switching to another heat source, such as a heat pump. Ground heat is by far the most expensive heating system in terms of investment costs. However, the low operating cost makes it cheapest technology for larger houses when lifetime costs are considered. This is illustrated in Figure 3, which shows how lifetime heating costs calculated over 20 years depend on house size. The discount rate is set at 5 percent, the total electricity price is 11 c/kWh and the heat need of the house is 99 kWh/square meter. This corresponds to the heat need in the region of Uusimaa, where most new houses are built.

Table 2. Investment cost estimation

Dependent variable: investment cost (€)			
	Electric	Hydroelectric	Ground heat
House size	43.248***	56.217***	33.895***
	(4.091)	(2.199)	(4.010)
Interaction effects with house size			
House size	-0.100***		
	(0.020)		
Location: town			8.503***
			(1.932)
Cost determinants in levels			
HDD			-0.9780***
			(0.3379)
High income	2625.723***		1137.391***
	(722.821)		(353.944)
Constant			15104.840***
			(1802.120)
Observations	248	174	720
R^2	0.61	0.80	0.22

Notes: The table presents results of an OLS estimation of reported heating system costs on cost determinants. House size refers to the total area of the house. The location variable is an indicator which takes value 1 if the house is built in an area where a town plan is in force. HDD refers to heating degerr days. High income is an indicator which takes value 1 if annual household income is higher than €80 000.

Table 3. Average costs and house characteristics by heating system

	Electric	Hydroelectric	Ground heat
Average size (m^2)	160	170	197
Average heat need (kWh)	16 642	17 474	20 040
Investment cost	4578	9218	18 064
Annual electricity cost	843	816	345
Annual distribution cost	793	764	327
Lifetime cost at T=20 and r=5%			
	26 599	30 485	27 109

Notes: The table shows average costs for installed heating systems in the data. The investment costs are based on cost estimates obtained from a survey of house builders. The operating costs are based on electricity and distribution prices, house size and expected annual heat consumption for each house.

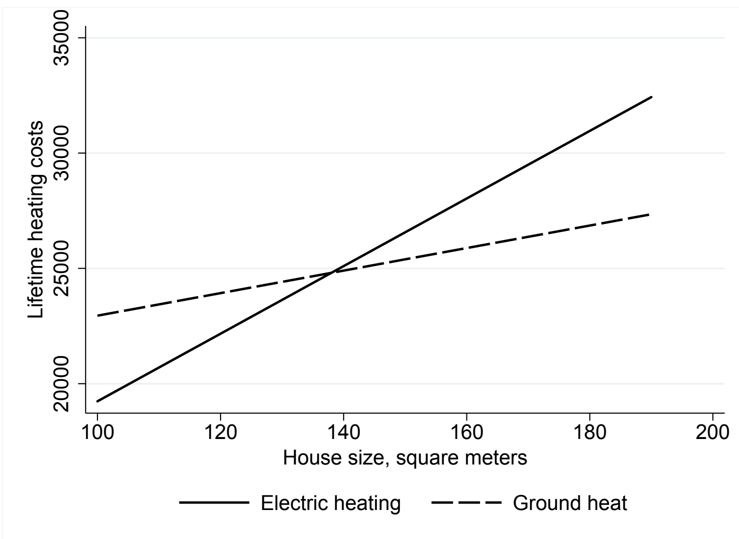

Figure 3. Lifetime costs of electric heating and ground heat by house size.

Notes: The figure illustrates the impact of house size on lifetime heating costs for electric heating and ground heat. The lifetime is set at 20 years, the discount rate is 5%, the electricity price is 11 c/kWh and the heat consumption of the house is 99 kWh/square meter.

4 Empirical analysis

4.1 Lifetime heating costs and optimal choice

This section illustrates how assumptions of lifetimes and interest rates impact the optimal heating technology choice, if choice is made purely on the basis of minimising total heating costs. Present value lifetime heating costs are calculated for each house in the sample at observed electricity prices, and the optimal choice is defined as the heating technology with the lowest costs. Table 4 presents the heating shares that would result at different assumptions. The observed shares in the data are 0.36 for electric heating, 0.21 for hydroelectric heating and 0.43 for ground heat.

This exercise reveals firstly, that based on costs only, hydroelectric heating is the optimal choice for a very small portion of houses. Contrasted with the fact that on average every fifth new house is nevertheless fitted with this technology, this implies that households place a high weight on attributes other than costs for hydroelectric heating. That is, builders recognise the value of fitting their house with a centralised heating system, which will allow alternative fuels to be used.

Secondly, the share of electric heating is not zero even at a very low discount rate of 2 percent combined with a long lifetime of 20 years. If the heating needs of the house are low due to a milder climate and small house size, electric heating may be the lowest cost option, especially in regions where electricity costs are low. Given that an interest rate of 2 percent is probably much lower than the rate applied by households in their decision making, the observed share of 0.36 for electric heating does not seem excessively high. In Table 4, the combination of interest rate and lifetime which produces a share of electric heating close to the observed one is 5 percent and 15 years.

4.2 Estimated willingness to pay for fuel cost reductions

Results from the estimation are presented in Table 5. All coefficients are estimated as monetary WTP values, divided by the coefficient on investment costs. This coefficient is reported at the bottom of the table. Note that the values on heating costs are negative, because the coefficient measures the WTP for an *increase* in the attribute. That is, the WTP for a *decrease* in heating costs is the negative of this number.

Table 4. Optimal heating shares based on lifetime heating costs

	Electric	Hydroelectric	Ground heat
	Discount rate: 2%		
T = 10	0.64	0.01	0.35
T = 15	0.09	0.01	0.90
T = 20	0.01	0.00	0.99
	Discount rate: 5%		
T = 10	0.84	0.01	0.15
T = 15	0.39	0.01	0.60
T = 20	0.12	0.01	0.87
	Discount rate: 10%		
T = 10	0.97	0.01	0.02
T = 15	0.86	0.01	0.13
T = 20	0.72	0.01	0.27

Notes: The table presents heating system shares in the estimation sample based on choosing the option with the lowest present-value lifetime costs. These costs are calculated at different assumptions on lifetimes (T) and discount rates.

Specification 1 is based on Equation 4 and includes no household characteristics. A constant for electric heating is included to capture differences in technologies between electric heating and central heating systems.[15] The WTP for a one Euro decrease annually in the use cost over the lifetime of the system is estimated to be 13 Euros. This can be interpreted as indicating that households assume a lifetime of at least 13 years for this investment; if no discount rate is used, the initial extra investment of €13 would be recovered in 13 years. If a discount rate of 5% is applied, at lifetime of 19 years would be needed to recover and initial investment of €13.

The second specification accounts for individual-level heterogeneity by allowing the coefficient on heating costs to be random. The estimated standard deviation, however, is not significant, indicating no heterogeneity in the WTP. Therefore, the results are the same as in specification 1. To check this result, the model was also estimated by a standard mixed logit specification, with no re-parametrisation of the coefficients and with the coefficient on annual heating costs allowed to be random. This produced

[15]Alternatively, a constant for ground heat could be used. This produces very similar results in terms of the WTP. A constant for hydroelectric heating is not significant and thus does not impact results.

the same result as the estimation in WTP-space.[16]

The third specification utilises the detailed data by interacting the heating cost coefficient with variables related to income, family size, age and education (Equation 5). This allows WTP to vary at the household level. Initially also the amount of debt and indicators for childcare and unemployment benefits were included. These variables were not significant, hence they are not included in the specification reported here. The interaction terms which do remain are highly statistically significant, and the coefficient on heating costs indicates a base WTP of €12. This result indicates notable heterogeneity in the WTP, contrary to the result of specification 2.

To further examine the source of heterogeneity, a fourth specification is estimated. This includes interactions of the technology constant with household characteristics, allowing the valuation of the technology itself to vary across households. The results of this estimation are displayed in column 4 of Table 5. The results imply that the WTP varies with income, the presence of children, family size and current house ownership. The interactions with the technology constant imply that electric heating is preferred by older home builders and by households who are building in an urban location. Highly educated households prefer central heating technologies. The valuation of electric heating is strongly negatively related to house size, even though costs are controlled for. The average valuation for the technology in the estimation sample is -1.620, indicating that in aggregate there is a preference for central heating technologies.

Specification 4 is used to calculate a WTP for each household in the estimation sample. The density of the resulting WTP measure is illustrated in Figure 4. The WTP ranges from €5 to €20, but high values are rare; the value at the 95th percentile is €12. The average WTP is €10. The peaks in the distribution correspond to the values of indicator variables for the presence of children and current house ownership.

Robustness checks with respect to the formation of heating costs are reported in Appendix E. Though the heat demand of a house should not be higher than that implied by the requirements of the National Building Code, it may be lower if the builder insulates more than is required. It is also possible that in colder regions households use more additional heat

[16] Mixed logit models with a random coefficient on investment costs were also estimated. Again, the standard deviations were not statistically significant, indicating no heterogeneity in the valuation of the investment cost.

sources, such as fireplaces, to reduce the amount of energy that needs to be bought. Appendix E reports estimates when all houses are assigned a low heat demand of 99 kWh per square meter.[17] In this case, all exogenous variation in heating costs is due to variation in distribution costs across the country. Furthermore, most households are now expected to have lower heating costs overall, due to the lower heat consumption. This specification results in an average WTP of €10. The sign and significance of the observable household characteristics do not change. A further alternative specification assigns to each house the retail price set by the local default supplier. There is now more variance in the heating costs, as retail prices range from approximately 4 c/kWh to 7 c/kWh. Some houses thus face higher annual heating costs than in the base specification, which assumes that all houses are buying electricity at the lowest price available nationwide. The average WTP is now €8, with a range of €4 to €17. Again, the results relating to the observable household characteristics do not change.

Appendix F presents the results in the form of an attention weight. The heating costs are defined as present-value lifetime costs, at a given discount rate and investment lifetime. When heating costs are calculated based on prevailing mortgage interest rates and a lifetime of 20 years, the estimation produces and average attention weight of 0.59, which would correspond to significant undervaluation of future costs. Yet this definition of costs may be placing too stringent conditions especially on the discount rate; mortgage interest rates were only around 2 percent during the sample period. Using a discount rate of 5 percent and a lifetime of 15 years produces an average attention weight of 0.87.

4.3 Variation in WTP with respect to household characteristics

The results of specification 4 indicate that WTP is impacted especially by income, the presence of children, family size and current dwelling type and ownership status. The coefficient on income indicates that each €10 000 increase in annual net income increases WTP by €0.49. Though highly significant, this effect is not high in magnitude. The result that income impacts heating choice can be viewed as evidence of credit constraints. If all households can borrow the needed amount at market interest rates, then current income should not impact the ability to pay

[17]This corresponds to the heat need of a standard house located in the metropolitan region in the south of Finland

Table 5. Results from estimation in WTP space

	1	2	3	4
Investment cost	1	1	1	1
Heating cost (WTP)	-13.307***	-13.307***	-11.914***	-9.515***
	(0.533)	(0.533)	(0.853)	(0.783)
Interaction terms				
Net income (€10 000)			-0.622***	-0.493***
Education			-1.682***	-0.307
Age (10 years)			0.318*	-0.135
Children			-1.431***	-1.386***
Family size			0.417***	0.669***
House owner			2.484***	1.696***
SD of random coefficients				
Heating cost (WTP)		0.005		
Constant for electric heating and interactions				
Electric heating	2.244***	2.244***	1.745***	10.803***
Year 2011	-1.368***	-1.368***	-1.504***	-1.433***
Location:town	0.472	0.472	1.127***	1.031***
House size ($10m^2$)				-0.864***
Net income (€10 000)				0.276
Education				-1.287***
Age (10 years)				0.616***
Children				0.277
Family size				0.106
House owner				-0.039
Coefficient on investment costs				
	-0.140***	-0.140***	-0.139***	-0.189***
	(0.011)	(0.011)	(0.011)	(0.012)
Log likelihood	-8469	-8469	-8339	-8015
Number of households: 8413				

Notes: The table presents results from a logit estimation of heating system choice. The options are electric heating, hydroelectric heating and ground heat. The coefficients are directly interpreted as willingness to pay-values. The indicator variables include education (=1 if at least Bachelor-level), children (=1 if family with children), house owner (=1 if current dwelling is a detached house) and location (=1 if town plan in force at building site). Net income refers to total household income net of taxes. Significance levels: * 10%, ** 5%, *** 1%.

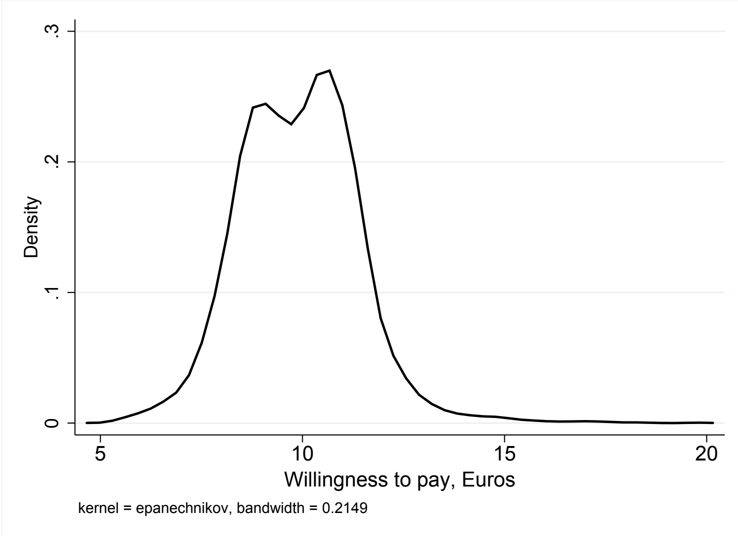

Figure 4. Distribution of WTP from specifications 3 and 4.

Notes: The figure illustrates the density of willingness to pay in the estimation sample, based on specification 4 presented in Table 5.

upfront investment costs. Households who want to install an expensive technology would simply take more debt, and the amount of debt would be positively correlated with the probability of installing an expensive system. It is possible that income is correlated with other factors influencing the investment decision, such as personal time preferences or unobserved tastes for heating system attributes. If this is the case, the income variable does not measure the impact of income alone. However, the extensive set of included characteristics should control for these factors to a large extent.

The presence of children is estimated to have a large impact on WTP; the value is estimated to be €1.39 higher in families with children. This is likely to reflect several aspects of the investment decision. First, families with children may expect to reside in the house for a long time, and hence be willing to accept longer payback times for the investment. This would translate into a higher WTP. Second, the presence of children has been found to be associated with lower personal discount rates, which again implies higher values of WTP. Though the presence of children increases the WTP, increasing family size is estimated to have an opposite effect. This may be related to disposable income; large families must spend more of their income on necessary expenditures, and hence be less willing to give up current income to pay high investment costs.

The indicator for house ownership measures whether the household currently is a house owner.[18] House owners will have experience of operating a heating system, and they should have a good understanding of the total costs of living in a house, including heating costs. House ownership has a strong impact on WTP; it decreases WTP by €1.70. This is not an evident result. One might expect current house owners to have higher WTP, as they should be able to comprehend the magnitude of costs savings available by investing into ground heat. A counteracting influence could be familiarity with electric heating. The most common heating technology in the current housing stock is electric heating (44 percent share), followed by oil (25 percent) and wood (22 percent). Previous positive experiences of a technology could decrease the willingness to install a different technology in the new house. Exploring this hypothesis further would require information on the current dwelling of the household.

4.4 Discount rates implied by WTP estimates

The estimated WTP measures the discount factor of the household (see Equations 4 and 3). Discounting over the lifetime forms a finite geometric series, so that:

$$\sum_{t=1}^{T_i} \delta_i^t = \sum_{t=1}^{T_i} (1/1+r_i)^t = \frac{1-(1+r_i)^{-T_i+1}}{1-(1+r_i)^{-1}}$$

When T_i is defined, this can be solved numerically for r_i. As the discount rate is not a linear function of the WTP, a discount rate solved from the mean WTP is not necessarily the mean rate in the sample. To obtain statistics on the discount rate, it must be calculated for each individual in the sample.

It should be noted that the discount rate implied by the WTP estimates is not a measure of the time preference, or personal discount rate, of the household. Rather, it is the discount rate specific to this durable good investment. It will reflect the personal discount rates of the household heads, but will also depend on factors such as risk measures and financial discount rates, which are specific to this investment.

Discount rates implied by the WTP estimates of specification 4 in Table 5 are presented in Table 6. These will depend on the time assumed; hence, different investment lifetimes are used in the calculation. In gen-

[18] Almost half of the households in the data reside in an owner-occupied detached house at the moment building starts. The remaining households either own an apartment or live in a rented dwelling.

Table 6. Implied discount rates (%) from estimated WTP

	T=15	T=20	T=25
Mean	7.6	9.6	10.4
Minimum	-2.8	0.5	2.3
Maximum	25.9	25.5	25.7

Notes: The table presents discount rates implied by willingness to pay-estimates based on specification 4 in Table 5. In this specification, the variance in WTP is based on observable household characteristics. A WTP and the corresponding discount rate is calculated for each household in the estimation sample, amounting to 8413 observations.

eral, heating system lifetimes are very long, easily exceeding 30 years. However, over long time periods differences in maintenance requirements become relevant. At a lifetime of 20 years, the costs of the different technologies are still considered comparable, as maintenance costs do not yet kick in.

On average, the discount rates obtained at different lifetimes are at reasonable levels. They are higher than mortgage interest rates which were on average 2 percent during 2010-2011. However, given that some risk premium is likely to be relevant to the investment, and that personal time preferences typically correspond to discount rates higher than 10 percent (for example Newell and Siikamäki, 2014), it is not surprising to find that the discount rates obtained here are higher than market interest rates. Figure 5 illustrates the density of the implied discount rates calculated at a lifetime of 20 years. The very low values are obtained for those households with highest income.

4.5 Elasticity of heating choice

To give an alternative interpretation to the importance of costs in heating technology choice, the estimation results of specification 4 are used to produce elasticity measures of heating choice with respect to heating costs. First, annual heating costs for all technologies are increased by one percent from the observed values. The heating shares predicted by the model are used to calculate the number of houses in each heating category after the cost increase. The results are presented in the top panel of Table 7. An increase in annual heating costs causes households to switch from electric heating to ground heat. Note that also the operating cost of ground heat were increased by one percent. If the cost increase had been imposed on electricity prices, the costs of ground heat would have risen

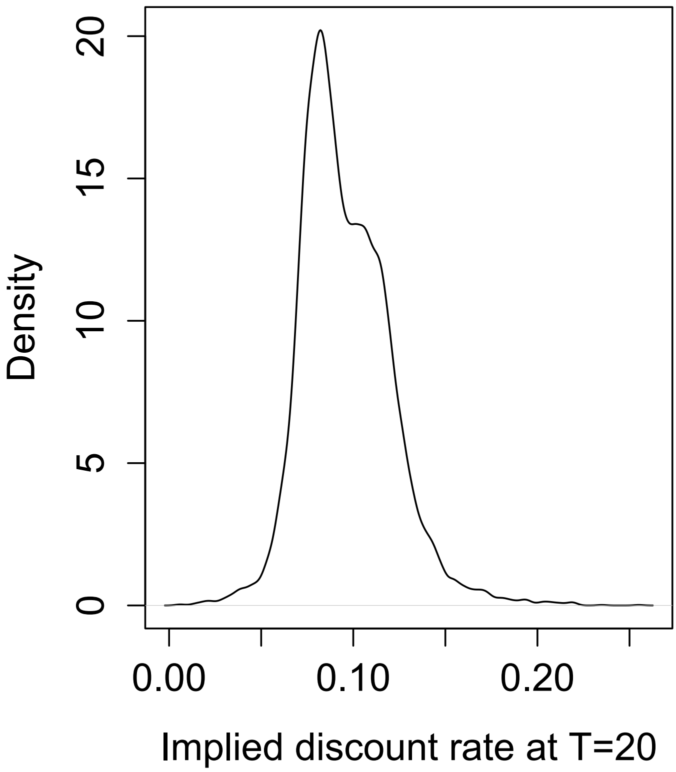

Figure 5. The density of implied discount rates in the estimation sample.

Notes: The figure illustrates the density of the implied discount rates in the estimation sample. Discount rates are based on estimation of willingness to pay using observable household characteristics (specification 4, Table 5). The discount rates are calculated using a lifetime of 20 years.

Table 7. Estimated elasticity of heating technology choice

	Base	Predicted change	Elasticity
1% increase in annual heating cost			
Electric heating	3056	-24	-0.79
Hydroelectric heating	1739	-12	-0.69
Ground heat	3618	36	1.00
1% increase in investment cost			
Electric heating	3056	30	0.98
Hydroelectric heating	1739	5	0.29
Ground heat	3618	-35	-0.97

Notes: The table presents elasticity measures based on model specification 4 reported in Table 5. The first column shows the predicted number of houses in each heating category when costs are kept at their observed levels. The second column shows the predicted changes in the number of houses due to a one percent increase in annual heating costs (upper panel) or in investment cost (lower panel). The final column shows the elasticity calculated from these numbers.

proportionally less than the costs of electric heating.

Second, the investment costs for all options are increased by one percent, keeping operating costs at the observed level. Again, the predicted number of houses in each heating category is calculated based on the heating shares produced by the model, and the results are reported in the lower panel of Table 7. Higher investment costs induce households to choose options with a lower magnitude of investment costs.

Overall, the elasticity measures are rather high, with absolute values close to one for electric heating and ground heat. Also, the values are similar in magnitude for both components of total cost. However, electric heating is estimated to have a higher sensitivity to investment costs than use costs, indicating that there is some discrepancy in the sensitivity to immediate versus long-term cost.

5 Summary and conclusion

This study investigates household heterogeneity in the valuation of upfront investment costs versus lifetime operating costs of an energy-using durable good. The analysis utilises detailed, individual-level data on households in the process of building a house, and the investment considered is the heating system choice. The valuation of lifetime operating costs is expressed as the willingness to pay higher investment costs in order to obtain lower use costs over the lifetime of the heating system.

The estimation exploits two sources of exogenous variation in the tradeoff between investment costs and use costs. The first is the regional variation in electricity prices, resulting from differences in the pricing of electricity distribution. Distribution fees are regulated and based on local grid characteristics, and consumers must buy this service from their local provider. The second source of variation is varying climate conditions across the country. A house built in the northern parts will consume much more energy per square meter than a house built in milder regions, leading to higher heating costs.

The data include observations of household characteristics in several dimensions. This allows making the willingness to pay a function of household characteristics, explicitly accounting for heterogeneity among households. The differences in willingness to pay can thus be linked to specific household characteristics, which is an advantage over using a random coefficients-specification to introduce heterogeneity across households.

The results indicate that willingness to pay varies notably in the population of home builders. The variables with the largest impact on the WTP are the presence of children and whether the household has experience of being a house owner. These impact the magnitude of the WTP, while the level of income drives the highest values of the WTP distribution. On average, the households are willing to pay €10 in investment cost to save €1 annually in heating costs over the lifetime of the investment. Converting the WTP to implied discount rates using a lifetime of 20 years results in values ranging from 0 to 26, with an average of 10 percent.

This evidence implies that, on average, there is no significant undervaluation of costs occurring in the future. The implied discount rates are not excessively high, and are close in magnitude to the range of values obtained in Busse, Knittel and Zettelmeyer (2013) and to the average personal discount rate elicited in Newell and Siikamäki (2014). Yet, the financial interest rates prevailing during the sample period were very low at around 2 to 3 percent. It can be argued that the difference between these rates and the implied discount rate is excessively high for certain households, even when accounting for personal time preferences and risk attitudes which will raise the household-specific discount rate above the market rates. According to the results, such excessive discounting is associated especially with low income and large family size.

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A The survey data

This appendix describes the survey data which are used to construct estimates of investment costs. The data are provided by RTS Ltd. This company annually surveys new house builders in order to produce statistics and information for different market actors in the housing industry. The respondents are selected randomly, and the survey covers the whole country. The basic structure of the survey remains the same throughout the years, but questions related to specific topics vary.

The survey data are available for the same time period as the full registry data: 2000-2011. Questions related to heating include the installed heating system, the considered heating systems, reasons for choosing the installed system and opinions on different heating technologies. These are included in the survey every year. The cost of the heating system is only included in 2010 and 2011.

Table 8 shows summary statistics of both data for the years used in estimation. The samples exclude district heat areas. The survey seems to have an over-representation of houses located in urban areas and more households in the income category that is just above the median income of house builders (the median income in the registry data is 59 000 Euros) . Furthermore, the share of ground heat is much larger in the survey data than in the registry data. This could be indicative of a selection issue; households who install ground heat are also more willing to participate in surveys. The joint share of electric heating, hydroelectric heating and ground heat is 78 percent in the survey data, while it is 90 percent in the registry data.

Table 9 shows some further information on heating choices that is available in the survey data. The columns indicate the installed technology. In the first panel, the rows show the most common heating technologies and

Table 8. Comparison of summary statistics from survey and registry data

	Survey data	Registry data
Income>€60 - 80 000, share	0.30	0.25
Income>€80 000, share	0.19	0.20
Pensioner, share	0.05	0.08
Family size	3.27	3.36
Area (m^2)	178	177
Town plan area, share	0.71	0.61
Metropolitan region, share	0.16	0.20
Electric heating, share	0.14	0.35
Hydroelectric heating, share	0.12	0.18
Ground heat, share	0.52	0.37
Number of households	1661	12 605

Notes: The table presents summary statistics from the registry data on new detached houses and from an annual survey on households in the process of building a new house. Both samples include years 2010-2011 and houses ranging from 100 to 300 square meters in size. The town plan area refers to the share of houses built on a site where a town plan is in force. The metropolitan region refers to the share of houses built in the region where the capital city is located.

the share of households who had considered these. Only around one third of households who installed electric heating had considered hydroelectric heating or ground heat as an alternative. Only 5 percent considered wood. This implies that the preference for an electric heating system is strong, as a central system is not even considered by most households who install electric heating. Conversely, if the household installs a central heating system, it seems to be more open to considering alternative heat sources; for example half of the households who installed hydroelectric heating also considered ground heat. Overall, the number of alternatives considered is low: a vast majority of households only considered at most two technologies.

The lower panel of Table 9 shows the stated reasons for the chosen heating system. The importance of costs is evident: 64 percent of households who installed electric heating stated low investment costs as one reason for their choice. Respectively, 77 percent of households who chose ground heat stated low use costs as a basis of their choice. The option to change the source of heat is clearly relevant for hydroelectric heating. Furthermore, environmental aspects play a role in the technology choice.

Table 9. Heating options considered and choice basis

	Electric	Hydroelectric	Ground heat
Alternative technologies considered, share			
Electric heating		0.23	0.13
Hydroelectric heating	0.27		0.93
Ground heat	0.32	0.50	
Wood heating	0.05	0.10	0.14
Considered at most 2 technologies, share			
	0.90	0.79	0.85
Reasons for heating system choice, share			
Low investment cost	0.64	0.32	0.03
Low use cost	0.06	0.10	0.77
Easy maintenance	0.59	0.40	0.36
Option to change fuel	0.01	0.42	0.09
Ecological	0.09	0.19	0.60

Notes: The first panel of the table shows the share of households in each heating category who had considered one or more of the four most common heating technologies as an alternative to their final choice. The second panel displays the share of households who had considered at most two technologies. The third panel lists some of the factors that were stated as the reasons for the installed heating system.

B Definition of heating costs and investment costs

B.1 Annual heating costs

To form the expected annual heating cost for each house, the energy price must be multiplied by the amount of energy consumed for heating. The energy price is the sum of the electricity retail price p^e and the distribution fee p^d. For ground heat, the electricity costs are divided by three, which is the coefficient of performance for ground heat pumps. The expected annual amount of energy used for heating is expressed in kWh per square meter. The annual heating costs thus are

$$C_{ij} = (p_j^e + p_j^d) m_i^2 (kWh/m^2)$$

Summary statistics on electricity prices are presented in Table 10. The two customer groups relevant to this study are houses with electric heating and houses with hydroelectric heating. Overall, the pricing for these groups is very similar. Prices for electric heating are on average 10 percent higher than prices for hydroelectric heating, but in terms of the range of prices available and the development over time, the prices do not differ. The distribution prices for both groups increase by over 20 percent from 2010 to 2011. This price increase is due to a large increase in the electricity tax faced by consumers.

The lower part of Table 10 shows measures of price stability for distribution prices. The autocorrelation calculated from a panel of distributors over the time period 2003-2011. The autocorrelation is high, illustrating the persistence in the distributor-specific price level. Another way to express the stability of distribution prices is to annually rank distributors according to price. The autocorrelation in rank is high at 0.96. This indicates that differences in price levels between areas tend to prevail.

The information on heating energy consumption is based on Sirén and Jokisalo (2014). Theirs is an engineering model designed to model the heat needs of a house, taking into account outside temperature and heat losses through building structures. The model is designed to represent an average house in size and construction, and it has been calibrated for different time periods, corresponding to the building regulations in place at each point in time. The values relevant for this study are those that correspond to the 2010 building standards.[19] The model of Sirén and Jok-

[19]The revision to the National Building Code in 2010 resulted in approximately

Table 10. Annual statistics on electricity costs.

	Distribution prices				Retail prices	
	Electric		Hydroelectric		Lowest national price	
	Mean	Sd	Mean	Sd	Electric	Hydroelectric
2010	4.39	0.51	3.94	0.45	4.8	4.52
2011	5.35	0.52	4.89	0.45	5.68	5.02
Autocorrelation in distribution prices during 2003-2011: 0.92						
Autocorrelation in ranking of distributors during 2003-2011: 0.96						

Notes: The table presents annual summary statistics on distribution prices. For retail prices, the annual value is the lowest price available to all customers nationwide. The prices are presented for two customer groups: those with electric heating and those with hydroelectric heating. The autocorrelations in distribution prices are calculated from a panel of distribution system operators over 2003-2011. All monetary variables in 2010 values.

isalo takes as input the outside temperature, which has been defined at the regional level. It then produces a value for heat consumption, based on the thermodynamic properties of the building structures. The model thus produces 19 different consumption values for an average house, one for each region. This model has been used to represent the heat consumption of the existing building stock in Corbishley (2015), where checks on the accuracy of the model show that heat consumption values produced by the engineering model account for over 90 percent of observed aggregate heat consumption.

B.2 Investment costs

The investment costs are based on the estimates reported in Table 2. Figures 6 to 8 plot the actual reported costs and the cost estimates for each heating option. Common features for all the options are that there is a large variance in the reported costs and that the observations are concentrated around even sums. For example, for hydroelectric heating there is notable concentration around 10 000 and for ground heat at values of 15 000 and 20 000. This is probably due to the formulation of the survey question: it asked to state heating system costs as ” total approximate costs”.

Costs for electric heating are shown in Figure 6. Most reported costs lie well below 10 000 euros, but there are two outliers at unrealistically

a 20 percent reduction in the heat consumption.

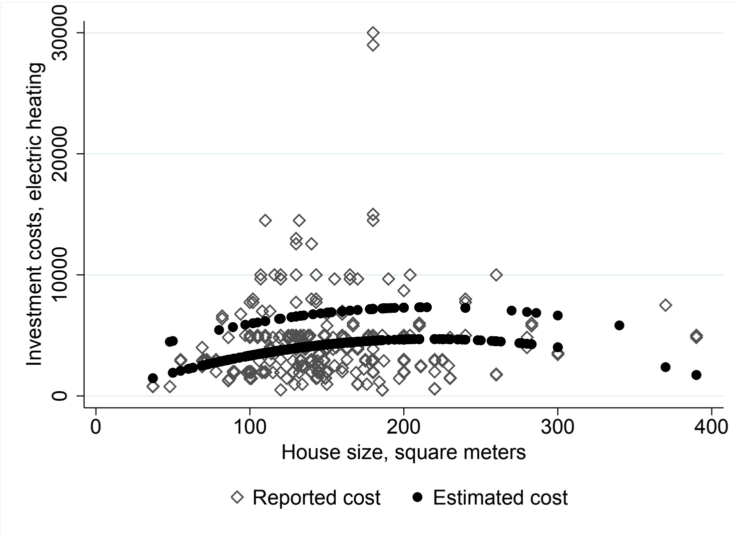

Figure 6. Reported and estimated costs for electric heating.

Notes: The figure displays the reported costs for electric heating in the survey data, as well as the cost estimates based on these observations.

high values of 30 000. The estimated costs capture the average cost level reasonably well, but are estimated on very few observations towards the higher end of the house size distribution.

Figure 7 shows the costs for hydroelectric heating. Again, the estimated costs match the reported average well, but the large variance in the reported costs cannot be captured by the estimation.

Finally, Figure 8 plots the data and the estimates for ground heat. The reported costs show some unrealistically low values close to zero costs. The heat pump and the drilling of the borehole both cost around 5000 Euros, hence it is not possible that investment costs would be much lower than 10 000 euros. For this reason, costs below 8 000 were not included in estimation in order not to make the level of estimated costs too low.

There are few observations of electric heating and hydroelectric heating for large house sizes, making the estimated costs unreliable for larger houses. Also, the heating consumption estimates from the engineering model are most accurate for average sized houses.[20] For these reasons, the WTP estimation only uses houses that range from 100 to 300 square meters in total size. This restriction cuts out the tails of the area distribution and removes 10 percent of observations (see Figure 9).

[20]Specifically, the size of the house in the engineering model is 180 square meters.

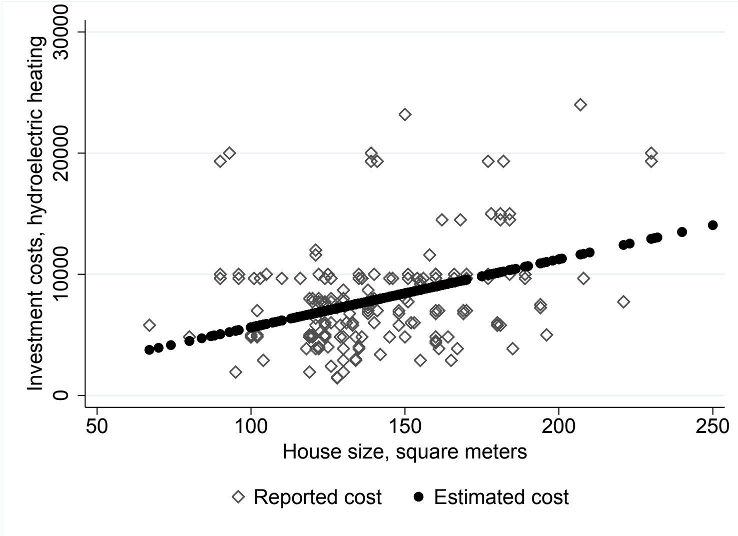

Figure 7. Reported and estimated costs for hydroelectric heating.

Notes: The figure displays the reported costs for electric heating in the survey data, as well as the cost estimates based on these observations.

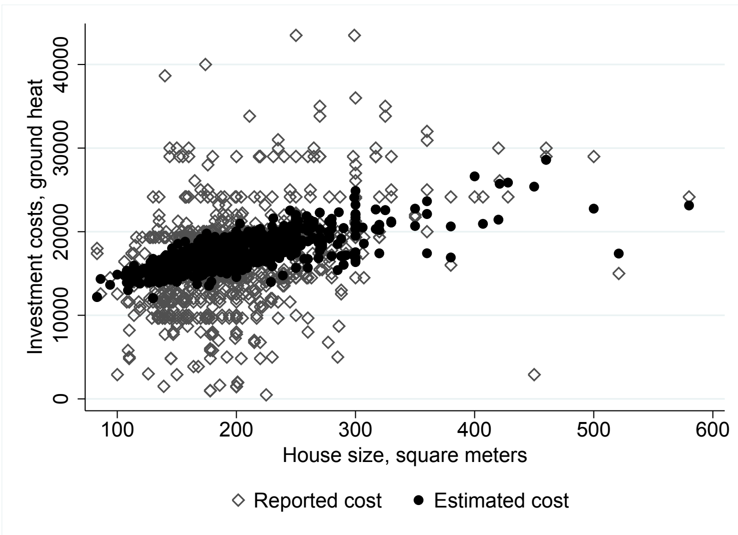

Figure 8. Reported and estimated costs for ground heat.

Notes: The figure displays the reported costs for ground heat in the survey data, as well as the cost estimates based on these observations.

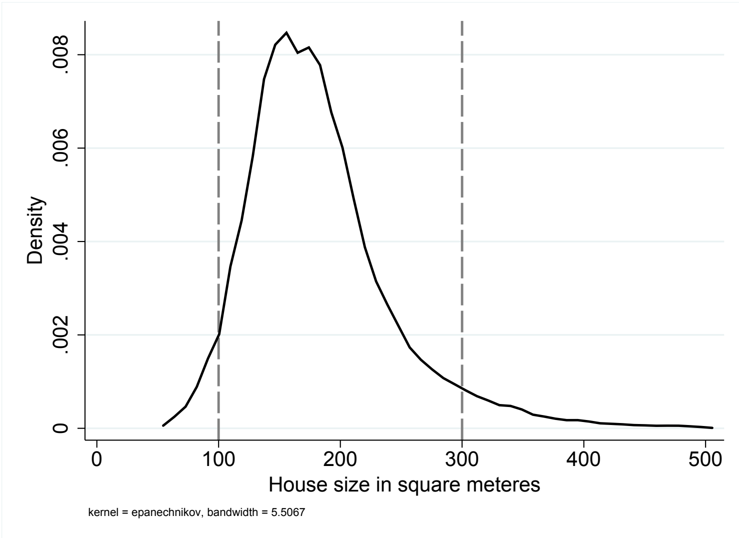

Figure 9. Density of house size and sample selection points.

Notes: The figure illustrates the density of house size and the cutoff points beyond which houses are excluded from the estimation sample due to investment and heating cost estimates not being accurate for extreme house sizes.

C Estimation on a subset of alternatives

Limiting the number of alternatives in discrete choice analysis may be necessary if the number of alternatives is very large, or if information is missing on some of the alternatives. McFadden (1978) shows that consistent estimates of the parameters can be obtained on a subset of alternatives when the standard logit model of choice is used in analysis. This requires modifying the choice probability to include the probability $q(K|j)$ of the subset K for each individual n:

$$P_n(i|K) = \frac{e^{V_{ni}+lnq(K|i)}}{\sum_{j\in K} e^{V_{nj}+lnq(K|j)}}$$

When the probability of subset K is the same for all alternatives in the set K, the expression $q(K|j)$ cancels out of the choice probability, and estimation can be carried out using the standard logit formula for subset K. This occurs when the subset is fixed, independent of the observed choice.

D The generalised multinomial logit model in STATA

The estimations are run using the gmnl command in STATA. This appendix briefly describes the manner in which the command is used for the estimations in this study. For a more in-depth presentation of the command and examples of use, see Gu, Hole and Knox (2013).

The gmnl command allows for introducing heterogeneity both in tastes and in the variance of the error terms (scale heterogeneity). The parameters of the utility function are defined as

$$\beta_i = \sigma_i \beta + [\gamma + \sigma_i(1-\gamma)]\eta_i$$

Here σ_i is the individual-specific scale of the error (scale heterogeneity) and η_i is the random error (preference heterogeneity), distributed $MVN(0, \sum)$. Scale heterogeneity is distributed lognormal, with mean $\overline{\sigma} + \theta z_i$ and standard deviation τ. The variables z_i are observable individual characteristics. The scale heterogeneity is estimated as $\sigma_i = exp(\overline{\sigma} + \theta z_i + \tau\nu)$.

This specification nests several different models. For example, the standard multinomial logit model results if $\sigma_i = 1$ and the variance of η_i is zero. The mixed logit model can be obtained by setting $\sigma_i = 1$.

When estimating this model in WTP space with fixed coefficients, the coefficient on the base variable is constrained to one. In the case of heating investment, this is the coefficient on investment costs. The vector z_i is defined only to include a constant, and the standard deviation of scale heterogeneity, τ, is set to zero. In this case, the scale heterogeneity simply becomes $\sigma = exp(\theta)$, and because preference heterogeneity is not included (implying that η_i is not estimated), the coefficients are defined as $\beta = \sigma\beta$. The transformation into WTP space thus is obtained by multiplying each coefficient with $\sigma = exp(\theta)$, which corresponds to the coefficient on the base variable.

When preference heterogeneity in WTP is estimated, the scale parameter, which stands for the base coefficient, is again defined as $\sigma = exp(\theta)$, and the mean and standard deviation of the random vector η_i are estimated. In this case, constrain $\gamma = 0$, so that the coefficients are defined as $\beta_i = \sigma(\beta + \eta_i)$. Preference heterogeneity is now included for coefficients other than the base coefficient. This is the formulation used in specification 2 of the WTP estimation.

E Robustness checks

This appendix reports results on robustness checks with respect to the definition of annual heating costs. Results are based on specification 4 presented in Table 5. WTP values resulting from different definitions for the heating cost are presented in Table 11. Specification 1 assigns the same unit heat demand of 99 kWh per square meter to each house. This value corresponds to the heat demand of a standard house built in the southern region of Uusimaa. This definition of heating costs thus assumes that houses in colder regions use additional heat sources, such as fireplaces, or better insulation to reduce the amount of heat to purchase. The estimated WTP is not distinguishable from the value reported in column 4 of Table 5.

The second column reports results when heating costs are formed by assuming that each household buys electricity from the local retailer at the lowest standard contract price offered. The main results were based on the assumption that households buy at the lowest rate available nationwide for a standard contract. There is now more variance in the heating costs, and some households are faced with notably higher prices; the price range for electric heating is 3.59 to 7.66 c/kWh, whereas the lowest price available nationwide was 4.80 c/kWh in 2010 and 5.68 c/kWh in 2011. The estimated WTP is now slightly lower, averaging €8 in the sample.

F Attention weight estimation

This appendix reports results in form of an attention weight, which is used in Allcott and Wozny (2014), and Sallee, West and Fan (2015) as the measure of use cost valuation. To obtain an attention weight, the heating costs must be expressed as discounted costs over the lifetime of the system. That is, the heating cost is multiplied by the discount factor and estimation is carried out in the same way as when estimating WTP. Now the obtained coefficient on heating costs should equal one if investment costs and lifetime use costs are equally valued.

Table 12 reports results for three different specifications. Column 1 reports estimates when the discount rate is set equal to the average mortgage interest rate in each year and the lifetime is assumed to be 20 years. The interest rate is thus 2.14 in 2010 and 2.64 in 2011. This results in an average attention weight of 0.59, implying significant undervaluation of future costs. However, this result is obtained for very low discount rate levels combined with a long lifetime. These may be reasonable values for evaluating the investment purely on the basis of costs. But consumers' decision-making will be influenced by preferences concerning risk and time, which is likely to lead to discount rates higher than those observed

Table 11. Results from robustness checks

	1	2
Investment cost	1	1
Heating cost (WTP)	-10.119***	-8.025***
	(0.674)	(0.711)
Interaction terms		
Income (€10 000)	-0.377***	-0.428***
Education	-0.172	-0.235
Age	-0.114	-0.128
Family size	0.605***	0.566***
Children	-1.057***	-1.238***
House owner	1.379***	1.578***
Coefficient on investment costs		
	-0.237***	-0.172
	(0.013)	(0.012)
Log likelihood	-7976	-8038
Number of households: 8413		
Mean WTP in sample		
	10	8

Notes: The table presents results from a logit estimation of heating system choice. The options are electric heating, hydroelectric heating and ground heat. The estimated coefficients represent monetary willingness to pay-values. The indicator variables are education (=1 if at least Bachelor-level), children (=1 if family with children) and house owner (=1 if the current dwelling is a detached house). Income measures total household income net of taxes. All specifications also include a constant for electric heating, interacted with household characteristics, house size, an indicator for location, and year effects. Specification 1 assigns the same unit heat consumption value to all houses: 99 kWh/m^2. Specification 2 assigns the local retail electricity price to each house. These specifications are to be compared to specification 4 in Table 5. Significance levels: * 10%, ** 5%, *** 1%.

on the market.

Column 2 thus reports estimates using the same lifetime of 20 years but a higher discount rate of 5 percent. The mean attention weight in the sample is now 0.74. Finally, column 3 illustrates how results change with the lifetime. This final specification uses a discount rate of 5 percent and a lifetime of 15 years. It is around the lifetime of 15 to 20 years that maintenance costs start to become relevant. This shorter lifetime increases the average attention weight, which is now 0.87. According to this specification, 14 percent of the households have an attention weight of at least one.

G Estimation on survey data

As a comparison to results obtained on approximated investment costs, the estimation is performed on the survey data, using the reported heating system costs for the chosen option. The estimation sample is restricted to include only electric heating, hydroelectric heating and ground heat, and house size is restricted to the interval of 100 to 300 square meters. The estimation sample is thus analogous to the registry data sample. The costs of the non-chosen options are based on the estimations reported in Table 2. The survey data include no additional information with respect to expected heating costs; therefore, these are formed in the same way as for the registry data.

The survey data do not include the same set of household characteristics as the registry data. Also, most of the variables, such as income and age, are measured in categories as opposed to actual values. The only household characteristic which proved to impact estimation results was an indicator for high income (annual household income higher than €80 000). Furthermore, the specifications shown here do not include technology-specific constants, as these turned out to be very weakly significant. Adding the constants also increased the standard error on the investment cost, resulting in a very imprecisely estimated WTP.

The results from the estimations are reported in Table 13. Column 1 shows results when no heterogeneity is incorporated into estimation. The WTP is estimated to be €32, with a wide confidence interval of €22 to €42. The second specification introduces an interaction of the heating cost variable with the indicator for high income. This interaction is highly significant, and indicates that high income households have much higher WTP

Table 12. Results from attention weight estimation

	1	2	3
Investment cost	1	1	1
Attention weight	-0.566***	-0.707***	-0.836***
	(0.047)	(0.105)	(0.069)
Interaction terms			
Income (€10 000)	-0.029***	-0.037***	-0.043***
Education	-0.019	-0.023	-0.027
Age	-0.008	-0.010	-0.012
Family size	0.040***	0.050***	0.059***
Children	-0.083***	-0.103***	-0.122***
House owner	0.099***	0.126***	0.149***
Log likelihood	-8018	-8015	-8015
Number of households: 8413			
Summary statistics on the estimated attention weight			
Mean	0.59	0.74	0.87
Range	0.29-1.18	0.36-1.48	0.43-1.75

Notes: The table presents results from a logit estimation of heating system choice. The options are electric heating, hydroelectric heating and ground heat. The coefficient on investment costs is constrained to one, and heating costs are expressed as present discounted value over the lifetime of the system. Specification 1 assumes a lifetime of 20 years and interest rates corresponding to average mortgage interest rates of around 2 percent. Specification 2 assumes a lifetime of 20 years and an interest rate of 5 percent. Specification 3 assumes a lifetime of 15 years and an interest rate of 5 percent. The indicator variables are education (=1 if at least Bachelor-level), children (=1 if family with children) and house owner (=1 if the current dwelling is a detached house). Income measures total household income net of taxes. All specifications include a constant for electric heating interacted with a year indicator, a location indicator (=1 if building in an urban area), house size and the observable household characteristics. Significance levels: * 10%, ** 5%, *** 1%.

compared to the rest of the sample. The base WTP is reduced slightly to €30. The third specification allows for further heterogeneity in the WTP by introducing a random coefficient on the heating cost variable. This, however, does not change results, as the standard error of heating costs is not statistically significant. The investment cost coefficient, which multiplies other coefficients to form WTP, does not change across the specifications.

These results based on actual reported heating costs mirror the results obtained on the registry data in two aspects. First, the income variable is an important determinant of the WTP, and the WTP increases with income. In the survey data the income variable also reflects other characteristics correlated with income, such as education. Second, the use of random coefficients does not capture the heterogeneity in the estimation sample, though it is certainly plausible that WTP is not constant across households.

However, the WTP estimated on the survey data significantly larger than that obtained from estimation on the registry data. This is likely due to at least two factors; sample selection and reporting errors. The share of ground heat in this estimation sample is 69 percent, which is much higher than the share of 43 percent observed in the registry data estimation sample. This sample is thus not representative of the actual population of house builders, but rather has an over-representation of households with higher income and education.

Furthermore, there is a very large variance in the reported investment costs for all heating technologies. These include some extremely low and high values. Given the inaccurate formulation of the question in the survey[21], it is very likely that not all respondents are reporting costs for the same definition of a heating system. This means that there is a lot of measurement error in the investment cost values, making the estimates reported here a very imprecise measure of WTP. If this large variance in reported costs is reduced by replacing reported costs with estimated costs, the base WTP is estimated to be €24, which can be contrasted with the value of €30 obtained in specification 2.

[21]The survey asked: ”Approximately how much did your heating system cost (excluding fireplaces)”

Table 13. Results from WTP estimation on survey data

	1	2	3
Investment cost	-1	-1	-1
Heating cost (WTP)	-32.045	-29.990***	-29.820***
	(4.958)	(4.564)	(4.488)
Interaction terms			
High income		-9.157***	-8.992***
SD of random coefficients			
Heating cost			1.318
Coefficient on investment cost			
	-0.068***	-0.068***	-0.069***
Households	1082	1082	1082
Log likelihood	-842	-835	-834

Notes: The table presents results from a logit estimation of heating system choice. The options are electric heating, hydroelectric heating and ground heat. The coefficient on investment costs is constrained to one, other coefficients are directly interpreted as willingness to pay-values. Significance levels: * 10%, ** 5%, *** 1%.

Determinants of Households' Heating Technology Investments

Anna Sahari

Abstract

This paper analyses Finnish households' investments into energy-using durable goods using micro-level data on the heating technology choice at the moment of building a detached house. The information on new residential houses is drawn from administrative registries, and the houses are linked to several characteristics of the house owner and to local energy prices. A multinomial logit model of technology choice is estimated to uncover the most important determinants of technology choice. The results are used to analyse the potential existence of investment inefficiencies and to evaluate the substitution between technologies caused by electricity price increases. The findings indicate that upfront investment costs and fuel costs are strong determinants of the investment decision. Increasing electricity prices induce substitution especially into ground source heat pumps and wood heating. This is leading to reductions in electricity demand and emissions due to heating; the elasticity of electricity demanded for heating purposes is estimated to be on average -0.35. The results on the impact of household characteristics on heating technology choice suggest that some households may be subject to investment inefficiencies. This is implied especially by the significant effects of income and education.
Keywords: *Energy efficiency, Durable goods, Households*
JEL codes: *D12, Q41*

1 Introduction

Current energy policy both in the European Union and the US is focused on cutting greenhouse gas emissions and reducing dependence on imported fuels through increasing energy efficiency and the share of renewable energy sources. According to EU targets, renewable energy sources should constitute 20 percent of final energy consumption by 2020, and the share is to increase to 27 percent by 2030. Similar targets have been set with respect to savings in energy use compared to baseline projections.

Though industry and services are in most developed countries the biggest energy using sectors, household energy use plays an important role. In the EU, residential energy use constituted one third of final energy consumption in 2010 (Eurostat).[1] The technology choices that households make with respect to heating, cooling or appliances are especially important as these are long-term investments, which therefore determine the level of energy use in the residential sector for years to come.

This paper studies one example of such an investment, namely Finnish households' choice of heating technology at the moment of building a new house. The analysis is based on extensive administrative registry data on new detached residential houses. The houses are linked to individual-level information on the households acting as builders, which allows explicitly associating essential socio-demographic variables with observed investment decisions. The impact of these variables is interpreted in the context of a model of durable good choice which incorporates possible misoptimisation by consumers.

Such misoptimisation, resulting from limited attention to the operating costs of durable goods, has been proposed as one reason for the energy efficiency gap (also called the energy paradox, see Shama, 1983; Jaffe and Stavins, 1994). This gap refers to the perceived failure by firms and households to realise profitable investments regarding energy efficiency (Allcott and Greenstone, 2012; Gillingham and Palmer, 2013). Other reasons why investment into energy efficiency may be too low include pollution externalities and investment inefficiencies (Allcott and Greenstone, 2012). If externalities are not accounted for in energy prices, the price level is too low compared to social optimum, and households will invest too little in energy efficiency. On top of this, there may be investment inefficiencies

[1] In areas with extreme temperatures household consumption plays an even larger role. In Finland, energy use for residential heating alone makes up 27% of total energy use.

resulting in the same outcome. These include lack or asymmetry of information about energy saving potentials, constraints in access to credit for financing of efficiency investments, and the failure of housing markets to capitalise home improvements into house prices.

The presence of investment inefficiencies may validate the use of policy instruments. However, identifying the need for policy measures and designing efficient policy requires information on how households make investment decisions. Recent research on optimal energy policy design has emphasised the need to discover both the possible existence of inefficiencies as well as their distribution across consumers (Allcott, Mullainathan and Taubinsky, 2014; Allcott and Taubinsky, 2015).

The aim of this research is to uncover which factors are most strongly related to technology choice, and to use this information to evaluate the existence of possible investment inefficiencies. The quality of the data allows addressing several issues which often pose challenges to evaluation of long-term investment behaviour. Firstly, the timing of the investment is determined by factors such as availability of a lot and access to financing. It is therefore not subject to the type of dynamic considerations examined in Rapson (2014).[2] Because the information refers to the start of the building project, the variables describe the situation of the households at the moment of investment. Furthermore, the investment decision is not constrained by existing building structures, and no subsidies or investment schemes have been in place for new builds.[3] Previous studies on heating choice, including Braun (2010), Mansur, Mendelsohn and Morrison (2008), Nesbakken (2001) and Vaage (2000), have relied on survey data which does not relate specifically to the heating investment.

Secondly, the data include a measure of long-term electricity prices. This measure is the distribution price of electricity, which is linked to each new house at the postal code level. Distribution prices are regulated, and the pricing is based on grid characteristics. There are several grid operators who manage grids in very distinct locations. This leads to prices which are stable over time at the local level, yet there is significant variation in the price levels across distribution networks. Therefore, it is reason-

[2]Rapson (2014) studies the purchase of air conditioners and models also the timing of the investment, not only what type of appliance is bought. He finds consumers to be very sensitive to developments in energy efficiency.

[3]Building in Finland is regulated by the National Building Code, which determines minimum requirements for building structures, including insulation levels.

able to use current price levels to measure expected prices. In addition to the distribution price, the retail price of electricity is matched to each house. Observing these prices separately allows evaluating whether consumers respond differently to the distinct components of their total electricity costs.

Finally, the comprehensive set of observable household characteristics enables investigating in detail whether systematic differences prevail between the households choosing different technologies. It has been shown both theoretically and empirically that household heterogeneity is crucial in policy evaluation and design (Grigolon, Reynaert and Verboven, 2014; Allcott, Mullainathan and Taubinsky, 2014; Allcott and Taubinsky, 2015). Random coefficients or information on the distribution of variables such as income can be used to incorporate heterogeneity into the analysis (for example Grigolon, Reynaert and Verboven, 2014; Busse, Knittel and Zettelmeyer, 2013). However, explicitly characterising how investment behaviour varies with respect to consumer characteristics necessitates individual-level data. Registry data has the advantage of combining several accurate measures of this heterogeneity with a large amount of observations. Furthermore, sample selection or reporting bias are not present in data originating from administrative registries.

The analysis is based on a standard multinomial logit model of discrete choice, where the choice variable is one of six possible heating technologies including electric heating, water central electric heating, a ground source heat pump, wood heating, oil heating and the category "other". Of these technologies, ground source heat pumps utilise geothermal heat, making them a very efficient option in terms of purchased energy. The determinants of the utility function include house characteristics related to heating consumption, household characteristics, the price of electricity and indicators for time and region, which control for changes in cost levels and regional climate.

The findings indicate that households are sensitive to the operating costs of heating. This is implied by the very high impact of house size on heating system choice and by the sensitivity to the electricity price. Electricity is the main source of heat in the existing and new stock of detached houses. Higher electricity prices induce substitution from electric heating most notably into wood heating and ground source heat pumps. The substitution to wood is especially strong in rural areas, where the costs of wood are lower. The price elasticity of heating by electricity is estimated to be -0.50 at the average price level. This result is in line with the research on attentiveness to vehicle fuel efficiency, which suggests that consumers' inattention to usage costs of durables is likely to be at most modest (Allcott and Wozny, 2014; Busse, Knittel and Zettelmeyer, 2013; Sallee, West and Fan, 2015).

Income is found to be a statistically significant determinant of technology choice, though the magnitude of its impact is small across the different technologies. Higher income is positively associated with the choice of a ground source heat pump. This is the technology which needs very small energy inputs to create heat, but it is characterised by high upfront costs. Correspondingly, lower income is related to the choice of electric heating, which has the lowest investment cost of all options. This result is obtained controlling for education and the amount of debt, and thus it implies that lower income households may be constrained in their ability to pay the high initial costs associated with energy efficient technologies. Credit constraints are often mentioned as one possible investment inefficiency contributing to the energy efficiency gap, however lack of data has hindered analysing this issue (Allcott and Greenstone, 2012; Palmer, Walls and Gerarden, 2012).

The influence of education on the heating choice is strong. The education variable identifies those households with a Bachelor-level or at least a Master-level education. The impact is found to be increasing with the level of education; the higher it is, the more likely is the choice of a ground source heat pump. Again, the effect is opposite for the choice of electric heating. This is consistent with several other studies which have found higher education to be positively correlated with higher willingness to pay for energy efficiency and with lower personal time discount rates (Harrison, Lau and Williams, 2002; Newell and Siikamäki, 2015; Simon, Warner and Pleeter, 2015). It is possible that the higher willingness to pay is due to higher educated individuals being more attentive to lifetime costs of durable goods.

These results thus indicate that consumers recognise the importance of operating costs. Higher electricity prices induce investment especially into heating technologies that rely on renewable energy sources. This is leading to reductions in the electricity demanded for heating; the elasticity is estimated to be on average -0.35. Consequently, also the CO2 emissions from electricity production are reduced. However, the net impact on actual emissions is positive due to the shift into wood, which has a much higher emission factor than electricity production.

2 Theoretical framework

This section discusses household investment following Allcott, Mullainathan and Taubinsky (2014). They model a consumer who is investing into an energy-using durable good, and has to choose between an inefficient and efficient option.[4] In addition to the traditional pollution externality resulting from energy consumption, the model incorporates an internality: the consumer may misoptimise at the investment stage by undervaluing energy costs. The context is similar to that of sin taxes (O'Donoghue and Rabin, 2006), where self-control problems cause consumers to make choices that decrease their welfare in the future.

The first subsection will present how Allcott, Mullainathan and Taubinsky model the consumer's choice problem. The second subsection will recast the setting into the context of heating technology investment. Due to data limitations, the model as such cannot be directly taken to data and estimated. The purpose of this section is to provide a framework for understanding the different aspects of the investment decision, and for interpreting the effects which can be estimated from data.

2.1 A model of durable good choice

There are two goods, an inefficient one (subscript I) and an efficient one (subscript E). To produce a unit of utilisation m, these goods consume amount e_j of energy, where $e_I > e_E$. A consumer gains utility $u(m)$ from the services provided by the good, and the total utility from purchasing good j is

$$u(m) + \varepsilon_j - p_g m e_j - p_j \tag{1}$$

Here p_g is the price of energy and p_j is the purchase price of good j. The taste shocks ε_j have a joint, atomless distribution denoted by F.

Denote by $m_j^* = argmax\,\{u(m) - p_g m e_j\}$ the optimal utilisation level. At this level, the value of utilisation, net of operating costs, is $v(e_j, p_g) \equiv u(m_j^*) - p_g m_j^* e_j$. The gross utility gain from choosing the efficient good is defined as $V(e_E, e_I, p_g) \equiv v(e_E, p_g) - v(e_I, p_g)$. To finalise the notation,

[4] The full model of Allcott, Mullainathan and Taubinsky is set up to analyse optimal policy, and hence includes the policy maker's objective function in addition to the consumer. The presentation here will summarise only the consumer part of their model.

$\varsigma = (e_E, e_I, p_g)$ denotes the parameters that determine the gross utility gain, and $\varepsilon = \varepsilon_E - \varepsilon_I$ is the random difference in taste shocks, which has a distribution G.

The consumer will choose the efficient durable good E if and only if the gross utility gain exceeds the incremental upfront payment:

$$V(\varsigma) + \varepsilon > p_E - p_I \tag{2}$$

If energy prices correctly account for pollution externalities from energy production and consumption, this choice will lead to investments which are at the socially optimal level.

However, the consumer may place a so-called internality on herself by incorrectly valuing the gain from efficiency. This can be modelled by adding a valuation weight $\Gamma(V, \varsigma)$ to the choice problem. This weight may be endogenous, and it can be correlated with the taste shocks ε_j. Accounting for misoptimisation, the consumer will choose the efficient good E if and only if

$$\Gamma(V, \varsigma)V(\varsigma) + \varepsilon > p_E - p_I \tag{3}$$

2.2 Households' choice of heating technology

A heating system is a durable energy-using good with a very long lifetime. The available technologies have different costs and characteristics, and the household must evaluate these in light of their own preferences and heat needs. When a new house is built from scratch, all technologies are in principle available. These include: electric heating, water central electric heating, ground source heat pumps, wood heating and oil.[5]

Using the notation of Allcott, Mullainathan and Taubinsky, there are J goods to choose from, which have differing efficiencies e_j, energy prices p_{gj} and investment costs p_j. The utilisation level m corresponds to the heat consumption of the house. This is a function of house size, measured in square meters, and of the unit heat consumption measured in kWh per square meter. The unit heat consumption depends on the insulation of the house and on the local climate. Though it is possible that the energy efficiency of the heating system could influence how much heat the household chooses to consume, this is unlikely in the case of heating. Hence, the utilisation level m is not indexed by j. However, it is possible that households value specific characteristics of distinct technologies, irrespective of the

[5] District heat can only be installed if the house is built within a district heat network.

costs of use. For example, ground heat pumps may be appreciated for environmental reasons, or direct electric heating for very low maintenance. These characteristics are denoted by x_j, and the utility is $u(m, x_j)$.

Because heating technologies have very long lifetimes and the annual consumption values are large, lifetime operating costs form a large share of the total costs of any technology. Therefore, it is important to explicitly incorporate discounting into the model. To account for price expectations, the fuel price is now indexed with t, and the total lifetime of the system is denoted by T.[6] The discount factor is $\delta = 1/(1+r)$, where r is the discount rate. Incorporating technology characteristics and discounting into the total utility of equation 1 gives the following

$$U_j = u(m, x_j) + \varepsilon_j - \sum_{t=0}^{T} \delta^t p_{gjt} m e_j - p_j \tag{4}$$

Given these components of the decision process, the household will invest in technology j if

$$v(e_j, p_{gjt}, \delta) - p_j + \varepsilon_j > v(e_k, p_{gkt}, \delta) - p_k + \varepsilon_k, \forall j \neq k \tag{5}$$

This specification does not yet allow for household heterogeneity. Even without any misoptimisation, households' discount rates will vary. This is because households will have different time preferences (personal discount rates) and because they will face different financial interest rates due to differing personal financial situations. Also the level of utilisation m will be household-specific.

To allow for misoptimisation, the valuation weight is added to the choice problem. Also the index i is included to denote the household-specific variables: the valuation weight, the discount factor and the taste shock.

$$\Gamma_i v(e_j, p_{gjt}, \delta_i) - p_j + \varepsilon_{ij} > \Gamma_i v(e_k, p_{gkt}, \delta_i) - p_k + \varepsilon_{ik}, \forall j \neq k \tag{6}$$

The choice of heating may be subject to different kinds of biases captured by the valuation weight. Using the categorisation in Allcott, Mullainathan and Taubinsky, the most relevant ones in this context are salience bias, endogenous inattention, and present bias.

Salience bias refers to the fact that the gross utility gain from efficiency, transmitted through utilisation levels and use costs, may be only partially accounted for at the investment stage. This may be the case because this

[6] The lifetime could be technology-specific. It is assumed here that households compare technologies across an identical utilisation phase, in order to facilitate comparisons.

part of the decision is more complex and less easily observable than investment costs which are paid immediately, before actual utilisation begins. Thus the upfront investment costs are more salient than other aspects of the good. Salience bias can be modelled by defining the valuation weight as $\Gamma \equiv \gamma$, where $\gamma \in (0, 1)$.

Endogenous inattention is present if attention is a function of the components of the decision. For example, a consumer with high utilisation levels will have more to gain from investing into energy efficiency, and hence may be more attentive to the gross utility gain from efficiency. This can be incorporated in the model by making the attention weight a function of the gain.

Present bias will cause consumers to place less weight on energy costs, which occur in the future, than investment costs which reduce immediate consumption. Though this bias is conceptually different from salience bias, it can be modelled analogously by setting $\Gamma \equiv \beta$ where $\beta \in (0, 1)$.

3 Empirical strategy

Household i is observed choosing technology j if condition 6 holds. Denote by y_j an indicator which takes value 1 if the observed choice is option j. The probability of this observation is

$$Pr(y_j = 1) = Pr(U_{ij} - U_{ik} > \varepsilon_{ik} - \varepsilon_{ij}) \tag{7}$$

If the taste shocks ε_{ij} are distributed i.i.d. extreme value type I, then the difference $\varepsilon_{ik} - \varepsilon_{ij}$ has a logistic distribution, and the probability $Pr(y_j = 1)$ takes the following form:

$$Pr(y_j = 1) = \frac{exp[U_{ij}]}{\sum_k exp[U_{ik}]} \tag{8}$$

The coefficients of the utility function are estimated via maximum likelihood estimation. The empirical counterpart of the utility specification in Equation 4 will include observable house and household characteristics which are correlated with the utilisation level, the valuation weight and the discount factor. The estimation also includes the cost of electricity, which is the main source of heat in detached residential houses. Differences in levels of investment costs and other fuel costs across time and location will be captured by time and location fixed effects. The following specification will be used in estimation:

$$u_i = \beta^{el} p^{el} + \beta^d p^d + \sum_k \gamma_k z_{ik} + \sum_g \alpha_g w_{ig} + A_j + T + R + L + \varepsilon_{ij} \tag{9}$$

Here p_r is the retail price of electricity, p_d is the distribution fee for electricity, z stands for house characteristics and w denotes household characteristics. Annual time effects are denoted by T and regional fixed effects by R. There are 19 administrative regions in Finland, of which the island Åland is not included in the estimation sample due to missing electricity price information. The indicator L controls for building in an urban versus a rural location. Alternative-specific constants are denoted by A_j. These constants capture other attributes of the technology besides price, thus measuring the contribution of x_j to the utility.

House characteristics include the size of the house, the building material and building method. The size of the house refers to total area, and this is the main determinant of heat consumption, together with the level of insulation. Insulation is not observed in the data and is therefore proxied by building material and method.[7] Stone as a material has better insulation properties than wood, and if the house is built from elements it is more likely to be a standard build. The house characteristics thus stand for the level of utilisation, denoted by m_i^* in the theoretical model. In addition, house size can be a determinant of the valuation weight Γ_i, if valuation is endogenous to the amount of energy consumed.

Household characteristics include household income net of taxes, indicators for whether the household receives childcare or unemployment benefits, a measure of total debt, the education level and age of the building owner, family size and an indicator for the presence of children in the family. Of these characteristics, education is likely to be correlated with the valuation weight Γ_i; it can be hypothesised that higher educated consumers may be less subject to the salience bias. Education has also been shown to be correlated with the personal time preference of households (Harrison, Lau and Williams, 2002; Simon, Warner and Pleeter, 2015), which means it will be a determinant of the discount factor.

The financial situation of the household is described by income, the reliance on benefits and by the measure of debt. These variables will be correlated with the price of money that the household faces, hence impacting the discount factor that the household uses when evaluating the investment.

In addition to education, the personal time preference has been shown to be correlated with age, income, and the presence of children in the fam-

[7] All houses must meet the insulation standards defined in the National Building Code.

ily.[8] The coefficients on these variables can hence be used to draw inferences on the impact of discounting on the investment decision. However, it will not be possible to identify separately personal time preferences from investment-specific discounting. Also, some of these variables may be correlated with the environmental attitudes of the household, which are likely to also influence investment choices.

Family size stands for financial and time constraints imposed by larger families. At a given income level, disposable income will be smaller in large families. Also, households with many members may have different preferences for technology-specific attributes such as maintenance.

Annual time effects control for any changes in levels of investment costs, building costs and building regulations. Regional effects control especially for differences in local climate, which impact the heat consumption of the building. The indicator for an urban location controls for factors such as availability of firewood for additional heating, for possible impacts that plan requirements may have on the building process, and for costs of land and labour which are usually much higher in densely populated areas.

Electricity costs are included to account for the costs of heating. This is the most common source of heat in new detached houses, as almost 90% of new houses outside of district heat areas install electric heating, water central electric heating or a ground source heat pump, which all operate with electricity. The other fuels available are oil and wood, but detailed price data is not available for these options. The electricity costs include the retail price of electricity and the distribution fee, which are included separately in the estimation.

4 Data

The data combine information from different administrative registries, and are based on an annual 90% random sample of all new detached residential houses built during 2000-2011.[9] On average 11 000 houses are constructed each year, and the original data include 132 002 houses. To construct the estimation sample, other ownership categories besides private persons are dropped, as well as semi-detached houses and exception-

[8]See the aforementioned references, as well as Frederick, Loewenstein and O'Donoghue (2002) for a review of personal discount rates.
[9]Statistics Finland does not grant access to full samples of individual-level data.

ally large or small houses. This leaves 109 289 houses in the base data.[10]

The information on new houses originates from building permits. These are granted by local municipal authorities, and recorded by the Population Register Centre and Statistics Finland. All new builds require a permit, which will expire if building does not commence within three years. A notification must be given when building starts and once the house is finished. The variables in the data are taken from a form the builder has to submit when applying for a building permit. The data include only those houses for which the start of building has been documented.

The main heating system is reported by choosing from given options. First, the technology is chosen to be water central, air central, electric heating or stove heating.[11] Second, the fuel is identified as district heat, oil, electricity, gas, wood, ground heat, coal, peat or other. For the analysis, the different options are first grouped by technology into electric heating versus central heating, and then by fuel. For example, wood heating includes both water central and air central technologies using wood as the source of heat, as well as stove heating.[12] Coal, peat and gas are extremely rare in residential houses, and they account for less than one percent of observations. These are grouped into the category ”other”.

The individual-level information on building owners comes from registries of Statistics Finland. Each building is linked to its owner using the personal identity number. The owners are then linked to spouses, both married and cohabiting, in order to create household level data.

In addition to house and household characteristics, the data include local electricity costs matched to each house by the postal code. Electricity prices are provided by the Energy Authority, comprising both the price of distribution and the retail price of electricity. Distribution of electricity is a regulated service, provided by local distribution system operators (DSO). During the sample period, the number of DSOs goes from 87 to

[10]The cutoff for small houses is 60 square meters and for large houses 500 square meters. Houses below or above these sizes are unlikely to be normal residential houses. These extremes amount to 629 observations, which is 0.6% of the observations on private persons and detached houses. Semi-detached houses are buildings which incorporate two dwellings. There are 2627 such houses built by private persons in the original data. In these cases, it is unclear whether the builder is solely responsible for decision-making at the building stage, and therefore these houses are not included in the analysis.

[11]Also the option "no heating" is possible. This was reported for one house in the whole sample.

[12]A more detailed classification would not be meaningful, as air central heating and stove heating both make up only percent of observations.

81, where the reduction in the amount of operators is due to small distributors merging with a neighbouring grid operator. The Energy Authority monitors the pricing of distribution; DSOs are allowed to cover costs and earn a reasonable return on investment. Distribution prices are thus defined by local grid characteristics, and this induces regional price differences across the country. Since distribution must be bought from the local operator, consumers cannot avoid this price dispersion. On average, distribution prices make up 40 percent of the total cost of electricity, but within the cross section this varies from 30 to 60 percent. Determinants of distribution prices are discussed in more detail in Sahari (2016a).

The electricity retail market is deregulated, and consumers may freely choose their electricity supplier. There are 67 retailers in the price data, of which 35 serve customers in any location. The remaining retailers choose to operate only within the grid area of the local distribution company. Typically these are smaller companies which also act as the local distribution system operator. The law obliges the retailer/distributors to separate these activities at least at the level of bookkeeping. Notable price dispersion remains in the retail electricity market. However, consumers may switch suppliers and hence it is not possible to know what price is relevant to each household. For the purpose of this analysis, each house has been assigned the local default price. The law defines a default supplier for every distribution grid area in order to ensure that no consumer is left without a retail contract. This supplier is the one who has a dominant market position within the local grid, and the default price is the lowest standard contract price set by the default supplier.[13]

Both distribution prices and retail prices are defined in cents per kilowatt hours, and the prices used in the analysis refer to the price levels for customers in detached houses with electric heating. Though there is a distinct price for houses with water central electric heating, the prices for these two customer types are very highly correlated and hence including both in estimation is not meaningful.

[13]A standard contract refers to a permanent contact where price changes must be preceded by a notification given several weeks beforehand. This was the most common contract type during 2000-2011. Market-based contracts with frequently changing prices were very uncommon during the time, and block-rate contracts are not used in the Finnish electricity market.

4.1 Descriptive statistics

Summary statistics by heating technology are presented in Table 1. These are calculated for the whole sample period, excluding areas with district heat. Overall, district heat is installed in 13% of new houses. However, in many areas it is obligatory for houses to join the district heat network, hence these households are excluded from the analysis of investment behaviour. The remaining main heating technologies are electric heating, water central electric heating (referred to as hydroelectric heating), ground source heat pumps (referred to as ground heat), wood heating and oil. The category "other" includes any other main heating technology, for example new technologies such as air-to-water heat pumps, which are not yet established enough to be classified into their own category.

The income variable is defined as all income and benefits, net of taxes. This measure varies notably across heating choices. Households installing wood or electric heating have the lowest income, whereas ground heat is installed by higher income households. The amount of debt the household has is measured in proportion to net income. The differences in debt across technologies reflect the differences in average income.

There are also large differences in the level of education of the building owner. The education variable takes value 1 if the owner of the house has education at least at the level of a Bachelor's degree. Almost half of the households installing ground heat have higher level education. This can be contrasted with a share of around one third for wood, oil and electric heating.

An interesting feature of house builders is that around half of them already live in a detached house. This is illustrative of the fact that detached houses are a very common dwelling form in Finland; according to Statistics Finland, 41 percent of residences were detached houses in 2010.[14]

In terms of house characteristics, the biggest difference across heating systems is observed for house size. Houses with central heating systems based on water circulation are notably larger than houses with electric heating. This is to be expected, as central heating systems are characterised by higher investment costs but lower fuel costs. In larger houses, the savings in operating costs are enough to make up for high upfront

[14] The number of detached houses built before 2000 is 895 619. The base data therefore represents a 12 percent increase in the stock of detached houses.

costs.

The share of houses built in a town plan area also varies greatly across heating systems. The town plan variable is a proxy for house location. Town plans are typically in force in urban, densely populated areas, whereas rural areas tend to rely on less detailed master plans. Rural areas are characterised especially by lower costs of land and a larger lot size. The share of houses built in a town plan area is very low for houses with wood heating. This reasserts the view that wood heating is often installed where firewood is available close by. Wood also requires storage space, which could be too costly to build in areas where land is expensive.

The last row of Table 1 reports the overall share of different technologies in the new housing stock. Electric heating is the most common technology with a share of over 50 percent. However, this average masks a significant time trend. Over the sample period the share of electric heating declines from around 60 percent to 30 percent. Of the other technologies, the share of ground heat increases the most over time, suggesting that this is the main substitute for electric heating.

Examples of investment costs and heating costs by technology are presented in Table 2. These numbers illustrate the magnitude of the tradeoff that the households face at the investment stage. Ground heat is about three times as expensive to install as electric heating, yet the costs of use are low enough to make this a cheaper option when total costs are considered. The fuel efficiencies reported in the table are based on average values given in the National Building Code's guidelines for calculating the energy consumption of a house. These values will vary for each specific installation, as they depend on the type of boiler and furnace, and in the long term also on maintenance and usage habits.

5 Results

5.1 Coefficient estimates

This section presents results from a multinomial logit estimation of heating choice, based on Equation 9. To allow the impact of electricity costs to vary by location, an interaction of the distribution price with the location indicator is added to the specification.[15] Coefficient estimates are

[15] Several interactions were examined, also with household characteristics. Only the interaction of location with the electricity price proved to be significant, in

Table 1. Household and house characteristics by heating

	Electric	Hydroelectric	Ground heat	Wood	Oil	Other
Household characteristics						
Net income	40 723	44 805	50 193	37 772	41 350	44 234
Debt to income ratio	3.63	3.95	3.90	3.64	3.36	3.64
Age	38	37	37	37	37	36
High education, share	0.30	0.39	0.47	0.28	0.29	0.37
Own house, share	0.51	0.48	0.41	0.54	0.45	0.44
Own apartment, share	0.14	0.14	0.18	0.11	0.15	0.14
House characteristics						
House size (m^2)	166	184	217	188	213	189
Material: wood, share	0.94	0.87	0.80	0.92	0.83	0.87
Element build, share	0.46	0.57	0.44	0.30	0.35	0.48
Town plan in force, share	0.63	0.69	0.54	0.22	0.58	0.63
Overall share	0.53	0.13	0.20	0.07	0.04	0.03

Notes: The table displays summary statistics of house and household characteristics by heating system for the time period 2000-2011. High education refers to the share of house owners with at least Bachelor-level education. Own house and own apartment refer to the ownership status and type of the building owner's current residence. The town plan variable takes value one if the new house is built on a lot where a town plan is in force.

Table 2. Average heating costs by technology

	Electric	Hydroelectric	Ground heat	Wood	Oil
Investment cost, €	4540	8290	16 820	10 769	10 230
Fuel cost, c/kWh	10.72	9.97	10.72	5.23	7.75
Fuel efficiency	1	1	2.5	0.8	0.9
Total cost for varying house size, lifetime 20 years and discount rate 5%					
Area: 160m^2	27 627	29 761	26 055	24 848	28 775
Area: 180m^2	30 512	32 445	27 209	26 608	30 884
Area: 200m^2	33 398	35 129	28 363	28 368	33 411

Notes: The table presents examples of investment and use costs for different heating technologies. The wood technology considered is pellets. All values refer to the price level of 2010. The investment costs are from a survey of house builders carried out by RTS Ltd. The price of pellets and heating oil is taken from annual averages reported by Statistics Finland. The fuel efficiency refers to the units of heating energy obtained by one unit of fuel input. These values are based on values reported in the National Building Code guidelines for calculating the energy consumption of a house. The lifetime cost calculation is based on an assumed heat consumption of $100kWh/m^2$. This is the expected consumption of a standard house built according to the regulations in place 2010.

presented in Table 3. The base technology is electric heating, hence the coefficients measure the impact on utility *relative* to electric heating. The estimation is based on a sample including years 2006-2011, because electricity retail price data is not recorded at a detailed enough level for years prior to 2006.

House size, which is a measure of the magnitude of heating costs, is positive for all options, indicating that technologies other than electric heating are preferred as house size increases. Electric heating has the lowest investment costs but highest unit heating costs; hence trading higher investment costs for lower use costs becomes more favourable as house size increases.

The coefficients on the building material variable are also positive, again indicating a preference for central heating systems compared to electric heating in stone houses. This indicates that households' tastes for stone houses and central heating systems are positively correlated, as there are no technical reasons why stone houses should be fitted with central heating as opposed to electric heating.

Income, the debt to income-ratio and indicators for unemployment and childcare benefits all measure the financial situation of the household. The coefficients on income indicate that higher income households prefer ground heat relative to electric heating, whereas the effect is opposite for wood heating. For the other technologies the effect of income relative to electric heating is not significant, and overall the effect is small in magnitude. The debt to income-ratio mirrors the income variable both in sign and magnitude. The indicators for unemployment and childcare benefits are not significant, with the exception of wood heating which is positively correlated with unemployment benefits. This indicates that the effect of these variables on technology choice does not differ across technologies.

The house ownership and apartment ownership variables refer to the current dwelling status of the household. These are related to experience with heating systems; house owners may be more aware of the total costs of heating. In apartments the costs of heating, hot water and maintenance are shared among the building inhabitants. The coefficients indicate that current house owners are less likely to install hydroelectric heating or ground heat than electric heating. The utility from oil or wood heating relative to electric heating is not impacted by this variable. This implies that current house owners have a preference for those technolo-

terms of magnitude and statistical significance.

gies that are prevalent in the existing housing stock.[16] The coefficients on apartment ownership are negative across all technologies, indicating that electric heating is preferred to the other alternatives by households who currently reside in an apartment.

The coefficients on age indicate that older home builders prefer electric heating to the other technologies. Electric heating has the lowest maintenance needs, and it may therefore be an attractive option especially for the oldest builders. Age can also be correlated with the lifetime used for evaluating the investment. If the builder does not expect to occupy the house for a very long time, they may not be willing to invest in an expensive technology with a long payback time. Especially so if there is low trust in the housing market to correctly price the heating technology.

The coefficients on education are highly significant and large in magnitude for hydroelectric heating and ground heat. These technologies are strongly preferred by households with higher education, and the result is especially strong for the highest education level. Education has been found to be positively associated with preferences for energy efficiency and low personal discount rates (for example Newell and Siikamäki 2014, 2015; Ramos, Labandeira and Löschel, 2016). The effect measured here likely reflects both these factors. Education could also be related to the probability of misoptimisation. It can be argued that higher educated individuals could be less subject to the salience bias.

The presence of children has a positive impact on the choice of ground heat and wood heating in contrast to electric heating. These are the two technologies based on renewable energy sources, hence this impact could reflect a higher degree of environmental consciousness in households with children. The presence of children has also been found to be associated with lower personal discount rates (Harrison, Lau and Williams, 2002). Households with children would thus be willing to accept longer payback periods for the heating investment, which would make them more willing to accept the high investment costs of ground heat.

Once the presence of children is controlled for, increasing family size has a negative impact on the utility from central heating systems compared to electric heating. Electric heating has low maintenance, low investment costs and takes up no space in the building. These all are qualities which

[16] In 2010, the share of electric heating in the residential detached housing stock was 44%, the share of oil heating was 25% and the share of wood heating was 20%.

may increase the willingness to install electric heating in larger families.

The estimates on the urban location indicator imply a strong preference for electric heating in densely populated areas. This could reflect a cost issue; building costs tend to be higher in urban areas, which can impose credit constraints on some households. Also, in densely populated areas ground heat must be extracted via a borehole, which is more expensive to implement than collecting the heat with horizontally laid piping in the ground. This option requires space and is therefore not possible if the house is built on a small lot. The location effect is especially strong for wood heating. This is consistent with the presumption that many households who install wood heating have access to own firewood on the lot or close by. In addition, wood for heating needs to be stored in relatively large quantities, and this storage space would be very expensive in areas where land costs are high.

Finally, the coefficients on electricity costs indicate that higher electricity prices induce households to switch to fuels other than electricity. However, this effect is only statistically significant for the distribution price. This implies that households are more sensitive to the price which is a fixed characteristic of the building location. The local retail price does not necessarily measure the price level relevant to the household, as households can choose the price level and type of contract from those available on the market.

5.2 Marginal effects

Table 4 presents average marginal effects of selected variables based on the coefficient estimates. These effects measure the impact of the variables on the choice probability of each technology. Oil heating is not included in the comparison, due to its very small importance in the estimation sample. As indicated by the coefficient estimates, the education variables, house ownership and the building location are most influential for all technologies. Of the continuous variables, house size and electricity distribution price are most notable. Though age and disposable income are highly statistically significant, their impact is small in magnitude.

Figure 1 shows the effect of house size on the choice probability of the four most common heating technologies. The impact of house size is important especially for electric heating and ground heat. As house size increases, the probability of installing electric heating strongly declines, while the choice probability for ground heat increases. For the other tech-

Table 3. Coefficient estimates from multinomial logit estimation

	Oil	Hydroelectric	Ground	Wood	Other
Area (10m^2)	0.185***	0.066***	0.191***	0.162***	0.115***
Material: stone	0.219	0.320***	0.380***	-0.011	0.383***
Element build	-0.257*	0.440***	0.047	-0.515***	0.081
Net income (€1000)	-0.001	0.000	0.007***	-0.009***	0.000
Debt to income ratio	0.005*	0.004	0.005*	-0.041***	0.001
Unemployment benefits	0.031	-0.046	-0.046	0.131**	-0.049
Childcare benefits	-0.254	0.011	0.056	0.043	-0.008
House owner	0.297**	-0.115***	-0.412***	0.033	-0.243***
Apartment owner	-0.149	-0.119**	-0.004	-0.149*	-0.256***
Age	0.009	-0.013***	-0.010***	-0.011***	-0.016***
Children	0.265	-0.033	0.104**	0.133*	0.119
Family size	-0.158**	-0.011	-0.086***	-0.133***	-0.107***
Education: bachelor	-0.354*	0.152***	0.247***	0.020	0.126*
Education: master	-0.220	0.234***	0.396***	-0.171*	0.059
Location: urban	-2.694***	-0.809***	-1.521***	-2.124***	-1.139***
Electricity: retail	-0.055	0.015	0.018	0.114*	0.129*
Electricity: distribution	0.701***	0.008	0.199***	0.762***	0.130
Interaction of distribution price with urban location					
	0.442*	0.180***	0.189***	-0.069	0.182*
Estimation includes indicators for year and region					
Number of observations: 30 808					
Log likelihood: -37 402					

Notes: The table presents results from a multinomial logit estimation of heating technology choice. The base category is electric heating, the coefficients are thus to be interpreted as the impact on utility relative to this category. The estimation includes alternative-specific constants and indicators for year and region. The other indicator variables are: unemployment benefits (=1 if household received benefits), childcare benefits (=1 if household received benefits), house owner (=1 if household's current residence is an owner-occupied house), apartment owner (=1 if household's current residence is an owner-occupied apartment), children (=1 if household has children), bachelor (=1 if house owner's education level is equivalent to bachelor's level), master (=1 if house owner's education level is equivalent to master's level), urban location (=1 if town plan is in force at building site). Significance levels: * 10%, ** 5%, *** 1%

nologies the impact is almost constant with respect to house size. This indicates that households are aware of the increasing importance of use costs as house size increases. These choice probabilities are also consistent with endogenous attention: larger houses will have higher energy costs, hence the inhabitants of these houses may be more attentive to heating costs.

The corresponding illustration for the distribution price of electricity is presented in Figure 2. The choice probabilities are shown for the two technologies that were estimated to be most sensitive to electricity costs: electric heating and wood heating. The choice probability is calculated separately for houses built in an urban or a rural area, to illustrate the interaction of building location and price sensitivity.

The probability of electric heating is very strongly affected by the price level, again implying cost-sensitive households. The shape of the impact does not differ by location, but the choice probability overall is higher in urban locations. In contrast, for wood heating the importance of location is clear: as electricity prices increase, the choice probability rises much faster in rural locations than in urban areas. Though the share of wood heating in the stock of new houses is low, it may well be the preferred substitute to electric heating in areas where the costs of wood are low.

Finally, Figure 3 illustrates how income influences the choice probabilities for the two forms of electric heating, ground heat and wood heating. The impact is almost constant across income levels, except for ground heat where a notable increase in choice probability is observed for the highest income levels.

5.3 Heating energy demand and emissions

This section uses the estimation results to examine substitution patterns across technologies and to evaluate to what extent the substitution away from electric heating is induced by electricity prices. A price elasticity of heating electricity demand can be calculated, given assumptions about the heat consumption of the houses.

To investigate the impact of an increase in electricity costs, predicted choice probabilities for each household are calculated at a distribution price level of 4 c/kWh, and predicted market shares for each technology are defined based on average choice probabilities. Price is then increased by one percent, and new market shares are derived. The changes in the predicted choices are illustrated in Table 5, which shows the annual

Table 4. Average marginal effects

	Electric	Hydroelectric	Ground heat	Wood	Other
Area ($10m^2$)	-0.028***	-0.003***	0.024***	0.004***	0.001***
Net income (€1000)	-0.000**	-0.000*	0.001***	-0.001***	-0.000
Debt to income-ratio	0.000	0.001***	0.002***	-0.003***	-0.000
House ownership	0.047***	0.005	-0.065***	0.013***	-0.004
Age	0.002***	-0.001***	-0.001***	-0.000*	-0.000***
Family size	0.014***	0.005*	-0.010***	-0.006***	-0.003*
Education: bachelor	-0.034***	0.007	0.035***	-0.006*	0.001
Education: master	-0.049***	0.013**	0.063***	-0.020***	-0.005
Electricity: distribution	-0.063***	-0.011*	0.025***	0.040***	0.002
Urban location	0.124***	0.048***	-0.078***	-0.092***	0.001
Share in estimation sample	0.41	0.16	0.31	0.07	0.04

Notes: The table presents average marginal effects based on coefficients reported in Table 3. The indicator variables are: house ownership (=1 if household's current residence is owner-occupied house), bachelor (=1 if house owner's level is equivalent to bachelor's level), master (=1 if house owner's education level is equivalent to master's level), urban location (=1 if town plan is in force at building site). Significance levels: * 10%, ** 5%, *** 1%.

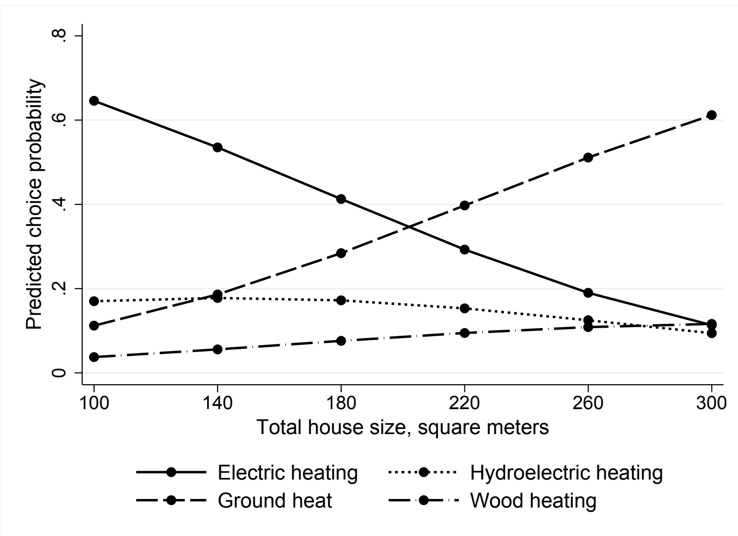

Figure 1. Choice probability and house size.

Notes: The figure illustrates how choice probability for selected technologies varies with house size. The probability is calculated based on the heating technology choice estimation reported in Table 3.

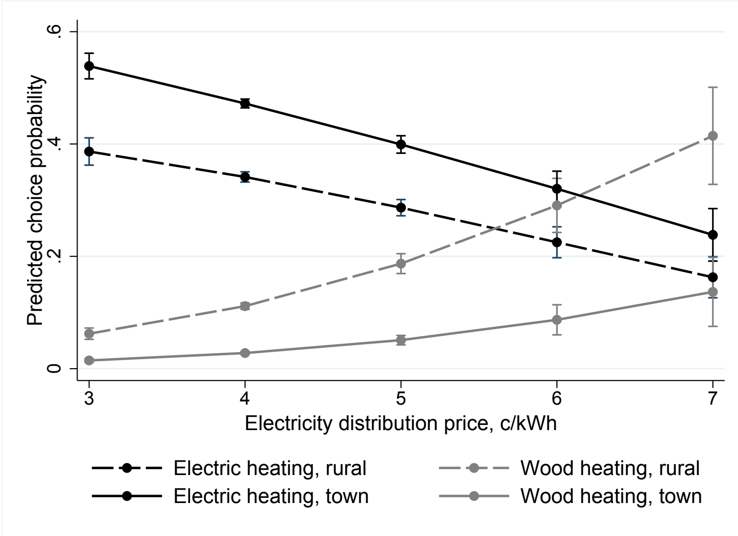

Figure 2. Choice probability and electricity distribution price.

Notes: The figure illustrates how choice probability for electric heating and wood varies with electricity distribution price, separately for urban areas (town plan in force) and rural areas (no town plan). The probability is calculated based on the heating technology choice estimation reported in Table 3. The vertical bars indicate the 95% confidence interval of the prediction.

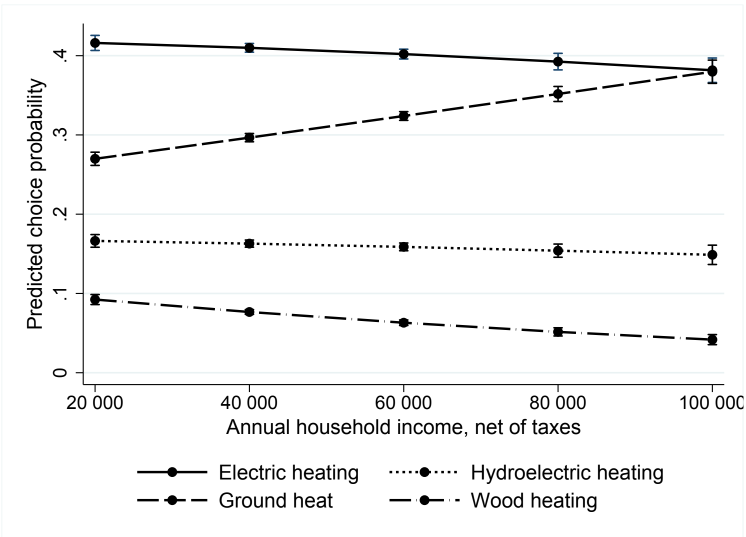

Figure 3. Choice probability and household income.

Notes: The figure illustrates how choice probability for selected technologies varies with household annual net income. The probability is calculated based on the heating technology choice estimation reported in Table 3.

change in the number of houses installing each technology due to the increase in distribution costs. The cost increase induces 130 houses in total to switch away from using electricity as the main source of heat. This corresponds to an elasticity of -0.50. Calculating the elasticity separately for the two technologies results in a value of -0.61 for electric heating and -0.24 for hydroelectric heating. These houses are allocated mostly to ground heat pumps and wood heating. There seems to be a time trend in the preferred alternative technology; wood is installed less towards the end of the sample period whereas ground heat gains popularity over time.

To construct the amount of heating energy demand that is allocated away from electricity, the predicted market shares and the resulting changes in the number of houses installing each technology are defined at the regional level. Taking location into account is important because of differences in climate, and also because the number of new houses is not distributed evenly across the country. Average house size by technology and region, as well as engineering estimates of heating energy needs are used to construct a measure of heating energy demand for the houses in the sample. The calculations are detailed in Appendix A. It is then assumed that the houses switching away from electricity correspond in size and heat need to an average house, where the average is calculated by heating technology and region.

Given the assumptions on the heat consumption of new houses, the total amount of heating energy to reallocate is 2538 MWh.[17] The final impact on total electricity consumption and on emissions will depend on which technology replaces electricity. Allocating this amount according to the shares implied by the number of houses in Table 5 results in 225 MWh going to oil heating, 882 MWh to ground heat, 1350 MWh to wood and 81 MWh to other technologies. Assuming that ground heat pumps have a fuel efficiency of 3, the final electricity demand from ground heat pumps would be 294 MWh.[18] The category "other" is undefined, but is likely to mostly include other heat pump technologies which also operate on electricity. To arrive at a conservative measure of reductions in heating electricity demand, it is assumed that the energy demand in this category will

[17]The average house-specific heat consumption in the data is 21 526 kWh.

[18]The National Building Code's guidelines for calculating the expected energy use of a house use a value of 2.5 for the coefficient of performance of ground heat. However, actual observed values around this time were around 3, and in recent years the efficiency has increased to close 4 (personal communication with Juha Jokisalo from Aalto University School of Technology).

contribute to electricity demand. Therefore, the total annual reduction in heating electricity demand due to a one percent price increase in the distribution price is 2163 MWh. Given a total heating electricity demand of 615 GWh at the distribution price of 4 c/kWh, this translates into an elasticity of -0.35.

These values were calculated for a one percent increase in the distribution price. Price changes that have actually occurred are much larger. For example, the average distribution price increased by 22 percent from 2010 to 2011, and this change was for the most part due to an increase in the electricity tax faced by consumers. The impact of this price increase can be examined by comparing model predictions for 2011 at observed prices and assuming that prices would have remained at 2010 levels. The results of this exercise are displayed in Table 6. Due to the increase in electricity prices from 2010 to 2011, the number of electrically heated homes is reduced by 427. Almost half of these houses switch to ground heat. Using the assumptions on house size and average heating energy needs, the second column of Table 6 shows the resulting change in the amount of energy to purchase by fuel. The total amount of heating energy to reallocate is 7210 MWh. Of this, 2432 MWh are savings in purchased energy due to the use of geothermal heat by ground heat pumps. A further 2871 MWh are allocated to wood. This amounts to 5303 MWh being shifted to renewable energy sources. The final column shows the impact on emissions. Actual emissions are not reduced, due to the large amount of energy produced from wood which has a much higher emission factor than electricity production. However, if wood is assigned zero emissions, the reduction is 1099 tonnes of CO2.

These are small amounts when compared to the annual CO2 emissions from the energy industry or from households, which were 24 326 thousand tonnes and 1545 thousand tonnes, respectively, in 2011. Yet, these are permanent changes to the structure of heating energy demand. Increasing electricity prices drive households towards other sources of heating energy, which are predominantly based on renewable energy sources. Especially the shift into heat pump technologies is observable in the data. This implies that the emissions due to heating residential buildings will decline over time.[19]

[19] This conclusion is subject to assuming no important rebound effects. It is possible that because heat pump technologies notably decrease the price of a unit of heat, households will increase their consumption of heat. Such a rebound effect would mitigate some of the energy savings.

Table 5. Substitution across technologies due to increases in electricity costs

	Oil	Electric	Hydroelectric	Ground heat	Wood	Other
2006	5	-29	-2	5	20	1
2007	3	-25	-3	7	18	0
2008	1	-17	-4	6	13	1
2009	0	-13	-2	7	7	1
2010	1	-16	-3	11	6	1
2011	0	-13	-3	11	4	1

Notes: The table presents changes in the number of houses installing each technology due to a one percent increase in the distribution costs of electricity. The number of houses is inferred from predicted market shares and the number of observations.

Table 6. Impact of 2011 electricity price increase

	No. of houses	Energy demand (MWh)	Electricity demand (MWh)	Emissions (tCO2)
Oil	16	270	0	71
Electric	-337	-5691	-5691	-1195
Hydroelectric	-90	-1520	-1520	-319
Ground heat	216	1216	1216	255
Wood	170	2871	0	1133
Other	25	422	422	89
Total	0	-2432	-5572	34

Notes: The table presents changes in heating energy demand, electricity demand and emissions resulting from the increases in electricity prices in 2011, relative to a base scenario of prices remaining constant at 2010 levels. The values are based on engineering assumptions of heating energy demand and on emission factors detailed in Appendix A.

6 Conclusions

Household energy use plays an important role in total energy consumption, and is consequently associated with the negative environmental externalities resulting from energy production. The level of energy use is determined by the stock of durable energy-using goods, hence targeting lower energy consumption in the long run requires that households invest in energy efficient appliances and residential buildings.

However, there is concern that household investment behaviour may be subject to inefficiencies and behavioural biases which cause energy efficiency investments to be taken up at a rate that is too low compared to private or social optimum. If this is the case, corrective policy measures may be needed to induce higher investment rates. The design of optimal policy is dependent on information about the importance and magnitude of possible inefficiencies, as well as on which types of households are most subject to sub-optimal behaviour.

This paper aims to provide such information by analysing data on a major investment decision: the choice of heating technology at the time of building a new, detached house. The data are drawn from administrative registries, including detailed information on private persons acting as builders in Finland during 2000-2011. The individual-level data on households and houses are complemented by information on local electricity prices. The cross-sectional variation in electricity costs allows estimating the impact of price on the investment decision, conditional on time, location and a number of observable household characteristics. Estimation is carried out using a multinomial logit model of heating technology choice.

The results imply that costs are an important determinant of the heating investment. Households are sensitive to the electricity price and substitute away from electric heating as the price rises. This effect is only observed for the distribution price of electricity, which can be argued to be a relevant measure of long-term price expectations, given that distribution prices are determined by local grid characteristics which evolve very slowly over time. This indicates that households are sensitive specifically to the lifetime costs of heating. However, this substitution can be hindered by high initial investment costs. This is implied by the statistically significant impact of income and debt on the choice of heating. Moreover, electric heating is strongly preferred in densely populated areas, where the substitute technologies tend to have higher investment costs.

The level of education is found to be an important determinant of heating choice. Higher education increases the probability of installing ground heat, which is characterised by very high investment costs but low lifetime operating costs. This is consistent with findings that higher education is correlated with lower personal discount rates. Additionally, education can be correlated with the valuation weight. The importance of education can therefore indicate the possible presence of issues such as salience bias. That is, some households may be placing disproportionate weight on the upfront costs at the investment stage.

The results also indicate that households whose current residence is a house are more likely to install electric, oil or wood heating into the new house. These heating systems are prevalent in the existing stock of houses, and thus this finding speaks for the importance of experience in technology choice. This may influence technology choice at least through two channels. Experience of a technology may induce the choice of this same technology into a new building simply due to familiarity. Alternatively, it could reflect an information issue: a house owner may be well aware of how to optimise the use of a technology they already have experience with. In either case, this result highlights the importance of clear, reliable information on the costs and attributes of different technologies at the point of making the investment decision.

This evidence thus points to the existence of some inefficiencies in households' investments. These could be alleviated by the provision of information and possibly by providing aid in financing the upfront investment. Based on the results, such financial measures should be targeted at lower income families with children. Nevertheless, in aggregate there is still notable price sensitivity. The results imply a price elasticity of -0.35 for heating electricity demand, and an elasticity of -0.50 for the investment into electric heating. Due to increasing prices, households are shifting especially to renewable energy sources: wood and ground source heat pumps. This means an overall reduction in the amount of heating energy purchased, and also in the emissions resulting from heating residential houses.

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A Assumptions for calculating heating energy demand and emissions

To calculate estimates of average heating energy demand, the model predictions are aggregated to form market shares for each region annually. The market shares are multiplied by the number of new houses observed in each region to arrive at the number of new houses estimated to install each technology. Each house is assigned the average house size in the respective heating category and region. This produces the aggregate

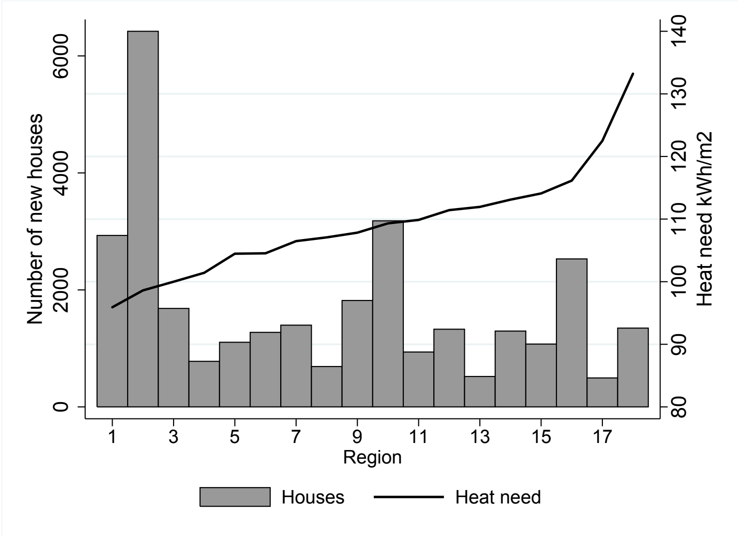

Figure 4. Number of observations and unit heating energy demand by region.

Notes: The figure illustrates the number of observations in the estimation sample by region, and the heating energy needs of an average house expressed in kWh per square meter.

number of square meters in each category. Engineering estimates of heating needs can then be applied to arrive at the total amount of energy demanded. These estimates take into account the prevailing building standards at each point in time, and the differences in outdoor temperature across the country. (See Sirén and Jokisalo (2014) and Sahari (2016b) for more details). The values are illustrated in Figure 4, which plots the regions with respect to climate from mildest to coldest and displays the heat need of an average house, as well as the total number of observations in each region in the estimation sample.

Estimates of CO_2 emissions are based on emission factors reported in table 7. The values for electricity are taken from Saari et al. (2010) for 2006-2008 and for 2009-2011 the value is taken from Motiva (2012). Emissions for oil heating are based on Motiva (2012), and the values for wood are from Statistics Finland (2016). To convert the emission factor for wood into units of Kg/MWh, note that 1 MWh equals 3.6 GJ.

Table 7. Emission factors

	Electricity (Kg/MWh)	Oil (Kg/MWh)	Wood (kg/GJ)
2006	309	261	109.6
2007	280	261	109.6
2008	215	261	109.6
2009	210	261	109.6
2010	210	261	109.6
2011	210	261	109.6

Notes: The table lists the emission factors used in calculating emissions from heating.

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