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Anna Sahari, VATT Institute for Economic Research, anna.sahari@vatt.fi and Aalto University.

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Valtion taloudellinen tutkimuskeskus
VATT Institute for Economic Research
Arkadiankatu 7, 00100 Helsinki, Finland

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Abstract

This paper studies consumers' sensitivity to energy costs at the moment of making a long-term energy technology investment. The analysis exploits within-region variation in local, regulated electricity distribution prices that are very persistent over time and therefore a good measure of long-term price expectations. Price impacts are estimated on extensive administrative registry data of private persons acting as home builders in Finland during 2006-2011. The results show that electricity prices notably influence builders' heating choices, and price increases that are mostly due to taxation have induced demand for technologies based on renewable energy. However, the results on the comprehensive set of observable individual-level characteristics imply that issues related to information and credit availability may hamper price sensitivity.

Key words: Elasticity, Electricity, Discrete choice, Consumer behaviour

JEL classes: D12, D83, Q41, R22

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 makes use of exceptional microdata originating from administrative registries. Such data have not previously been used to study consumers' energy investment behaviour.[1] The data include detailed information on consumers, combined with energy price data that explicitly differentiate the short-term and long-term price faced by consumers. The contribution of this paper stems from the high-quality data, which allow addressing two challenges related to the analysis of long-run investments: namely, that future energy prices are unobserved and that consumers are heterogeneous in their use of energy and in the valuation of future energy costs.

Understanding the role of prices and individual characteristics in consumers' investment into energy-intensive durable goods key in energy policy design. The vast literature on the energy efficiency gap suggests that standard price instruments may not be sufficient to induce investments into energy efficiency (Allcott and Greenstone 2012, Gillingham and Palmer 2013, Jaffe and Stavins 1994). Recent research has highlighted the importance of consumer heterogeneity in assessing both price sensitivity and the existence of behavioural biases and other investment barriers (for example: Allcott, Knittel and Taubinsky 2015, Bento, Li and Roth 2012, Grigolon, Reynaert and Verboven 2015, Houde 2017, Newell and Siikamäki 2014).

Using a standard model of discrete choice, this paper shows that households' heating technology investments are highly sensitive to energy costs. The elasticity of demand for electric heating technology with respect to the electricity price is estimated to range from -0.37 to -1.69 depending on the price level. This implies that consumers do respond to price signals and instruments such as taxes can induce investment into energy efficiency. However, households systematically choose different technologies based on certain individual-level characteristics, the most prominent ones being the level of education and experience of house ownership. These results indicate the presence of behavioural factors and potential market failures, which may restrict the response to energy prices.

The identification of price impacts is based on local variation in prices for electricity, which is the main source of heating energy in new residential houses. The comprehensive set of observable individual characteristics ensures that price sensitivity estimates are not confounded by consumer heterogeneity. The estimation also includes detailed fixed effects at the level of time, region and building location to control for unobserved vari-

[1] Davis, Fuchs and Gertler (2014) use Mexican registry data to evaluate an appliance replacement program concerning refrigerators and air conditioners.

ation in factors that influence construction, such as building cost levels and the overall economic environment.[2]

The analysis relies on the standard assumption that consumers expect future energy prices to equal today's price level.[3] The setting of the Finnish electricity market offers a natural measure for the long-term price level because the retail electricity market is distinct from the distribution service. Local, regulated monopolies provide distribution, and prices reflect the costs of operating and maintaining the grid. This leads to prices that are stable over time locally, yet there is significant variation in the price levels across distribution networks. These properties make the distribution price a long-term price, and justify the assumption that consumers base price expectations on current price levels.

The results have implications for the design of energy efficiency policies targeted at residential buildings. Especially in central Europe, renovations to the building stock are timely, and the European Union is seeking further measures to accelerate investments (European Commission 2016). This study shows that, although consumers recognise the importance of long-term energy costs, high initial costs may constrain investments for lower-income households. This result for newly constructed houses plausibly carries over to renovations in the existing building stock, and suggests that instruments facilitating the financing of investments could be effective. Furthermore, results on the education level of builders and experience of house ownership indicate notable differences across consumers in the willingness and ability to acquire and process information.

The findings contribute to the literature on consumer investment into energy-using durable goods. What is exceptional about this study is that it combines extensive individual-level information with data on actual investments. This type of data are rarely available. For example, the research on vehicle choice and fuel efficiency exploits at most millions of observations on car purchase, 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 individual-level data is available, it often originates from surveys or experiments, which may suffer from issues related to sample selection and the accuracy of reporting. These problems are not present in registry data.[4]

The price-sensitivity results are in line with recent research on cars, which finds no significant undervaluation of future energy costs at the moment of investment (Allcott and Wozny 2014, Busse, Knittel and Zettelmeyer, 2013, Sallee, West and Fan, 2015). For the housing market, Myers (2017) and Liski and Harjunen (2014) have shown that the energy costs capitalise into house prices, implying reasonable discounting of future costs

[2]The data include the years 2009 and 2010, when new construction was clearly impacted by the financial crisis.

[3]See Anderson, Kellogg and Sallee 2013 for discussion and empirical evidence on the validity of this assumption.

[4]Previous studies on heating and cooling have relied on survey data (Braun 2010, Mansur, Mendelsohn and Morrison 2008, Nesbakken 2001, Rapson 2014, Vaage 2000) or stated-preference methods (Rouvinen and Matero 2013, Ruokamo 2016, Scarpa and Willis 2010).

at 8-10 percent discount rates. Also Rapson (2014) finds evidence of forward-looking consumers, using a dynamic model of air conditioner purchase. Explicitly incorporating consumers' expectations about energy prices and the development of energy efficiency over time, his results show high sensitivity to improvements in the energy efficiency of air conditioners.

The results on consumer characteristics and technology choice can be interpreted in the light of other studies that have linked heterogeneity to aspects of residential energy investments. Using survey data, Brounen, Kok and Quigley (2013) and Ramos, Labandeira and Löschel (2016) show that higher education and income are positively related to choice of a cost-efficient heating system and installing double glazing. Conversely, older respondents were less likely to choose these alternatives. Similar impacts of income, education and age have been documented in the extensive literature concerning the choice of appliances. Recent examples include Blasch, Filippini and Kumar (2017), who show that higher income and education increase the probability of choosing a cost-efficient refrigerator, and Houde (2017) who finds that consumers with a graduate degree are more likely to be fully informed about the energy costs of regrigerators.

Given the very long lifetime of heating systems, the consumer characteristics will also reflect the differences in personal and financial discount rates to the extent that these are correlated with the observable characteristics. The literature on personal time preferences has demonstrated that income, age, education and family composition are associated with personal discount rates (Frederick, Lowenstein and O'Donoghue 2002, Harrison, Lau and Williams 2002, Simon, Warner and Pleeter 2015). In the context of energy efficiency and durable good choice, Newell and Siikamäki (2014, 2015) illustrate how discount rates relate to individual characteristics, and how assuming homogeneous discounting across consumers distorts the estimation of willingness to pay for energy efficiency.

This paper proceeds as follows. The next section describes the institutional setting and empirical framework for studying the heating technology investments of Finnish home builders. Section 3 details the data, with a special focus on the electricity prices. Section 4 presents results, and section 5 draws together the main conclusions and policy implications.

2 Empirical framework

2.1 Institutional context: houses and heating in Finland

Detached, single-family houses are a common dwelling form in Finland, accounting for 41 percent of the residential housing stock. In contrast to apartment buildings and row houses, which are typically built by building companies and then marketed to consumers, detached houses are most often built by the households themselves acting as developers for their own building project. This means that the future resident of the house is in charge of investment decisions.

Construction of new homes is closely monitored: all building activity requires a permit from the local authorities, which will expire if building does not commence within three years. Reporting to the authorities has three stages: an initial request for a building permit, a notification once building has started and finally a notification of the completion of the project. New buildings must comply with the National Building Code, which sets mandatory requirements for building structures, insulation and heat, plumbing and ventilation. In addition, the energy label for buildings became mandatory for new residential houses in 2008. During the period analysed in this paper, these regulations were identical for all buildings regardless of the chosen heating technology. Furthermore, there were no financial incentives in place regarding energy-related investments in new houses.[5]

Finland is a northern country, with annual mean temperatures ranging from six degrees Celsius (43F) in the south to zero degrees Celsius (32F) in the north. Due to the climate, all houses must be fitted with a main heating system at the moment of building. The range of options is limited and the technologies are well-established. These include: electric heating, water central electric heating, ground source heat pumps, wood heating and oil.[6] If the house is built within a district heat network, this option is also available. However, district heat areas are excluded from the analysis of investment behaviour, because many municipalities have in place an obligation for new houses to join the network.

Electricity, wood and oil are the predominant sources of heat in the existing stock of residential houses, while electricity or a ground source heat pump are most often installed in new houses. The latter technology extracts heat from a borehole drilled deep underground, and requires electricity only to operate the pump and act as a back-up source of energy. Ground source heat pumps can thus produce on average two thirds of the required heat at no cost from renewable geothermal energy. During the sample period, a permit was not required for drilling the borehole.

The different heat sources make use of distinct technologies to produce heat, but in new houses the heating systems are highly automated and do not require active attention on a daily basis. In the long run, maintenance needs differ. For example, the furnace and chimney in oil or wood systems need regular cleaning whereas electric heating is practically maintenance free. Furthermore, the heating system is not a visible characteristic of the building. From the outside, it is not possible to distinguish which technology is installed, and inside the house heat is almost always distributed via cables or hot water pipes installed under the floor.

The heating system is very much a fixed characteristics of the house, as changes to it are expensive to carry out. The long time horizon and irreversibility of the investment mean that lifetime use costs form the largest share of total costs for most technologies. The heating investment thus has notable economic consequences for the household, and it will impact the resale value of the house.[7]

[5]The National Building Code was revised in 2012, resulting in differentiated standards depending on the heating technology. For example, houses with electric heating must have more insulation than houses heated by ground heat or district heating.

[6]Residential use of gas is extremely rare in Finland.

[7]Recent empirical studies have shown that consumers do place value on energy-related fixed charac-

Table 1: 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
Energy cost, c/kWh	10.72	9.97	4.29	6.54	8.61
Total cost for varying house size, lifetime 20 years and discount rate 5%					
Area: $150m^2$	26 184	28 419	25 482	23 973	27 614
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 from annual averages reported by Statistics Finland. The fuel efficiency refers to the units of heating energy obtained from one unit of fuel input. The actual energy cost is thus obtained by dividing the fuel cost by the fuel efficiency. These values are based on numbers 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 house built according to the building code prevailing in 2010. The average size of new houses during 2006-2011 was $180m^2$

Examples of purchase costs and heating costs by technology are presented in Table 1. These numbers illustrate the magnitude of the tradeoff that the households face at the investment stage. The fuel efficiencies reported in the table are based on values given in the National Building Code's guidelines for calculating the energy consumption of a house. In practice these values will vary slightly 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.

It is worth noting that the differences in purchase price and energy cost across technologies are significant, and therefore discovering the cost-efficient option for a given house requires calculating the present-value lifetime costs of use. For example, ground heat is about three times as expensive to install as electric heating, yet the costs of use are low enough to make this the least-cost solution for an average house when total costs are considered.

2.2 Empirical strategy

The empirical analysis links the observed choice of heating technology to electricity prices, house characteristics and socio-demographic variables at the level of individual builders. The specification is kept simple in order to allow for a clean interpretation of

teristics of buildings. See for example Brounen and Kok (2011), Harjunen and Liski (2014) and Myers (2017) for evidence on the capitalisation of energy costs into house prices.

the impact of each variable and to exploit the data to the full extent.[8] Because a main heating system must be installed at the point of building, outside options or elements of timing are not built into the empirical specification.

The analysis is based on a standard model of discrete choice. The builder must choose a technology j from the set of available options J. Denoting by $U_{ij} = V_{ij} + \varepsilon_{ij}$ the utility for builder i form option j, the probability of choosing this option is

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

Assuming that the unobservable part of utility is distributed i.i.d. extreme value type I results in the logit model, where the choice probability takes the following form:

$$P_{ij} = \frac{e^{V_{ij}}}{(\sum_j^J e^{V_{ij}})}$$

The following utility specification will be used in estimation:

$$u_{ijtrl} = \beta_j^r p^r + \beta_j^d p^d + \sum_k \eta_{jk} z_{ik} + \sum_g \alpha_{jg} w_{ig} + \phi_j s_{rt} + \xi_{jl} + \tau_{jt} + \varepsilon_{ij}, \qquad (1)$$

where p^r is the retail price of electricity, p^d is the distribution price of electricity, z_{ik} are house characteristics and w_{ig} denote household characteristics. Factors that are common to all households building within a similar location l (urban or rural) in the same geographic region are captured by location-by-region fixed effects ξ_{jl}. Local conditions are also described by the average sale price of detached houses s_{rt}, defined annually at the level of municipality types (urban, densely populated or rural) by region. Time effects τ_t capture factors such as changes in average price levels or building regulations that will impact all builders in the same way.

The empirical specification thus tests whether households that are identical in terms of a comprehensive set of observable characteristics will choose different heating systems based on differences in electricity prices. If consumers are not attentive to the costs of heating, energy prices should not be a significant determinant of technology choice. Conversely, if prices do matter, a higher electricity price should increase the choice probability for technologies that are less dependent on electricity, and decrease the choice probability for electric heating. This inference hinges on assumptions concerning price expectations, investment costs and movements of other fuel prices. These assumptions as well as the role of the main unobservable variables are discussed below.

[8] Many studies using aggregate data estimate the relationship between purchase price and lifetime use costs to evaluate whether consumers give equal weight to these costs at the moment of purchase (Allcott and Wozny 2014, Busse, Knittel and Zettelmeyer 2013, Myers 2017). Here this approach would require using additional data for investment costs, which would limit the time period available for estimation. Moreover, combining the electricity prices, house size and location into an annual heating cost would not allow separately examining the impact of the short-term (retail) price and long-term (distribution) price.

2.3 Energy price expectations

The total electricity cost is composed of the retail price of electricity and the price of distribution: $p = p^r + p^d$. If these prices are relevant measures for future heating costs, investment decisions of price-sensitive consumers will respond to changes in current prices. In the context of the Finnish electricity market, the assumption of constant prices may be questionable regarding the retail cost of electricity, but less so for the distribution price. Because these prices are regulated and depend on local grid characteristics, it is reasonable to assume that today's price level is a good indicator for the future price level, in real terms. Section 3.1 and Appendix A provide evidence on the persistence of distribution prices over time and information on the determinants of distribution prices.

The unit prices of oil and wood are not available at a detailed enough level to be included in the analysis. This could potentially confound the inferences based on the estimated impact of electricity prices, as the relevant cost measure for consumers is the price difference between the energy sources. However, electricity is the most common source of heat in new detached houses, as almost 90 percent 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 importance of oil prices is not likely to be large. The amount of oil heating installed is very small and declining over time, 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 wood.

2.4 Expected heat consumption

The building characteristics z_{ik} include k variables related to the amount of heating energy to purchase. The variables are house size, an indicator for building material, an indicator for building method and a measure of local climate, expressed in heating degree days. House size and insulation determine the amount of heating energy needed. Building standards set a maximum allowable level for heat consumption, but some households may opt to build a house with better insulation than is required. The insulation level is not observed in the data. 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.

Secondary heat sources, such as fireplaces, are not recorded in the data. Together with the unobserved level of insulation this means that the actual heat consumption for some houses will be lower than the level implied by the observable characteristics. Improper measurement of the heat need of the house will influence the estimated sensitivity to electricity price, but 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.

2.5 Investment costs

The investment costs are not observed. If there are differences in the investment cost levels that would exactly offset the differences in operating costs resulting from electricity price variation, consumers would not switch to other heat sources and the results would imply no response to energy prices. Investment costs are influenced by the overall level of building costs, which varies especially with building location. Costs are higher in growing, urban areas. These differences are captured by the location-by-region fixed effects and by the average sale price of detached houses by municipality type and region. Similarly, changes to price levels over time are captured by time fixed effects. For a specific house, the investment cost for any option is strongly dependent on house size. This is especially true for the two most common technologies, electric heating and ground heat. For ground heat the largest cost component is the drilling of the borehole from which geothermal heat is extracted. These costs are a function of the depth of the hole, which in turn is a function of heat consumption: the higher is consumption, the deeper must be drilled. Heat consumption is largely determined by house size and local climate, which are captured by observable house size and local heating degree days.

2.6 Household characteristics

Household characteristics relevant to the heating choice are represented by w_{ig} in the utility specification. These variables include net income, the debt-to-income ratio, an indicator for unemployment benefits, an indicator for childcare benefits, age, education, family size, an indicator for the presence of children, and indicators for whether the household owns a house or apartment at the time of building. These variables include characteristics which have been shown to be correlated with personal discount rates (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). They are also likely to be determinants of the lifetime the household uses in assessing the heating costs over time. In principle, households should consider at least the full lifetime of each technology, as the housing market should capitalise lifetime heating costs into house value. However, if the the household does not expect this to happen, they may consider only the time period in which they themselves will occupy the house. The household characteristics will also capture differences in tastes, for example a preference for renewable energy, to the extent these are correlated with the observable characteristics.

2.7 Building location

The building location l is described by an indicator which takes value one if a town plan is in force at the building site. The existence of a town plan is an indicator for an urban or densely populated area; town plans tend to prevail in such areas, whereas rural locations more often rely on general master plans. This controls especially for the availability of firewood as a substitute fuel, and for the indirect effect of building restrictions. 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 impact of location is defined separately at the level of administrative regions. There are 19 regions in Finland, of which the island of Åland is not included here due to missing electricity price information. Regional characteristics that can influence both distribution prices and heating choices include factors such as climate. For example, eastern Finland tends to have very different snow conditions from 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. To further control for regional economic factors, the estimation includes the average sale price of detached houses, defined annually over regions and municipality types. The municipality type is defined by Statistics Finland as urban, densely populated or rural.

3 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, representing a 15 percent increase in the total stock of detached houses. To construct the estimation sample, other ownership categories besides private persons are dropped, as well as semi-detached houses and exceptionally large or small houses. This leaves 109 289 houses in the base data.[10]

The information on new houses originates from building permits. The variables in the data are taken from a form the builder has to submit when applying for a building permit, but 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

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

[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.

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] The technologies thus 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. 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". This category includes any other main heating technology, for example less common devices such as air-to-water heat pumps. District heat areas are excluded from the analysis.[13]

The individual-level information on building owners is drawn 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. Summary statistics of these variables are presented in Table 2. These are calculated by technology for the estimation sample, which includes years 2006-2011.

On average, home builders are families with children, with higher earnings than the population overall.[14] Houses are typically built from wood and located in urban areas. The exception is houses with wood heating, of these only one fifth are built in urban locations. The other variables which vary notably across technologies are income, education, house size and building method. Households who install ground heat have higher income and education than the rest of the sample. These households are also the least likely to already be house owners, though the share of house ownership is rather high in the sample in general. Houses with central heating systems 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. As for building method, houses built from ready-made elements are more likely to be fitted with electric heating or hydroelectric 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

[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 each make up only two percent of observations.

[13] Overall, the 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. However, it is not possible to distinguish whether this is due to free choice because many municipalities impose this technology on new houses within the network.

[14] According to Statistics Finland, the average household income was approximately €36 000 in 2010.

Table 2: Summary statistics: household and house characteristics by technology

	Electric	Hydroelectric	Ground heat	Wood	Oil	Other
Household characteristics						
Net income €	46 375	47 800	53 481	43 046	48 267	47 972
Debt to income ratio	3.38	3.67	3.58	3.21	4.09	3.37
Age	37	36	36	36	38	35
Family size	3.3	3.4	3.4	3.3	3.4	3.3
Undergraduate degree, share	0.20	0.24	0.26	0.21	0.15	0.25
Graduate degree, share	0.12	0.16	0.22	0.09	0.13	0.14
House owner, share	0.54	0.49	0.41	0.57	0.61	0.46
Apartment owner, share	0.13	0.13	0.18	0.10	0.11	0.13
House characteristics						
House size (m^2)	166	177	215	194	214	189
Material: wood, share	0.93	0.90	0.81	0.91	0.80	0.86
Element build, share	0.50	0.60	0.45	0.32	0.38	0.49
Town plan in force, share	0.65	0.67	0.56	0.23	0.48	0.62
Overall share	0.41	0.16	0.31	0.07	0.01	0.04

Notes: The table displays summary statistics of house and household characteristics by heating technology for the time period 2006-2011. The number of observations is 30 777. Monetary values are expressed in 2010 prices. Net income is calculated as total household income net of taxes. The individual-specific variables (age and education) refer to the building owner. The variables "house owner" and "aparment owner" refer to the ownership status and type of the builder'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.

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. On average, distribution fees constitute around 40 percent of the total cost of electricity. Electricity bills separately show the retail price, the distribution fee and taxes, so the differences in these costs are visible to consumers.[15] Retail prices and distribution fees both include a fixed monthly fee and a unit cost defined in c/kWh. Block price contracts are not offered on the Finnish 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.[16] The electricity price used in the analysis refers to the price for customers in detached houses with electric heating.

3.1.1 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 at most 89 distribution companies, and hence 89 distinct price areas.[17] The companies vary widely in size and administration; there are small distributors who manage the grid within the area of a single municipality, and very large distributors with grids 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 owner types.

The differences across DSOs are illustrated in Table 3, 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 that is underground. The number of power cuts also varies widely. This number refers to the average number of times a customer faces a disruption in the distribution service during a year. Power cuts are more 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; DSOs are allowed to cover costs and earn a reasonable return on capital. Ap-

[15]If the consumer is contracted with a retailer who is not also acting as the local distribution system operator, the consumer will receive separate bills for retail and distribution.

[16]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 hydroelectric heating (20 000 kWh).

[17]The number of DSOs declines from 89 to 86 during the sample period.

Table 3: DSO technical characteristics, 2006-2011.

	Average	Std.Dev.	Min	Max
Grid length (km)	4476	10 706	125	71 633
Ground cables (%)	43	25	0	98
No. of connections	20 249	47 693	737	368 397
Distributed energy (GWh)	423	818	11	5851
No. of power cuts	6.5	8.4	0	106
No. of transformers	1498	3620	7	23 580

Notes: The table presents summary statistics of technical characteristics of distribution system operators during 2006-2011. The figures are based on data published by the Energy Authority. The number of DSOs observed annually declines from 89 to 86 during this time period, due to small distributors merging with a neighbouring, bigger company.

Table 4: Measures of autocorrelation in DSO prices.

	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 are calculated based on the full range of available distribution price data: years 2003-2014.

pendix A provides evidence on how prices relate to DSO characteristics.[18] 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 distribution price data is illustrated in Figure 1, which shows the observations over the time period 2006-2011 used in the estimation. The prices include taxes. The average price level is around 4 c/kWh, both in the data overall and annually across time. Increases in the price level during this time period are largely due to taxation: the electricity tax was increased in 2008 from 0.73 c/kWh to 0.87 c/kWh, and in 2011 from 0.87 c/kWh to 1.69 c/kWh. This latter price change caused a notable jump in the overall level of distribution prices. In addition, the VAT was increased in 2010.

In terms of annual differences across distribution areas, the prices range from approximately 3 c/kWh to around 6 c/kWh. For an average house heated with electricity, this difference of 3 c/kWh amounts to an annual difference in heating costs of €510. These price differences tend to be very persistent, which is illustrated by high autocorrelation in distributor-specific prices and in the annual ranking of distributors with respect to price. The values for these autocorrelations are presented in Table 4.

The cross-sectional variation in observations and distribution prices is presented in

[18] Kuosmanen (2012) shows how these characteristics relate to marginal costs of DSOs, and discusses the regulatory model.

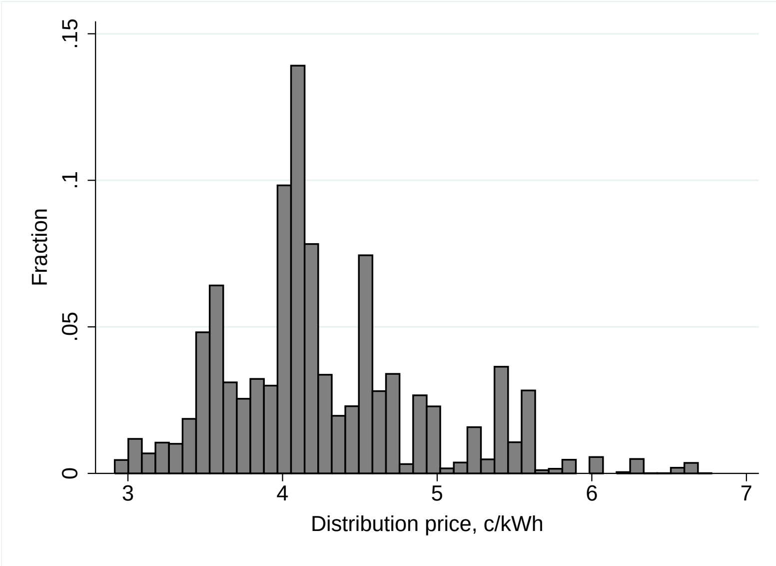

Figure 1: Histogram of distribution price data used in estimation.

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

Figure 2 for year 2008. The figure illustrates the variation used in estimating the impact of distribution prices. The bars, read on the left-hand axis, present the total number of observations in each region. The horizontal line depicts the annual average distribution price level, captured by time fixed effects, and the region-specific averages by urban/rural location are illustrated by the diamond/circle. The range of prices observed within the given year for each region is shown by the vertical dashed line.

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.

3.1.2 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, of which approximately half 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

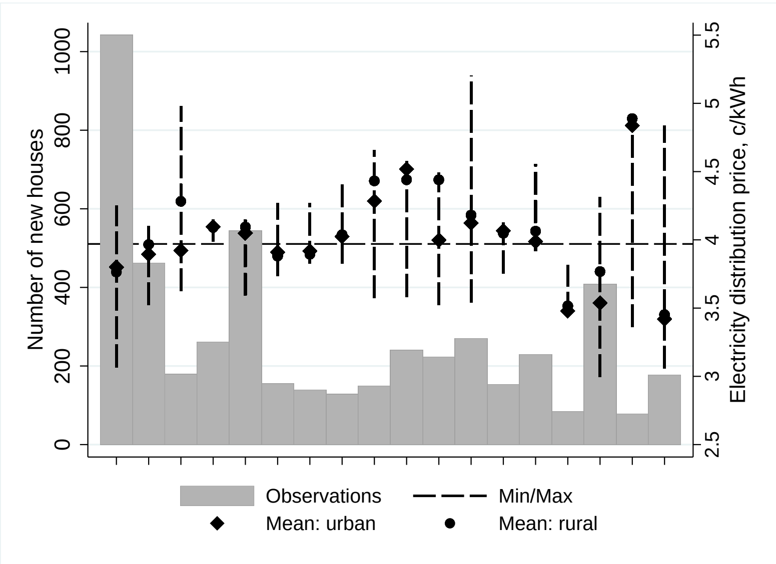

Figure 2: Range of distribution prices and number of observations by region, year 2008.

Notes: The figure illustrates the variation used in estimating the impact of electricity price on technology choice. The horizontal axis lists the 18 regions observed annually. The number of new houses observed by region is indicated by bars and read on the left-hand axis. The horizontal dashed line indicates the annual average distribution price, captured by time fixed effects. The vertical dashed lines illustrate the range of distribution prices observed in each region. The diamonds and circles indicate the region-specific average distribution price in urban and rural building locations. These are captured by location-by-region fixed effects in estimation.

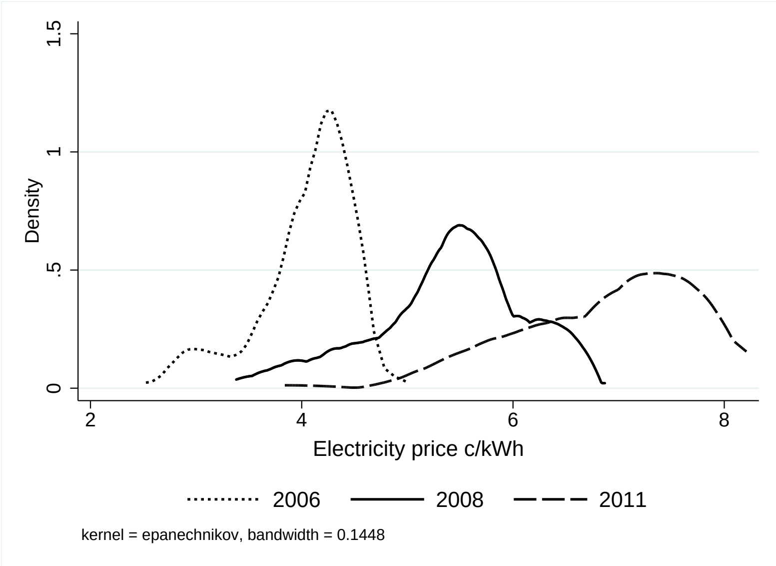

Figure 3: Annual density of electricity retail price for selected years.

Notes: The figure illustrates the development of electricity retail price levels over time. The price depicted is the lowest price offered by each retailer to customers in detached houses with electric heating. Prices in 2010 values.

the lowest price of a standard contract offered by the default supplier.[19] 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 default suppliers and over 80 distribution areas.

Standard contracts set 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.

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).

[19] Other ways of assigning retail prices to houses are expored in the robustness checks.

4 Results

This section presents a set of results from a logit estimation of heating choice, based on Equation 1. 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. Interactions with other house and household characteristics did not prove to be statistically significant, and are not discussed here.[20] Estimation results are presented as average marginal effects, reported in Table 5. Oil heating is left out of the table, due to its very small importance in the estimation sample. The underlying coefficients are reported in Appendix B.

4.1 Household heterogeneity in technology choice

The results on the observable household characteristics show that there are systematic differences between households' technology choices, conditional on the electricity price level, building location and type of house built. The variables with the largest impact on choice probabilities are house size, the level of education and current dwelling type.

Figure 4 illustrates how increasing house size reduces the probability of installing electric heating and increases the choice probability of ground heat. This implies that builders are well aware of the importance of heating costs: ground heat is the least-cost option for larger houses due to the very low operating costs of the technology. The result is also consistent with endogenous attention to energy costs. Larger houses will have higher heating costs, hence the inhabitants of these houses may be more attentive to these costs and more likely to choose the low-cost option (see Allcott, Mullainathan and Taubinsky, 2014, for discussion on endogenous attention and possible biases related to technology investments).

The results on the education level of the house owner indicate that ground heat and hydroelectric heating are strongly preferred by households with higher education, and the result is increasing in the level of education. An undergraduate degree increases the probability of installing ground heat by 3.5 percentage points, and the impact of a graduate degree is 6.4 percentage points. The effects are opposite and of similar magnitude for electric heating. This in line with the findings in the literature that higher education is positively related to financial literacy (Blasch, Filippini and Kumar 2017, Brounen, Kok and Quigley 2013). Discovering the cost-effectiveness of ground heat requires making an investment calculation involving assumptions about lifetimes, discounting and expected energy costs. It is plausible that individuals with higher education are more willing and able to perform this task. The effect of education may also be related to preferences for energy efficiency and low personal discount rates. These have been found to be associated with higher education (for example Newell and Siikamäki 2014 and 2015, Ramos, Labandeira and Löschel, 2016).

[20]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.

The current dwelling type of the builder is measured by indicators for house ownership and apartment ownership. The results indicate that house owners have a preference for electric heating and wood heating, technologies that are prevalent in the existing housing stock.[21] Conversely, house owners are much less likely to install ground heat. Interpreting this result is not straightforward. On the one hand, builders who have experience of house ownership should be well informed of the importance of heating costs and arguably should be well-equipped to evaluate the different aspects related to heating of their new home. On the other hand, their knowledge and experience may be limited to the technology in use in their current home. This familiarity may induce them to choose the same technology for the new building.

Household income, family size and the builder's age all have a statistically significant but small impact on technology choice. The effect of income is illustrated in Figure 6. The impact is almost constant across income levels, except for the choice probability of ground heat, which increases notably with income. This can be viewed as evidence of credit constraints. If all households can borrow more to finance the upfront investment, then income should not influence technology choice, once education and age are controlled for. Yet, higher income clearly increases the likelihood of choosing the technology which is characterised by very high upfront costs. The impact of family size may also reflect this aspect. Conditional on income and debt, larger families will have less disposable income. They may thus be constrained in their ability to finance high investment costs, which could be an explanation for the negative result of family size on the choice probability of ground heat.

4.2 Sensitivity to electricity prices

The heating technology investment is clearly responsive to electricity prices. The estimation results show that higher prices increase the probability of choosing ground heat or wood over electric heating, conditional on the comprehensive set of observable characteristics of the household and the building. However, this effect is only visible for the distribution price of electricity. This implies that households are more sensitive to the price which is a fixed characteristic of the building location. The retail price may be an imperfect indicator of future price developments, as retail prices are based on market conditions which may be volatile. Furthermore, the null effect of the retail price could also be due to measurement error: the local retail price is an incorrect measure if the builder is not contracted with the local retailer, or if consumers base their retail price expectations on other factors, for example average price levels.

The marginal effect indicates 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, this is a reduction of 15 percent. Higher electricity costs induce the share of ground heat and wood heating to increase. The effect is especially strong for wood heating, where the marginal effect

[21] 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%.

implies an increase of 3 percentage points in the probability of choosing wood heating, while the overall share of this technology in new houses is 7 percent.

These effects are illustrated in in Figure 5. The figure shows how the choice probabilities for electric heating and wood heating change as the distribution price of electricity increases from 3 c/kWh to 7 c/kWh, which is the range observed in the data. 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. Electric heating is very strongly affected by the price level. 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 is clearly an attractive substitute to electric heating in areas where wood is easily accessible.

The energy price sensitivity can be expressed as the elasticity of the aggregate amount of installed electric heating with respect to the distribution price of electricity. The elasticity is obtained by calculating the predicted share of electric heating for 10 000 draws of the distribution price coefficients, at a given price level. 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 technology demand with respect to the distribution price. Table 6 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 -0.65. The elasticity increases with the price level, going up to -1.69 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. However, at these higher price levels the variance of the elasticity measure increases. Using this method to calculate the electricity price elasticity for the choice of ground heat and wood results in values of 0.25 and 1.72, respectively.

These elasticity values imply notable switching to alternative heat sources as the costs of electricity increase. To illustrate the substitution to other technologies, Table 7 shows the estimated annual change in the number of houses installing each technology due to a one percent increase in distribution costs from an initial price of 4 c/kWh. The cost increase induces 75 houses in total to switch away from using electricity as the main source of heat. These houses are allocated mostly to ground heat pumps and wood heating. There is 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.

4.3 Heating energy demand and emissions

The shift away from electric heating will reduce electricity demand and influence the emissions originating from heating energy production. These amounts can be approximated using average heat consumption measures and the predicted changes in the number of houses fitted with each technology. In order to account for regional differences in

Table 5: Average marginal effects from technology choice estimation

	Electric	Hydroelectric	Ground heat	Wood	Other
Electricity price	-0.008	-0.002	-0.000	0.006	0.005
Distribution price	-0.058***	-0.004	0.024***	0.032***	0.001
Area (10m^2)	-0.028***	-0.003***	0.025***	0.005***	0.001***
HDD	-0.040**	0.011	0.025	0.017*	-0.014
Material: stone	-0.063***	0.019**	0.045***	-0.009	0.008
Type: element	-0.021***	0.059***	-0.001	-0.036***	0.001
Urban location	0.122***	0.046***	-0.077***	-0.088***	0.001
Av. property price (1000€)	0.001	0.003***	0.001	-0.005***	-0.000
Net income (1000€)	-0.000**	-0.000*	0.001***	-0.001***	-0.000
Debt to income-ratio	0.000	0.001***	0.002***	-0.002***	-0.000
House ownership	0.047***	0.006	-0.064***	0.012***	-0.004
Apartment ownership	0.015*	-0.012*	0.011	-0.005	-0.008***
Age	0.002***	-0.001***	-0.001***	-0.000**	-0.000***
Children	-0.013	-0.012*	0.014*	0.005	0.003
Family size	0.014***	0.005*	-0.010***	-0.005***	-0.003*
Education: undergraduate	-0.034***	0.007	0.035***	-0.005	0.001
Education: graduate	-0.049***	0.012**	0.064***	-0.019***	-0.005
Share in estimation sample	0.41	0.16	0.31	0.07	0.04

Notes: The table presents average marginal effects from a logit estimation of heating technology choice based on equation 1. The estimation includes year and location-by-region fixed effects. The underlying coefficients are reported in Appendix B. Significance levels: * 10%, ** 5%, *** 1%.

Table 6: Elasticity of electric heating demand with respect to distribution price.

	Median	Mean	Std.Dev.	95 % Conf.Int. Lower	Upper	p-value
3 c/kWh	-0.37	-0.37	0.08	-0.54	-0.21	0.000
4 c/kWh	-0.63	-0.65	0.19	-0.97	-0.34	0.000
6 c/kWh	-1.57	-1.69	0.58	-2.82	-0.56	0.003

Notes: The table reports the elasticity of electric heating technology demand with respect to the distribution price of electricity. The elasticity measures are based on predicted market shares from a logit model of heating choice, reported in Appendix B. The values are based on a bootstrap over 10 000 draws of the price coefficients. The values are calculated for three price levels corresponding to the low, average and high prices observed in the estimation sample.

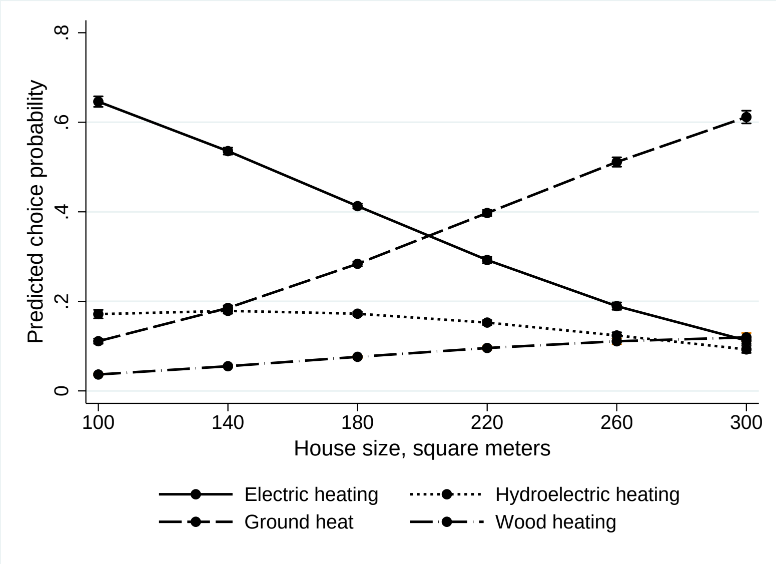

Figure 4: Choice probability and house size.

Notes: The figure illustrates how the predicted choice probability for selected technologies varies with house size. The 95% confidence interval of the prediction is represented by vertical lines. The probability is based on the heating technology choice estimation reported in Table 5 and Appendix B.

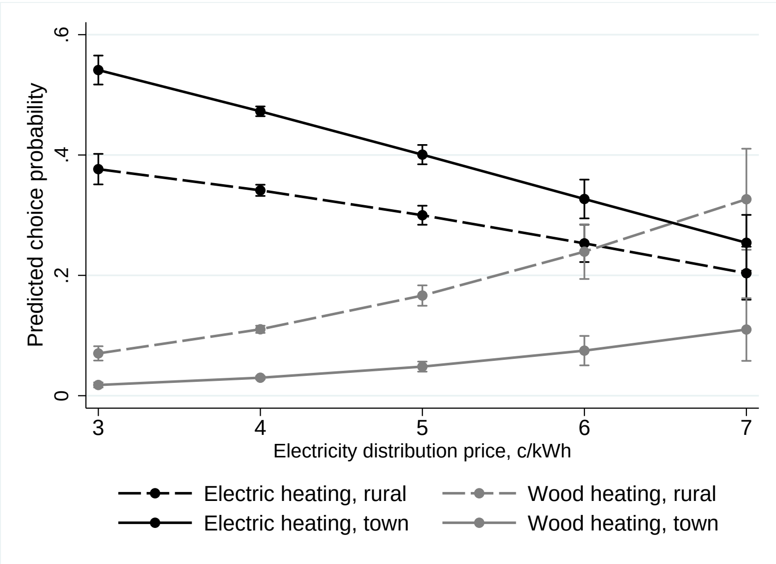

Figure 5: Choice probability and electricity distribution price.

Notes: The figure illustrates how the predicted choice probability for electric heating and wood varies with the 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 5 and Appendix B. The vertical lines indicate the 95% confidence interval of the prediction.

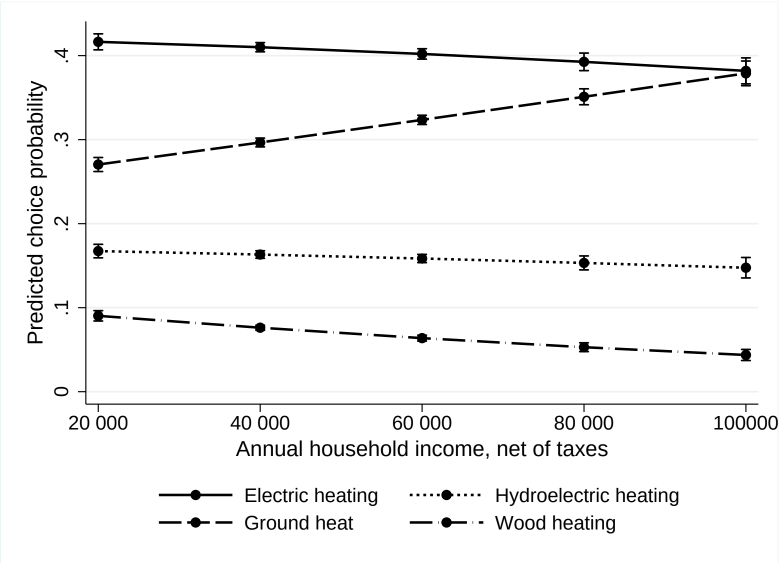

Figure 6: Choice probability and household income.

Notes: The figure illustrates how the predicted 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 5 and Appendix B. The vertical lines indicate the 95% confidence interval of the prediction.

Table 7: Predicted substitution across technologies due to increases in electricity costs

	Oil	Electric	Hydroelectric	Ground heat	Wood	Other
2006	2	-16	0	4	10	0
2007	2	-15	-1	5	9	0
2008	1	-11	-1	4	7	0
2009	0	-9	0	5	4	0
2010	1	-12	0	7	4	0
2011	0	-9	-1	7	3	0
Total	6	-72	-3	32	37	0

Notes: The table presents predicted changes in the number of houses installing each technology due to a one percent increase in the distribution costs of electricity. The initial price level is set at 4 c/kWh, which corresponds to the average in the sample. The number of houses is inferred from market shares predicted by the choice model reported in Table 5 and Appendix B.

climate and in the number of new houses built, the individual predictions are aggregated to the level of regions. Average house size by technology and region, as well as engineering estimates of heating energy needs are used to construct a measure of total heating energy demand for the houses in the sample. The calculations are detailed in Appendix D. 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 due to a one percent increase in electricity distribution prices is 1494 MWh.[22] The final impact on total electricity consumption and on emissions will depend on which technology replaces electricity. Allocating this amount according to the substitution patterns documented in Table 7 results in 128 MWh going to oil heating, 607 MWh to ground heat, 737 MWh to wood and 22 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 202 MWh.[23] The category "other" is undefined, but is likely to mostly include other heat pump technologies which also operate on electricity. The National Building Code uses an efficiency of 1.5 for such technologies, and this same value is assumed here. This results in an electricity demand of 15 MWh. Therefore, the total annual reduction in heating electricity demand due to a one percent price increase in the distribution price is 1277 MWh. Given a total estimated heating electricity demand of 450 GWh at the distribution price of 4 c/kWh, this translates into an elasticity of -0.28.

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, due to an increase in the electricity tax faced by consumers. The impact of this price increase can approximated 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 8. Due to the increase in electricity prices from 2010 to 2011, the number of electrically heated homes is reduced by 278. Over half of these houses switch to ground heat. Using the assumptions on house size and average heating energy needs, the second column of Table 8 shows the resulting change in the amount of energy to purchase by fuel. The total amount of heating energy to reallocate is 4767 MWh. Of this, 1778 MWh are savings in purchased energy due to the use heat pumps. A further 1808 MWh are allocated to wood. This amounts to 3586 MWh being shifted to renewable energy sources. The final column shows the impact on emissions.

These are small amounts when compared to the annual CO_2 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

[22]The average house-specific heat consumption in the data is 22 189 kWh.

[23]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 around 4 (personal communication with Juha Jokisalo from Aalto University School of Technology).

Table 8: Estimated impact of 2011 electricity price increase on heating energy demand and emissions

	No. of houses	Energy demand (MWh)	Electricity demand (MWh)	Emissions (tCO2)
Oil	10	176	0	46
Electric	-240	-4115	-4115	-864
Hydroelectric	-38	-652	-652	-137
Ground heat	149	850	850	179
Wood	105	1808	0	713
Other	14	155	155	33
Total	0	-1778	-3762	-30

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 house quantities are inferred from market shares predicted by the model of technology choice reported in Table 5 and Appendix B. The heat and emission values are based on average house sizes, engineering assumptions of heating energy demand and on emission factors detailed in Appendix D.

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.[24]

4.4 Additional results and robustness checks

Additional results and robustness checks are presented in Appendix C. Section C.1 examines determinants of house characteristics other than heating. These include house size, building material and building method. These characteristics are strongly correlated with each other and with many of the household characteristics. In addition, house size and building material are negatively correlated with electricity distribution prices. These results emphasize the importance of including observable heterogeneity in the technology choice estimation. This is illustrated in section C.2, which reports how the estimates of electricity price sensitivity change as household and house characteristics are incorporated into the estimation. When only time and location fixed effects are included, the impact of the distribution price is biased downwards. Adding observable heterogeneity to the estimation improves the precision of the estimated price coefficients and increases their magnitude.

Section C.3 presents results using alternative definitions for electricity prices. These include: using lags of distribution and retail prices in estimation, defining the distribution

[24]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.

price as an average over three preceding years, and using the minimum retail price available to each household. These result in small changes to the estimated effect of the distribution price, but the differences in results are not statistically significant.

5 Conclusions and policy implications

This paper studies how sensitive households' energy technology investments are to energy prices, and how socio-demographic variables relate to investment decisions. The analysis makes use of individual-level registry data combined with detailed information on costs of electricity at the local level.

The results give rise to two main findings. First, households are highly sensitive to energy costs at the investment stage. Home builders substitute away from electric heating as electricity prices rise, resulting in increased installations of wood heating and ground source heat pumps. The elasticity of demand for electric heating technology with respect to the electricity price is estimated to be -0.65 at the average price level. This result implies that increasing energy prices, for example through taxation, will shift demand towards technologies that are less dependent on energy purchased from the market. These include technologies such as heat pumps and solar panels, which make use of renewable, free energy sources.

Second, the results on certain household characteristics imply that investment decisions are influenced by financial and informational issues, which can constitute barriers to investment. Investments into energy efficiency or renewable energy sources are often characterised by high investment costs. In the context of heating technologies, this applies to ground source heat pumps which are very expensive to install but inexpensive to operate due to the utilisation of geothermal heat. The estimation results show that, conditional on education and age, the probability of installing ground heat rises steadily with income. This implies that credit constraints influence investment decisions.

Furthermore, ground heat is strongly preferred by highly educated home builders, who may be more able to fully evaluate the financial and technical aspects of the investments. In contrast, builders who already are home owners are more likely to install a conventional technology such as electric or wood heating. This may be due to the ease of choosing a technology that is already familiar. These results highlight the importance of clear, reliable information on the costs and attributes of different technologies at the point of making the investment decision.

Overall, the findings of this study indicate that households characterised by low disposable income and low education potentially lack the funds and information necessary to make the optimal technology choice. Instruments that aid in financing as well as targeted information provision could therefore be useful if higher investment levels are desired. Heating technology investments are similar to other energy-related investments in buildings in that these investments typically involve high initial costs, savings that accrue over a long lifetime and technological details which home owners may perceive as difficult to understand. These findings are therefore likely to carry over to other investments related to cooling, insulation or energy-efficiency improving retrofits. Such investments are timely for a large share of the stock of residential houses in Finland and elsewhere in Europe.

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A Distribution prices

This appendix provides additional information and 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, including the price set by each DSO for each customer group and information on the technical characteristics of DSOs. The customer groups analysed here include households with low electricity consumption, typically in apartments (annual load 2000 kWh), and households in electrically heated detached houses (annual load 18 000 kWh). The latter price is used in the technology choice estimations.

Figure 7 shows the differences in average price levels and the observed range of prices by DSO. The prices refer to the price for detached houses, and exclude taxes. The circle marks the average price level of each DSO, and the vertical lines mark the range of prices observed over time for each DSO. This figure illustrates that the mean price levels are distinctly different across distribution areas. Also, prices change very little for most DSOs, despite the rather lengthy time period of 11 years summarized in the figure.

Distribution prices are a function of the technical characteristics of DSOs, which in turn are determined by the type of area the distributor is serving. For example, urban areas are characterised by dense connections to the grid, large values of transmitted energy and a higher share of underground cables. Table 9 illustrates how these characteristics relate to distribution prices. The left panel shows results from an OLS regression of tax-free distribution prices on technical variables. The right panel shows summary statistics of these variables. The estimation also includes indicators for regulatory periods. These are the time periods over which pricing is monitored and regulatory parameters may be changed. For ease of presentation, some of the variables with very large numerical values have been rescaled for estimation. The summary statistics are shown in the original scale.

The results indicate that prices tend to be lower in distribution areas with dense connections to the grid. 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. The coefficients imply that prices are 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 very weakly related to prices, however higher prices are associated with areas where customers experience more power cuts. This is measured as hours of disturbance annually, and the first

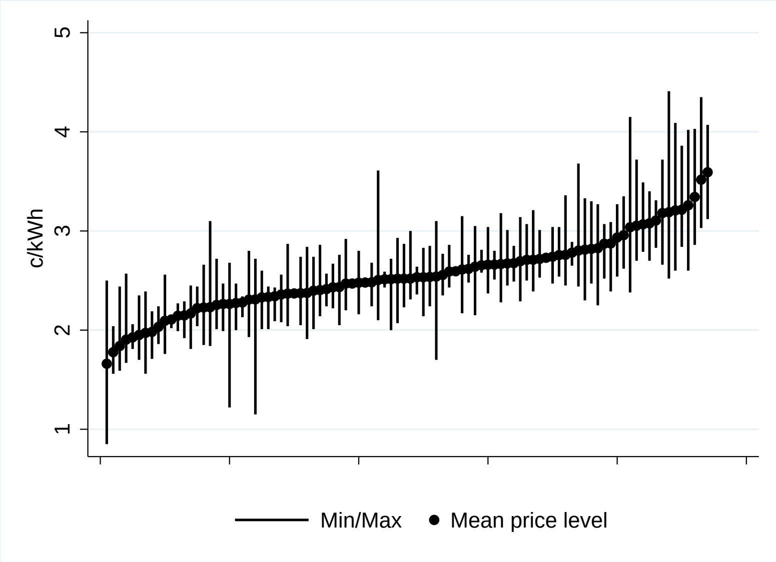

Figure 7: Average price and observed price range by DSO.

Notes: The figure shows the average price level (black circle) and the range of price observed over 2003-2014 for each distribution system operator.

lag is used in estimation. 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, however this result only applies to the price for customers in detached houses.

B Estimation results

Table 10 presents the coefficients from the technology choice estimation, based on equation 1. Standard errors are reported in parentheses. The base technology is electric heating, hence the coefficients measure the impact on utility *relative* to electric heating.

C Additional results and robustness checks

C.1 Determinants of house characteristics

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 11 presents results of OLS regressions of these variables on house and household characteristics, as well as year and region fixed effects. The set of included 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,

Table 9: Determinants of distribution prices

	OLS results		Summary statistics		
	Apartments	Houses	Mean	Min	Max
Connections per km	-0.098***	-0.050***	8.79	4.29	61.43
	(0.015)	(0.009)			
100 GWh, 0.4kv grid	-0.220***	-0.066***	417	1.20	5851
	(0.028)	(0.011)			
100 GWh, 1-70kv grid	0.205***	0.092***	135	0	1871
	(0.038)	(0.015)			
Ground cables (%)	-0.007***	0.000	43.49	0.01	100
	(0.001)	(0.001)			
Transformers (unit: 1000)	0.328***	0.125***	1533	0	24047
	(0.036)	(0.015)			
Power cuts (h), 1. lag	0.019***	0.007***	2.98	0	64.78
	(0.005)	(0.003)			
Personnel (unit: 10)	0.016	-0.024***	30.44	0	439
	(0.016)	(0.007)			
Time: 2008-2012	0.316***	0.080***			
	(0.065)	(0.030)			
Time: 2013-2014	0.803***	0.260***			
	(0.097)	(0.045)			
Constant	5.504***	2.841***			
R^2	0.43	0.30			
Number of observations: 761					

Notes: The table presents results from an OLS regression of tax-free distribution prices on DSO characteristics and indicators for regulatory time periods. The last columns show summary statistics on the variables used in estimation, in original numerical values. 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 rescaled in estimation to units of 100 GWh. Ground cables measures the share of underground cables. Transformers refers to the number of low-voltage transformers, rescaled in estimation to units of 1000 transformers. Power cuts are defined as the total number of hours a customer has been cut off from the grid during a year. The first lag of this variable is used. Personnel measures the number of people working in distribution operations, rescaled in estimation to units of 10. Significance levels: *** 1%, ** 5%, * 10%.

Table 10: Coefficient estimates from a logit estimation of heating technology choice

	Oil	Hydroelectric	Ground heat	Wood	Other
Electricity price	-0.030	0.009	0.025	0.112*	0.131*
	(0.169)	(0.045)	(0.039)	(0.064)	(0.079)
Distribution price	0.649**	0.009	0.154***	0.595***	-0.002
	(0.254)	(0.069)	(0.057)	(0.084)	(0.117)
Interaction of distribution price with urban location					
	0.291	0.200***	0.228***	0.107	0.321***
	(0.245)	(0.063)	(0.052)	(0.094)	(0.107)
Area ($10m^2$)	0.184***	0.065***	0.192***	0.166***	0.115***
	(0.011)	(0.004)	(0.004)	(0.005)	(0.006)
HDD	0.106	0.185	0.232**	0.394**	-0.187
	(0.429)	(0.130)	(0.116)	(0.156)	(0.245)
Material: stone	0.247	0.318***	0.385***	0.065	0.374***
	(0.215)	(0.075)	(0.062)	(0.111)	(0.109)
Type: element	-0.276**	0.439***	0.047	-0.523***	0.076
	(0.132)	(0.036)	(0.032)	(0.052)	(0.060)
Av. sale price	-0.033	0.015 **	-0.002	-0.083***	-0.007
	(0.023)	(0.006)	(0.006)	(0.009)	(0.011)
Net income (1000€)	-0.001	0.000	0.007***	-0.008***	-0.000
	(0.003)	(0.001)	(0.001)	(0.002)	(0.001)
Debt to income-ratio	0.005*	0.004	0.005*	-0.039***	-0.001
	(0.003)	(0.003)	(0.002)	(0.009)	(0.007)
Unemployment benefit	-0.046	-0.046	-0.048	0.135**	-0.061
	(0.158)	(0.043)	(0.038)	(0.057)	(0.072)
Childcare benefit	-0.253	0.012	0.054	0.039	-0.008
	(0.171)	(0.044)	(0.039)	(0.064)	(0.074)
House ownership	0.293**	-0.113***	-0.410***	0.012	-0.238***
	(0.147)	(0.039)	(0.035)	(0.055)	(0.065)
Apartment ownership	-0.124	-0.118**	-0.002	-0.118	-0.249***
	(0.225)	(0.056)	(0.048)	(0.088)	(0.094)
Age	0.009	-0.013***	-0.010***	-0.012***	-0.016***
	(0.006)	(0.002)	(0.002)	(0.003)	(0.003)
Children	0.275	-0.035	0.101**	0.133*	0.117
	(0.198)	(0.056)	(0.050)	(0.076)	(0.094)
Family size	-0.153**	-0.011	-0.087***	-0.127***	-0.104***
	(0.076)	(0.022)	(0.019)	(0.029)	(0.037)
Education: undergraduate	-0.330*	0.149***	0.248***	-0.037	0.128*
	(0.180)	(0.044)	(0.039)	(0.063)	(0.072)
Education: graduate	-0.207	0.237***	0.400***	-0.155*	0.058
	(0.201)	(0.053)	(0.046)	(0.088)	(0.091)

Estimation includes year and location-by-region fixed effects
Number of observations: 30 777
Log likelihood: -37 212, Log likelihood, constants only: -42 823

Notes: The table presents results from a 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 location-by-region. The location is defined by an indicator taking value 1 if a town plan prevails at the building site. The existence of a town plan indicates an urban environment. The region refers to one of 18 administrative regions. Significance levels: * 10%, ** 5%, *** 1%

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 are related to building characteristics are income, education, age and whether 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. House size and building material are also strongly related to heating degree days and regional average house prices. Both these variables capture aspects of building location. 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. This especially important in non-linear models, where omitted variables will influence coefficient estimates even if they are not correlated with the included variables (Greene, 2008; Mood, 2010)

C.2 Observable heterogeneity and price sensitivity

This section illustrates how inclusion of individual-level observable heterogeneity impacts the estimated marginal effects of electricity prices on technology choice. This analysis is done using a linear probability model, as in this context coefficients can be compared across alternative model specifications. In non-linear discrete choice models this is not the case.[25]. Furthermore, using a linear probability model allows investigating how the portion of explained variance changes when more variables are added to the estimation.

Table 12 includes coefficients from a set of OLS regressions. Each column stands for a distinct dependent variable, which equals 1 if the respective technology is chosen. Panel A shows the marginal effects of electricity retail and distribution prices on the choice probability for each technology when only aggregate-level variables are included as controls. These variables are: average property prices by municipality type in each region and indicators for region, year and urban location.

Panel B illustrates how adding observable house characteristics to the estimation changes the results. The distribution price is now estimated to have a stronger effect on choice of electric heating and ground heat, while the result on the retail price does

[25]In logit models, the coefficients measure the effect of the observed variables relative to the variance of unobserved factors (Train, 2009). Because the unobserved portion of utility changes when the sample changes or the included variables change, coefficients across different specifications or samples cannot directly be compared (see also Mood, 2010). Average marginal effects are less effected by unobserved heterogeneity.

Table 11: Determinants of house characteristics

Dependent variable	Area ($10m^2$)	Material:stone	Element build
Net income (€1000)	0.041***	0.001***	0.001***
Debt to income	0.001	0.000***	0.000
Childcare benefits	0.153**	-0.005	0.013*
Unemployment benefits	-0.080	0.002	-0.026***
Age (10 years)	-0.022***	0.000***	-0.002***
Undergraduate degree	0.693***	0.004	0.023***
Graduate degree	1.300***	0.021***	0.032***
Children	-0.059	0.006	0.012
Family size	0.951***	-0.007***	-0.000
Own house	-0.546***	-0.008**	0.039***
Own apartment	0.280***	0.010*	-0.006
Town plan	-0.536***	0.034***	0.065***
HDD	-1.582***	-0.018**	0.023
Mean house price (€10 000)	0.100***	0.004***	0.001
Material:stone	4.907***		-0.295***
Element build	-0.994***	-0.084***	
Area		0.013***	-0.009***
Electricity price	0.089	0.003	0.004
Distribution price	-0.281***	-0.008*	0.008
Constant	20.942***	-0.123**	0.535***
R^2	0.23	0.16	0.07
Number of observations: 30 777			

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. All specifications include annual time fixed effects and location fixed effects at region-level. Significance levels: *** 1%, ** 5%, * 10%.

not change. There is also a notable increase in the R-squared for these two technologies, indicating that house characteristics capture an important share of the variance in technology choice.

Panel C displays the results when observable heterogeneity is included in the form of household characteristics. This has a similar effect as the inclusion of building characteristics. However, the R-squared increases much less, indicating that though most household observables are strongly statistically significant determinants of technology choice, they don't have as much explanatory power as house characteristics do.

Finally, panel D shows the marginal effects of electricity prices on the technology choice when all observable heterogeneity is included in the estimation. The results on the retail price are not affected, but impact of the distribution price is further increased in magnitude for the two main technologies: electric heating and ground heat. The marginal effects of electricity prices on technology choice are almost exactly identical to the average marginal effects obtained from the logit estimation.

These comparisons illustrate the importance of including consumer heterogeneity in the estimation of sensitivity to energy costs. If heterogeneity is not accounted for, the estimated impacts of costs are downward biased. This issue has been discussed for example in Bento, Li and Roth (2012) and Grigolon, Reynaert and Verboven (2015). Furthermore, the comparison of alternative specifications reveals that house characteristics are more important in explaining technology choice than household characteristics.

C.3 Alternative definitions of electricity prices

This appendix documents results when alternative definitions of electricity prices are used in the estimation of heating technology choice. These are to be compared to the base specification reported in Table 5 and Table 10 of Appendix B. An identical specification is used in all robustness checks. Overall, these alternative price definitions cause changes in the estimated effect of the distribution price on heating choice, but the differences compared to the base specification are not statistically significant.

Panel A of Table 13 displays the average marginal effects of the retail and distribution prices when first lags of these variables are used. The retail price is now a statistically significant determinant of the choice of electric heating and wood. The results on the distribution price are slightly lower in magnitude. Because this way of defining the prices drops one year of data from estimation, the estimation sample now consists of 23 250 observations.

Panel B reports results when the distribution price is defined as an average over the preceding three years. The retail price is defined in levels. Because distribution prices are available from 2003 onwards, this specification can be estimated on the same sample as the base specification, using years 2006-2011. The impact of the distribution price is now larger in magnitude, but also the standard errors increase.

Panel C shows marginal effects when the minimum available retail price is assigned to each household. This means that the retail price is defined as the price of the cheapest standard contract offered nationwide, unless the local electricity retailer offers a lower price to customers within the local distribution network. In this case the local price

Table 12: Marginal effects from alternative model specifications

	Oil	Electric	Hydroelectric	Ground	Wood	Other
Panel A: No observable heterogeneity						
Retail price	-0.000	-0.008	-0.001	-0.001	0.006*	0.004
Distribution price	0.004**	-0.035***	-0.001	0.000	0.030***	0.001
R2	0.00	0.06	0.02	0.05	0.06	0.01
Panel B: Including house characteristics						
Retail price	-0.000	-0.006	-0.001	-0.003	0.006	0.004
Distribution price	0.004***	-0.051***	-0.004	0.016**	0.033***	0.001
R2	0.01	0.15	0.03	0.16	0.06	0.01
Panel C: Including household characteristics						
Retail price	-0.000	-0.011*	-0.001	0.001	0.006*	0.004
Distribution price	0.004**	-0.044***	-0.003	0.01	0.029***	0.001
R2	0.01	0.09	0.02	0.09	0.07	0.01
Panel D: Including house and household characteristics						
Retail price	-0.000	-0.008	-0.000	-0.001	0.006*	0.004
Distribution price	0.004***	-0.054***	-0.004	0.022***	0.031***	0.001
R2	0.01	0.16	0.03	0.18	0.08	0.01
Number of observations: 30 777						

Notes: The table presents coefficients from a set of OLS regressions, where the dependent variable is the choice of each alternative technology. All specifications include average regional property prices, year effects and location-by-region fixed effects. The included house characteristics are: house size, building material (=1 if stone), building method (=1 if elements) and heating degree days. The included household characteristics are: household net income, debt-to-income ratio, an indicator for unemployment benefits, an indicator for childcare benefits, indicators for current dwelling ownership and type (own detached house, own apartment), age, indicators for education (graduate, undergraduate), an indicator for the presence of children, and family size. Significance levels: * 10%, ** 5%, *** 1%

is used. This significantly reduces the variance in retail prices: most observations are now assigned a common, rather low retail price. The variance that remains originates from observations of houses that are built in areas where a very low price is available to local customers. These locations are often found in less-populated municipalities where a small company acts as the distribution system operator and local default retailer.

This change in the definition of retail prices does not change the results on the distribution price. The average marginal effect of the retail price is now stronger in magnitude for wood and the category "other", yet not statistically significant. However, the effect of the retail price on the choice of ground heat is now estimated to be very strongly negative and statistically significant. This is a counter-intuitive result. Yet, it is based on very few observations and limited variance at the low end of the retail price distribution. The result is therefore not representative of the average effect in the whole population.

In summary, the results on the distribution price are robust to different ways of defining the electricity prices. In contrast, the results on the retail price are more sensitive and drawing conclusions from these varying results is not straightforward. Analysing the importance of the retail price for decision-making would require knowledge on the price and type of contract the households have chosen, but such data are not currently available.

D Assumptions for calculating heating energy demand and emissions

To calculate estimates of average heating energy demand for the stock of new houses, 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 number of square meters to heat 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 for more details). The values are illustrated in Figure 8, 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 CO2 emissions are based on emission factors reported in table 14. The values for electricity are taken from Saari et al. (2010) for 2006-2008 and for 2009-2011 the value is taken from Motiva's instructions for calculation of CO2-emissions resulting from heating of buildings (Motiva 2012)[26]. Emissions for oil heating are also based on

[26] Motiva is a government-owned company responsible for producing and disseminating information related to energy efficiency to consumers and companies.

Table 13: Average marginal effects of alternative price definitions

	Oil	Electric	Hydroelectric	Ground	Wood	Other
Panel A: First lags of prices						
Retail price	-0.001	-0.016*	0.001	-0.005	0.011**	0.010**
Distribution price	0.005***	-0.048***	-0.003	0.021**	0.024***	-0.000
Average LL: -1.21						
Panel B: Distribution price average over 3 preceding years						
Retail price	-0.000	-0.006	-0.002	-0.002	0.005	0.005
Distribution price	0.008***	-0.062***	-0.001	0.018*	0.036***	0.001
Average LL: -1.20						
Panel C: Minimum retail price available						
Retail price	0.001	0.006	0.005	-0.089**	0.029	0.048
Distribution price	0.005***	-0.059***	-0.004	0.025***	0.032***	0.001
Average LL: -1.20						
All specifications include year effects and location-by-region effects.						

Notes: The table presents marginal effects from a multinomial logit estimation of heating technology choice. The estimation includes observable house and household characteristics, year effects and location-by-region effects. Significance levels: * 10%, ** 5%, *** 1%

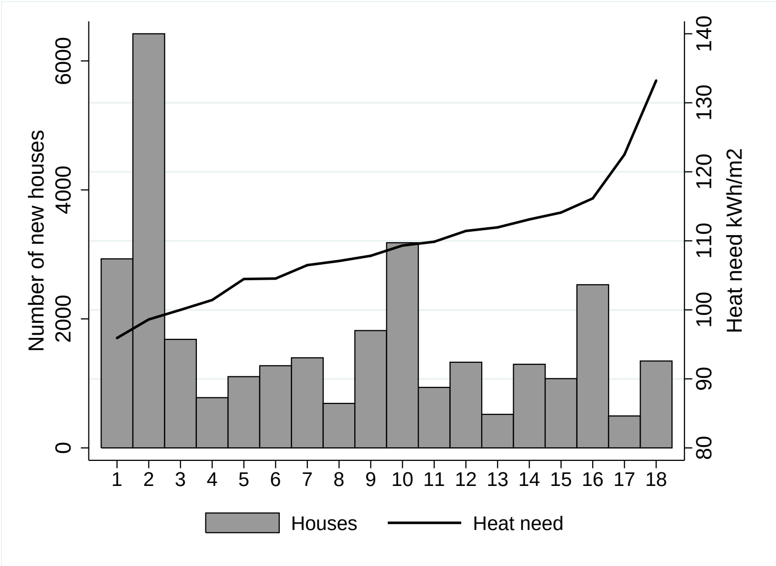

Figure 8: Number of observations and unit heating energy demand by region.

Notes: The figure illustrates in bars the number of observations in the estimation sample by region, read on the left-hand axis. The heating energy needs of an average house, expressed in kWh per square meter in each region, are read on the right-hand axis. These differences result from temperature differences across the country. The 18 regions are ordered by climate from warmest to coldest.

Motiva (2012), and the values for wood are from Statistics Finland's fuel classification (2016). To convert the emission factor for wood into units of Kg/MWh, note that 1 MWh equals 3.6 GJ.

Table 14: 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. The values are taken from Motiva (2012), Saari et al. (2010) and Statistics Finland (2016).