Consumer adoption of energy efficient technologies:

Evidence from a UK district heating scheme

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This paper is draft form and is circulating for discussion and comments only.

Abstract

This paper investigates the decision-making process leading residential consumers to adopt energy efficient technologies on the basis of financial and other considerations; contributing to the debate about the so-called efficiency paradox. We explore the validity of various theories of consumer behaviour using information on the decision to connect to the district-heating system, a greener alternative to the prevailing individual heating systems, using a quasi-experimental survey of 784 households conducted in 2014. The results suggest an internal discount rate of at least 30 per cent for homeowners, a signal that consumers undervalue future energy costs. In addition, we find the household's decision to be significantly and negatively affected by inattention and years of payback up to around 7 years. Our findings further suggest that neglecting inattention can lead to severe biases which cast doubt on the existence of the energy efficiency paradox. We believe these results help explain why consumers in the UK, particularly those on a low-income, are unlikely to invest in energy efficient technology.

Keywords: consumers, technology adoption, energy efficiency, district heating

JEL codes: D12, C35, O35, D91

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1. Introduction

In the wake of the historic 21st Conference of Parties (COP21) agreement on climate change, the immediate impact on the United Kingdom (UK) is still to some extent unclear. Nevertheless, one aspect *is* crystal clear: the fact that UK must continue towards the target of reducing carbon (CO_2) emissions by at least 80 per cent compared to 1990s levels by 2050, as legislated in the Climate Change Act (2008). But, improving energy efficiency in the domestic sector – which consumes around two fifths of the energy used in the UK and produces one third of total CO_2 emissions – remains a fundamental roadblock. Despite the availability of subsidies for residential consumers, such as the Energy Company Obligation, consumer uptake of seemingly profitable technologies has remained low. This highlights the possible existence of what the literature identifies as the 'energy efficiency paradox'.

Arguably, the so-called energy efficiency paradox[1], whereby consumers fail to adopt cost-effective, energy-efficient technologies over comparatively inefficient technologies, is a phenomenon which hinders the consumers' efforts to reduce energy consumption and CO_2 emissions (Jaffe and Stavins, 1994). Our paper contributes to this literature by investigating the very nature of the decision-making process of UK residential customers leading to the adoption of energy efficient technologies, which can support policy aimed at reducing energy consumption required for a more sustainable allocation of energy resources.

The energy efficiency paradox can be traced back to Hausman's seminal paper (1979) based on automobile purchases but applicable to other energy-using durables. The consumers' reluctance to adopt energy efficient technologies was considered by Hausman as internally consistent, according to traditional economic theory, if consumers discount too heavily the future financial benefits accrued from energy efficient consumption (Train, 1985). In this context, the energy efficiency paradox is said to exist if consumers' discount rates exceed on average the market interest rate[2]. Empirical evidence largely based on traditional consumer goods in the US, such as air

[1] It is important to note that this paper explores the 'energy efficiency paradox', not the 'energy efficiency gap', since the former relates to the privately optimal decision to install energy efficient technologies whereas the latter refers to the socially optimal decision (Gerarden, Newell and Stavins, 2015).

[2] For recent reviews on the debate surrounding the existence of the energy efficiency paradox and gap see Gillingham and Palmer (2014) and Gerarden et al. (2015).

conditioners, has supported this argument although with little consensus on the exact magnitude of the discount rate (Gillingham and Palmer, 2015).

More recently, economists have offered behavioural theories to explain the energy efficiency paradox, some of which, including heuristic decision-making, perceive consumer choices as systematically deviating from rational behaviour as dictated by classical theory. Numerous lab experiments have revealed that consumers often simplify complex tasks, for example using 'rules-of-thumb', which create biases in decision-making which do not conform to the general predictions derived using models of rational utility-maximising consumers with full information (Kahnemann and Tversky, 1974; Kahnemann, 2011). Adopting these quick-fire tactics therefore may lead to the choice of inefficient technologies over profitable alternatives (Kempton and Montgomery, 2011).

In a contrasting stream of literature, economists perceive (rational) inattention as a potential mechanism explaining the paradox. First and foremost, consumers are assumed to be rational agents. Attention is scarce and the process of collecting information is costly, therefore an agent engages in search if and only if the benefits are greater than costs (Reis, 2006). Therefore, some consumers' may choose not to partake in search activity in the energy efficiency market, since the expected discounted savings do not justify the costly effort of becoming fully informed (Sallee, 2014). As a result inattention can potentially exacerbate the energy efficiency paradox

Moreover, empirical evidence suggests consumers make cost inefficient decisions due to inattention and systematic biases in beliefs (Allcott, 2011). Allcott's paper highlights that consumers are not only inattentive to fuel costs but also implement heuristic methods to ease cognitive overload. Such behaviour becomes more apparent when placed within a complex decision-making scenario, such as calculating the cost difference between automobiles. Our paper further explores whether inattention and heuristic decision-making explains the energy efficiency paradox or if the classic economic model of decision-making would suffice.

Our evidence is based upon a survey carried out in 2014 on the decision to connect to an existing district heating network by residential consumers in Birmingham, the second largest city in the UK. An independent marketing company collected the sample using Random Digit Dialling from a representative frame of (listed and unlisted) residential consumers. The sample includes 784 observations and provides a very reasonable representation of the Birmingham population.

Every participating residential consumer completed a telephone questionnaire which included a novel vignette experiment emulating a real life decision-making scenario. In the scenario the consumer must deliberate over participating in a district-heating scheme. Our experiment allows us to model the changes in consumer attitudes following a change in the upfront and annual costs of energy efficient technology, from which we are able to calculate the average internal discount rate.

This paper contributes to the existing literature by first exploring whether the consumer's decision to switch to a new energy efficient technology in the UK, namely district heating, is affected by the energy efficiency paradox (i.e. consistent with the traditional economic theory of high internal discount rate). We then extend the traditional economic analysis by modelling two behavioural traits which potentially underpins technology adoption, these are, inattention and heuristic decision-making.

This aim is achieved through the use of two measures of inattention, based on questions revealing the consumers' preferences for direct and indirect mediums of energy efficiency information, and the consumers' ability to calculate a simplified estimate of expected savings. Furthermore, we empirically test whether the residential consumers' behaviour is in line with a heuristic measure of profitability, specifically the payback period, calculated using randomly assigned district heating costs and the actual annual energy and heating replacement costs provided by the participants prior to engaging with the vignette.

Our results suggest that the energy efficiency paradox advocated by traditional economic theory applies also in the case of district heating technology investigated here. Most significantly, by nesting the behavioural theories within the traditional framework, we uncover for the first time that heuristics and inattention are not only central characteristics of the decision to connect but their inclusion also reveals biases in the traditional approach of modelling technology adoption.

The remainder of this paper is organised as follows. In the next section, we review the key literature on the energy efficiency paradox, inattention and heuristics. Section 3 outlines the data and experimental design followed by the empirical strategy in Section 4. In Section 5 we present our analysis, before providing concluding remarks in Section 6.

2. Background

Hausman's (1979) seminal contribution revealed how utility maximising consumers often fail to adopt energy efficient technologies. The author emphasised a tendency for consumers to purchase low-cost technologies and reject the more expensive yet efficient alternatives which can deliver a profitable stream of discounted net savings. Nevertheless, Hausman suggested that this behaviour is internally consistent if consumers behave as if they have high individual discount rates (estimated at around 25 per cent). Therefore, heavy discounting of the future can induce consumers to perceive upfront savings as more attractive and helps to explain why consumers choose less efficient technologies. This approach forms the cornerstone of the energy efficiency paradox literature.

The mainstream research in this area, since the late 1970s, sought to explore the magnitude of the discount rate. Train's (1985) and Gillingham, Newell and Palmer's (2009) reviews of the literature reveal that the estimated discount rate ranges between 25 to more than 100 per cent, depending on the technology. Although these finding are generally greater than the market rate of return, in stark contrast to what economic theory would predict, the calculation incorporates standard neo-classical assumptions and is therefore able to theoretically justify why the paradox might exist under optimising consumer behaviour (Loewenstein and Thaler, 1989; Jaffe and Stavins, 1994). Furthermore, the existence of an energy efficiency paradox casts doubt on engineers' appraisals of financially viable technologies, which tend to use discount rates far below those found in the economics literature (Gillingham and Palmer, 2014).

To date, internal discount rates exceeding the market rate of interest have been calculated for established product markets including automobiles and air conditioners, with the vast majority of studies based in the US. However, Read, Starmer and Poen (2010) argue that the range of discount rates observed across markets in the US sheds little light on the discount rates for alternative technologies, especially those in other countries. We contribute to this debate by first testing for the presence of an efficiency paradox in the market for district heating, which is currently unexplored in the literature. This is a necessary step in our empirical strategy to show that the energy efficiency gap indeed exists, before assessing its relevance once combined with the behavioural approach.

As such we pose that the discount rate, in the context of the UK district heating market, deviates from the market rate of interest in accordance with earlier findings. Given the presence of such a discount rate, an increase in the discount rate would significantly and negatively affect adoption rate, hence:

Hypothesis 1a: *Consumers discount the financial benefits accrued from the use of energy efficient technologies too heavily, i.e. their internal discount rates are significantly higher than the market rate of interest.*

Hypothesis 1b: *The consumer's adoption decision is significantly and negatively affected by the consumer's internal discount rate.*

2.1. Inattention and the energy efficiency paradox

The theory of inattention is intrinsically linked to the field of economics of information, more specifically to the theory of costly 'search', and draws on the psychology of behavioural economics (Stigler, 1961; Kahneman, 1979). In theory, a perfectly rational, utility maximising consumer may decide to remain inattentive if the cost of effort required by gathering information is greater than the return (Sallee, 2014). As a result, some consumers may rationally purchase less efficient technologies due to individual search costs, thereby potentially exacerbating the energy efficiency paradox (Sallee, 2014).

Empirical evidence exploring the relationship between inattention and the energy efficiency paradox is sparse, a gap this paper aims to help address. One of the few current examples is provided by Allcott (2011), whose findings suggest that the vast majority of consumers either do not consider fuel costs when deciding to purchase an automobile or have a faint idea of fuel costs but do not make any calculations based on them.

In addition, Palmer and Walls (2015) adopt a proxy for inattention which they created by asking consumers to declare the presence of a series of specific energy efficient technologies within their home. The authors add up the 'not sure' responses and then normalise the variable to create an inattention index. Their paper argues that the likelihood of a residential consumer having had an audit to assess the energy efficiency of their home decreases by 11 per cent if a residential consumer is fully inattentive in comparison with being fully attentive.

Our paper differs from Allcott's (2011) and Palmer and Walls' (2015) in several crucial dimensions. Firstly, we use a proxy for inattention based on the consumers preferred method of information delivery, if they were to receive any in the future. Therefore, unlike the previous studies we are able to directly control for the inattention implied by the search costs underlying the chosen method of information delivery.

Secondly, in contrast to Allcott (2011), who defines inattentive consumers using a subjective self-assessment of the extent to which prices were central to their purchase decision, we use an objective measure of the consumers' ability to calculate the savings needed to encourage their participation in a district-heating scheme, provided all the upfront costs had been paid for. Since the upfront costs were eliminated, any further reduction required by a consumer would necessarily aim to recover the unobserved costs of the installation (such as psychological, time and hassle). We infer from this that the consumers who replied 'not sure' to this question were inattentive at the time of the survey.

We therefore pose that inattention related to the installation of energy efficient technology negatively impacts the investment behaviour undertaken by UK residential consumers and potentially inflates the estimated internal discount rate.

Hypothesis 2: *The adoption of energy efficient technologies is negatively affected by consumers' inattention.*

2.2. Heuristic decisions and the energy efficiency paradox

An alternative behavioural approach to the energy efficiency paradox is cognitive bias, known also as heuristics, related to the use of simplifying methods when deciding among energy products. Kempton and Montgomery (1984) provides an initial but valuable insight into how consumers use general rules-of-thumb when investing in efficient technology, such as relying on annual energy bills instead of energy consumed and using payback period rather than net present value. Likewise, experimental studies have shown how consumers are deceived by changes in fuel efficiency, since many were found to perceive gas consumption as decreasing linearly (instead of non-linearly) with miles-per-gallon (MPG) (Allcott, 2011; Larrick and Soll, 2008). Similarly, Attari et al. (2010) suggest that consumers to some extent overestimate the potential savings associated with low-energy intensive activities and substantially underestimate the energy savings related to durable appliances. Biases such as these can lead to an inefficient allocation of energy efficient technologies.

An empirical study by Anderson and Newell (2002) suggests the financial decisions made by firms resemble simplified methods such as the number of years required to recoup an initial investment in the energy efficient market. In contrast, Klemick, Kopits and Wolverton (2015) findings indicate that firms assess energy efficient investments using methods ranging from basic intuition to sophisticated financial evaluation techniques. Furthermore, a qualitative study of 57 consumers suggests the majority of automobile owners have little understanding of annual fuel expenditures, MPG or the payback period calculation required to rationalise their initial investment costs (Turrentine and Kurani, 2007). However, the hypothesis that consumer behaviour is in line with heuristic measures, such as payback period (which involve a far more straightforward computation than lifetime costs), remains untested. Our aim is to fill this gap by exploring the role of heuristics in explaining the slow rate of adoption of energy efficient technologies. Specifically:

***Hypothesis** 3: consumers are less likely to install energy efficiency technology following an increase in the number of years of payback.*

Finally and most crucially, we add to the literature by evaluating the respective importance of the traditional and behavioural theories in a nested empirical framework. Implementing this broad empirical approach we aim to shed further light on consumer behaviour in the energy market and provide answers as to why the energy efficiency paradox may be so prevalent in the UK.

3. Survey data and experimental design

3.1. Sample size and representativeness

In this study we use the case of District Heating (DH) systems. They supply heat and electricity from centralised Combined Heat and Power (CHP) plants to a wide range of buildings, including commercial and residential. CHP recycles the waste heat recovered from electricity generation, to produce hot water and steam for the purpose of heating and additional electricity generation, a process that significantly reduces CO_2 emissions compared to less efficient forms of power generation. A global survey carried out by United Nations Environment Programme (between 2013 and 2015) identified DH as a low-cost approach to achieve the necessary efficiency gains to reduce residential CO_2 emissions in cities worldwide (UNEP, 2015). Furthermore, the efficiency gains associated with the expansion of DH are anticipated to reduce household heating bills by up to 20 per cent compared to traditional technologies, according to Routledge and Williams (2012). Also, DH provides an opportunity to investigate the appeal of an up-and-coming technology over the traditional heating options, since the technology is yet to be delivered in many regions across the UK. Therefore, we carried out a telephone survey across residential customers in Birmingham, the second largest city in the UK, investigating how likely they were to connect to DH should it become available in the near future[3].

An independent marketing company (IFF Research) utilised Random Digit Dialling (RDD) to contact survey participants from a frame of households listed and unlisted in the telephone directory designed to be representative of Birmingham. The screening process restricted the sample to adults (18 years or older) who are at least partially responsible for the household's bills and thereby most likely to be responsible for major investment decisions. Between May and June 2014, IFF collected the random sample of 784 households based on the standard sample size calculation with a 3 per cent margin of error. The sample was stratified proportionately by postcode. Therefore each household is selected with equal probability[4]. All 784 households completed the experiment outlined in the following subsection.

The majority of the sample statistics for the social and economic variables expected to influence the household's decision to connect to a DH scheme are close to the population statistics collected in the UK Census (ONS, 2011) for Birmingham and (to a lesser extent) England. The main differences between the sample and the Birmingham population are the proportion of single (21% vs. 33%) and elderly households (35% vs. 24%).

[3] Presently, the Birmingham DH scheme does not supply consumers. This helps to ensure that all the participants in our survey are as equal as possible in terms of prior *experience* using the technology.

[4] Hence sampling weights are equivalent to a simple random 'self-weighted' sample. A Chi^2 test of equal proportions in the sample and population postcodes cannot be rejected at the 1 or 5 per cent level (p-value=0.06).

3.2. Experimental design and outcome variable

The survey was carried out to compare and contrast the classical and behavioural theories of residential household's decision-making. We use the contrastive vignette technique (CVT)[5] to generate our outcome variable of interest – the consumers' attitudes towards installing energy efficient technologies. CVT is an indirect-structured method of attitude elicitation (stated preference) which exploits between-group variation in order to evaluate the effect of a systematic change in the elements within a scenario on the participants' response (Alexander and Becker, 1978; Burstin, Doughtie and Raphaeli, 1980). One of the main advantages of CVT is that it emulates a scenario in which a real-life decision is made; CVT is particularly appealing when a decision cannot be observed, such as the decision to participate in a district-heating scheme (Wason, Polonsky and Hyman, 2002). CVTs thereby intend to reveal the behaviour of individuals if the hypothetical scenario were to occur in the future (Caro et al., 2009). This method provides a unique opportunity to analyse the existence of the energy efficiency paradox using a traditional and behavioural framework.

We allocate a single vignette which describes the capital costs and environmental benefits to each participant, while randomly varying the values in the cost structure for DH in order to determine the effect of capital costs, prices and profitability of investment (Table 1). The experiment systematically changes scenarios (1) and for each cost element it randomised the: (2) interface cost (equivalent to a replacement boiler), (3) average annual bill, and (4) maintenance cost. Therefore, costs (2, 3, and 4) were allowed to vary across three respective levels, creating 27 distinct vignettes[6]. To alleviate bias, we randomised the order in which the investment costs and benefits were allocated to the participants (Cue 2 and 3, Table 1). Overall, the random allocation of the costs worked well, as each cost element has been assigned to a rather equal proportion of the sampled households (Table 2).

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[5] CVT has been implemented in many areas of research including the investigation of university networks, racism, happiness, elderly residential choices and public attitudes towards policy 'nudges' to name a few (Ouwersloot and Reitveld, 1996; Visser et al., 2000; Caro et al., 2009; Felson, Castelo and Reiner; 2013).

[6] In our experimental design we introduced a partially neutral status quo, whereby the participants are randomly allocated one of two potential scenarios, which requires them to imagine that either the current heating system needs replacing, or that is fully functional. The scenarios are introduced to control for the impact of sunk investment costs (or endowment effects) of the current heating system on the decision to install the new technology. However, we did not find any significant effect due to being allocated into either of these groups on the final decision. Therefore we exclude this variable from the final analysis.

Table 1: Experimental attributes and cues

Attributes			
Scenarios (1)	Fully functional	Needs Replacing	
Average yearly bill (2)	£550	£700	£800
Interface cost (3)	£1500	£1750	£2000
Maintenance cost (4)	Free	£60	£100
Cues			
Cue 1	We would like to give you some information on district heating. **But first please imagine** the scenario where your current heating system **(see randomised attribute 1).**		
Cue 2	• District heating is able to transport central and water heating through a network of insulated pipes from a local energy source to households in Birmingham. • An interface unit connects each house to the network replacing the current heat generator whilst providing the user control over the amount of heat needed. • It would offer an environmentally friendly and sustainable alternative to your current heating system.		
Cue 3	**Please imagine a scenario where:** • The yearly bill for heating would be of about **(see randomised attribute 2)** for a household with average use. • Interface would cost **(see randomised attribute 3)**. • Annual maintenance costs are **(see randomised attribute 4)**.		

Table 2: Experimental variables

Variable	N	Mean	S.D.	Median	Min	Max
Experimental variables						
£550	784	0.33	0.47	0	0	1
£700	784	0.31	0.46	0	0	1
£800	784	0.36	0.48	0	0	1
Annual maintenance						
Free	784	0.31	0.46	0	0	1
£60	784	0.36	0.48	0	0	1
£100	784	0.33	0.47	0	0	1
Installation costs						
£1500	784	0.34	0.47	0	0	1
£1750	784	0.34	0.47	0	0	1
£2000	784	0.32	0.47	0	0	1

One of challenges of basing our decision-making scenario on the participation in a DH was the relatively limited public information available on domestic prices for UK schemes before the survey commenced. Nevertheless, using the information available at the time of the study we were able to deduce prices which have been confirmed in a recent study to be representative of a competitive DH scheme (Which?, 2015).

Our values simulate a 'low', 'medium' and 'high' price scenario, which corresponds respectively to: a 20 per cent reduction in annual expenditure given average use in the West Midlands (i.e. £550 is equivalent to 4.1p/kWh); average gas expenditure in the West Midlands (i.e. £700 is equivalent to 5.2p/kWh); and a 20 per cent increase in average expenditure in the West Midlands (i.e. £800 is equivalent to 6.0p/kWh). Most importantly, recent research found the average price for DH (metered) consumers fell between 5.51p/kWh and 15.0p/kWh (Which?, 2015). Hence, our price range, 4.1p/kWh-6.0p/kWh fits neatly around the lower bound price provided by DH schemes in the UK (Which?, 2015).

We also compare the potential savings made on the upfront cost of installing a DH heat interface unit (HIU). Davies and Woods (2009) suggest that a typical HIU would cost £2300 including the capital and installation costs. We use £2000 as our high-end benchmark so the HIU would be competitive against a straightforward gas-boiler replacement with an A-rated level of efficiency (Energy Savings Trust, 2014). Our medium-price of £1750 is competitive with a slightly cheaper gas boiler replacement with a high level of efficiency around 90% (uSwitch, 2015). Our low-price scenario represents the cost of medium-price HIU less a £250 government subsidy, similar to the discount offered in a scrappage scheme (Which?, 2015). Thus, our capital costs reflect a competitive rate in comparison with current DH and gas boiler markets.

Finally, we vary the maintenance costs using £60 as our 'average price' scenario (Which?, 2012). Our high price for a standard service on a heating system is set equal to £100. The low price scenario reflects the 'zero' maintenance costs offered by many DH systems in the UK, including E.ON's DH schemes (E.ON, 2015; Which?, 2015).

The cost elements range utilised in our experiment provides a realistic approximation for insights to be drawn on the appeal of a DH system that is both competitive with existing schemes in the UK and its main competitor, the gas boiler market.

Finally, the households attitudes towards participating in a DH system is measured on a 5-point Likert scale ranging from: 1 if 'definitely unlikely' to 5 'definitely likely' to participate. The proportion of respondents who chose each of the categories based on the costs and benefits provided by the interviewer is presented in Table 3.

Almost a majority of respondents chose the category 'likely' to connect to DH, whereas less than 8 per cent chose 'definitely likely' to connect. In contrast around 18 and 17 per cent of the respondents chose 'definitely unlikely' and 'unlikely' to connect, respectively. Fewer than 8 per cent of respondents were unsure about their participation in a DH scheme. Hence, there is an overwhelming preference towards connecting to DH in this sample.

Table 3: Decision to Connect

Dependent Variable Categories (j)	N	%
1 = Definitely unlikely	143	18.2
2= Unlikely	131	16.7
3= Unsure	62	7.9
4= Likely	386	49.2
5= Definitely Likely	62	7.9
Total	784	100

4. Methodology

We use a standard utility function approach to model the household's taste and preferences for heating systems based on the values allocated by the vignette and the household's current energy costs (in the calculation of payback period). Most importantly, we test the validity of three competing theories of the energy efficiency paradox via their significance in the reported likelihood to connect to DH.

4.1. The consumer discount rates

Our empirical model uses the lifetime-cost (LTC) of a new energy efficient technology. Following Hausman (1979), we specify the consumer's choice based on the *LTC* of capital calculated on the basis of the annual cost of the energy bills *(AC_i)* and upfront interface costs *(UC_i)* provided to the survey participants in the vignette:

$$LTC_i = UC_i + \sum_{t=1}^{\tau} \frac{AC_i}{(1+\rho)^{\tau}}$$

$$LTC_i = UC_i + AC_i \frac{(1-(1+\rho)^{-\tau})}{\rho} \tag{1}$$

Where the annual cost is discounted at the rate ρ with a lifetime durability τ[7]. After a simple parameterisation Equation 1 can be written as:

$$U_i = \beta_1 UC_i + \beta_2 AC_i + X_i'\gamma + \varepsilon_i \tag{2}$$

Whereby, X is a matrix containing socio-economic and housing characteristics specific to household $i=1,\dots,N$, and ε_i is the independent and identically distributed error component containing the unobserved factors related to the taste or preferences for heating systems. Furthermore, $\beta_1=1$ and $\beta_2=\frac{(1-(1+\rho)^{-\tau})}{\rho}$ assuming that households' trade-off a marginal increase in upfront costs and discounted annual costs when purchasing efficient technologies, the discount rate, by definition, equals the ratio of the two coefficients β_1 and β_2:

$$\frac{\beta_1}{\beta_2} = \left[\frac{(1-(1+\rho)^{-\tau})}{\rho}\right]^{-1}$$

Thus, the internal discount rate represents the point at which consumers' are indifferent. If there are no market or internal inefficiencies in the consumers' decisions, we would expect that, according to the theory, they will be indifferent between trading-off £1 in upfront costs and a £1 change in discounted annual costs and therefore to find a discount rate close to the market rate of interest (Hausman, 1979).

Empirically we assume that the upfront and annual costs enter a standard latent utility function U, representing the household's decision to connect to the new heating system, and estimate the likelihood of connecting to DH using an ordered probit model. Though we cannot observe the utility function (2) underpinning the willingness to connect to DH, we do observe the household's choice of category j. As

[7] The typical assumptions in the literature are made herein including: annual costs do not rise in real terms; the decision to connect is irreversible (i.e. the technology cannot be re-sold); and the heating system does not depreciate and lasts for a lifetime durability τ after which the heating interface technology has zero scrap value. The lifetime durability τ of a district heating interface unit is typically assumed to be 15 years (Davies and Woods, 2009).

is standard, the probability (P) of choosing one of the five categories is determined by the household's utility which is ranked between a series of thresholds α_j:

$$P(D_i = j) = \Phi(\alpha_j - \beta_1 UC_i - \beta_2 AC_i - X_i'\gamma) - \Phi(\alpha_{j-1} - \beta_1 UC_i - \beta_2 AC_i - X_i'\gamma)$$

Furthermore, the error term in (2) is assumed to follow standard normal cumulative distribution function Φ. The coefficients and thresholds are estimated such that the log likelihood function is maximised[8].

In line with Hypothesis 1a, an average internal discount rate in excess of the market rate of interest would imply that households weigh the upfront cost of energy efficiency excessively relative to the annual costs.

Since coefficients β_1 and β_2 are hypothesised to be less than zero (Hypothesis 1b), we anticipate that an increase in either coefficient will decrease the probability that a household will adopt the new energy efficient technology, holding all else constant.

4.2. Inattention and unobserved costs

In order to test our second hypothesis, we model inattention using two proxy variables. Our first measure of inattention is created using the households' preferences towards methods of information delivery. Our second measure is based on the households' ability to calculate expected savings.

The intrinsic link between search theory and inattention, as presented by Sallee (2014), guides the construction of our first inattention variable. We anticipate that households' choose the search method which minimises the cost of effort and maximises utility. Hence (2) becomes:

$$U_i = \beta_1 UC_i + \beta_2 AC_i + \sum_{j=1}^{3} \delta_j (IN_{1i}) + X_i'\gamma + \varepsilon_i \qquad (3)$$

As search costs for household i increases, the probability that the household is inattentive (IN_1) increases (Sallee, 2014). As a result the probability that a household derives utility from engaging with the energy market decreases.

In our survey the households indicated which method they would prefer to deliver additional information regarding DH, within a defined range of categories. Since the choice of information method is a signal of the households expected search costs, we

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[8] The marginal effects are calculated, in general, by: $\frac{\partial P(D_i = j)}{\partial X_i} = \gamma[\Phi'(\alpha_j - X_i'\gamma) - \Phi(\alpha_{j-1} - X_i'\gamma)]$.

can aggregate the categories into three groups: 1) direct search methods which require little effort to receive information, including post, email, face-to-face consultation or a telephone call; 2) indirect search methods which require at least some costly search activity including information made available online and a community information day; and 3) zero search activity i.e. the households indicating that they do not wish to engage in any information acquisition about the new energy technology (Table 4).

Clearly those in category 3 are the most inattentive to the DH market, followed by the indirect search methods (category 2) and households who are willing to receive information directly (category 1) – incurring the lowest search costs – are therefore most likely to be attentive to the market. In line with Hypothesis 2, we expect coefficients $\delta_3 < \delta_2 < 0$.

Table 4: Tabulation of 'preferred method of information provision'

Information provision	N	%
1= Direct information	594	75.8
2= Indirect information	148	18.9
3= No information	42	5.4
Total	784	100

Our second measure of inattention is founded on research which indicates that consumers are often 'unsure' of questions related to energy savings (Houston, 1983; Turrentine and Kurani, 2007; Allcott, 2011; Palmer and Walls, 2015). Building on this line of research, we measure the households' attentiveness by asking the following question: 'What is the minimum you would need to save per year before you would consider connecting to district heating, assuming zero upfront costs?'

By eliminating upfront costs, we are able to assess the households' attention to all the unobserved costs related to an energy efficient investment. In previous research it has been assumed that households are rational and fully informed about their unobserved monetary costs (such as time and effort) and non-monetary costs (including the psychological burden) of investment (Houston, 1983). However, Houston (1983, pp. 237) argues that households who choose 'not sure or don't know' are 'generally non-rational'. An alternative explanation, adopted in this paper, is that households are rationally attentive (Sallee, 2014). Therefore, households who choose 'not sure' are assumed to do so because the cost of becoming fully informed is higher than the benefits (Salle, 2014). Furthermore, for households that are fully informed, any positive level of expected savings they require would necessarily cover all other unobserved costs, since the cost of installation is set equal to zero.

The households were requested to provide answers within a specified range as well as state a value if their expected savings exceeded £400. The variable is set equal to 1 if the minimum needed is less than £300, 2 if greater than £300 and 3 if the participant responded 'unsure' (Table 5). The utility function (3) is extended as follows:

$$U_i=\beta_1 UC_i + \beta_2 AC_i + \sum_{j=1}^{3} \delta_j (IN_{1i}) + \sum_{j=1}^{3} \lambda_j (IN_{2i}) + X_i' \gamma + \varepsilon_i \tag{4}$$

We anticipate that the coefficient for the second category will be negative, as an increase in required savings would imply higher unobserved costs and a fall in utility, reducing the likelihood of adoption. Furthermore, in line with Hypothesis 2, we expect coefficient λ_3 to be negative as its respective category implies that the household is inattentive, thereby lowering the probability of a consumer participating in DH. Moreover, an inattentive consumer is less willing to participate in DH than someone who would connect for a positive level of savings, such that $\lambda_3 < \lambda_2 < 0$.

Table 5: Tabulation of 'minimum needed to connect to district heating'

Minimum needed		
1=Less than £300	326	41.6
2=£300 or more	186	23.7
3=Not sure	272	34.7
Total	784	100

4.3. Heuristic decision-making

The last empirical adjustment includes payback period to estimate the household's probability of connecting to DH. Due to its simplicity, the payback method reflects or at least approximates the perceived risk calculated on the basis of current costs and expected annual savings by the households (Kempton and Montgomory, 1984).

We define payback time (in years) as:

$$Payback_i = \frac{UC_i}{S_i} = \frac{UC_i^{DH}}{AC_i^{C} - AC_i^{DH}}$$

where UC_i denotes the upfront cost for the installation of a district heating interface unit. S_i represents the expected annual savings – calculated by the taking difference between annual bills *(AC_i)* accrued by installing district heating *(DH_i)* and remaining with the current heating system *(C_i)*. It is important to note that the former refers to the values randomly allocated to the households during the vignette whereas the latter represent the observed energy bills of the current system.

One potential issue related to the calculation of payback period arises due to the fact that around 100 households are 'unsure' of their energy bills. Following Palmer and Walls (2015) we use this response to control for inattention towards household energy consumption by including an indicator variable equal to 1 if the household reported their energy bill and 0 otherwise. Therefore, we use an estimate of the savings for the households who are attentive to annual gas bills to calculate payback.

An additional modelling issue arises as a result of negative savings. Prior to the survey we were unable to obtain individual energy consumption levels for each household, to circumvent this problem we simulated a real life decision making scenario (the vignette) in which we randomly allocated a district heating annual gas bill estimated for an average user to each household. Due to random allocation and varied energy consumption levels, households can potentially save money by remaining with their current heating system. Hence, we are unable to calculate the number of payback years for the households with negative savings (431 in total). We control for the impact of negative savings by including an indicator variable equal to 1 if savings are less than zero and 0 otherwise (the coefficient for this variable will undoubtedly fall below zero).

The payback variable has been log transformed to help to control for right skew and potential outliers. In addition we create a categorical variable by separating the log of the payback distribution into five quintiles to pick up any nonlinearity – similar to the mean reversion found by Anderson and Newell (2002).

We arrive at our full model by including the payback variable *(PB_i)* extending (4) as follows:

$$U_i=\beta_1 UC_i + \beta_2 AC_i + \sum_{j=1}^{3} \delta_j (IN_{1i}) + \sum_{j=1}^{3} \lambda_j (IN_{2i}) + \sum_{j=1}^{5} \xi_i (PB_i) + X_i' \gamma + \varepsilon_i \qquad (5)$$

Hypothesis 3 suggests that an increase in the number of years of payback, due to an increase in the upfront costs or a fall in annual savings, would decrease the household's utility, and consequently decrease the probability of a household connecting to DH.

4.4. Control variables

In all specifications we include a number of socio-economic, demographic and housing variables, which have been previously highlighted in the literature as important determinants of household investment in energy efficient technologies, to address potential omitted variable bias related to the households' utilization, taste and experience of energy efficiency – variable definitions and respective labels are outlined in Table 6.

Most importantly we control for income and energy use. In an analysis of the determinants of energy efficient uptake, Ameli and Brandt (2014) and Caird et al. (2008) suggest that income plays a key role in the investment decision. Heat demand has also been highlighted as an important determinant of investment (Michelsen and Madlener, 2012). Acknowledging the importance of both income and fuel expenditure we create a low-income-high-cost indicator[9] to control for the relative impact of poverty and affordability on the investment decision (Hills, 2012). We anticipate that the Low-Income-Low-Cost (LILC) group to be the least likely to participate due to financial constraints, followed by Low-Income-High-Cost (LIHC) as the relative burden of higher bills may motivate households to find alternative sources of energy. Following the same reasoning, the High-Income-Low-Cost (HILC) group is expected to be more likely to connect than LIHC though less likely than the High-Income-High-Cost (HIHC) group.

The variables expected to have a positive influence on technology adoption include: homeownership (Gillingham et al., 2012) and education (Michelsen and Madlener, 2012). Although gender has been previously noted as having limited influence (Ameli and Brandt, 2015) we include this variable alongside marital status and education to control for differences in attitudes towards risky investments and assume that males are more likely to adopt (Collard, 2009).

[9] Low-income is defined as annual income falling below 60 per cent of the median. High-cost is defined as annual energy expenditures exceeding the median.

In contrast, variables expected to exert a negative influence include age, particularly over 60 years (Ameli and Brandt, 2014; Mills and Schleich, 2012) and unemployment (Davis, 2010). Parliamentary constituency effects could be positive or negative depending on the local factors (Davis, 2010; Michelsen and Madlener, 2012; Mills and Schleich, 2012).

Finally, we include an indicator variable to control for the use of prior knowledge of energy efficient technologies in the investment decision (Mills and Schleich, 2012). The variable is set equal to 1 for 'at least average' knowledge of DH and 0 otherwise. Further, the effect on adoption could be positive or negative depending on the general public perception of district heating technology. We interact the DH knowledge indicator with annual and installation costs of district heating to capture the effect on the perception of the costs of participation between those who have a above average knowledge of district-heating schemes as compared with below average knowledge.

In Table 7 we report the sample statistics for the social and economic variables expected to influence the household's decision to connect to a DH scheme.

Table 6: Variable definitions

Variable Name	Definition
Vignette Variables	
Annual Bill	Annual district heating gas bill allocated to household (£100s) (DH BILL)
Interface Cost	Upfront cost of district heating heat interface unit allocated to household (£100s) (INTERFACE)
Heuristic Variables	
Log(Payback Period)	Low-mid (2nd) quintile of payback period (PBK-LM = 1 if yes/ 0 if no) Mid (3rd) quintile of payback period (PBK-M = 1 if yes/ 0 if no) Mid-High (4th) quintile of payback period (PBK-MH = 1 if yes/ 0 if no) Highest (5th) quintile of payback period (PBK-H = 1 if yes/ 0 if no)
Negative Savings	Current annual gas bill < district heating gas bill (NEG SAVINGS = 1 if yes/ 0 if no)
Unsure of current gas bill	Household is unsure/does not know last gas bill (DK GAS = 1 if yes/ 0 if no)
Inattention Variables	
Indirect Information	Household prefers indirect information delivery (INDIRECT = 1 if yes/ 0 if no)
Inattentive to information	Household prefers to remain inattentive (INATTENTIVE A = 1 if yes/ 0 if no)
High unobserved costs	Household requires at least £300 reduction in annual energy bill to join a DH scheme (given upfront costs are zero) (HIGH UNOBSERVED COSTS = 1 if yes/ 0 if no)
Unsure of unobserved costs	Household unsure/does not know reduction in annual energy bill required to join DH scheme (given upfront costs are zero) (INATTENTIVE B = 1 if yes/ 0 if no)

Low-Income-High Cost Indicator	
Low Income High Cost	Annual income falls below 60% of median income *and* annual energy expenditure is above the median (LIHC = 1 if yes/ 0 if no)
Low Income Low Cost	Annual income falls below 60% of median income *and* annual energy expenditure is below the median (LILC = 1 if yes/ 0 if no)
High Income High Cost	Annual income above 60% of median income *and* annual energy expenditure is above the median (HIHC = 1 if yes/ 0 if no)
High Income Low Cost	Annual income above 60% of median income *and* annual energy expenditure is below the median (HILC = 1 if yes/ 0 if no)
Unsure of energy bills/prefer not say income	Household representative is unsure of annual energy bills and/or prefers not to say annual income (UNSURE BILLS/INCOME) = 1 if yes/ 0 if no)
Demographic and housing variables	
Unemployed residents	At least one resident is unemployed (UNEMPLOYED=1 if yes/ 0 if no)
Male	Household representative is male (MALE=1 if yes/ 0 if no)
Single	Household representative's marital status is single (SINGLE=1 if yes/ 0 if no)
Elderly	Household representative is aged over 60 (ELDERLY=1 if yes/ 0 if no)
Higher education	Highest educational attainment of the household is a degree qualification or higher (DEGREE=1 if yes/0 if no)
Property tenure	Household does not own their property (NON-OWNER=1 if yes/0 if no)
Structural problems in the home	At least one structural problem in the home e.g. damp, rot or leaky roof (DAMP=1 if yes/0 if no)
Knowledge of district heating	Household representative has at least an 'average' understanding of district heating schemes (KNOWS DH=1 if yes/0 if no)

Regional variables	
Parliamentary constituency	Household lives in the parliamentary constituency of: (ERDINGTON =1 if yes/0 if no) (PERRY BARR=2 if yes/0 if no) (HODGE HILL=3 if yes/0 if no) (LADYWOOD =4 if yes/0 if no) (EDGBASTON=5 if yes/0 if no) (YARDLEY=6 if yes/0 if no) (HSS =7 if yes/0 if no) (SELLY OAK=8 if yes/0 if no) (NORTHFIELD=9 if yes/0 if no) *Note: HSS includes Hall Green, Sparkbrook and Small Heath*

Table 7: Income and socio-economic variables

	Sample					
Variable	N	Mean	S.D.	Median	Min	Max
Income variables						
Annual income	645	22994	18396	18462	2830	201460
Energy variables						
Annual gas bill	683	711.79	431.25	611.56	0	3577.82
Demographic variables						
ELDERLY	784	0.35	0.48	0	0	1
MALE	784	0.43	0.50	0	0	1
SINGLE	784	0.21	0.41	0	0	1
UNEMPLOYED	784	0.36	0.48	0	0	1
DEGREE	784	0.30	0.46	0	0	1
NON-OWNER	784	0.65	0.48	0	0	1
DAMP	784	0.67	0.47	1	0	1
KNOWS DH	784	0.15	0.36	0	0	1
Low-Income-High-Cost Indicator						
LIHC	784	0.11	0.31	0	0	1
LILC	784	0.12	0.33	0	0	1
HIHC	784	0.22	0.41	0	0	1
HILC	784	0.23	0.42	0	0	1
UNSURE BILLS/INCOME	784	0.33	0.47	0	0	1

5. Analysis

5.1 The energy efficiency paradox, inattention and heuristic decision making

This section presents the results of our econometric analysis of the decision to participate in a DH scheme, using a classic lifetime cost model aimed at calculating the average internal discount rate whilst controlling for consumer inattention and heuristic decision-making.

The results presented in Table 7 (Column 1) suggest that the discount rate for homeowners, as a whole, is around 35 per cent[10]. However, due to the (statistical) insignificance of the interface coefficient, the discount rate also appears to be insignificantly different from zero[11]. Therefore, in our full model, the discount rate appears unable to explain the average investment behaviour of consumers in our sample.

After removing the inattention variables, the discount rate for homeowners increases to 47 per cent and is significant at the 10 per cent level (Table 8, Column 2). In other words, in this specification homeowners appear indifferent between an upfront cost of £0.47 and a £1 change in discounted annual bill. This is higher than the estimates found in Train's (1985) survey of the literature, where the discount rates for space heating ranged between 6 and 36 per cent depending on fuel type.

However, the high rate could be capturing inattention and unobserved costs, related to search costs and the expected cost of disruption (for example), respectively. Hence our results suggests that the discount rate is biased downward by around 12 percentage points, if one does not control for inattention. Again, the discount rate becomes insignificant (and slightly lower compared to Column 1) after reintroducing the inattention variables while at the same time removing the heuristic variables (Table 8, Column 3).

Therefore, inattention and unobserved costs appear to be important factors inhibiting household participation in a DH scheme; leaving these factors unaccounted for appears to bias the estimate of discount rates away from zero which is plausible if inattention leads consumers to overestimate energy costs, as suggested by Allcott

[10] In a review of the literature Read et al. (2010) suggest that a discount rate of 37 per cent to be a reasonable approximation.

[11] Though the homeowners' upfront and annual cost coefficients are individually and jointly significant at the 5 per cent level (p-value=0.0197).

(2011), and underestimate the use of durable technologies, as discussed by Attari et al. (2010). Upon removing the inattention and heuristic variables the discount rate increases (to 41 per cent) and becomes significant at the 10 per cent level (Table 8, Column 4).

The full model which nests the classic and behavioural theories of technology adoption are tested against the specifications in which the latter are excluded (Table 8, Columns 2 to 4) and the former are removed (Table 8, Columns 5 to 6). A likelihood ratio test consistently rejects the null hypothesis that the parsimonious specifications improve our ability to predict the household's decision making (Table 8, Final Row). Hence, our 'preferred' model is the mixed framework which nests both the classical *and* behavioural theories.

As an additional robustness check we estimate the discount rate using a probit model. The dependent variable in this case is an indicator equal to 1 if the household is 'at least likely' to connect to district heating and 0 if the household is 'at most unlikely' to connect to district heating[12]. Column 7 and 8 present the full specification results and the 'classic' model, respectively. Consistent with our earlier findings the discount rate is only significant for the latter. However, it is worth noting that the discount rate is around 10-20 percentage points higher using this probit model. This could be due to the removal of the 'not sure' category, which contains households who are more likely to be inattentive and provides further evidence to support that neglecting inattention may lead to biased estimates of household discount rates.

Thus, our findings suggest that household behaviour appears to be driven by attention and in line with simple heuristic measures of profitability. Moreover, our results are indicative of bounded rationality, whereby consumers simplify the decision-making process and rely on a subset of information, since the cost of either acquiring or internalising the extra information is larger than the benefits of using the full set of information or exceeds the consumer's cognitive capabilities within a given timeframe (Golove and Eto, 1996).

[12] I.e. 'at least likely' combines categories 'likely' and 'definitely likely', whereas 'at most unlikely' consists of categories 'unlikely' and 'definitely unlikely'. The 'not sure' category is omitted leading to an 8 per cent reduction in the sample size; hence these results may not be fully representative of the population.

Table 8: Decision to Connect to District Heating – Ordered Probit and Probit Coefficients

	Ordered Probit						Probit	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Discount rate	0.347	0.470*	0.313	0.412*	-	-	0.534	0.647*
	(0.242)	(0.272)	(0.198)	(0.215)	-	-	(0.438)	(0.386)
Experimental Variables			Coefficients					
DH BILL	-0.164**	-0.160**	-0.193***	-0.190***			-0.146	-0.173**
	(0.0697)	(0.0682)	(0.0683)	(0.0669)			(0.0932)	(0.0864)
NON-OWNER	-1.324	-2.079**	-1.405	-2.127**	0.0295	0.0355	-2.205	-2.952**
	(0.987)	(0.968)	(0.982)	(0.964)	(0.0938)	(0.0925)	(1.342)	(1.246)
NON-OWNER x DH BILL	0.0315	0.0681	0.0477	0.0829			0.00385	0.0543
	(0.0827)	(0.0811)	(0.0821)	(0.0806)			(0.113)	(0.104)
INTERFACE	-0.0570	-0.0753**	-0.0606*	-0.0782**			-0.0782*	-0.112**
	(0.0358)	(0.0352)	(0.0356)	(0.0350)			(0.0472)	(0.0453)
NON-OWNER x INTERFACE	0.0651	0.0941**	0.0616	0.0894**			0.123**	0.146***
	(0.0427)	(0.0420)	(0.0425)	(0.0417)			(0.0584)	(0.0543)
KNOWS DH	-2.375*	-2.311*	-2.732**	-2.683**	-0.0938	-0.117	-3.803	-2.867*
	(1.314)	(1.292)	(1.305)	(1.284)	(0.113)	(0.111)	(2.456)	(1.711)
KNOWS DH x DH BILL	0.102*	0.102*	0.116**	0.115**			0.208**	0.135*
	(0.0567)	(0.0561)	(0.0563)	(0.0558)			(0.105)	(0.0757)
KNOWS DH x INTERFACE	0.0713	0.0582	0.0833	0.0736			0.0100	0.0537
	(0.114)	(0.112)	(0.113)	(0.111)			(0.209)	(0.147)
Heuristics (Years of Payback)								
PBK-LM	-0.515**	-0.464*			-0.552**	-0.489**	-1.343***	
	(0.251)	(0.248)			(0.250)	(0.246)	(0.461)	
PBK-M	-1.036***	-0.997***			-1.087***	-1.031***	-1.718***	
	(0.255)	(0.251)			(0.253)	(0.249)	(0.459)	
PBK-MH	-0.712***	-0.571**			-0.697***	-0.555**	-1.276***	
	(0.251)	(0.247)			(0.250)	(0.246)	(0.464)	

PBK-H	-0.520**	-0.571**			-0.574**	-0.608**	-1.023**	
	(0.253)	(0.249)			(0.250)	(0.246)	(0.460)	
NEG SAVINGS	-0.755***	-0.703***			-0.865***	-0.788***	-1.317***	
	(0.210)	(0.205)			(0.206)	(0.201)	(0.416)	
DK GAS	-0.764***	-0.722***			-0.848***	-0.789***	-1.286***	
	(0.199)	(0.195)			(0.196)	(0.193)	(0.403)	
Inattention variables								
INDIRECT INFORMATION	-0.400***		-0.384***		-0.398***		-0.437***	
	(0.105)		(0.105)		(0.105)		(0.139)	
INATTENTIVE A	-1.357***		-1.306***		-1.382***		-1.909***	
	(0.212)		(0.211)		(0.213)		(0.415)	
HIGH UNOBSERVED COSTS	-0.214**		-0.187*		-0.225**		-0.281*	
	(0.106)		(0.105)		(0.106)		(0.146)	
INATTENTIVE B	-0.648***		-0.654***		-0.628***		-0.884***	
	(0.102)		(0.100)		(0.101)		(0.133)	
Low Income High Cost Indicator								
LIHC	-0.178	-0.223	-0.150	-0.202	-0.168	-0.214	-0.173	-0.248
	(0.156)	(0.153)	(0.154)	(0.151)	(0.155)	(0.152)	(0.221)	(0.204)
LILC	-0.300*	-0.382**	-0.373**	-0.451***	-0.284*	-0.365**	-0.534**	-0.613***
	(0.160)	(0.157)	(0.149)	(0.147)	(0.159)	(0.156)	(0.217)	(0.189)
HIHC	-0.158	-0.195	-0.221*	-0.255**	-0.120	-0.163	-0.161	-0.263*
	(0.136)	(0.133)	(0.122)	(0.120)	(0.135)	(0.132)	(0.189)	(0.157)
UNSURE BILLS/INCOME	-0.296**	-0.433***	-0.339***	-0.477***	-0.272**	-0.410***	-0.519***	-0.685***
	(0.125)	(0.121)	(0.117)	(0.113)	(0.124)	(0.120)	(0.173)	(0.149)
Demographic Characteristics								
UNEMPLOYED	-0.223**	-0.270***	-0.234**	-0.283***	-0.209**	-0.255**	-0.187	-0.273**
	(0.102)	(0.100)	(0.101)	(0.0996)	(0.101)	(0.0992)	(0.137)	(0.127)
MALE	0.0404	0.112	0.0393	0.115	0.0594	0.125	0.0644	0.118
	(0.0850)	(0.0834)	(0.0842)	(0.0826)	(0.0839)	(0.0824)	(0.115)	(0.108)

SINGLE	-0.318***	-0.338***	-0.338***	-0.362***	-0.307***	-0.320***	-0.551***	-0.553***
	(0.104)	(0.101)	(0.102)	(0.100)	(0.103)	(0.101)	(0.139)	(0.130)
ELDERLY	-0.271**	-0.365***	-0.269**	-0.363***	-0.260**	-0.347***	-0.494***	-0.537***
	(0.110)	(0.107)	(0.109)	(0.107)	(0.110)	(0.107)	(0.151)	(0.138)
DEGREE	0.234**	0.248***	0.212**	0.231**	0.236**	0.247***	0.180	0.165
	(0.0943)	(0.0915)	(0.0929)	(0.0903)	(0.0938)	(0.0911)	(0.129)	(0.116)
DAMP	0.162*	0.180**	0.196**	0.217**	0.166*	0.188**	0.274**	0.299**
	(0.0919)	(0.0903)	(0.0907)	(0.0892)	(0.0913)	(0.0898)	(0.127)	(0.117)
Parliamentary Constituency								
ERDINGTON	0.0543	0.0577	0.0939	0.0893	0.0349	0.0464	0.194	0.194
	(0.173)	(0.170)	(0.172)	(0.169)	(0.172)	(0.169)	(0.237)	(0.220)
HODGE HILL	0.551**	0.526**	0.511**	0.480**	0.556**	0.545**	0.963***	0.880***
	(0.224)	(0.220)	(0.222)	(0.218)	(0.223)	(0.219)	(0.327)	(0.306)
LADYWOOD	-0.198	-0.182	-0.179	-0.173	-0.139	-0.132	0.177	0.254
	(0.230)	(0.226)	(0.228)	(0.224)	(0.229)	(0.224)	(0.306)	(0.284)
EDGBASTON	0.156	0.250	0.187	0.273*	0.149	0.243	0.442**	0.555***
	(0.161)	(0.158)	(0.159)	(0.157)	(0.160)	(0.157)	(0.219)	(0.204)
YARDLEY	0.0963	0.0961	0.0841	0.0833	0.0512	0.0574	0.0539	0.0753
	(0.147)	(0.145)	(0.147)	(0.144)	(0.146)	(0.144)	(0.200)	(0.184)
HSS	0.0210	0.0962	0.0415	0.107	-0.0135	0.0706	0.255	0.310
	(0.153)	(0.149)	(0.151)	(0.148)	(0.152)	(0.149)	(0.211)	(0.192)
SELLY OAK	-0.0433	-0.0451	-0.0112	-0.0122	-0.0596	-0.0569	0.0805	0.134
	(0.145)	(0.143)	(0.144)	(0.142)	(0.144)	(0.142)	(0.194)	(0.179)
NORTHFIELD	0.158	0.227	0.144	0.212	0.164	0.238	0.335	0.376**
	(0.152)	(0.149)	(0.151)	(0.148)	(0.151)	(0.148)	(0.204)	(0.191)
Cut 1	-4.580***	-4.380***	-4.164***	-4.008***	-2.492***	-1.978***		
	(0.883)	(0.868)	(0.865)	(0.850)	(0.254)	(0.240)		
Cut 2	-3.931***	-3.796***	-3.525***	-3.432***	-1.850***	-1.400***		
	(0.881)	(0.866)	(0.863)	(0.848)	(0.250)	(0.237)		

Cut 3	-3.667***	-3.556***	-3.265***	-3.196***	-1.590***	-1.164***		
	(0.880)	(0.865)	(0.862)	(0.847)	(0.249)	(0.236)		
Cut 4	-1.760**	-1.757**	-1.390	-1.427*	0.290	0.612***		
	(0.874)	(0.860)	(0.857)	(0.843)	(0.244)	(0.234)		
Constant							4.804***	3.858***
							(1.193)	(1.082)
Observations	784	784	784	784	784	784	722	722
LR X^2	270.4***	158.9***	249.2***	139.4***	254.3***	143.6***	257.2***	139.4***
LR X^2(Ho: Model 1=Model j)	-	111.5***	21.2***	131.0***	16.07**	126.8***	-	-

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses.

5.2 Marginal effects

Table 9 presents the marginal effects for the full specification using the ordered probit model. For brevity we focus on the interpretation of the 'likely' response, since the majority of the households fall into this category (Column 4).

Column 4 shows a £100 increase in the annual cost and interface cost for district heating decreases, as would be expected, the probability of a homeowner being likely to connect to DH by 5 and 2 per cent, respectively. The former and joint effect is significant at the 5 per cent level.

The quintile specification of payback period suggests a potential non-linear relationship between the number of years taken to recuperate the initial investment and decision to connect. A higher number of years required to repay the investment is associated with a lower probability of deciding to connect to district heating, as expected. The middle quintile group shows that a households have a 23 percentage point lower probability of stating 'likely' to connect, as compared with the lowest quintile group. In addition, these effects are all significantly different from zero at the 1 per cent level. Akin to Anderson and Newell's (2002) research on the adoption of energy efficient technologies by firms, we find this result in the presence of a payback period in excess of 6-7 years (the mid-quintile group). Hence, similar to firms, households may tend to ignore the information provided by payback period after 6-7 years and become increasingly likely to connect (though remain less likely to connect compared with a payback period of 0-2 years (i.e. the lowest quintile group)).

Furthermore, the marginal effects of inattention are also significant and substantial. Firstly, the probability of adoption by households who are unable to quantify the amount of compensation needed to encourage their participation in a DH scheme is 42 percentage points lower than for those who would be interested given a reduction in bills equivalent to less than £300. And secondly, the probability that households who anticipate high search costs and have chosen to remain completely inattentive (i.e. do not want to receive any information) is 19 percentage points less than households who would prefer to be contacted directly. Thus, the marginal effects support our previous findings that the household's attention is a significant barrier preventing the uptake of energy efficient technology.

There are a number of socio-economic variables worth highlighting as important drivers of the decision to connect. For instance, low earnings unemployment, nonhomeownership, being single and over 60 years of age, are negative and significantly related to being ‘likely’ to participate in a DH scheme – these findings are consistent with the literature (Section 4.4).

Table 9: Decision to Connect to District Heating – Ordered Probit Marginal Effects

	Ordered Probit				
	(1)	(2)	(3)	(4)	(5)
	Definitely Unlikely	Unlikely	Not Sure	Likely	Definitely Likely
Experimental Variables	Marginal Effects				
DH BILL	0.0351**	0.0235**	0.00542**	-0.0487**	-0.0153**
	(0.0150)	(0.0103)	(0.00252)	(0.0209)	(0.00670)
NON-OWNER	0.232	0.174*	0.0528	-0.274***	-0.185
	(0.147)	(0.0973)	(0.0359)	(0.0876)	(0.194)
NON-OWNER x DH BILL	-0.00674	-0.00453	-0.00104	0.00937	0.00294
	(0.0177)	(0.0119)	(0.00274)	(0.0246)	(0.00773)
INTERFACE	0.0122	0.00819	0.00189	-0.0170	-0.00532
	(0.00769)	(0.00520)	(0.00124)	(0.0107)	(0.00339)
NON-OWNER x INTERFACE	-0.0139	-0.00936	-0.00216	0.0194	0.00608
	(0.00916)	(0.00620)	(0.00148)	(0.0128)	(0.00404)
KNOWS DH	0.745**	-0.00958	-0.0565	-0.589***	-0.0899***
	(0.324)	(0.133)	(0.0376)	(0.123)	(0.0348)
KNOWS DH x DH BILL	-0.0153	-0.0102	-0.00236	0.0212	0.00665
	(0.0244)	(0.0164)	(0.00379)	(0.0339)	(0.0106)
KNOWS DH x INTERFACE	-0.0218*	-0.0146*	-0.00336*	0.0303*	0.00949*
	(0.0122)	(0.00827)	(0.00198)	(0.0170)	(0.00539)
Heuristics (Years of Payback)					
PBK-LM	0.0614*	0.0735**	0.0302**	-0.0713	-0.0939*
	(0.0332)	(0.0352)	(0.0148)	(0.0441)	(0.0492)
PBK-M	0.182***	0.143***	0.0437***	-0.231***	-0.138***
	(0.0544)	(0.0316)	(0.0133)	(0.0636)	(0.0460)
PBK-MH	0.0993**	0.103***	0.0382***	-0.125**	-0.115**
	(0.0405)	(0.0345)	(0.0139)	(0.0537)	(0.0472)

PBK-H	0.0623*	0.0742**	0.0305**	-0.0725*	-0.0945*
	(0.0332)	(0.0353)	(0.0149)	(0.0434)	(0.0497)
NEG SAVINGS	0.109***	0.109***	0.0396***	-0.138***	-0.119**
	(0.0244)	(0.0280)	(0.0134)	(0.0268)	(0.0463)
DK GAS	0.111***	0.110***	0.0398***	-0.141***	-0.120***
	(0.0213)	(0.0266)	(0.0131)	(0.0227)	(0.0456)
Inattention variables					
INDIRECT INFORMATION	0.0906***	0.0549***	0.0111***	-0.122***	-0.0346***
	(0.0271)	(0.0139)	(0.00285)	(0.0346)	(0.00836)
INATTENTIVE A	0.434***	0.0678***	-0.0217	-0.422***	-0.0580***
	(0.0822)	(0.0221)	(0.0137)	(0.0514)	(0.00878)
HIGH UNOBSERVED COSTS	0.0375*	0.0323**	0.00988**	-0.0533*	-0.0264**
	(0.0195)	(0.0160)	(0.00493)	(0.0276)	(0.0128)
INATTENTIVE B	0.146***	0.0869***	0.0177***	-0.193***	-0.0576***
	(0.0247)	(0.0149)	(0.00448)	(0.0311)	(0.0112)
Low Income High Cost Indicator					
LIHC	0.0341	0.0265	0.00734	-0.0483	-0.0197
	(0.0309)	(0.0230)	(0.00622)	(0.0434)	(0.0167)
LILC	0.0615*	0.0435*	0.0108*	-0.0857*	-0.0301*
	(0.0345)	(0.0229)	(0.00575)	(0.0470)	(0.0160)
HIHC	0.0298	0.0236	0.00662	-0.0423	-0.0177
	(0.0256)	(0.0203)	(0.00583)	(0.0362)	(0.0155)
UNSURE BILLS/INCOME	0.0606**	0.0430**	0.0107**	-0.0845**	-0.0298**
	(0.0250)	(0.0185)	(0.00525)	(0.0347)	(0.0138)
Demographic Characteristics					
UNEMPLOYED	0.0493**	0.0313**	0.00673**	-0.0675**	-0.0198**
	(0.0234)	(0.0143)	(0.00307)	(0.0316)	(0.00894)
MALE	-0.00862	-0.00581	-0.00135	0.0120	0.00379
	(0.0181)	(0.0122)	(0.00287)	(0.0252)	(0.00802)

SINGLE	0.0753***	0.0427***	0.00773***	-0.100***	-0.0255***
	(0.0269)	(0.0134)	(0.00237)	(0.0343)	(0.00769)
ELDERLY	0.0605**	0.0378**	0.00792**	-0.0825**	-0.0237**
	(0.0258)	(0.0153)	(0.00321)	(0.0345)	(0.00950)
DEGREE	-0.0476***	-0.0342**	-0.00863**	0.0667***	0.0238**
	(0.0183)	(0.0141)	(0.00409)	(0.0258)	(0.0106)
DAMP	-0.0335*	-0.0235*	-0.00572	0.0469*	0.0159*
	(0.0185)	(0.0136)	(0.00361)	(0.0260)	(0.00960)
Parliamentary Constituency					
ERDINGTON	-0.0122	-0.00762	-0.00160	0.0166	0.00472
	(0.0384)	(0.0245)	(0.00525)	(0.0528)	(0.0153)
HODGE HILL	-0.0925***	-0.0815**	-0.0261**	0.127***	0.0729*
	(0.0323)	(0.0325)	(0.0131)	(0.0412)	(0.0387)
LADYWOOD	0.0503	0.0250	0.00340	-0.0650	-0.0138
	(0.0621)	(0.0273)	(0.00317)	(0.0774)	(0.0146)
EDGBASTON	-0.0331	-0.0225	-0.00530	0.0460	0.0149
	(0.0335)	(0.0233)	(0.00578)	(0.0467)	(0.0159)
YARDLEY	-0.0211	-0.0137	-0.00301	0.0291	0.00870
	(0.0322)	(0.0210)	(0.00470)	(0.0444)	(0.0134)
HSS	-0.00478	-0.00291	-0.000584	0.00650	0.00177
	(0.0347)	(0.0212)	(0.00428)	(0.0473)	(0.0129)
SELLY OAK	0.0102	0.00589	0.00108	-0.0137	-0.00346
	(0.0343)	(0.0197)	(0.00363)	(0.0460)	(0.0116)
NORTHFIELD	-0.0335	-0.0228	-0.00537	0.0465	0.0151
	(0.0319)	(0.0219)	(0.00538)	(0.0443)	(0.0149)
Observations	784				
LR X^2	270.4***				

6. Conclusion

Residential heat demand poses a significant challenge to the United Kingdom's 2050 target of cutting CO_2 emissions by 80 per cent, relative to 1990s levels, due to the fact that the largely energy inefficient housing[13] stocks accounts for almost half of the national CO_2 emissions[14] and the uptake of energy efficient technology remains stunted (DECC, 2012).

This paper explores the decision to connect to the alternative technology embodied in a district heating system, using a survey of residential energy consumers. Referring to the hypothesis addressed in our empirical analysis we can conclude that high internal rates of return, exceeding 30 per cent, are consistent with the apparent low uptake of energy efficient technologies by homeowners in the UK.

Yet, when controlling for inattention and heuristic decision-making, the importance of high discount rates as an explanatory factor in the decision to adopt energy efficient technology severely diminishes. Therefore, we do not find evidence in support of an energy efficiency paradox, once controlling for behavioural factors, at least for homeowners.

In addition, the household's decision to connect to a district-heating scheme is negatively and significantly affected by an increase in years of payback – up to about 6-7 years. One could claim that consumer behaviour is in accordance with simple strategies or heuristics, which produce decisions that perform well in comparison with more sophisticated approaches when evaluating the financial implications of an energy efficiency investment.

Our results also reveal some concerning aspects of the adoption decision which seem to be consistent with the possibility that the information about the financial profitability of the investment might become 'valueless' beyond a certain time horizon, in which case consumers may use other heuristic or quick-fire tactics to guide their decision to invest in the technology. In our case, after 6-7 years of payback, households appear to become increasingly interested in the technology once more.

[13] The average Standard Assessment Procedure (SAP) rating (measured on a 100 point scale) for all homes in England has increased to 59 in 2015, i.e. a low Band D (DECC, 2015a).

[14] Comparably, Birmingham's residents' contribute over one-third of the city's CO_2 emissions (Birmingham Green Commission, 2013).

Therefore, some consumers appear to be either vulnerable to making inefficient decisions when faced with an increasingly unprofitable investment or are inclined to purchase ‘clean’ technologies at any cost.

To conclude, our paper indicates that the classic approach of calculating the discount rate in order to explain the apparent reluctance of the low uptake of energy efficient technologies by domestic consumers is subordinate with respect to the inclusion of our measures of inattention and heuristic decision-making. Therefore, policy may need to be shaped to cope with, for example, the various levels of consumer attention that exist in the energy market and the appropriate measures of contacting or supporting inattentive consumers to implement energy efficient technologies, particularly those with a low-income.

Hence, if grants or subsidies aimed at reducing the upfront cost, such as the Energy Company Obligation, are to continue to be preferred policy despite economists arguing in favour of the use of (Pigouvian) taxes, then information provision to consumers may need to be revised. This could be done, for example, by introducing new search technologies (similar to price comparison websites) that use basic socio-economic and housing characteristics to calculate payback periods and lifetime costs at the point of purchase for energy efficient technologies, thereby both decreasing the cost of attention as well as tapping into the heuristic methods that appeal to residential consumers.

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