ESRI

Working Paper No. 558

April 2017

Identification of the information gap in residential energy efficiency: How information asymmetry can be mitigated to induce energy efficiency renovations

Matthew Collins* and John Curtis

Abstract: Improving the energy efficiency of residential dwellings is seen by policy-makers as an important contributor to the mitigation of climate change, a topic of ever increasing interest. Many countries have put in place policies aimed at stimulating the adoption of energy efficiency retrofit measures in private households. These policies generally focus on reducing costs to home owners, which in turn increases the net benefit of retrofitting, making a retrofit more attractive. We examine the drivers of retrofitting from an information point of view, looking mainly at how expected gross benefits can be increased as a means of inducing retrofitting activities. Using survey data, we examine how perceived effects of retrofitting impact on the likelihood that a home owner possesses an expressed interest in engaging in certain retrofit measures. We find the existence of information asymmetries in many cases between those who have and have not engaged in retrofit measures, while asymmetries are present in almost all instances between those who possess an expressed interest in retrofitting and those who do not. The most effective information that can be used to bridge this asymmetry and could lead to a greater interest in retrofitting among home owners are centred around energy costs and comfort. Perceived impacts of retrofitting on occupant health, property value and mould growth are not found to be significant drivers of interest in retrofitting.

*Corresponding Author: matthew.collins@esri.ie

Keywords: energy efficiency retrofitting, information asymmetry, household behaviour

JEL Codes: D12, D38, Q48

Acknowledgements: We thank Kieran McQuinn and contributors at the Sustainable Energy Authority of Ireland for helpful comments and suggestions. This research has been financially supported by the Sustainable Energy Authority of Ireland and the Energy Policy Research Centre.

1. Introduction

Recent years have seen an increased international focus on the mitigation of climate change, with the European Union mandating a 20% reduction in energy use by 2020 (European Parliament and the Council of the European Union 2012). Likewise, the Paris Agreement emphasises a need to reach peak greenhouse gas emissions as soon as possible, as a target to help achieve the limitation of global warming below 2°C (United Nations 2015). In the EU, one-sixth of emissions occur in residential buildings (European Commission 2011a). Similarly, the residential sector comprises 22.5% of energy consumption in the U.S. (Department of Energy 2012), while within the residential sector in the EU, space and water heating account for 67% and 14% of residential energy consumption, respectively (European Commission 2011b). As such, improving the energy efficiency of the residential sector provides a significant policy opportunity to help reach 2020 energy targets.

In addition to reducing energy use in the economy, energy efficiency retrofits have various benefits for households. Commonly cited benefits include cost savings and improvements in comfort within the home. These are discussed as the main drivers of retrofitting activity from the perspective of private households (Sorrell et al. 2009; Gillingham et al. 2009). In addition, energy efficiency, as measured by energy performance certificates, provides a price premium in housing purchase and rental markets in various countries (Bloom et al. 2011; DG Energy 2013; Cajias and Piazolo 2013; Brounen and Kok 2011; Fuerst et al. 2015, 2016; Hyland et al. 2013). In addition, retrofitting has been found to provide health benefits, such as improved self-reported health, fewer self-reported GP visits and fewer sick days from school or work (Chapman et al. 2009; Howden-Chapman et al. 2012; Ormandy and Ezratty 2012). There also exist some potential costs to retrofitting, beyond the initial capital outlay. Poorly installed energy efficiency retrofits can lead to damages, losses and potential health impacts (Willand et al. 2015; Hagentoft 2011; Totten et al. 2008). Ultimately, home owners make the decision to retrofit based on the trade-off between these gross benefits available and costs involved, i.e. the net benefits accrued from retrofitting are the main determinant of the decision to engage in retrofitting works.

As a result, various European governments have introduced incentives for home owners to engage in retrofitting works to improve the energy efficiency of their homes, with varying levels of success. For example, in the UK, the *Green Deal* provided loan financing for home owners to engage in certain retrofit measures with repayments made via energy bills, but this has been discontinued following low take-up. Germany's *KfW-Effizienzhaus* scheme provides loan financing for home owners to improve their homes to specific overall standards, with rising levels of funding available for more efficient standards. In France, a tax credit, known as *crédit d'impôt développement durable*, is awarded for retrofitting works which improve energy efficiency. In Ireland, the Sustainable Energy Authority of Ireland provides grant aid under the *Better Energy Homes* and *Better Energy Warmer Homes* (for households subject to fuel poverty) schemes to support home owners engaging in retrofitting works, while many retrofit measures also qualify for a tax credit known as the *Home Renovation Incentive.* Considering the household decision to retrofit as based on a trade-off between expected costs and benefits, each of these incentives possess a common scope in that they aim to induce retrofitting activities by reducing expected costs and hence increasing expected net benefits.

Costs are not the only barriers to energy efficiency, however. It is commonly believed that a market failure exists in energy efficiency retrofitting with regard to information. An information asymmetry refers to the idea that one or more parties to a transaction possess more, or better information than other parties. As a result, some parties may accrue untoward gains by taking advantage of this better information or those who believe they possess less, or poorer information may choose to abstain from the market in order to avoid undue losses. Markets can therefore become more efficient if information asymmetries are mitigated. Various studies exist showing evidence of information asymmetries as a barrier to retrofitting. Sorrell et al. (2000), for example, discuss barriers to energy efficiency for public and private organisations, although the barriers discussed may also be applied to households. Barriers are divided into three categories, being organisational, behavioural and economic barriers. Economic barriers include the neo-classical barriers, such as access to capital, hidden costs and lack of information. This paper is primarily concerned with this information barrier, the presence of which is confirmed in the residential sector by various studies. Achtnicht and Madlener (2014) find uncertainty surrounding the payback period of investment to be a significant barrier to retrofitting, while Clinch and Healy (2000) cite lack of information on the nature and extent of benefits as one of the most important barriers. Similar descriptions of uncertainty and information as barriers to retrofitting are found throughout the literature (Caird et al. 2008; Jaffe and Stavins 1994; Mills and Schleich 2012).

By improving information, it is likely that the propensity of households to engage in retrofits would increase. By providing better information on the benefits of retrofitting, households' expectations regarding the gross benefits of retrofitting might rise, in turn increasing expectations regarding net benefits, making retrofitting a more attractive investment for households. This research aims to consider whether expected gross benefits can be increased as a means of inducing retrofitting activities. Reducing costs can stimulate more demand for retrofitting works and thus a larger retrofitting market, which in turn may lead to innovations in practices which increase benefits. We consider, however, the role of information in increasing expected gross benefits. Specifically, we examine whether an information asymmetry exists regarding the overall benefits among home owners who have not previously engaged in retrofitting works. In the presence of this asymmetry, we investigate which information can most efficiently bridge this gap in information and therefore increase the propensity of home owners to engage in energy efficiency retrofitting.

An extensive literature exists with regard to energy efficiency retrofitting, including the analysis of household willingness-to-pay, retrofit adoption and household propensities to retrofit. Much research has been devoted to choice modelling of retrofitting alternatives to estimate the willingness-to-pay of households for improved energy efficiency, using data on stated preferences (Achtnicht 2011; Cameron 1985; Jaccard and Dennis 2006; Banfi et al. 2008; Kwak et al. 2010) and revealed preferences (Grösche and Vance 2009). With regard to adoption, Bollinger and Gillingham (2010) use a hazard model framework to examine the effect of the installed base of solar PV technologies on adoption at zip-code and street level in Calfornia. Song (2008) visually analyses adoption of retrofit measures spatially and uses a count model of adoption by region in a residential energy efficiency program in Canada. Hlavinka et al. (2016) estimate and forecast the adoption of ductless heat pumps in the US Pacific Northwest as a function of market potential, tax credits available, income and seasonality. Panel approaches are more common in the literature, however. Noonan et al. (2013), for example, use a panel model of adoption to examine the effects of the installed base on adoption of energy efficient Heating, Ventilation and Air Conditioning systems within neighbourhoods in Greater Chicago in a period, while Richter (2013) uses a similar panel approach, modelling adoption of solar photovoltaic panels in the UK during each period as a function of area characteristics and the installed base.

With regard to household propensities to retrofit, research is often constrained to participants in energy efficiency programs due to data limitations. Gamtessa (2013) examines households who undertake a home energy audit as part of Canada's *EnerGuide* for Houses program, examining which households were most likely to continue to engage in retrofit installation. Probability and count models are used to model the number of measures undertaken following audit, ranging from zero to eight, finding that households expecting larger cost savings were more likely to engage in a retrofit. Collins and Curtis (2016) examine participants in the *Better Energy Homes* scheme in Ireland, examining the propensity of homes engaging in deep retrofits. Probability and count models are used to examine administrative data of households who engaged in retrofit works, finding that households applying in Winter and households engaging in works via an energy supplier or retailer were less likely to engage in a deeper retrofit. Aravena et al. (2016) examines the propensity of households who applied for aid under the *Better Energy Homes* scheme to complete retrofitting works. Using a probit regression to model survey data, households expecting larger cost savings and comfort improvements were most likely to complete retrofit works. Collins and Curtis (2017) also examine this scheme, paying particular attention to the likelihood that applications to the scheme are abandoned by the applicant. Using administrative data, Collins and Curtis (2017) find that shallower retrofits and retrofits made via energy retailers and suppliers are less likely to be abandoned.

Some studies have used survey data to examine the propensity of homes to engage in retrofits incorporating a sample of households who have engaged in energy efficiency retrofit works and households who have not. Nair et al. (2010) examine survey data of Swedish home owners, descriptively analysing patterns in retrofitting works. Higher income households, those living in older properties and those who perceived their energy consumption as being high were more likely to engage in retrofitting works. Ramseier (2013) uses a survey of Swiss households to examine the propensity to retrofit. Using a linear probability and a two-stage least squares model, households with a home energy efficiency consultant nearby and households who have been assessed by a consultant were found more likely to engage in retrofit works. Households who believed that retrofit works have a positive effect on the environment were also found to be more likely to engage in retrofitting works.

We add to the literature through an examination of a survey of households who are and are not interested in retrofitting, examining whether certain information specific to retrofitting alternatives have a positive effect on the likelihood that a household possesses such an interest. We find that perceptions regarding the impacts of retrofitting on property values, occupant health and mould growth do not possess any significant relationships with the likelihood that home owners are interested in retrofitting. Perceived improvements in comfort and reductions in energy costs are found to be significant drivers of interest in retrofitting, although the effects of these perceptions are heterogeneous across measures.

The rest of this paper is structured as follows. Section 2 provides a description of the data used. Section 3 contains a discussion of modelling and estimation issues. This is followed by the presentation and discussion of the estimation results in Section 4, while Section 5 concludes.

2. Data and descriptive analysis

2.1. Data collection

To explore the information gap between those who have and those who have not engaged in an energy efficiency retrofit, responses were collected as part of a wider survey of energy related decision-makers in Ireland. We designed an online survey in three iterations. Firstly, the survey was developed and pre-tested by a small sample of respondents, most of which possessed post-graduate degrees in economics or other social sciences. This led to the exclusion or modification of several items. A soft launch was then used to test the survey with a small sample of respondents, recruited by a market research firm, and finally, the full survey was launched online. A nationally representative sample of the Republic of Ireland was recruited in the final stage (n=2,430) using the panel book of *ResearchNow*, an international online consumer panel company. This sample is demographically representative of age and region in Ireland. Of this sample, 1,495 responses were made by individuals living in owner-occupied homes.

Of the recruited panel, screening questions were used to first ensure respondents were involved, either solely or jointly, in energy-related decision-making and secondly to ensure data quality. All respondents were asked to state their year of birth at the beginning of the survey and then asked to select their respective age category later in the survey. Respondents whose year of birth did not match their age category were invalidated. Respondents were also provided with a ‘question’ instructing the respondent to choose a particular option in a multiple choice setting. Those who chose an option from the choice set other than the option instructed were also deemed to provide invalid responses. We then excluded any respondents who completed the survey in a time below the 1st percentile or above the 99th percentile of the distribution of respondents. Our final sample thus consists of 1,007 respondents, each of which declared themselves to be either sole or joint decision-makers with regard to energy-related decisions in the home.

2.2. Descriptive analysis

The survey included several modules related to energy efficiency and background characteristics. After gathering information on the characteristics of the respondents' dwellings, their ownership and tenure, respondents were asked whether they had previously undertaken a number of energy efficiency retrofit measures. Namely, these were insulation, draught-proofing, window and/or door replacement, installation of a high efficiency boiler, installation of heating controls and installation of a solar thermal or photovoltaic collector. Respondents were then asked to state the likelihood that they would undertake any of those six retrofit measures in the next three years using a five-point likert scale, ranging from very unlikely to very likely, as well as an option to opt-out of the question on the basis that the measure had previously been undertaken. A further module asked respondents to state the perceived extent of positive/negative effects of each of the six measures on a number of characteristics of their dwelling. These were energy costs to the household, comfort in the home, the health of the occupants, the value of the property and, for measures pertaining to the thermal envelope of the building, i.e. insulation, window and/or door replacement and draught-proofing, condensation and mould growth. These were also measured using a five-point likert scale, ranging from very negative to very positive, as well as a *don't know* option.

The survey then included a module on self-reported pro-environmental behaviour, a module on energy and environment-related knowledge and, finally, a module on socio-demographic characteristics. The answers to these questions are collated to create knowledge and behaviour indices, both of which are standardised about zero. Details of questions asked in the behaviour and knowledge modules and the calculation of these indices are provided in appendices A and B, respectively. Information gathered includes the length of a respondents tenure in their home, the type of dwelling, the dwelling's Building Energy Rating (BER), level of education, age and whether the household includes children. Unknown BERs were estimated according to Curtis et al. (2015). Descriptive statistics are presented in table 1.

Figures 1 and 2 present the distribution of perceived effects of retrofitting alternatives among sub-groups of respondents. The first of these groups comprises those who have previously completed that measure. Secondly, respondents expressing themselves either somewhat or very likely to undertake the retrofit measures are categorised as *Likely*. Thirdly, those expressing themselves to be either very or somewhat unlikely or neither likely nor unlikely are categorised as *Not likely*. As can be seen, in most cases, there appears to be a more positive perception of the effects of each alternative on each characteristic among the likely cohort, relative to the not likely cohort. In many cases this pattern continues across cohorts, with those who have completed each alternative in the past possessing more favourable views on the effects of retrofitting than those in the likely cohort. There are exceptions to this, however. For example, those who have insulated their home do not perceive as positive an effect on property value than the likely cohort, while those who have completed a solar collector installation do not perceive as positive an effect on energy costs. As will be discussed in section 3, we aim to identify whether these patterns represent a statistically significant information asymmetry.

3. Methodology

3.1. Testing for the presence of information asymmetries

To identify the presence of information asymmetry, a Kolmogorov-Smirnov test is used to examine the statistical significance of differences in the distributions of the perceived effects of retrofitting. Following Arnold and Emerson (2011), this non-parametric goodness-of-fit test is used to assess whether differences exist between the distributions of the perceived effects of retrofitting across cohorts. To test the null hypothesis that the distributions are equal, the test statistic is calculated as follows:

$$D = \sup_{x} |F_0(x) - F_h(x)| \tag{1}$$

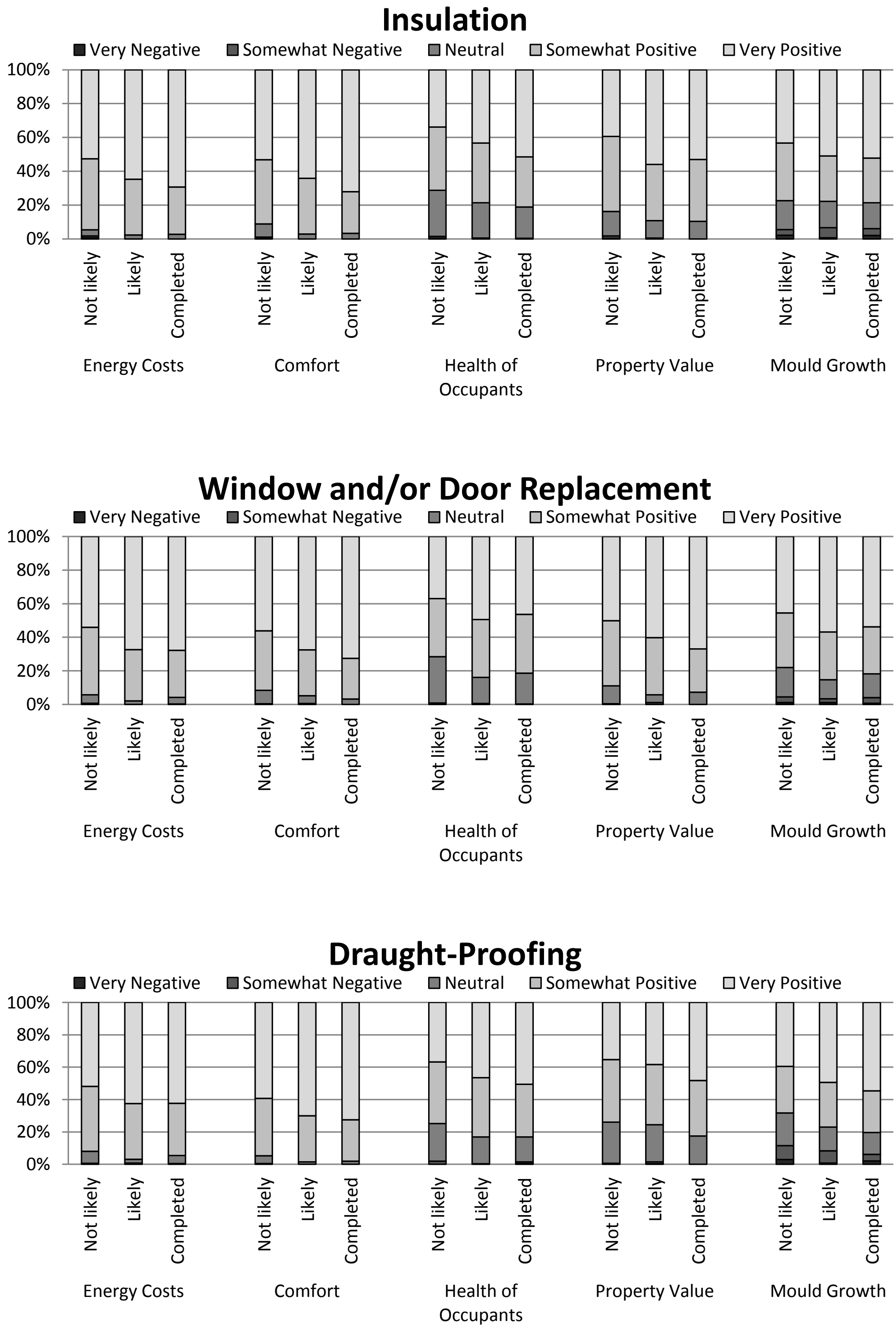


Figure 1: Perceived effects of energy efficiency retrofit works on characteristics of dwelling and inhabitants

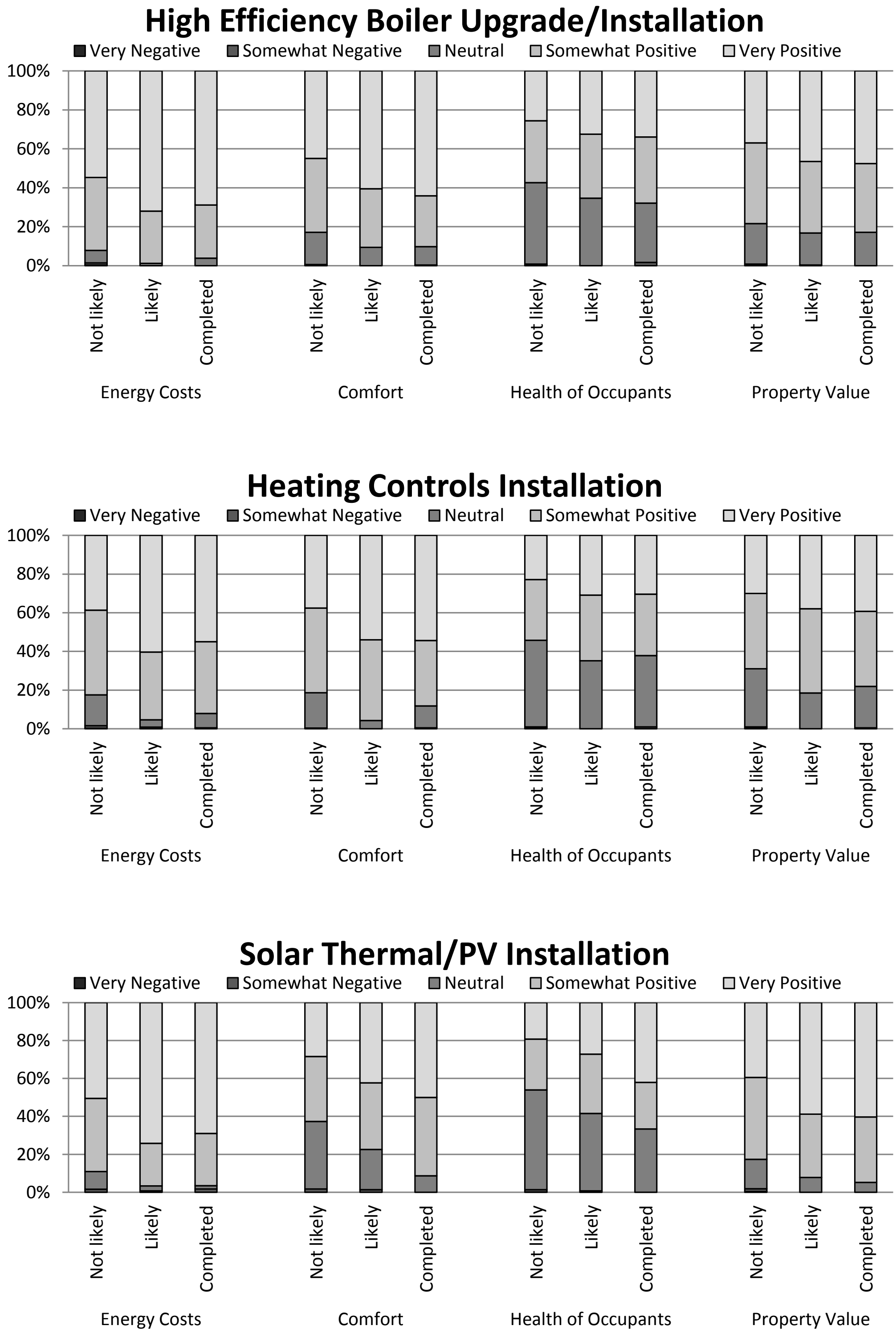


Figure 2: Perceived effects of energy efficiency retrofit works on characteristics of dwelling and inhabitants

Table 1: Descriptive Statistics

	Frequency	Proportion		Frequency	Proportion
Insulation			*High efficiency boiler*		
Very unlikely	129	0.1281	Very unlikely	129	0.1281
Somewhat unlikely	87	0.0864	Somewhat unlikely	87	0.0864
Neither likely nor unlikely	81	0.0804	Neither likely nor unlikely	81	0.0804
Somewhat likely	116	0.1152	Somewhat likely	116	0.1152
Very likely	66	0.0655	Very likely	66	0.0655
Already Completed	528	0.5243	Already Completed	528	0.5243
	1,007			1,007	
Window/Door replacement			*Heating Controls*		
Very unlikely	237	0.2354	Very unlikely	214	0.2125
Somewhat unlikely	153	0.1519	Somewhat unlikely	153	0.1519
Neither likely nor unlikely	95	0.0943	Neither likely nor unlikely	187	0.1857
Somewhat likely	117	0.1162	Somewhat likely	167	0.1658
Very likely	80	0.0794	Very likely	77	0.0765
Already Completed	325	0.3227	Already Completed	209	0.2075
	1,007			1,007	
Draught-proofing			*Solar thermal/PV*		
Very unlikely	184	0.1827	Very unlikely	374	0.3714
Somewhat unlikely	150	0.1490	Somewhat unlikely	222	0.2205
Neither likely nor unlikely	162	0.1609	Neither likely nor unlikely	190	0.1887
Somewhat likely	202	0.2006	Somewhat likely	118	0.1172
Very likely	95	0.0943	Very likely	44	0.0437
Already Completed	214	0.2125	Already Completed	59	0.0586
	1,007			1,007	
Length of Tenure			*Building Energy Rating*		
Less than one year	42		A, B, C	431	0.4280
1 - 3 years	84		D, E, F, G	576	0.5720
3 - 5 years	64			1,007	
5 - 10 years	148				
10 + years	669		*Education*		
	1,007		Secondary or lower	300	0.2979
			Technical or vocational qualification	260	0.2582
Type of dwelling			Bachelors degree and/or professional qualification	329	0.3267
Detached house	486	0.4826	Postgraduate degree	118	0.1172
Semi-detached house	332	0.3297		1,007	
Terrace house	145	0.1440			
Apartment	44	0.0437	*Family with children*		
	1,007		Yes	366	0.3635
			No	641	0.6365
				1,007	

	Observations	Mean	Std. Dev.	Min	Max
Age	1,007	50.5750	14.2470	18	88
Energy-related behaviour index (0 - 1)	1,007	0.6380	0.1320	0.1942	0.9583
Energy-related knowledge index (0 - 14)	1,007	5.8590	1.7902	0	12

where $F_0(x)$ represents the cumulative distribution function of the distribution of perceived effects among those who have not retrofitted and $F_h(x)$ the empirical cumulative distribution function of same among those who have retrofitted. For a detailed discussion of the calculation of the test statistic in the presence of a discrete distribution, see Gleser (1985).

3.2. Modelling framework

With regard to the mitigation of information asymmetry, it could be considered unwise to attempt to communicate all of the potential benefits and costs of retrofitting and how they may vary to households. Not only because this would require a significant communications outlay, but because that form of information overload may actually paralyse decision-makers (Eppler and Mengis 2004). It is therefore of interest to identify the most important pieces of information that can increase the propensity of home owners to engage in energy efficiency retrofitting works.

Following the literature, the energy efficiency renovation decision is presented in a cost-benefit framework

(Aravena et al. 2016; Collins and Curtis 2017; Wilson and Dowlatabadi 2007). Home owners decide whether to engage in energy efficiency renovation works in instances where the expected benefits exceed expected costs, provided net benefits will not rise at any foreseen time period in the future. This decision is described by the following determinate function:

$$E[B_i] - E[C_i] \geq 0 \tag{2}$$

whereby the expected benefits, B to household i of engaging in the chosen retrofit must exceed the costs, C_i, of same. Benefits include those discussed in section 1, expectations of which are heterogeneous across households due to the presence of non-standard beliefs and preferences (DellaVigna 2009). Costs include the direct monetary costs of retrofitting, costs of financing and transaction costs, such as search costs associated with researching appropriate renovation works and finding a suitable contractor and disruption while retrofit works are being installed, etc. Also included are opportunity costs, which could include the benefits available through using household income for other priorities. Grant aid, tax credit and low-cost financing schemes aim to increase expected net benefits and thereby induce retrofitting activities by reducing expected costs to households.

Expected benefits and costs are a function of various characteristics. These include technical dwelling characteristics, such as the type and existing level of energy efficiency, socio-demographic characteristics of the occupants and the characteristics of occupancy, including ownership or acquisition arrangements and tenure length. In addition, we introduce a vector of information characteristics which may also influence cost and benefit expectations. As discussed in section 2, respondents were asked their perception of the effects of six retrofit measures on energy costs, comfort, occupant health, property value and mould growth. We are interested in how expectations with regard to these effects can impact on the retrofitting decision. For each retrofit measure, we categorise those who expressed that they were either"Likely" or "Very likely" to engage in each measure as being interested in engaging in a retrofit, with all those who have not engaged in the measure as not being interested. It follows that the probability that a respondent is interested in engaging in a retrofit is modelled as a function of these characteristics affecting expected benefits and costs:

$$P(Interested_i = 1) = f(E_i, X_i) \tag{3}$$

where E_i represents the vector of expectations held by respondent i where asymmetries are found, as discussed in section 3.1, and X_i represents those characteristics of the dwelling and applicant which affect the retrofitting decision. This paper aims to gain an understanding of the relationship between these vectors of characteristics and whether a respondent is interested in engaging in an energy efficiency retrofit. This is done using a logistic regression, specified as follows:

$$P(Interested_i = 1) = \frac{e^{(\Sigma\beta E_i + \Sigma\lambda X_i)}}{1 + e^{(\Sigma\beta E_i + \Sigma\lambda X_i)}} \tag{4}$$

where β and λ represent vectors of the estimated coefficients.

4. Results and discussion

4.1. The presence of information asymmetry

As discussed in section 3.1, we use a discrete Kolmogorov-Smirnov test to identify the significance of information asymmetries. We first test this asymmetry among those who have not previously completed each measure relative to those who have. Table 2 presents the estimated Kolmogorov-Smirnov test statistics for each perceived effect of undertaking each measure, alongside the critical values at each level of significance, as these vary according the sample size of those who have not previously undertaken the measure. As can be seen, asymmetries exist for various items of information. For each of the six measures examined, asymmetries exist regarding the perceived effects on the comfort of the home. Similarly, asymmetries exist regarding the health of occupants for all measures, with the exception of heating controls, while asymmetries exist regarding the effects of all measures other than draught-proofing and boiler installation on energy costs. The largest asymmetries between those who have retrofitted and those who have not exist in the perceived impact of solar collectors on property values and occupant health, followed by the effect of a boiler installation/upgrade on comfort. Perceived positive effects on both costs and comfort were found to possess significant relationships with the likelihood of being interested in installing or upgrading to a high efficiency boiler and installing heating controls.

Table 2: Testing for differences in the distribution of expected benefits between those who have and have not engaged in retrofitting works

Retrofit Measure	Discrete Kolmogorov-Smirnov Test Statistics					Critical Values by confidence level		
	Energy Costs	Comfort	Occupant Health	Property Value	Condensation/ Mould	α=0.10	α=0.05	α=0.01
Insulation	0.0957***	0.1283***	0.1039***	0.0489	0.0305	0.0552	0.0613	0.0735
Window/Door Replacement	0.0821***	0.1104***	0.0482*	0.107***	0.0195	0.0462	0.0513	0.0615
Draught-Proofing	0.0392	0.0638***	0.101***	0.0985***	0.0747***	0.0431	0.0478	0.0574
High Efficiency Boiler	0.0406	0.1283***	0.0533**	0.0355		0.0441	0.0490	0.0588
Heating Controls	0.051**	0.0877***	0.0395	0.0387		0.0431	0.0479	0.0574
Solar	0.066***	0.2291***	0.1341***	0.1315***		0.0400	0.0444	0.0532

*** p<0.01, ** p<0.05, * p<0.1

Moreover, we are interested in the types of information which can be best utilised to improve residential energy efficiency. As such, we aim to identify information which can lead to the development of an interest in retrofitting among home owners. We therefore compare, using the same Kolmogorov-Sminov method, asymmetries in information between those who have expressed themselves to be likely to retrofit, relative to those who have not. Results of this test are presented in table 3. In this case, asymmetries are found for every item of information tested, with the exception of the effect of draught-proofing on property value. For this reason, this information is excluded from analysis in section 4.2. The largest asymmetries in this case appear to pertain to the effects of solar panels on energy costs and property value, followed by the effects of heating controls and boiler upgrade/installation on energy costs. While these asymmetries are found to exist, which specific pieces of information can help to induce retrofitting activities are of greater interest. Section 4.2 is therefore concerned with identifying the most important pieces of information that might help to mitigate this overall asymmetry.

4.2. Interest in retrofit works

Table 4 presents the estimated marginal effects of the logistic regression models discussed in section 3.2. Probit regressions were also considered but these did not cause any significant changes to the estimates of the models. All pieces of information where statistically significant information asymmetries were found are included as independent variables, alongside other information discussed in section 2.

Table 3: Testing for differences in the distribution of expected benefits between those expressing intent and those not expressing intent on engaging in retrofitting works

Retrofit Measure	Discrete Kolmogorov-Smirnov Test Statistics					Critical Values by confidence level		
	Energy Costs	Comfort	Occupant Health	Property Value	Condensation/ Mould	α=0.10	α=0.05	α=0.01
Insulation	0.086***	0.0836***	0.0521**	0.1255***	0.0463*	0.0431	0.0479	0.0574
Window/Door Replacement	0.1177***	0.0946***	0.1006***	0.0737***	0.0938***	0.0436	0.0484	0.058
Draught-Proofing	0.083***	0.0891***	0.0966***	0.0267	0.0691***	0.0465	0.0516	0.0619
High Efficiency Boiler	0.1419***	0.0836***	0.0546**	0.0587**		0.0448	0.0498	0.0597
Heating controls	0.1668***	0.1303***	0.0772***	0.102***		0.0448	0.0498	0.0597
Solar	0.2092***	0.1164***	0.0854***	0.1465***		0.0425	0.0472	0.0566

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Estimated marginal effects on the likelihood of possessing an interest in undertaken retrofit works

	Insulation	Window/ Door Replacement	Draught-Proofing	High Efficiency Boiler	Heating Controls	Solar thermal/PV
Model	(1)	(2)	(3)	(4)	(5)	(6)
Perceived Effects on Energy Costs (ref = Neutral)						
Negative (Somewhat/Very)	-	-	0.332	-	0.0778	0.0393
			(0.245)		(0.127)	(0.149)
Somewhat Positive	-0.0804	0.0839	0.179**	0.190***	0.136***	0.0409
	(0.195)	(0.0977)	(0.0768)	(0.0627)	(0.0484)	(0.0441)
Very Positive	-0.0962	0.117	0.191**	0.279***	0.268***	0.141***
	(0.202)	(0.107)	(0.0795)	(0.0654)	(0.0559)	(0.0488)
Perceived effect on comfort (ref = Neutral)						
Negative (Somewhat/Very)	-	-	-	-	-	0.202
						(0.192)
Somewhat Positive	0.146	-0.0158	0.171	0.0385	0.150***	0.0117
	(0.116)	(0.0838)	(0.107)	(0.0546)	(0.0498)	(0.0383)
Very Positive	0.198*	0.0237	0.174	0.123**	0.220***	0.0109
	(0.120)	(0.0942)	(0.111)	(0.0593)	(0.0625)	(0.0500)
Perceived effect on occupant health (ref = Neutral)						
Negative (Somewhat/Very)	0.203	-	-	-	-	-0.0669
	(0.382)					(0.107)
Somewhat Positive	0.0265	0.0385	0.0456	-0.00287	-0.0488	0.0245
	(0.0643)	(0.0501)	(0.0518)	(0.0440)	(0.0407)	(0.0355)
Very Positive	0.0202	0.0882	0.0497	-0.0341	-0.0505	-0.00260
	(0.0804)	(0.0590)	(0.0608)	(0.0546)	(0.0524)	(0.0427)
Perceived effect on property value (ref = Neutral)						
Negative (Somewhat/Very)	-0.0185	-	-	0.204	-	-
	(0.241)			(0.346)		
Somewhat Positive	-0.0486	0.0826	-	-0.0239	0.0247	0.000645
	(0.0818)	(0.0679)		(0.0516)	(0.0467)	(0.0468)
Very Positive	0.0457	0.0716	-	-0.0383	-0.0605	0.0343
	(0.0896)	(0.0708)		(0.0590)	(0.0542)	(0.0528)
Perceived effect on condensation/mould growth (ref = Neutral)						
Negative (Somewhat/Very)	0.0712	0.0141	0.00966			
	(0.126)	(0.114)	(0.0742)			
Somewhat Positive	-0.0344	-0.00596	0.00138			
	(0.0772)	(0.0629)	(0.0564)			
Very Positive	-0.0487	-0.0193	0.0391			
	(0.0763)	(0.0638)	(0.0612)			
Length of tenure (ref = Less than 1 year)						
1 - 3 years	0.103	0.0521	0.0126	0.287***	0.110	0.0554
	(0.115)	(0.0831)	(0.106)	(0.0730)	(0.0730)	(0.0658)
3 - 5 years	0.157	0.0744	-0.00411	0.232***	0.185**	0.0748
	(0.119)	(0.0974)	(0.111)	(0.0759)	(0.0892)	(0.0723)
5 - 10 years	0.0673	0.0290	0.0232	0.295***	0.188**	0.0799
	(0.101)	(0.0774)	(0.0978)	(0.0590)	(0.0732)	(0.0616)
10 + years	0.0969	0.129*	0.0523	0.301***	0.189***	0.0716
	(0.0985)	(0.0723)	(0.0926)	(0.0449)	(0.0628)	(0.0555)
Type of dwelling (ref = Detached House)						
Semi-detached house	0.0987*	0.0561	0.0463	0.0393	0.0174	-0.110***
	(0.0520)	(0.0389)	(0.0398)	(0.0397)	(0.0379)	(0.0289)
Terrace house	-0.0278	0.0784	-0.0189	0.0538	-0.0663	-0.117***
	(0.0700)	(0.0640)	(0.0543)	(0.0515)	(0.0479)	(0.0356)
Apartment	-0.125	-0.0985	-0.00395	-0.129*	0.00519	-0.206***
	(0.0869)	(0.0758)	(0.0942)	(0.0712)	(0.0790)	(0.0392)
Building Energy Rating = DEFG	-0.0431	0.0327	0.0692*	-0.0128	0.0315	0.0219
	(0.0489)	(0.0368)	(0.0374)	(0.0367)	(0.0347)	(0.0274)
Education level (ref = Bachelors Degree and/or Professional Qualification)						
Secondary or Lower	-0.0108	0.000464	-0.0236	-0.112**	-0.0895**	-0.0201
	(0.0616)	(0.0455)	(0.0456)	(0.0438)	(0.0422)	(0.0350)
Technical or vocational qualification	0.0985	0.0222	0.0385	0.0442	0.0171	-0.0377
	(0.0608)	(0.0447)	(0.0470)	(0.0469)	(0.0465)	(0.0335)
Postgraduate degree	0.110	0.0949	0.00777	-0.106*	-0.128**	-0.00616
	(0.0749)	(0.0619)	(0.0606)	(0.0594)	(0.0514)	(0.0464)
Age	-0.00197	-0.00653***	-0.00226	0.00138	-0.00365**	-0.00202*
	(0.00227)	(0.00153)	(0.00160)	(0.00165)	(0.00149)	(0.00121)
Family with one or more children	0.0153	0.0423	0.0474	0.00625	-0.000950	0.0276
	(0.0559)	(0.0411)	(0.0426)	(0.0421)	(0.0398)	(0.0299)
Behaviour (z)	0.0380	0.00608	0.0304*	0.0270	0.0212	0.0342***
	(0.0240)	(0.0171)	(0.0175)	(0.0176)	(0.0170)	(0.0127)
Knowledge (z)	0.00371	-5.15e-05	0.0197	0.0352**	0.0433**	0.0133
	(0.0240)	(0.0177)	(0.0185)	(0.0174)	(0.0171)	(0.0125)
Observations	439	631	716	695	729	825

Standard errors in,parentheses (*** p<0.01, ** p<0.05, * p<0.1). Marginal effects calculated for each variable, holding all others at their mean values. Estimation results are provided in Appendix C.

4.2.1. Structure of the information gap

Of most interest to this analysis are the relationships between positive views of the effects of retrofitting and household interest in retrofitting. As such, we identify certain information possessing significant relationships with household interest in five of the six retrofit measures examined. More positive views on the effects of any retrofit measures on occupant health, property value or condensation/mould growth were not found to lead to a greater likelihood of being interested in retrofitting. Significant evidence is found, however, of a significant relationship between the perceived effects on energy costs and comfort on the likelihood that a household is interested in pursuing certain energy efficiency retrofit measures. As shown, perceived positive impacts on comfort possess a positive effect on the likelihood of being interested in insulation, while positive perceptions regarding energy costs possess a positive effect on the likelihood of being interested in draught-proofing and installing solar panels.

The strongest relationship found is that of the effects on energy costs of high efficiency boilers. For example, holding all other variables at their mean values, those perceiving a 'somewhat positive' effect of installation on energy costs are 19 percentage points more likely to have an expressed interest in installing a high efficiency boiler than those perceiving a neutral impact. This rises to 27.9 percentage points for those perceiving a 'very positive' effect, relative to those perceiving a neutral effect. Regarding insulation, only those perceiving 'very positive' effects on comfort are more likely to be interested in insulation than those perceiving a neutral impact on comfort, possessing a marginal effect of 19.8 percentage points on the probability of being interested, relative to those perceiving a neutral effect on comfort. Only those perceiving 'very positive' effects on costs were found to be more likely to be interested in solar technology, relative to those perceiving a neutral effect, while we do not find any evidence of any information possessing a positive effect on the likelihood of being interested in window and/or door replacement. The most effective pieces of information with regard to inducing retrofits can be identified by ranking the strongest relationships found in models one to six for effects perceived to be 'very positive'. The effect of a high efficiency boiler on costs is followed by the effect of heating controls on costs and comfort, respectively. These are followed in turn by the effect of insulation on comfort, the effect of draught-proofing on costs, the effect of solar panelling on costs and, finally, the effect of a high efficiency boiler on comfort.

These are expected results as cost savings and comfort improvements are the most commonly cited benefits of retrofitting. It is perhaps surprising, however, that some of those pieces of information where the largest asymmetries were found to occur are not found to possess significant relationships with the likelihood of being interested in retrofitting measures. For example, the largest asymmetries between those with an interest in retrofitting and those without were found with regard to the effects of solar panelling on comfort and property value, the effects of insulation on property value and the effects of window/door replacement on energy costs and occupant health. None of these pieces of information were found to have a significant relationship with household interest in retrofitting.

These findings point to the idea that a one size fits all approach to improving interest in retrofitting works may not be suitable. Comfort improvements are found to be the main informational driver of interest in insulation, while costs are found to be the main driver of interest in draught-proofing and solar panels. A combination of cost reductions and comfort gains then drive interest in high efficiency boilers and heating controls. Window and/or door replacements, however, appear not to be driven by information but rather wear and tear, as will be discussed in section 4.2.3.

These findings are comparable to others in the field. Like Aravena et al. (2016), we find comfort improvements and cost reductions to be the main drivers of retrofitting activities. Nair et al. (2010) found that those perceiving themselves as facing high energy costs were more likely to retrofit, which is consistent with our findings, as those perceiving high costs prior to works are likely to expect large reductions in costs as an effect of retrofitting. Ramseier (2013) found that households perceiving environmental benefits to retrofitting were more likely to engage in retrofit works. While we did not examine respondents' perceived environmental impacts, environmental concerns were not found by Aravena et al. (2016) to be a significant driver of retrofit completion in Ireland.

4.2.2. Property type

Holding all other variables at their mean values, less efficient homes were found to be more likely to be interested in draught-proofing. This could be seen as expected, as less efficient homes are less likely to possess appropriate levels of draught-proofing. It might be considered unexpected, however, for those in less efficient homes to not be any more likely to possess an interest in any other measures. It is likely that these households are more likely to perceive greater comfort and cost benefits from retrofitting and, as such, controlling for these expectations reduces the marginal likelihood of being interested in retrofit measures. Those living in semi-detached homes were found to be more likely to be interested in insulation than detached homes, while apartment dwellers were less likely than those in detached homes to be interested in a high efficiency boiler. Relative to detached homes, all other dwelling types were found to be less likely to be interested in solar panels, particularly apartments, whose occupants were found to be over 20% less likely, holding all other variables at their means. This is a naturally expected outcome, as many apartments do not possess a roof to install a solar panel. Moreover, detached houses are more likely to be situated in the countryside than terrace or semi-detached houses and, as such, are less likely to have the delivery of sunlight impeded, increasing the benefits of solar panels.

4.2.3. Tenure and socio-demographic characteristics

The length of time occupants have been living in a home was found to play a role in the likelihood of a respondent being interested in certain measures. Those living in their homes for greater than ten years were found to be more likely to be interested in replacing their windows and/or doors, relative to those living in their home for less than one year. Similarly, all respondents living in their homes for more than one year were found to be more interested in a high efficiency boiler, relative to those living in their home for less than one year, although the differences in likelihoods among categories are not significant. These are perhaps expected, as general depreciation in the condition of boilers and fixings would lead to an increased desire to replace them over time. Those living in their homes for greater than three years were also found to be more likely to be interested in heating controls. Other than age, tenure length was the only variable found to possess a positive relationship with the likelihood of being interested in replacing windows and/or doors. It is likely that home owners do not consider the replacement of windows or doors as significant contributors to improving energy efficiency and instead, wear and tear likely necessitates replacement.

Households with one or more children were not found to be any more or less interested in any measures, while the likelihood of being interested in window and/or door replacement, heating controls and solar panels was found to decrease with age. Relative to those with an undergraduate degree and/or a professional qualification, both those with secondary educations or lower and those with postgraduate degrees were found to be less likely to be interested in either a high efficiency boiler or heating controls. Participants scoring highly with regard to pro-environmental behaviour were found to be more likely to possess an interest in draught-proofing and solar panels, while those with greater energy-related knowledge scores were found to be more likely to be interested in high efficiency boilers and heating controls.

5. Conclusion and policy implications

Improving the energy efficiency of residential dwellings is seen by policy-makers as an important contributor to the mitigation of climate change, a topic of ever increasing interest. Many countries have put in place policies aimed at stimulating the adoption of energy efficiency retrofit measures in private households. These policies generally focus on reducing costs to home owners, which in turn increases the net benefit of retrofitting, making a retrofit more attractive. We examine the drivers of retrofitting from an information point of view, looking mainly at how expected gross benefits can be increased as a means of inducing retrofitting activities. Using survey data, we examine how perceived effects of retrofitting impact on the likelihood that a home owner possesses an expressed interest in engaging in certain retrofit measures.

We find the existence of information asymmetries in many cases between those who have and have not engaged in retrofit measures, while asymmetries are present in almost all instances between those who possess an expressed interest in retrofitting and those who do not. We find that the perception of more positive comfort improvements is the main informational driver of interest in insulation, while perceived cost reductions are found to be the main driver of interest in draught-proofing and solar panels. A combination of cost reductions and comfort gains are then found to be significant drivers of households' interest in high efficiency boilers and heating controls. Window and/or door replacements, however, appear not to be driven by information but rather by wear and tear. Despite the existence of large asymmetries in information regarding effects on property value and occupant health this was not found to possess a statistically significant relationship with possessing an interest in undertaking any of the retrofit measures examined.

We add to the literature on informational drivers of retrofitting by taking an ex-ante approach, examining which information is held by those possessing an interest in retrofitting that is not held by others who have not previously engaged in energy efficiency works in the home. The policy implications of this research are clear. Information asymmetries exist between those who are not interested in retrofitting and those who are. The most effective information that can used to bridge this asymmetry and could lead to a greater interest in retrofitting among home owners are centred around energy costs and comfort. Information regarding the effects of retrofitting on improvements in comfort and reductions in energy costs are found to possess significant relationships with retrofitting. However, these are not equally important across measures. The results of this research therefore imply that policy makers tasked with increasing the adoption of residential energy efficiency retrofit measures should focus on costs and comfort in the dissemination of information to households and not to focus on other benefits, i.e. occupant health, property value or mould. Whether cost and/or comfort benefits should be included or given prominence in the communication of information should depend on the retrofit measure being promoted.

References

Achtnicht, M., 2011. Do environmental benefits matter? evidence from a choice experiment among house owners in Germany. Ecological Economics 70 (11), 2191–2200.

Achtnicht, M., Madlener, R., 2014. Factors influencing german house owners' preferences on energy retrofits. Energy Policy 68, 254–263.

Aravena, C., Riquelme, A., Denny, E., 2016. Money, comfort or environment? priorities and determinants of energy efficiency investments in irish households. Journal of Consumer Policy 39 (2), 159–186.

Arnold, T. B., Emerson, J. W., 2011. Nonparametric goodness-of-fit tests for discrete null distributions. The R Journal 3 (2), 34–39.

Banfi, S., Farsi, M., Filippini, M., Jakob, M., 2008. Willingness to pay for energy-saving measures in residential buildings. Energy economics 30 (2), 503–516.

Bloom, B., Nobe, M., Nobe, M., 2011. Valuing green home designs: A study of energy star® homes. Journal of Sustainable Real Estate 3 (1), 109–126.

Bollinger, B., Gillingham, K., 2010. Environmental preferences and peer effects in the diffusion of solar photovoltaic panels. Unpublished manuscript.

Brounen, D., Kok, N., 2011. On the economics of energy labels in the housing market. Journal of Environmental Economics and Management 62 (2), 166–179.

Caird, S., Roy, R., Herring, H., 2008. Improving the energy performance of uk households: Results from surveys of consumer adoption and use of low-and zero-carbon technologies. Energy Efficiency 1 (2), 149–166.

Cajias, M., Piazolo, D., 2013. Green performs better: energy efficiency and financial return on buildings. Journal of Corporate Real Estate 15 (1), 53–72.

Cameron, T. A., 1985. A nested logit model of energy conservation activity by owners of existing single family dwellings. The review of Economics and Statistics, 205–211.

Chapman, R., Howden-Chapman, P., Viggers, H., Odea, D., Kennedy, M., 2009. Retrofitting houses with insulation: a cost–benefit analysis of a randomised community trial. Journal of epidemiology and community health 63 (4), 271–277.

Clinch, J. P., Healy, J. D., 2000. Domestic energy efficiency in Ireland: correcting market failure. Energy Policy 28 (1), 1–8.

Collins, M., Curtis, J., 2016. An examination of energy efficiency retrofit depth in ireland. Energy and Buildings 127, 170–182.

Collins, M., Curtis, J., 2017. An examination of the abandonment of applications for energy efficiency retrofit grants in ireland. Energy Policy 100, 260–270.

Curtis, J., Devitt, N., Whelan, A., 2015. Using census and administrative records to identify the location and occupancy type of energy inefficient residential properties. Sustainable Cities and Society 18, 56–65.

DellaVigna, S., 2009. Psychology and economics: Evidence from the field. Journal of Economic literature 47 (2), 315–372.

Department of Energy, 2012. Buildings Share of U.S. Primary Energy Consumption (Percent). Buildings Energy Data Book: Table 1.1.1. Department of energy, United States of America.

DG Energy, 2013. Energy performance certificates in buildings and their impact on transaction prices and rents in selected eu countries. Tech. rep., European Commission.

Eppler, M. J., Mengis, J., 2004. The concept of information overload: A review of literature from organization science, accounting, marketing, mis, and related disciplines. The information society 20 (5), 325–344.

European Commission, 2011a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A roadmap for moving to a competitive low carbon economy in 2050. COM(2011) 112 final. European Union.

European Commission, 2011b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Energy efficiency plan 2011. COM(2011) 109 final. European Union.

European Parliament and the Council of the European Union, 2012. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending directives 2009/125/EC and 2010/30/EU and repealing directives 2004/8/EC and 2006/32/EC. European Union.

Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2015. Does energy efficiency matter to home-buyers? an investigation of EPC ratings and transaction prices in England. Energy Economics 48, 145–156.

Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2016. Energy performance ratings and house prices in Wales: An empirical study. Energy Policy 92, 20–33.

Gamtessa, S. F., 2013. An explanation of residential energy-efficiency retrofit behavior in Canada. Energy and Buildings 57, 155–164.

Gillingham, K., Newell, R. G., Palmer, K., 2009. Energy efficiency economics and policy. National Bureau of Economic Research.

Gleser, L. J., 1985. Exact power of goodness-of-fit tests of kolmogorov type for discontinuous distributions. Journal of the American Statistical Association 80 (392), 954–958.

Grösche, P., Vance, C., 2009. Willingness to pay for energy conservation and free-ridership on subsidization: Evidence from Germany. The Energy Journal, 135–153.

Hagentoft, C.-E., 2011. Probabilistic analysis of hygrothermal conditions and mould growth potential in cold attics. impact of weather, building system and construction design characteristics. In: Proceedings of International Conference on Durability of Building Materials and Components.

Hlavinka, A. N., W., M. J., Dharmasena, S., Holland, C., 2016. Forecasting the adoption of residential ductless heat pumps. Energy Economics 54, 60–67.

Howden-Chapman, P., Viggers, H., Chapman, R., OSullivan, K., Barnard, L. T., Lloyd, B., 2012. Tackling cold housing and fuel poverty in new zealand: a review of policies, research, and health impacts. Energy Policy 49, 134–142.

Hyland, M., Lyons, R. C., Lyons, S., 2013. The value of domestic building energy efficiencyevidence from ireland. Energy Economics 40, 943–952.

Jaccard, M., Dennis, M., 2006. Estimating home energy decision parameters for a hybrid energyeconomy policy model. Environmental Modeling & Assessment 11 (2), 91–100.

Jaffe, A. B., Stavins, R. N., 1994. Energy-efficiency investments and public policy. The Energy Journal, 43–65.

Kwak, S.-Y., Yoo, S.-H., Kwak, S.-J., 2010. Valuing energy-saving measures in residential buildings: A choice experiment study. Energy Policy 38 (1), 673–677.

Mills, B., Schleich, J., 2012. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. Energy Policy 49, 616–628.

Nair, G., Gustavsson, L., Mahapatra, K., 2010. Factors influencing energy efficiency investments in existing swedish residential buildings. Energy Policy 38 (6), 2956–2963.

Noonan, D. S., Hsieh, L.-H. C., Matisoff, D., 2013. Spatial effects in energy-efficient residential hvac technology adoption. Environment and Behavior 45 (4), 476–503.

Ormandy, D., Ezratty, V., 2012. Health and thermal comfort: from who guidance to housing strategies. Energy Policy 49, 116–121.

Ramseier, C., 2013. Essays in energy economics and policy: An empirical analysis of the determinants of energy efficiency investment decisions. Ph.D. thesis, ETH Zurich.

Richter, L.-L., 2013. Social effects in the diffusion of solar photovoltaic technology in the uk. Cambridge Working PApers in Economics.

Song, G. B., 2008. Spatial analysis of participation in the waterloo residential energy efficiency project. Master's thesis, University of Waterloo.

Sorrell, S., Dimitropoulos, J., Sommerville, M., 2009. Empirical estimates of the direct rebound effect: A review. Energy policy 37 (4), 1356–1371.

Sorrell, S., Schleich, J., Scott, S., Omalley, E., Trace, F., Boede, U., Ostertag, K., Radgen, P., 2000. Reducing barriers to energy efficiency in public and private organizations. Science and Policy Technology Research (SPRU), University of Sussex, Sussex, UK.

Totten, P. E., OBrien, S., Pazera, M., 2008. The effects of thermal bridging at interface conditions. Building Enclosure Science and Technology Conference.

United Nations, 2015. Paris Agreement.

Willand, N., Ridley, I., Maller, C., 2015. Towards explaining the health impacts of residential energy efficiency interventions: A realist review. part 1: Pathways. Social Science & Medicine 133, 191–201.

Wilson, C., Dowlatabadi, H., 2007. Models of decision making and residential energy use. Annu. Rev. Environ. Resour. 32, 169–203.

Appendix A. Pro-environmental and energy-related behaviour index

The following details questions regarding pro-environmental behaviours and the score attributable to each answer. The mean score across all applicable questions provides a raw score between 0 and 1, with 1 being the most preferred. Observed scores were standardised around 0 for use in analysis, using the following formula:

$$\frac{Score_i - \bar{Score}}{\sigma_{Score}}$$

1. How often would you say you engage in each of the following:
   - Average of:

	Rarely	Sometimes	Often
Turn off lights when leaving a room	0	0.5	1
Decide not to buy products due to excess packaging	0	0.5	1
Leave tap running while brushing your teeth	1	0.5	0
Bring your own bag when shopping	0	0.5	1
Walk of cycle for short journeys (up to 3km)	0	0.5	1
Car share with others who make a similar journey	0	0.5	1
Avoid disposable products in favour of reusable	0	0.5	1

2. Which of the following do you separate from your general waste? (Please select more than one if applicable)

   - Sum of:

0.33: Dry Recycling (paper, cardboard, plastic, tetra-pak)
0.33: Organic Waste (cooked or raw food, teabags, napkins, etc.)
0.33: Glass (bottles and jars)
0.33: I do not separate any of above

3. How do you dispose of small batteries?

   - One of:

1: Bring to shop or recycling centre
1: Bring in to work for recycling
1: Children bring to school for recycling
1: Other collection point
1: Other
0: General waste (do not recycle batteries)

4. Thinking of the last time your household purchased an electric appliance, such as a toaster, washing machine, etc., how much did each of the following influence your decision?

   - If applicable, sum of:

	Had no influence	Had only a minor influence	Had a major influence	Took precedence in influencing the decision
Price	0	0	0	0
Brand Reputation	0	0	0	0
Size	0	0	0	0
Colour	0	0	0	0
Energy efficiency Rating	0	0.33	0.66	1
Other aspect(s)	0	0	0	0

5. What is your households main method of disposing of small electrical and electronic equipment such as toasters, hair-dryers, mobile phones, etc.?

- If applicable, one of:

0:	Put them in household general waste
1:	Return them to retailer
1:	Bring to a recycling centre
1:	Re-use, e.g. give to a family member or friend
1:	Stored at home

6. How often do you change electricity and/or gas provider?

    - One of:

1:	Every year
0.75:	Every 2–3 years
0.5:	Every 4–5 years
0.25:	Every 6–10 years
0:	Never

7. If you own a car, how much did each of the following influence your decision when making the purchase?

    - If applicable, sum of:

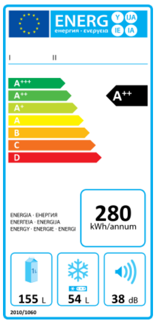
	Had no influence	Had a minor influence	Had a major influence	Took precedence in influencing the decision
Price	0	0	0	0
Annual level of motor tax	0	0	0	0
Fuel consumption	0	0	0	0
Other costs (insurance, servicing, etc.)	0	0	0	0
Environmental concerns (e.g. car emissions)	0	0.33	0.66	1
Resale Value	0	0	0	0
Family Requirements	0	0	0	0
Other aspects	0	0	0	0

Appendix B. Energy-related Knowledge Index

The following details questions regarding energy-related knowledge and the score attributable to each answer. The sum of all scores provides a raw score, which is then standardised about zero using the following formula:

$$\frac{Score_i - \bar{Score}}{\sigma_{Score}}$$

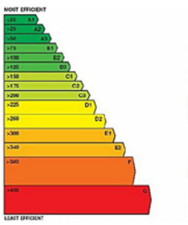
1. To which of the following does this label refer?



- One of:

0: Building Energy Rating
0: Vehicle fuel efficiency label
1: Home appliance energy efficiency label
0: Water efficiency label
0: Don't know

2. To which of the following does this label refer?



- One of:

1: Building Energy Rating
0: Vehicle fuel efficiency label
0: Home appliance energy efficiency label
0: Water efficiency label
0: Don't know

3. What is your yearly electricity consumption, in kilowatt hours?

- One of:

1: 0–5,000
1: 5,000–10,000
1: 10,000–15,000
1: 15,000–20,000
1: 20,000–25,000
1: 25,000–30000
1: 30,000+
0: Don't know

4. How much do you think each of the following fuels cost per delivered unit og energy (kilowatt hour)?

   - Sum of:

	1–10 cent	10–20 cent	20–30 cent	Don't know
Peat	1	0	0	0
Coal	1	0	0	0
Oil	1	0	0	0
Natural Gas	1	0	0	0
Electricity (day rate)	0	1	1	0

5. In each of the following cases, please choose the option which you think produces less emissions per unit energy produced

   - Sum of:

	A	B
A: Peat or B: Oil	0	1
A: Gas or B: Electricity	1	0
A: Gas or B Coal	1	0
A: Coal or B: Oil	0	1
A: Electricity or B: Peat	0	1

6. Do you know how much your last gas bill cost?

   - One of:

1: €0–€25
1: €26–€50
1: €51–€75
1: €76–€100
1: €101–€124
1: €125–€150
1: €150+
0: Don't know

Appendix C. Estimated results of logistic regressions

Model	Insulation (1)	Window/ Door Replacement (2)	Draught-Proofing (3)	High Efficiency Boiler (4)	Heating Controls (5)	Solar Thermal/PV (6)
Perceived Effects on Energy Costs (ref = Neutral)						
Negative (Somewhat/Very)	-	-	1.590	-	0.601	0.477
			(1.089)		(0.877)	(1.580)
Somewhat Positive	-0.358	0.523	0.941*	1.491*	0.950**	0.494
	(0.857)	(0.690)	(0.487)	(0.782)	(0.411)	(0.615)
Very Positive	-0.431	0.702	0.994**	1.938**	1.605***	1.278**
	(0.891)	(0.740)	(0.503)	(0.805)	(0.437)	(0.633)
Perceived effect on comfort (ref = Neutral)						
Negative (Somewhat/Very)	-	-	-	-	-	1.215
						(0.967)
Somewhat Positive	0.780	-0.0876	0.890	0.214	0.965**	0.0906
	(0.720)	(0.459)	(0.674)	(0.310)	(0.388)	(0.299)
Very Positive	1.018	0.126	0.901	0.637*	1.314***	0.0849
	(0.741)	(0.510)	(0.694)	(0.327)	(0.444)	(0.389)
Perceived effect on occupant health (ref = Neutral)						
Negative (Somewhat/Very)	0.896	-	-	-	-	-0.630
	(1.678)					(1.241)
Somewhat Positive	0.122	0.221	0.208	-0.0144	-0.256	0.182
	(0.298)	(0.293)	(0.239)	(0.221)	(0.214)	(0.263)
Very Positive	0.0936	0.479	0.226	-0.175	-0.265	-0.0205
	(0.372)	(0.330)	(0.279)	(0.282)	(0.280)	(0.337)
Perceived effect on property value (ref = Neutral)						
Negative (Somewhat/Very)	-0.0850	-	-	0.952	-	-
	(1.120)			(1.618)		
Somewhat Positive	-0.228	0.475	-	-0.119	0.127	0.00530
	(0.377)	(0.420)		(0.256)	(0.241)	(0.384)
Very Positive	0.204	0.416	-	-0.193	-0.331	0.262
	(0.403)	(0.439)		(0.298)	(0.298)	(0.418)
Perceived effect on condensation/mould growth (ref = Neutral)						
Negative (Somewhat/Very)	0.313	0.0733	0.0440			
	(0.550)	(0.589)	(0.337)			
Somewhat Positive	-0.156	-0.0316	0.00630			
	(0.349)	(0.333)	(0.259)			
Very Positive	-0.222	-0.104	0.175			
	(0.347)	(0.340)	(0.276)			
Length of tenure (ref = Less than 1 year)						
1 - 3 years	0.499	0.334	0.0590	2.616**	0.783	0.523
	(0.569)	(0.550)	(0.498)	(1.123)	(0.574)	(0.666)
3 - 5 years	0.736	0.462	-0.0195	2.329**	1.192*	0.674
	(0.579)	(0.614)	(0.527)	(1.132)	(0.624)	(0.690)
5 - 10 years	0.333	0.193	0.108	2.654**	1.207**	0.712
	(0.518)	(0.530)	(0.459)	(1.103)	(0.565)	(0.630)
10 + years	0.469	0.755	0.239	2.688**	1.211**	0.650
	(0.507)	(0.494)	(0.436)	(1.089)	(0.536)	(0.606)
Type of dwelling (ref = Detached House)						
Semi-detached house	0.437*	0.296	0.206	0.196	0.0895	-0.812***
	(0.231)	(0.204)	(0.177)	(0.197)	(0.195)	(0.227)
Terrace house	-0.131	0.405	-0.0870	0.266	-0.367	-0.876***
	(0.334)	(0.318)	(0.252)	(0.251)	(0.277)	(0.308)
Apartment	-0.651	-0.641	-0.0180	-0.767	0.0270	-2.345**
	(0.501)	(0.575)	(0.431)	(0.499)	(0.410)	(1.089)
Building Energy Rating = DEFG	-0.197	0.176	0.313*	-0.0647	0.166	0.169
	(0.224)	(0.199)	(0.171)	(0.185)	(0.184)	(0.214)
Education level (ref = Bachelors Degree and/or Professional Qualification)						
Secondary or Lower	-0.0515	0.00257	-0.108	-0.582**	-0.470**	-0.150
	(0.294)	(0.252)	(0.208)	(0.232)	(0.224)	(0.261)
Technical or vocational qualification	0.444	0.120	0.170	0.206	0.0833	-0.292
	(0.274)	(0.241)	(0.207)	(0.218)	(0.227)	(0.261)
Postgraduate degree	0.492	0.483	0.0348	-0.547*	-0.703**	-0.0446
	(0.332)	(0.305)	(0.271)	(0.327)	(0.303)	(0.338)
Age	-0.00903	-0.0350***	-0.0102	0.00701	-0.0192**	-0.0154*
	(0.0105)	(0.00862)	(0.00724)	(0.00838)	(0.00789)	(0.00935)
Family with one or more children	0.0700	0.224	0.211	0.0316	-0.00500	0.208
	(0.255)	(0.216)	(0.188)	(0.213)	(0.210)	(0.222)
Behaviour (z)	0.175	0.0326	0.137*	0.136	0.111	0.261***
	(0.111)	(0.0916)	(0.0793)	(0.0899)	(0.0898)	(0.0975)
Knowledge (z)	0.0170	-0.000276	0.0885	0.178**	0.228**	0.102
	(0.110)	(0.0949)	(0.0834)	(0.0891)	(0.0911)	(0.0960)
Constant	-1.170	-1.537	-2.712**	-5.576***	-2.876***	-2.320**
	(1.030)	(1.025)	(1.104)	(1.378)	(0.813)	(0.933)
Observations	439	631	716	695	729	825

Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1)

Year	Number	Title/Author(s) ESRI Authors/Affiliates *Italicised*
2017		
	557	Investment in knowledge-based capital and its contribution to productivity growth: a review of international and Irish evidence *Iulia Siedschlag, Martina Lawless and Mattia Di Ubaldo*
	556	The impact of investment in knowledge-based capital on productivity: firm-level evidence from Ireland *Iulia Siedschlag and Mattia Di Ubaldo*
	555	Making centralised data work for community development: an exploration of area-based training programmes in a unified framework *Seamus McGuinness, Adele Bergin and Adele Whelan*
	554	Residential energy efficiency retrofits: potential unintended consequences *Matthew Collins and Seraphim Dempsey*
	553	COSMO: a new COre Structural MOdel for Ireland *Adele Bergin*, Niall Conroy, *Abian Garcia Rodriguez*, Dawn Holland, *Niall McInerney*, *Edgar Morgenroth* and Donal Smith
	552	Recreational use of public waterways and the impact of water quality Benjamin Breen, *John Curtis* and Stephen Hynes
	551	Willingness-to-pay and free-riding in a national energy efficiency retrofit grant scheme: a revealed preference approach *Matthew Collins and John Curtis*
	550	The product and sector level impact of a Hard Brexit across the EU *Martina Lawless and Edgar L. W. Morgenroth*
	549	Scenarios and distributional implications of a household wealth tax in Ireland *Martina Lawless* and Donal Lynch
	548	Modelling the medium to long term potential macroeconomic impact of Brexit on Ireland *Adele Bergin, Abian Garcia Rodriguez, Niall Mc Inerney*, *Edgar Morgenroth*, Donal Smith
	547	The student perspective on in-school personal electronic devices and online safety: a qualitative study Bryan Coyne and *Selina McCoy*
	546	Recreational angling tournaments: participants' expenditures *John Curtis, Benjamin Breen* and Paul O'Reilly

For earlier Working Papers see http://www.esri.ie