Danish Energy Agency

Households' Choices of Heating Technologies[1]

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Abstract

In this paper, we propose a simple model of households' choices of heating technologies based on data from a survey of households.

The main focus is to estimate how price sensitive the choices of heating technologies are. We also estimate the households' valuation of non-monetary (non-measured) technology specific characteristics and households' tendency to choose the technology already installed – a status-quo-effect. A feature of the model is that households choose one "central heating" technology as well as none, one or more non-central heating technologies (supplementary heating).

Since we only have price data for a single year and heating data for two years and since the number of observations is small, the results are uncertain and different estimation models give different results. An example may illustrate the range in results: Suppose the annual costs of a heating technology are reduced by 5.000 DKK (a third or a quarter of a typical annual heating bill). With one of the estimated models, this will increase the probability for a household to switch to this technology by 0.4 percent within a two year period. In another model, the effect is 3.5 percent[2].

The estimated models can be used to forecast future heating in existing houses and to evaluate the effect of changes in heating costs.

[1] A version of the paper has been presented at the "Environmental Economic Conference" August 2017 arranged by the Danish Economic Council. Please, send comments to Martin Rasmussen, mra@ens.dk.

[2] The calculations are only correct under certain conditions, see the main text.

1. Introduction

During the last 30 years heating has become more climate-friendly. Oil has been replaced with district heating and natural gas, and production of district heating has become cleaner. Currently, oil boilers are replaced with heat pumps or biomass heating in many houses.

It is, however, still important that heating continues to become steadily more climate friendly and design of policies should support this development. Models of households' choices of heating technology could back up such design. In this paper, we propose a model that describes the choice of heating technology by households living in single family houses as a result of the costs of various heating technologies.

Empirically, the model is based on the results of a survey of households' heating technologies. Answers from 1.486 households living in single family houses describe the current heating technology and change in technology within the last two years. The survey data is combined with data on access to the district heating grid and to the natural gas grid, and with data on costs of heating.

Unfortunately, estimation of the price sensitivity is far from solid, because the data set has few observations and many variables are imprecise.

The model is used to forecast heating technologies for houses that exist today and to assess the effect of lower electricity prices.

Apparently there are few studies about the price effect on heating technology. Most likely, this is due to limitations in data. In some countries, e.g. Denmark, "engineering-type" models based on the assumption that households choose the cheapest heating are used.

2. Literature

There are few economic empirical studies on the choices of heating technology, presumably because good data are rarely available. Studies on car choices are much more common, presumably because data on car prices and gasoline price are more often available than investment costs for heating technologies and prices of some types of heating energy. Also, households' choices of heating is often more restricted and regulated than choices of cars, which will complicate traditional studies.

Below, some studies are reviewed.

Vaage (2000) models Norwegian households' choices between electrical panels, wood and oil in response to energy prices. The price sensitivity is identified via regional differences in energy prices. Vaage estimates use of energy in addition to choice of technology. As in this paper, Vaage's study is based on survey data (except for price information). As opposed to this paper, Vaage do not consider investment prices and use a static model. Vaage finds that the choice of technology is affected by prices (and so is the quantity of energy used). There is no comment in the paper about whether the price sensitivity is high or low, and the estimated parameter is not easily compared with the estimations in this paper.

Rouvinen and Matero (2013) set up an experimental choice model where 500 respondents are asked to choose between oil, district heating, wood pellets, wood, heat pumps and electrical panels in response to energy prices and investment costs. They estimate that the choice of heating technology is sensitive to prices, and also that convenience and emissions affect choices. The model is dynamic, because choice depends on current technology. Rouvinen and Matero find that "The choice modelling results emphasized the role of the investment cost as the main attribute affecting the decisions". Besides, Rouvinen and Matero estimate separate parameters for annual operating costs (including energy) and up-front investment costs. The parameter for annual costs is typically 5 to 10 times as large as the parameter for investment costs. If respondents have perfect foresight and operate under a number of other conditions, these factors parameter should approximate the life time for the investment. Hence, factors 5-10 could suggest that households are a bit short sighted.

Deckar and Menrad (2015) and Michelsen and Madlener (2012) are based on surveys with self-reported prices, which perhaps could cause bias due to ex post rationalization of price information. The latter paper is based on households who have received a subsidy, which might cause selection problems and biased responses. It is difficult to evaluate whether the studies find low or high price sensitivities. Finally, Braun (2010) estimates heating technology but without economic variables as determinant factors.

Often "engineering type" of models are used, by which I mean models that use technical and economic information – as econometric models do – but is based on the assumptions that households choose the technology with the lowest costs. The Danish Energy Agency uses this kind of model (a so-called TIMES model applied for Denmark). However, choices based solely on costs give rise to sudden "jumps" in technologies, and to overcome this problem choices are smoothed in the model used by the Danish Energy Agency. A description in Danish is found in the Danish Energy Agency (2017). Rather technical descriptions of the general TIMES model is found on the web site for IEA's "Energy Technology Systems Analysis Program", see IEA (2016).

A second type of models presumably often used is aggregated economic empirical models of the consumed quantity of various types of energy used for heating. For Denmark, the so called EMMA-model describes use of energy for heating. However, the type of energy used for heating is not estimated (The Danish Energy Agency (2010)).

3. Data

The paper is primarily based on two sets of data, a survey among households and a collection of data on energy prices, investment costs, and efficiencies for the heating technologies.

- The household survey

The Danish Energy Agency has carried out a survey among households to get general information on the type of technologies that are installed in households, on the use of various technologies, and on shifts in technologies, see The Danish Energy Agency (2018). The survey invitation was send to 11.150 households by email, December 2016-January 2017. Of these, 30.5 percent or 3.396 people responded of which 2.532

respondents lived in single family houses[3]. Some observations were excluded (see later), so 1.486 observations are used in this paper. Of these only 3.7 percent – 55 households – reported that they had changed central heating technology within the last two years. Households that replace a specific technology with a new installation of the same technology are not included in this figure. As will be clear later, households that change central heating technology are important for identification of the price sensitivity, and hence the empirical base for analysis of changes is very weak.

The central question used in this paper can be sketched as in table 1.

Table 1. Sketch of survey question

	Which types of technologies are installed now? *- tick off all installed technologies*	.. were installed two years ago?[1] *- tick off all installed technologies*
- District Heating		
- Natural gas		
- Oil		
- Heat pumps		
- Wood pellets		
- Wood stoves		
- Electric heating		
- Heat pumps (air-air)		
- Solar heating		
- Open fire stoves		

[1] If the family moved to the house less than two years ago, the question was "… were installed when you moved into the house".

The five first-mentioned technologies in table 1 are called central heating technologies. The next four technologies are called non-central heating technologies or supplementary technologies. A central heating technology heats water at one place in the building and distributes the hot water to radiators and hot water taps. Non-central heating technologies heat sections of a building and do not heat water for hot water taps. Open fire stoves are left out of the model because of limited use.

- Prices and efficiencies for technologies

For each of the nine technologies, data is collected energy prices, efficiency of technologies, and investment prices, cf. table 3.

Information on energy prices is obtained from various government data sources (see the notes to table 3), except for wood pellets and wood for wood stoves where no official data source exists. For these energy types, price information is collected from advertisements on the internet.

For efficiencies and investment prices, data is typically from the publications "Technology data for Energy Plants" by the Danish Energy Agency. The important exception is the efficiency for heat pumps where an alternative study of the efficiencies is the data source.

[3] In this paper, single family houses are detached dwellings, except farm houses or former farm houses, and semidetached or row houses that do not share heating installations with other dwellings.

Table 3. Efficiency, investment costs, energy price and capacities for heating technologies

	District heating	Gas	Heat pumps	Wood pellets	Oil	Wood stoves	Heat pumps (air-air)	Electrical panels	Solar heating
Efficiency (energy out/energy in)	0,98 (note 1)	0,97 (1)	2,7 (2)	0,82 (1)	0,92 (1)	0,65 (1)	5.1 (1)	1 (1)	na
Investment cost (DKK)	19504 (1)	28791 (1)	139313 (1)	63155 (1)	54796 (1)	23219 (1)	15789 (1)	26934 (1)	33435 (1)
Energy price (DKK/kWh)	0,70 (3)	0,65 (4)	1,81 (5)	0,49 (6)	0,95 (4)	0,47 (6)	1.81* (5)	1,81* (5)	0
Capacity (share total heating covered by the technology)						0.26 (1)	0.39 (1)	0.5 (1)	0.26 (1)

Sources and notes:

[1] Danish Energy Agency: "Technology data for Energy Plants", https://ens.dk/sites/ens.dk/files/Analyser/technology_catalogue_individual_heating_plants_energy_transport_aug16.pdf and updated versions of the data not yet published. For capacities, the figures in these sources are weighted averages of a percent for heating room, and 0 percent for heating water.

[2] Danish Energy Agency, see https://ens.dk/sites/ens.dk/files/Energibesparelser/9b_bilag_til_oekonomisk_analyse_0.pdf. Own calculations.

[3] Danish Energy Regulatory Authority, see http://energitilsynet.dk/varme/statistik/prisstatistik/udvidet-prisstatistik-pr-1-december-2016/ . Own calculations.

[4] Danish Energy Agency, Energistatistik 2015, see https://ens.dk/service/statistik-data-noegletal-og-kort/maanedlig-og-aarlig-energistatistik , see "Excel-fil til figurer", own calculations.

[5] Danish Energy Agency, see https://ens.dk/service/statistik-data-noegletal-og-kort/priser-paa-el-og-gas, see "Elpriser private forbrugere". Price for households with consumption above 4.000 kWh.

[6] Internet search, see dkbrænde.dk.

* There are two electricity prices for households, a low price for households that use electricity (panels or heat pumps) to cover at least half of their heating by electricity and a higher price for other households. 1.81 DKK is the low price and the high price is 2.30 DKK. The high price could be relevant for some households with heat pumps or electrical panels, but replacing this price will not change estimation results.

- Other data used

From registers we have information on households' access to district heating and gas.

4. Method

Results from the survey show that the pattern of technologies in households is complex:

1. Some households do not have (responds not to have) a central heating technology. No less than 823 and 994 of 2.532 households report no central heating currently or two years ago. These figures are not representative for the entire population of single family houses because the survey was stratified.
2. Many households, 59 percent, have supplementary heating technologies, and 33 percent of households have more than one supplementary heating.
3. Different types of non-central heating technologies seem to be complements rather than supplements. For example, the probability of having a wood stove is larger for a household with electric panels compared to households with no other non-central heating.

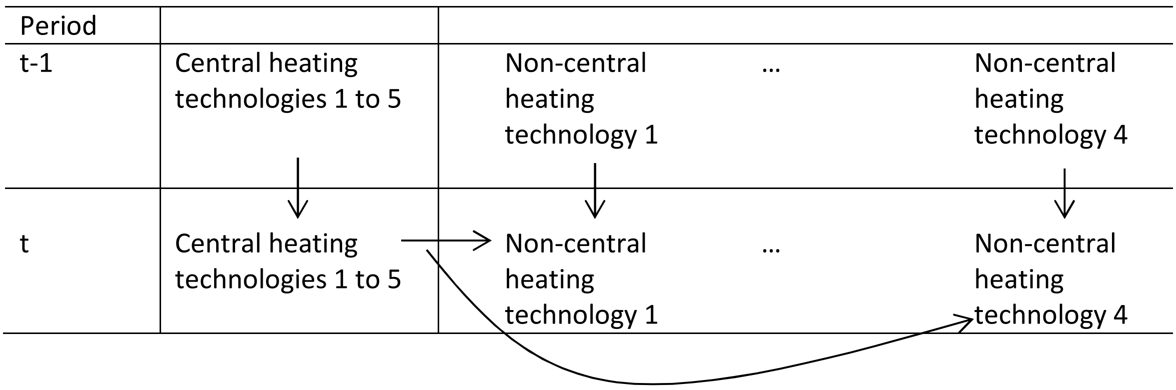
Households without central heating or with no information about access to the district heating or gas grid are left out of the model. This reduces the 2.532 households to 1.486.

One method is to define all relevant combinations of technologies and model households' choice of one of these combinations. But the total number of existing combinations is large, and this combination-method will be difficult to implement. Hence, we use a simple approach:

- Each household choose one central heating technology depending on the central technology they had last period, but independent of non-central heating technologies.
- Each household choose none, one or more non-central heating technologies, depending on the existing central heating system, and the non-central heating systems they already have installed.

Figure 1 aims to illustrate the simplifications of the "decision structure" of the model. In period t, households choose central heating technology depending on past central heating technology, but independent of non-central heating technologies. Each household choose exactly one from five central heating technologies. The choice of non-central heating technologies depends on past non-central heating and on central heating in the same period. Each of the four non-central heating technologies is considered a "0-1 choice" – this is a simple way to model that the non-central heating technologies appear not to be supplements.

Figure 1. Sketch of decision structure



We model the impact of costs in a simple way: Heating costs are equal to current annual cost plus annualized investment costs. If technology a is installed and is well functioning in a household, the annual heating costs for technology a consists only of current fuel costs. Current fuel costs for technology a are $\frac{p_a}{k_a}V$ where p_a is the fuel price for technology a, k_a is efficiency and V is the amount of energy necessary to give the required heating service (indoor temperature). V is measured as the energy in the output of the installed technology and is assumed to be 18.1 MWh per year. Annualized installation costs of technology a are I_a but are only relevant for technology decision if the technology is not already installed (if the cost is not sunk). A dummy, $d_{a\text{ not installed}}$, is 1 if technology a is not installed and investment costs for a is not sunk. Therefore, annual costs are

(1) $$c_a = \frac{p_a}{k_a}V + I_a d_{a\text{ not installed}}$$

We use this measure in the estimations. This means that households are assumed to consider only current values of prices as relevant for long term investment decisions. In a more advanced model, households might take expected price changes into account.

We use a multinomial logit model to estimate choice of central heating, and logit models for each non-central heating technology.

Households might have a tendency to stick to the technology they have had hitherto even if the installation needs to be replaced. To allow for this (and for empirical reasons, see below), we allow for a "status-quo"-term. We use the indicator variable $d_{a \text{ installed}}$ which has the value 1 if technology a is already installed and 0 otherwise. Hence $d_{a \text{ installed}} = 1 - d_{a \text{ not installed}}$.

The latent vector (utility) for *central heating-technologies* are (ignoring a random term)

(2) $$L_a = \beta_a + \beta_p \left(\frac{p_a}{k_a} V + I_a d_{a \text{ not installed}}\right) + \beta_q d_{a \text{ installed}}$$

where betas are parameters to be estimated. Parameter β_a is a constant that measures e.g. non-monetary "benefits" from technology a. Non-monetary "benefits" measure e.g. the disutility of having to handle wood pellets or the pleasure of using an environmental friendly type of heating. Off course, these parameters capture the effect of everything not specified in the estimation equations, including possibly wrongly specified costs. Hence, interpretation of the parameters is at best indicative. Parameter β_p is the price sensitivity and β_q is the status-quo parameter.

The probability to choose the central heating-technology a is

(3) $$P_a = \frac{e^{L_a}}{\sum_{a'=1}^{5} e^{L_{a'}}}$$

We take into account that district heating and natural gas are only accessible for households near the grids.

For non-central heating technologies, the choice depends on the type of central heating, because heat from the non-central heating replaces heat from the central heating. This means that households with expensive oil have a high incentive to choose supplementary heating. As mentioned, whereas each household is assumed to have exactly one central heating technology, a household may have none, one or more non-central heating technologies, and to simplify, we assume that households' take a 0-1 decision for each non-central heating technology. The utility for non-central heating technology a is as follows (variables explained afterwards)

(4) $$L_a = \beta_{s,a} + \beta_p \left(\left(\frac{p_a}{k_a} - \frac{p_{ch}}{k_{ch}} \right) s_a V + I_a d_{a \text{ not installed}} \right) + \beta_{s,q} d_{a \text{ installed}} + \sum_{ch=1}^{5} \beta_{s,ch} d_{ch}$$

The latent variable for non-central heating differs from central heating in two ways: Non-central heating is assumed to have a "capacity", $s_a \in (0,1)$ (see table 3), that measures the amount of heating that can be supplied from the non-central heating technology rather than from the existing central heating technology. The monetary benefit from non-central heating arise from the difference between the cost of heating for the non-central versus the central heating technology, $\left(\frac{p_a}{k_a} - \frac{p_{ch}}{k_{ch}}\right)$. Technology specific non-monetary benefits are $\beta_{s,a}$, and the status-quo effects are $\beta_{s,q}$. Finally, the non-monetary effect from central heating is captured in the last term where d_{ch} are 0-1-variables for occurrence of central heating of type ch.

The probabilities are

(5) $$P_a = \frac{e^{L_a}}{e^{L_a+1}}$$

- Identification

District heating is chosen as the reference for central heating technologies. Hence equation (2) is replaced with

(2') $$L_a = \beta_a - \beta_{DH} + \beta_p\left(\left(\frac{p_a}{k_a} - \frac{p_{DH}}{k_{DH}}\right)V + I_a d_{a\text{ not installed}} - I_{DH} d_{DH\text{ not installed}}\right)$$
$$+\beta_q(d_{a\text{ installed}} - d_{DH\text{ installed}})$$

For each of the non-central heating technologies, the implicit reference is no installation of the considered technology.

In (2') the central parameter β_p is identified only because of the dummy for last period's technology, $d_{a\text{ not installed}}$. Suppose this did not enter (2'), so that costs were $\left(\frac{p_a}{k_a} - \frac{p_{DH}}{k_{DH}}\right)V + I_a - I_{DH}$. Because we only have costs for one year (derived from the numbers in table 1), and therefore only one cost-number for each technology, costs differences could not be distinguished from non-monetary benefits for each technology, β_a, and hence β_p could not be estimated.[4] With $d_{a\text{ not installed}}$ there is variation in costs for each technology across households: Households with technology a have a "sunk-cost-advantage" to stick to a because they do not have to pay the investment costs for a. Therefore, the modelling of the costs explains why households rarely shift technology. However, we also directly allow for a status-quo variable in the model, and it is likely that parameters β_p and β_q are highly correlated.

The discussion motivates two variations of the "free" estimation of (2'): namely restrictions on β_a which will allow costs rather than non-monetary benefits a greater role in explaining the choice of central heating and restrictions on β_q which will allow costs a greater role in explaining why households stick to their central heating technology.

[4] To exemplify, put $c = \left(\frac{p_a}{k_a} - \frac{p_{DH}}{k_{DH}}\right)V + I_a - I_{DH}$ and consider the latent variable with two sets of parameter estimates, $\hat{\beta}_a, \hat{\beta}_p$ and $\widehat{\hat{\beta}_a} = \left[\hat{\beta}_a + c\right]$, $\widehat{\hat{\beta}_p} = \left[\hat{\beta}_p - 1\right]$. With the first set of parameters, the value of the latent variable is $\hat{\beta}_a + \hat{\beta}_p c$. But the same value is derived with the second set of parameters $\hat{\beta}_a + \hat{\beta}_p c = \left[\hat{\beta}_a + c\right] + \left[\hat{\beta}_p - 1\right] c = \widehat{\hat{\beta}_a} + \widehat{\hat{\beta}_p} c$. Hence the two sets of parameters gives the same probability to choose a. This is because there is perfect correlation between the set of technology indicators and the set of cost numbers.

For non-central heating there is an additional source of identification of the cost parameter, namely that costs depends upon the costs of the central heating. If non-central heating are much more prevalent in households with expensive central heating, the model could catch this effect via β_p.

- Discussion

The estimation model is very simple and could potentially be improved in a number of ways.

When do households decide heating technology? As the model is set up, households asses their heating technology and consider to replace existing technology each and every year. In some other models it is assumed that heating installations (and other durable goods) are well functioning for a certain number of years, a "lifetime". At the end of the lifetime, the installations break down, and replacements have to be decided. Such an approach is possibly more realistic. On the other hand, respondents in The Danish Energy Agency (2018) were asked why they changed heating installations, and the typical answer was not that the previous installation did not work. Rather they changed technology for economic reasons. Apparently this supports the assumption of yearly assessments. Nevertheless, the model would be improved by including variables that affects the probability to change heating, for example variables indicating the functioning of the existing installations. Such variables are unfortunately not available in this study.

Cross section: The model is a cross section study and is therefore open to the general criticism of cross section analysis, namely that individual, unobserved characteristics might correlate with explanatory variables. In this application, unobserved building or household characteristics might be correlated with heating costs. It appears however unclear why the general criticism should apply. Consider for example households that replace oil with an alternative. There might be unobserved building characteristics that affect the probability to replace oil (heat pumps are more efficient in new energy friendly houses), but these characteristics are presumably not correlated with heating prices, since there is only one number for the energy prices for each heating technology (new houses do not pay relative low or high prices for heat pumps). Furthermore, the lagged endogenous variable, i.e. previous heating technology, is included in the model and hence the model has a dynamic element that partly control for unobserved household characteristics. Nevertheless, the model could be improved if data for a number of years were available, particularly if relative prices changed significantly in these years.

5. Results

Table 2 shows results from five variations of the model defined by equations (1), (2')-(5). Model 1 is estimated without restrictions on the parameters. The parameters for "status quo" behaviour, β_q and $\beta_{s,q}$, are significant and the size of the parameters suggests a strong tendency to stick to the technology hitherto installed (i.e. replace an old oil boiler with a new one). The cost parameter is insignificant. Whether the value of cost parameter is "high" or "low" is discussed below.

Some of the parameters for non-central heating technologies' dependence on the central heating technology are insignificant and excluded in model 2-5. In model 2, the cost parameter is significant and numerically higher than in model 1. In model 3 the parameter for gas and oil is fixed to 0, i.e. it is assumed that non-monetary advantages and disadvantages are the same for district heating, gas and oil. This restriction is chosen because the three technologies are well known and require almost no effort to fuel and control. The cost parameter becomes larger than in model 2. If status-quo parameters are fixed at a less-high value, the numerical value of the cost parameter is increased, see model 4. Finally model 5 is equal to model 2 with the exception that households with district heating never switch to other central heating technologies and with the non-monetary parameter for natural gas as reference. This ad-hoc restriction is motivated by the observation that no households actually do so. The cost parameter is almost as in model 2.

With respect to the non-monetary benefits of central heating, far from all parameters are significantly different from zero (i.e. from benefits of district heating) and it is not tested whether parameters are significantly different pairwise. The most apparent result seems to be that there are greater benefits (i.e. lower disutilities) connected to heat pumps relative to oil. It should however be remembered that the parameters for non-monetary benefits are “black boxes” that capture everything not specified in the estimation equations.

Table 2. Estimation[#] results, five models

	Model 1		Model 2		Model 3		Model 4		Model 5*	
Parameter name[#]	Parame-ter value	Stan-dard devi-ation and p-value[#]	Par.	S.d.	Par.	S.d.	Par.	S.d.	Par.	S.d.
Non-monetary benefits, central heating										
β_{NG}	-1.453	0.382 ***	-1.407	0.370 ***			-1.766	0.406 ***	(0 ref)	
β_{HP}	-1.066	0.860 ~	-0.473	0.786 ~	2.135	0.502 ***	6.335	0.689 ***	1.321	0.945 ~
β_{WP}	-2.067	0.375 ***	-1.977	0.368 ***	-1.028	0.303 ***	-0.734	0.435 *	-0.308	0.401 ~
β_{Oil}	-3.099	0.802 ***	-2.608	0.696 ***			0.253	0.332 ~	-1.150	0.751 ~
Non-monetary benefits, supplementary heating										
$\beta_{s,WS}$	-3.988	0.289 ***	-3.687	0.246 ***	-3.299	0.210 ***	-1.209	0.109 ***	-3.679	0.304 ***
$\beta_{s,HP2}$	-4.549	0.248 ***	-4.345	0.212 ***	-4.524	0.203 ***	-4.353	0.162 ***	-4.147	0.263 ***
$\beta_{s,EL}$	-4.021	0.942 ***	-3.104	0.796 ***	-1.021	0.436 **	4.127	0.482 ***	-2.803	0.935 **
$\beta_{s,SH}$	-4.826	0.272 ***	-4.564	0.234 ***	-4.642	0.244 ***	-4.125	0.187 ***	-4.309	0.282 ***
Status-Quo										
β_q	4.217	0.544 ***	3.898	0.466 ***	2.679	0.193 ***	(3 fixed)	..	4.034	0.574 ***
$\beta_{s,q}$	6.213	0.266 ***	6.113	0.243 ***	5.737	0.204 ***	(3 fixed)	..	6.086	0.293 ***
Supplementary heating's dependence on central heating										
$\beta_{s,NG}$	-0.117	0.239 ~								
$\beta_{s,HP}$	0.467	0.314 ~								
$\beta_{s,WP}$	1.006	0.326 **								
$\beta_{s,Oil}$	0.673	0.308 **								
Price parameter										
β_p	-0.084	0.078 ~	-0.141	0.067 **	-0.325	0.034 ***	-0.712	0.047 ***	-0.151	0.080 *

[#] Subscript NG is short for heating with natural gas, HP=heat pumps appropriate for heating the entire house including hot water for domestic use, WP=heating with wood pellets, Oil=Oil heating, WS=wood stove, HP2= heat pumps appropriate for heating of (some) rooms, EL= electric panels, SH=solar heating. Subscript s is short for supplementary heating. In model 5, households are assumed not to consider alternatives, if district heating is installed.
The model is estimated with maximum likelihood, standard deviations are derived from the hessian and p-values by assuming normality of the parameter estimates, *** = p < 0.001, ** = p < 0.05, * p = < 0.1, ~ = p > 0.1.

To interpret the value of estimated parameters, we calculate a "money costs value" of non-cost parameters for central heating technologies. These are calculated by imagining the latent vectors with and without e.g. the technology specific parameter and the cost levels necessary to compensate for the technology parameter, that is $L_a^1 = \beta_a + \beta_p \text{Costs}^1$ and $L_a^2 = 0 + \beta_p \text{Costs}^2$ gives $L_a^1 = L_a^2 \Leftrightarrow \text{Costs}^1 - \text{Costs}^2 = -\frac{\beta_a}{\beta_p}$. The money values are shown in table 3. Hence, the money value of the NG-constant in model 1, β_{NG}, is -17.3 thousand DKK. In other words, it would affect the probability to choose natural gas equally much if β_{NG} vanished (were set to zero), as if the costs for natural gas were reduced by 17.300 DKK per year. This amount equals a typical annual energy bill. The money value of the status quo parameter is 50.000 DKK in model 1. This means that costs for energy has to be reduced by 50.000 DKK per year to compensate for the tendency to choose the same technology as in the previous period.

Table 3. Money values* of technology specific constants and status quo-parameters for central heating technologies, 1000 DKK per year.

		Model 1	Model 2	Model 3	Model 4	Model 5
Technology specific constant	NG	-17,3	-10,0		-2,5	
	HP	-12,7	-3,4	6,6	8,9	8,7
	WP	-24,6	-14,0	-3,2	-1,0	-2,0
	Oil	-36,9	-18,5		0,4	-7,6
Status-Quo		50,2	27,6	8,2	4,2	26,7

* See the main text above.

The calculations show that non-cost parameters are extremely large relative to the cost parameter in model 1 and that parameters depend strongly on the estimation chosen. For example the money value of the status quo parameter is reduced by a factor 0.08 from model 1 to 4. Unfortunately, there is no obvious way to determine the best model. Hence, the estimations do not give a precise estimate of the price sensitivity of the choice of technology. A way to interpret the results is that estimations give a range of parameter estimates, each consistent with data. The estimation problem is that it is difficult to disentangle whether households' strong tendency to stick to existing technology is because households aims to avoid new installation costs (an effect via the cost parameter) or they simply choose the technology they know (an effect via the status-quo parameter).

Another way to interpret the parameter values is to calculate the change in probability by changing costs or assuming that the technology specific parameter somehow becomes zero. Consider for example the probability to choose natural gas for a household with another type of installation. Suppose that this probability is 1 percent initially[5]. Using model 1, a 5.000 DKK reduction in the costs increases "NG-probability" by approximately 0.4 percent, from 1 to 1.4 percent. Removal of the "NG-parameter" increases probability by 1.5 percent, from 1 to 2.5 percent. With model 4, the same figures are an increase of 3.5 percent and an increase of 1.8 percent.

[5] The effects on the probability depend on the initial probability. This is seen by substituting equation (2) into (3) and calculating partial derivatives.

6. Conclusion

Survey data on households' historic choice of heating technology are used to estimate how much the cost of heating affects the choice of technology. Estimations give a range of cost sensitivities consistent with data.

The estimated models can be used to forecast future heating in existing houses and to evaluate the effect of changes in heating costs.

References

Frauke G. Braun (2010): "Determinants of households' space heating type: A discrete choice analysis for German households", Energy Policy 38 (2010) 5493–5503

The Danish Energy Agency [Energistyrelsen] (2010): "EMMA 10, Energi- og miljømodeller til ADAM", see https://ens.dk/sites/ens.dk/files/Analyser/emma10_energi-_og_miljoemodeller_til_adam_2010.pdf

The Danish Energy Agency [Energistyrelsen] (2015): "Baggrundsrapport til Basisfremskrivning 2017", see https://ens.dk/sites/ens.dk/files/Basisfremskrivning/baggrundsrapport_til_bf_2017.pdf page 108-109.

The Danish Energy Agency (2018): "Hvordan er landets boliger opvarmet og hvor tit skiftes opvarmningsform? – Resultater fra en spørgeskemaundersøgelse", see https://ens.dk/sites/ens.dk/files/Statistik/opvarmningsundersoegelsen.pdf

Thomas Decker, Klaus Menrad (2015): "House owners' perceptions and factors influencing their choice of specific heating systems in Germany", Energy Policy 85 (2015) 150–161

IEA (2016): "Documentation for the TIMES Model, Part I", see http://iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf

Carl Christian Michelsen, Reinhard Madlener (2012): "Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany", Energy Economics 34 (2012) 1271–1283

S. Rouvinen, J. Matero (2013): "Stated preferences of Finnish private homeowners for residential heating systems: A discrete choice experiment", biomass and bioenergy 57 (2013) 22-32

Kjell Vaage (2000): "Heating technology and energy use: a discrete - continuous choice approach to Norwegian household energy demand", Energy Economics 22, 2000, 649-666.