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An Examination of Energy Efficiency Retrofit Depth in Ireland

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Abstract: This study examines energy efficiency retrofit depth in Ireland using data from a national residential grant scheme for energy efficiency upgrades. We specifically examine both the number of retrofit measures adopted per dwelling, and also the comprehensiveness of retrofits upgrades, which are retrofits in excess of the most common and simple retrofit combinations. We find that certain obligated parties, who are obliged by the State to reduce energy consumption in Ireland, vary both positively and negatively in terms of number of retrofit measures relative to private retrofits, but perform negatively with regard to comprehensive retrofits. All parties are found to perform negatively with regard to comprehensive retrofits, relative to private applications. Newer homes, relative to older homes are more likely to invest in more retrofit measures but less likely to engage in more comprehensive retrofits. Regionally, homes in the Greater Dublin Area are less likely to undertake more retrofit measures but more likely to engage in more comprehensive retrofits, while the opposite is true of rural areas. A seasonal trend also exists, with applications made during autumn and winter much less likely to be made for more comprehensive retrofits. Demand for more measures and more comprehensive retrofits does not appear to be affected by financial incentives as the introduction of a bonus for three- and four-measure retrofits has not coincided with any increases in the demand for such retrofits.

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1 Introduction

As part of an ongoing series of energy efficiency directives from the European Union, Ireland is obliged to promote energy efficiency and achieve a targeted reduction in energy consumption of 20% by 2020 (European Parliament and the Council of the European Union, 2012). One means of contributing to this reduction is to improve the energy efficiency of the nation's building stock. Nearly 40% of final energy consumption occurs in buildings, with two thirds of the energy consumed in residential buildings used for space heating (European Commission, 2011). Given variations in energy consumption patterns across Europe, this 20% reduction in energy consumption must be implemented at national level, with each state required to develop a National Energy Efficiency Action Plan (NEEAP), to be revised every three years. Ireland's third NEEAP, published in 2014, concluded that by the end of 2012, Ireland had met 39% of its 2020 target (DCENR, 2014a).

Roughly 50% of residential properties in Ireland are believed to have an energy efficiency status equivalent to a Building Energy Rating (BER) of between D1 and G,[1] which are the lowest six grades on a 15-point scale. This provides an opportunity for policy aimed to improve the energy efficiency of residential buildings and in turn help meet Ireland's obligations under the directive. Ireland's national renovation strategy provides a roadmap of building renovations for residential and other buildings (DCENR, 2014b). The Sustainable Energy Authority of Ireland (SEAI) provides grant aid for home owners to improve the energy efficiency in their homes. With greater understanding of the decision to engage in home retrofitting, it may be possible to identify certain characteristics of households that are more or less likely to pursue multiple-measure retrofits. In the context of the BEH scheme, the number of measures that can be undertaken range from one to four. The four types of measure for which grant aid is available are categorised as roof insulation upgrades, wall insulation upgrades, boiler and heating control upgrades and solar collector installation.

In addition to examining the number of retrofit measures by household characteristics, we also explore the role of obligated parties. Obligated parties are energy distributors and retailers who are obliged under the NEEAP to achieve new energy savings of 1.5% of sales by volume each year to 2020. The role of these parties is described in more detail in section 2. Generally,

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[1] Central Statistics Office (2015) Domestic Building Energy Ratings Release, December 2015, Table 15, available: `http://www.cso.ie/en/releasesandpublications/er/dber/domesticbuildingenergyratingsquarter42015/`

more retrofit measures have the potential to provide greater energy efficiency improvements but, given the heterogeneity in household characteristics and behaviours, it is unclear which households are more likely to engage in more comprehensive retrofits beyond the most common and simple retrofit measures. Without such information, it is much more difficult to identify types of residential buildings where energy efficiency savings can be achieved most easily.

There exist many benefits to engaging in retrofit measures in the home, most notably the reduction in energy costs, increased comfort, environmental benefits (Clinch and Healy, 2000; Gillingham et al., 2009), health benefits (Howden-Chapman et al., 2012) and in many cases, an increased sale value of the property (Hyland et al., 2013). Previous literature has explored the drivers of energy efficiency retrofit behaviour. These include socio-economic conditions and specific household characteristics (Cameron, 1985), the cost and profitability of the home retrofit investment (Amstalden et al., 2007; Sadler, 2003) and the availability of financial subsidies (Neuhoff et al., 2012). Specifically in the Irish context, it has been found that the decision to invest in Energy Efficiency Measures (EEMs) is determined mainly by the cost of investment and gains in energy savings, followed by comfort gains. Moreover, environmental benefits were found to be of little concern (Aravena et al., 2016).

The literature in this field is dominated by analysis of the propensity of households to engage in energy efficiency retrofitting of the home. These studies generally look at whether a household makes a decision to engage in any retrofit measures, regardless of intensity. This literature exists within a wider literature on technology adoption, which is dominated by duration analysis (Hannan and McDowell, 1984; Karshenas and Stoneman, 1993; Kerr and Newell, 2003; Rose and Joskow, 1988). Within the more specific field of residential EEM adoption, there exists a greater variety of analyses. Young (2008) uses the duration model approach to study the replacement of appliances, such as freezers and washing machines in Canadian homes. Descriptive analysis of the trends in residential energy efficiency schemes have also been used (Hoicka et al., 2014; Nair et al., 2010; Neuhoff et al., 2012). Probit models have been used to assess the probability of adoption based on certain determining factors (Aravena et al., 2016; Gamtessa, 2013), while spatial analysis has been used to examine propensities to adopt based on interactions between the proximity to other adopters and other determining factors (Song, 2008). Others qualitatively analyse reasons given for participation by households who have used retrofit subsidisation schemes (Hirst et al., 1981).

Across several countries the proportions of residential retrofits that are attributed by the authors as being comprehensive is quite low. Comprehensive retrofits made up only 2% of claims for tax incentives in Italy and 3% in the Netherlands but In Germany rises to rises to 23% of applications for a loan financing intervention and 6% for a grant aid intervention (Neuhoff et al., 2012). This study focusses not on the propensity to adopt an energy efficiency measure but rather the retrofit depth among those who have adopted one or more EEMs through the Better Energy Homes (BEH) residential energy retrofit grant scheme in Ireland. This research complements a Canadian study by Gamtessa (2013) that considered property and household characteristics that are most closely associated with deeper retrofits.

For the purpose of this research, we analyse two concepts of retrofit depth. The first of these is simply the number of EEMs (e.g. wall insulation, roof insulation, boiler & heating control upgrades, or solar collector installation) and in our dataset can range from one to four measures. The second is referred to as retrofit comprehensiveness. The most common retrofit combinations undertaken by households under the BEH scheme are a one-measure retrofit of boiler with heating controls upgrades and a two-measure retrofit of attic insulation and cavity wall insulation. We view these, alongside all other one-measure retrofits, as simple, or less comprehensive retrofits. We therefore consider retrofit combinations made up of one of these measures, in addition to one or more other measures as a more comprehensive retrofit. The distinction between these two concepts of retrofit depth is that the former is simply a count of EEMs installed, whereas the latter attempts to differentiate by quality of energy efficiency savings potential.

The remainder of the paper is organised as follows: Section 2 provides a description of the BEH data. 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 Descriptive Analysis

The Better Energy Homes scheme, originally known as the Home Energy Savings scheme, commenced in 2009 and is administered by the Sustainable Energy Authority of Ireland (SEAI). It is a grant aid scheme for households to engage in energy efficiency improvements, with grants available for various energy efficiency measures (EEMs). Grants are available for roof/attic insulation, one of three types of wall insulation (cavity insulation, external wall insulation or internal dry-lining), three types of boiler upgrade (oil boiler or gas boiler with heating controls upgrade or heating controls upgrade only) and solar collector (panel or tube) installation. This means that a household may adopt up to a maximum of four EEMs as only one type of wall insulation or boiler upgrade may be awarded grant aid. Upgrades must satisfy SEAI standards for grant applications to be successful. The level of grant aid available has changed over time, with information on the dates of these amendments and the changes made detailed in Table 1. It may be noted that bonus payments for more intense retrofits, i.e three- and four-measure retrofits, were introduced as part of scheme 5.

Table 1: Grant Structure

Measure	Category	Sub-Category	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5
			Mar-09	Jun-10	May-11	Dec-11	Mar-15
			€	€	€	€	€
Roof	Attic Insulation		250	250	200	200	300
Wall	Cavity Wall Insulation		400	400	320	250	300
	Internal Dry-Lining		2500	2500	2000	.	.
		Apartment or Mid-terrace House	.	.	.	900	1200
		Semi-detached or End of Terrace	.	.	.	1350	1800
		Detached House	.	.	.	1800	2400
	External Wall Insulation		4000	4000	4000	.	.
		Apartment or Mid-terrace House	.	.	.	1800	2250
		Semi-detached or End of Terrace	.	.	.	2700	3400
		Detached House	.	.	.	3600	4500
Boiler	High efficiency boiler (oil or gas) upgrade with heating controls		700	700	560	560	700
	Heating Controls upgrade only		500	500	400	400	600
Solar	Solar Heating		.	.	800	800	1200
BER	Before & After Building Energy Rating		100	.	.	.	.
	Mandatory Before & After Building Energy Rating		.	100	80	50	50
Bonus	Bonus for 3rd measure		.	.	.	.	300
	Bonus for 4th measure		.	.	.	.	100

The BEH dataset includes a home-owner estimate of the year of construction of the household and an independently assessed estimate of the Building Energy Rating (BER) of the home prior to EEM adoption. This is provided by the contractor employed to install the relevant EEMs. The BER is measured as the primary energy use per unit floor area of a home each year ($kWh/m^2/yr$) and is also represented on a 15-point alphanumeric scale ranging from A1 to G. Information is also provided on the location of the household, which we have divided into four areas. The first of these is the Greater Dublin Area (Dublin, Meath, Kildare and Wicklow). Secondly, as a proxy for urban areas, we have identified the four largest urban areas outside of the GDA and categorised applications from the counties in which these cities are located (Cork, Limerick, Galway and Waterford). The remaining applications were then divided into the South and East NUTS II region (excluding the GDA, Cork, Limerick and Waterford) and the Border Midlands West NUTS II region (excluding Galway). The dataset includes information on the type of dwelling, i.e. house or apartment, and whether the dwelling is located on an island, in which case households are entitled to 150% of the grant aid available. Also included are data on GDP, measured in constant 2013 prices used to control for whether economic conditions influenced applications. It may be noted that for model estimation, GDP has been standardised about zero. This allows the estimated coefficients of this continuous variable to be interpreted relative to the standard case, where continuous variables are at their mean values. Descriptive statistics for these variables are presented in Table 2.

With regard to the contracting relationship, the majority of applications are made privately, with a household first contacting a SEAI registered contractor, before applying for the grant. The contractor then installs the relevant EEMs, which is followed by a BER assessment and processing of the grant application. Some applications are made via 'obligated parties' and 'counterparties'. Obligated parties are energy distributors and retail energy sales companies. The Energy Efficiency Obligation Scheme, pursuant to the EU Energy Efficiency Directive, imposes a legal obligation on member states to reduce annual energy sales to final consumers by 1.5% by 31 December 2020 (European Parliament and the Council of the European Union, 2012). Obligated parties are required by the State to reach certain energy targets, 20% of which must be achieved by reducing residential energy consumption. The remaining 80% is divided into 5% energy poor residential and 75% non-residential.[2] Of the 11 obligated parties, six have engaged customers via the BEH scheme. Obligated parties and counter parties have unique, anonymous identifiers within the dataset.

The relationship between these obligated parties and other agents involved in the grant process is described in Figure 1. As shown on the right of the Figure, obligated parties make initial contact with households to consider investment in EEMs for their property. If a household is interested in EEM adoption, the obligated party will then engage a counterparty to contact the household with regard to EEM installation. The counterparty will then assign a contractor to complete the works and process the grant application on behalf of the SEAI, who will then award the relevant grant aid, subject to satisfying technical standards. Private applications for grant aid are more

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[2] The obligated parties are SSE Airtricity, Bord Gáis Energy, Bord na Móna, Calor Gas, Electric Ireland, Energia, Flogas, Gazprom, Lissan, Vayu, and Enprova/REIL. Retrofit Energy Ireland Limited (REIL) is an obligated party representing the Irish oil industry for which Enprova is a designated counterparty. For further information see `http://www.seai.ie/eeos/`

common and the process is outlined on the left of Figure 1, where households engage contractors to install EEMs, before applying for the BEH grant, and the grant application is finally processed once the works are completed.

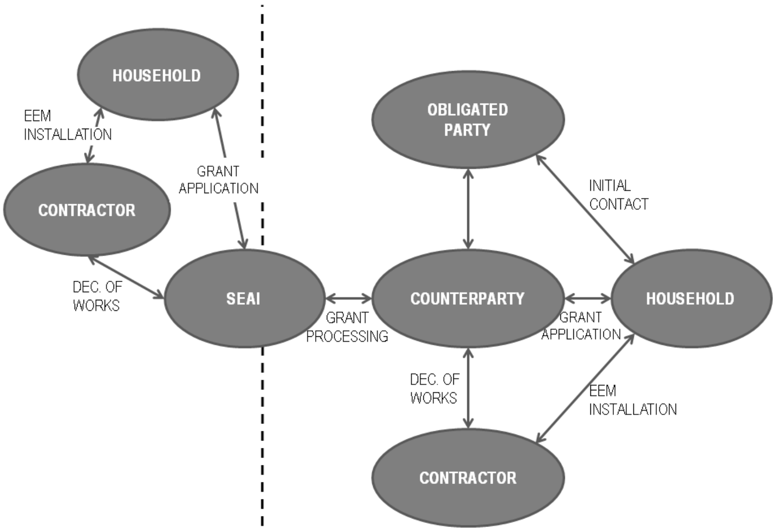

Figure 1: Obligated Parties and their Relationships

Only homes built prior to 2006 are eligible for BEH grant aid, and data is available only for households who made a BEH grant application, which means the data does not include any households who made the decision to adopt an EEM prior to the introduction of the scheme or who adopted an EEM privately, without applying for grant aid. Comparing the number of unique entries in the dataset to the housing stock according to 2006 census data, we infer that roughly 12% of qualifying households in the Republic of Ireland have made an application for a BEH grant.

Greater levels of retrofit depth are likely to result in greater increases in energy efficiency and therefore greater improvements in BER grades. Figure 2 shows the distribution of building energy ratings by letter grade among those households adopting between one and a maximum of four EEMs. Pre-retrofit the distribution of residential energy efficiency by BER letter rating are similar irrespective of the proposed level of EEM adoption (e.g. 1, 2, 3 measure retrofits etc.). Post-retrofit there is a noticeable difference in BER distributions. Households adopting one or two measures are most likely to attain C and D ratings, whereas households adopting three measures are

Table 2: Descriptive Statistics

	Observations	Proportion		Observations	Proportion
Measures			*Dwelling Type*		
1	54,172	0.3274	House	162,199	0.9804
2	103,603	0.6262	Apartment	3,245	0.0196
3	7,457	0.0451		165,444	
4	212	0.0013	*Island Status*		
	165,444		Mainland	165,276	0.9990
Type of Retrofit			Island	168	0.0010
Simple	145,459	0.8792		165,444	
More Comprehensive	19,985	0.1208	*Season*		
	165444		Spring	44,620	0.2697
Year of Construction			Summer	39,884	0.2411
-1950	20,573	0.1244	Autumn	36,405	0.2200
1951 - 1970	25,271	0.1527	Winter	44,535	0.2692
1971 - 1980	33,042	0.1997		165,444	
1981 - 1990	25,718	0.1554	*Obligated Party Status*		
1991- 200	37,020	0.2238	Private	151,560	0.9161
2001 -	23,820	0.1440	OP 1	1,432	0.0087
	165,444		OP 2	582	0.0035
Location			OP 3	9,600	0.0580
GDA	41,635	0.2517	OP 4	1,676	0.0101
County with City	55,080	0.3329	OP 5	298	0.0018
Border Midlands West	35,623	0.2153	OP 6	296	0.0018
South & East (ex. GDA)	33,106	0.2001		165,444	
	165,444				
Other	Observations	Mean	Standard Deviation	Min	Max
GDP (000,000)	164,538[1]	36,400	1,850	34,700	42,700

[1] Number of observations is reduced as GDP data was not available beyond June 2015 at the time of writing.

more likely to attain C or B ratings and those adopting the maximum four measures are most likely to attain B ratings. Looking at each distribution, it appears that greater relative proportions of homes engaging in three- and four-EEM retrofits possessed pre-retrofit BER ratings of F or G , perhaps signifying that homes with greater energy savings potential are more likely to engage in more intense retrofits. Similarly, looking at the pre- and post-works distributions of BERs by retrofit comprehensiveness, more homes with pre-works BERs of F or G appear to be undertaking more comprehensive retrofits. Homes undertaking less comprehensive retrofits improve to C and D ratings, while those undertaking more comprehensive retrofits are most likely to improve to a B or C rating.

It is apparent from Figure 2 that greater BER improvements can be accrued from engaging in multiple-measure and more comprehensive retrofits. As time has passed since the introduction of the BEH scheme there has been an increase in the proportion of energy efficient retrofits comprising of only one measure. Figure 3 shows the quarterly distribution of intensities of retrofits based on the date of grant application. As we can see, throughout the existence of the BEH scheme, relatively few retrofits have comprised 3- or 4-EEMs and over time 1-EEM retrofits have become more prevalent. There

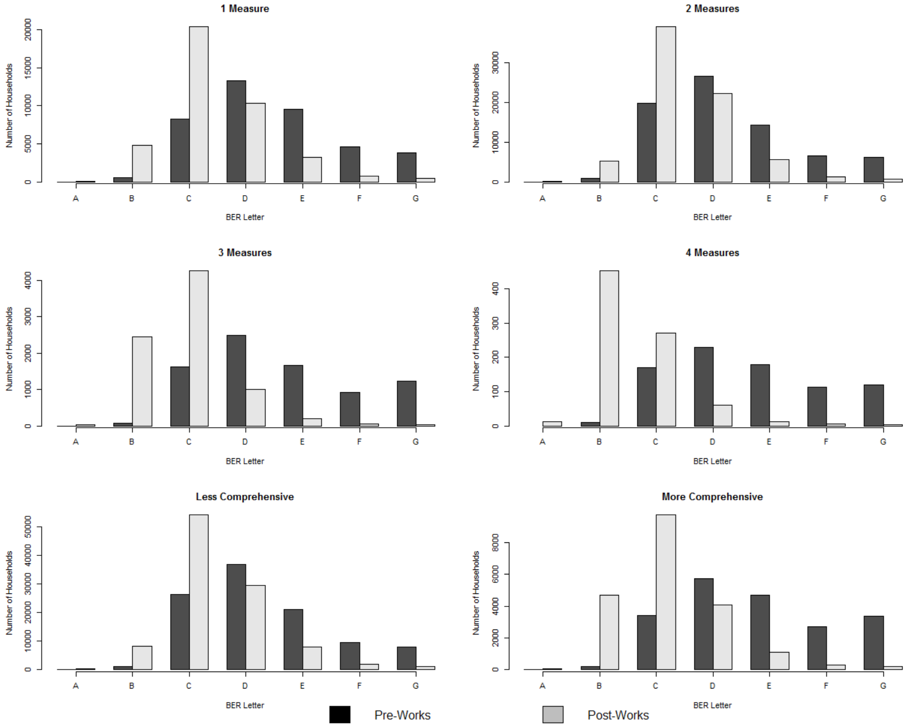

Figure 2: Pre- and Post-Works BER Distribution by Number of Measures Adopted

also appears to be a seasonal effect, with slightly more 1-EEM retrofits in spring and summer, relative to autumn and winter.

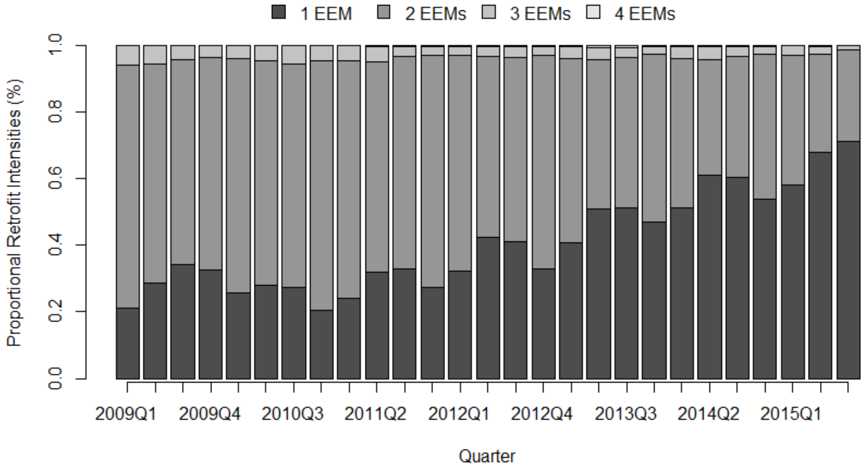

Figure 3: Retrofit Intensity by Quarter

In an attempt to determine what is driving retrofit depth, we examine the role of obligated parties. Figure 4 shows the variation in EEMs installed by obligated party. Very few retrofits are made up of more than two measures, although Obligated Party 6 (OP6) and private installations do have a noticeable proportion of 3-EEM retrofits. OP2 engages households in mostly 1-EEM retrofits, while OP4 and OP5 engage households mostly in 2-EEM retrofits. The remaining obligated parties and private retrofits possess more of a mix of 1- and 2-EEM retrofits.

Another interesting aspect of our data is the nature of the combinations of retrofit measures homes choose. Grant applications comprised of two-EEM retrofits total 62%, 88% of which are made for a combination of attic and cavity insulation. One EEM retrofits make up 32%, of which only 2% are for individual attic or cavity insulation. We thus consider 'shallow retrofits' to be all one-EEM retrofits as well as attic and cavity combinations, as these are likely to be the retrofits with least inconvenience to install. We consider the balance of applications as more comprehensive retrofits. Figure 5 shows the proportional distribution of applications on a quarterly basis. The largest variations occur in the proportion of attic and cavity retrofits, which decline over time; in boiler retrofits, which increase over time; whereas the proportion of deeper retrofits appears to be relatively static over time.

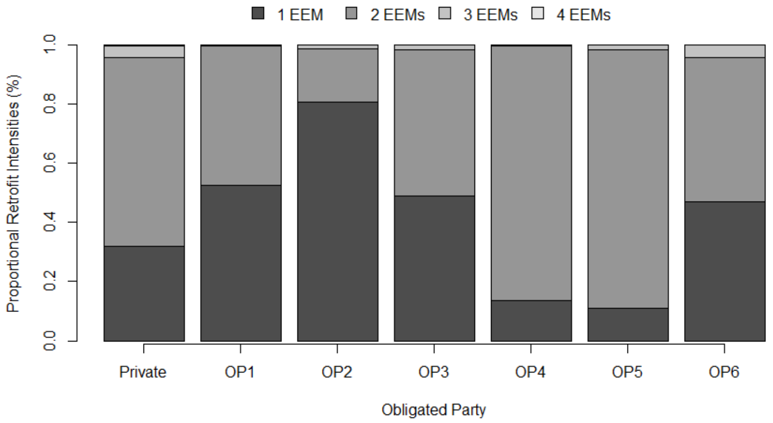

Figure 4: Retrofit Intensity by Obligated Party

One of the main behavioural patterns we aim to investigate is which homes are more likely to invest in more EEMs and also which homes are be more likely to engage in more comprehensive retrofits, as described above. We discuss the modelling frameworks used to examine this in the next section.

3 Methodology

3.1 Modelling the EEM-Adoption Decision in the Context of the BEH Scheme

We follow a similar approach to Gamtessa (2013) in defining the retrofit intensity decision. In the context of the Better Energy Homes scheme, we consider a situation where household H_h may invest in up to four energy efficient measures to retrofit the home. These measures are available to households at a cost K_0, with benefits B_t accruing over time based on energy cost savings each year and increased comfort in the home. Weighing up the benefits and costs, the decision to adopt can be seen as dependent on a positive net present value (NPV) of adoption:

$$NPV = \Sigma_{t=0}^{n}(1+r)^{-t}B_t - K_0 > 0 \tag{1}$$

where r is the discount rate and n is the lifespan of the capital investment, i.e. the retrofit conducted. As households are unlikely to possess full information on the exact monetary and other benefits, a level of uncertainty is introduced. The benefits and costs of EEM adoption also vary due to the number of agents

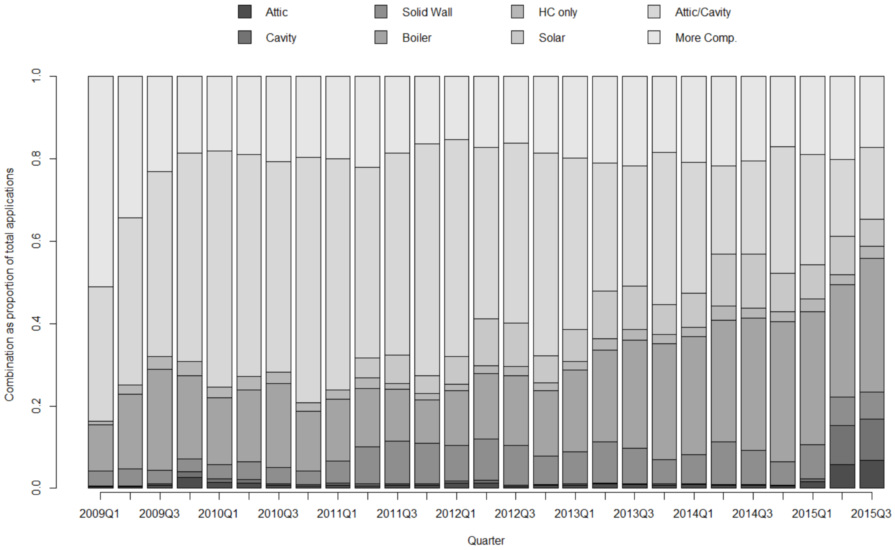

Figure 5: Applications by quarter

involved. The benefits of adoption, B_{hmt} are a function of the characteristics of the household, Z_h, the obligated party, O_m, where applicable, and the time t at which an investment is made. The costs of adoption, K_{hj} are a function of the characteristics of the household, Z_h, the contractor, C_j and the the level of grant aid available to the household, R_h. Households therefore choose to make an EEM investment when the expected net present value of investment is greater than zero:

$$E_0(NPV|Z_h) = E_0\Sigma_{t=0}^{n}(1+r)^{-t}[B_{hmt}|Z_h] - [K_{hj}|R_h] > 0 \qquad (2)$$

This profitability condition alone is not sufficient to define the retrofit intensity decision. Households will choose the number of EEMs which maximises the expected net present value of the retrofit investment, which may vary depending on opportunity costs, behavioural biases such as non-standard beliefs and preferences (DellaVigna, 2007) and non-monetary considerations such as the disruptive impact of EEM installation. As we do not possess information on the characteristics of the decision makers of a household, such as income levels, environmental awareness, etc., we specify our model by assuming that the investment decision Y_i is a function of the vector X_i. This vector which comprises factors similar to those entering the EEM adoption decision such as, B_{hmt}, K_{hj} and r:

$$Y_i = f(X_i) \qquad (3)$$

We use all complete applications from our dataset, i.e. all applications where retrofit works were completed and grant aid awarded. This includes multiple applications from 7,551 homes, making up 4.6% of our sample. Second, third or fourth applications from a household are treated as unique observations as, following the completion of one measure, the decision to make a further investment is affected by a different set of household characteristics to the previous investment decision. This is relevant to the bonus payment system. With the introduction of bonus payments, homes which had previously undertaken retrofit measures via the BEH scheme could receive a bonus payment for retrofits of fewer than three measures if the retrofit contributed to a total of three or four measures since the introduction of the grant scheme. These make up only 246 applications, or 0.0015% of successful applications.

This paper aims to understand the relationship between the characteristics outlined above and the number of retrofit measures that households adopt, conditional on the decision to engage in an energy efficient retrofit. We specify two models of estimation in order to exploit differences in how the data may be interpreted. An ordered logistic regression is used to estimate the probability of a household choosing each available level of retrofit intensity, whereas a double-truncated Poisson regression model specifically accounts for the integer values of the dependent variable between 1 and 4. These are described in sections 3.2 and 3.3 respectively. These models fail to take into account time-variance in certain characteristics, as it is possible that a household may choose not to invest ($Y = 0$) at a time t in order to generate a greater net present value at a later date. For a discussion of this type of duration analysis Karshenas and Stoneman (1993) provide a detailed review of modelling technology diffusion.

3.2 Number of EEMs: Ordered Logistic Regression

As the number of EEMs adopted by a household is both categorical and ordered, in that more EEMs generally lead to greater improvements in energy efficiency, even though improvements do not occur at equal increments due to the range of EEMs available and the inherent differences between household characteristics, an ordered logistic model is used. The ordered logit is used to measure the probability that the number of measures applied for, Y_i, is equal to a certain outcome. This is estimated as the probability that a linear function of the independent variables is within the range of the cutpoints estimated for the outcome:

$$Pr(Y_i = n) = Pr(k_{n-1} < \Sigma\beta_i X_i + u_i \leq k_n) \tag{4}$$

where X_i is a vector of independent variables made up of Z_h,R_h, C_j and O_m, and u_i is assumed to be normally distributed. The coefficients β_i are estimated along with the cutpoints k_1, k_2,...,k_{N-1}, where N is the number of possible outcomes, in this case four. the cutpoints k_0 and k_N are taken as -∞ and +∞, respectively (Cameron and Trivedi, 2005).

3.3 Number of EEMs: Double-Truncated Poisson Regression Model

An alternative approach to modelling retrofit intensity in the context of the BEH scheme is to exploit the count nature of the dataset. By the design of the scheme we know that the number of measures each applicant adopts is a positive integer value between 1 and 4. Previously, Gamtessa (2013) used a zero-truncated count model to examine retrofit behaviour, whereas in this instance we additionally incorporate truncation from above. We follow Suaiee (2013) who describes the double-truncated poisson model, in which the number of measures applied for, Y_{ijm}, is modelled as a function of the explanatory variables outlined in section 3.1 as follows:

$$E[Y_i = y_i | X_i, 1 \leq y_i \leq 4] = \frac{\Sigma_{k=1}^{4} \frac{\lambda_i^k}{(k-1)!}}{\Sigma_{k=1}^{4} \frac{\lambda_i^k}{k!}} \tag{5}$$

$$\lambda_i = e^{\Sigma\beta_i X_i} \tag{6}$$

where X_{ijm} is again a vector of explanatory variables comprised of Z_i,R_i, C_j and O_m and $E[Y_i]$ is the number of EEMs we expect from a randomly selected household, i.e. the mean of the variable Y_i and β_i is a vector of estimated coefficients.

3.4 More Comprehensive Retrofits: Logistic Regression

As discussed in section 2, we examine the likelihood that an application will be made for a more comprehensive retrofit, i.e. any retrofit comprised of two or more measures, excluding attic and cavity insulation retrofits. Viewing this as a binary choice between a less or a more comprehensive retrofit, a logistic regression is used to model the probability of an application being for a deeper retrofit. This probability is estimated as follows:

$$P(More\ Comp._i) = Y_i = \frac{e^{(\Sigma\beta_i X_i)}}{1 + e^{(\Sigma\beta_i X_i)}} \tag{7}$$

where Y_i represents the probability of an application being made for a more comprehensive retrofit, X_i is a vector of characteristics, as discussed in section 3.1 and β is a vector of estimated coefficients.

4 Results and Discussion

4.1 Number of EEMs: Ordered Logistic

An ordered probit specification was considered in addition to the ordered logit but results were consistent across both models and model comparison using the Akaike and Schwarz Bayesian information criterion, alongside Likelihood Ratio chi-squared statistics, indicated that the ordered logit specification performed slightly better. Table 4 presents these ordered logistic regression results (Model 1) alongside those of the zero-truncated Poisson regression (Model 2) and double-truncated Poisson model (Model 3), with Table 5 showing the average marginal effects calculated for each. Following the discussion of Cameron and Trivedi (2005), we estimate average marginal effects as our independent variables do not lend to a common or standard case to which we can base our analysis.

4.1.1 Obligated Parties

We discuss first the estimation results of Model 1 and note that variation exists across obligated parties, relative to private installations. The estimation results show that, relative to private installations, certain obligated parties are either more or less successful in engaging households in multiple-measure retrofits. Obligated parties (OPs) 1 and 2 are more likely to provide one-measure retrofits, while OPs 4, 5 and 6 are more likely to provide households with higher numbers of EEMs. OP4 possesses the greatest deviation from private applications, being 17 percentage points less likely to engage homes in 1-EEM retrofits and 9 percentage points more likely to engage in 2-EEM retrofits, as shown in Table 5. OPs 5 and 6 are both over 14 percentage points less likely to engage in 1-EEM retrofits, over 8 percentage points more likely to engage homes in 2-EEM retrofits and over 5 percentage points more likely to engage homes in 3-EEM retrofits.

4.1.2 Location and property type

We find that household location and type have a statistically significant association with number of EEMs. Breaking down households by year of construction, these divisions have a clear association with number of EEMs. Dwellings built after 1970 are more likely to invest in more EEMs than those built in the 1950s and 1960s, which are in turn more likely than pre-1950 dwellings. Regional variation exists with homes in rural areas more likely to undertake higher number EEM retrofits. The Border Midlands West region possesses the highest likelihood of engaging in a 2-, 3- or 4-EEM retrofit, followed by rural areas in the South and East region. This is followed by urban areas outside of the GDA, with the GDA the region with the highest prevalence of 1-EEM retrofits. Apartments, and dwellings located on islands are less likely to engage in deeper retrofits. A slight seasonal trend exists, with applications made during winter least likely to be for 1-EEM retrofits, although this effect is very small, with winter applications being only 3.85 percentage points less likely to be made for a 1-EEM retrofit than summer applications.

4.1.3 Scheme rule changes

Scheme rule changes have had mixed impacts. The highest levels of retrofit intensity occurred during Scheme 2, followed by Schemes 1 and 3, in turn followed by Schemes 4 and 5, consecutively. Scheme 5 possesses the lowest level of retrofit intensity despite this scheme specifically including an incremental bonus for installing three or four measures. This suggests that the number of EEMs retrofitted is not responsive to changes in financial incentives implemented in Scheme 5. It is also possible that the pattern observed in behaviour with regard to changes in the scheme is reflective of processes not included in the data. For example, there may be an early adopter effect prevalent in the earlier schemes that are not observed within the models. Promotional events may also have had an effect, as promotional material for the BEH scheme has varied over time, and may have been more effective in engaging homes with deeper retrofits during these schemes. These effects may become clearer with additional research.

4.2 Number of EEMs: Double-truncated Poisson

The regression estimates from the double-truncated Poisson model largely confirm the findings of the ordered logistic regression but also allow for a different interpretation of the estimated marginal effects. These are interpreted as variations in the number of measures applied for, rather than variations in the probability of applying for a certain number of measures.

4.2.1 Obligated Parties

On average, OP1 and OP2 engage households in 0.27 and 0.69 fewer EEMs than private grant applications, respectively. OPs 4, 5 and 6, meanwhile, engage households in an average of 0.4–0.5 EEMs more than private installations. While the number of EEM retrofits via OP3 is statistically different than from private grant applications, at a practical level the number of EEM retrofits are equivalent. The variation in retrofit intensity across obligated parties may reflect differing strategies for meeting their energy reduction targets. Obligated parties have set targets of energy reduction, 20% of which must be met in residential buildings, and calculated using the following formula (SEAI, 2014):

$$Target = (\frac{Supplier\ Annual\ Sales}{Total\ Eligible\ Supplier\ Sales\ Volume}) * 550 GWh/annum \quad (8)$$

For every energy saving measure implemented by an obligated party, a credit is awarded toward this target. The credits available for various measures under the BEH scheme are outlined in Table 3. Some obligated parties may focus on providing retrofits that earn the most credits, whereas others may choose to focus on attic and cavity retrofits as these provide less disruption and may be easier to implement. The outcome is that some obligated parties may provide more multiple-measure retrofits and more retrofits in total although this may perhaps lead to lesser energy efficiency improvements. For example, attic and cavity insulation in a house provides a credit of 4,550 kWh, whereas the highest grade of boiler with heating controls upgrade provides a credit of 8,070 kWh. Strategically, obligated parties may be making a choice between quality and quantity. As heating system upgrades and solid wall insulation provide the most credits, obligated parties may focus primarily on these EEMs because they provide greater credit toward their targets. This focus on certain types of retrofit measures over others may indicate mismatches between the credits awarded and the cost to the obligated parties of performing these measures, as obligated parties often offer discounts on energy bills to households who undertake retrofit measures.

The variation in credits available for differing energy efficient measures is reflective of greater energy efficiency improvements than can be achieved through some measures relative to others. Instead of focusing on the number of retrofit measures it is also instructive to examine the factors associated with more comprehensive refits, which we return to in section 4.3.

Table 3: Energy credits available for measures under the BEH scheme

Measure	Energy Credits House *kWh/yr*	 Apartment *kWh/yr*
Attic/Roof Insulation	1,300	800
Cavity Wall Insulation	3,250	2,050
Internal Dry-Lining	5,000	3,200
External Wall Insulation	5,900	3,750
High efficiency boiler with heating controls	4,790 - 8,070	3,050 - 5,130
Heating Controls only	3,700 - 4,070	2,350 - 2,580
Solar Heating	1,650	1,050

[1] Credits available online: `http://www.seai.ie/EEOS/Energy-Saving-Credits-Table.pdf`.

4.2.2 Property type, location and scheme rule changes

The same pattern with regard to the age of dwellings is seen in the Poisson specification, with a progressive increase in the number of EEMs undertaken when moving from older to more recently built dwellings. Properties built since 2000 invest in 0.5 EEMs more, on average, than similar properties built pre 1950. Properties outside of the GDA invest in 0.6–0.7 EEMs more, on average than similar properties in the GDA. This regional variation in the number of EEMs is likely due to the characteristics of homes across regions. In the Greater Dublin Area, where cavity walls are less common than in rural areas, the one-EEM retrofit of a boiler and heating controls upgrade is most popular, while in the rural areas of the Border Midlands West and South and East regions, cavity walls are more common, meaning attic and cavity retrofits can be completed quite easily and with less disruption than a boiler replacement or installation. Scheme 5, which provides a bonus payment for 3- and 4-measure retrofits, is again found to possess the lowest level of retrofit intensity.

Table 4: Retrofit Intensity Response to Household and Other Characteristics

Model	Ordered Logit (1)	Double-Truncated Poisson (2)
Scheme		
Scheme 2	0.280***	0.123***
	(0.0158)	(0.0083)
Scheme 3	-0.0267	0.0329***
	(0.0180)	(0.0098)
Scheme 4	-0.324***	-0.0654***
	(0.0194)	(0.0108)
Scheme 5	-0.663***	-0.264***
	(0.0549)	(0.0356)
Year of Build (ref=pre-1950)		
1951 - 1970	0.622***	0.228***
	(0.0206)	(0.0129)
1971 - 1980	0.919***	0.323***
	(0.0196)	(0.0121)
1981 - 1990	1.114***	0.378***
	(0.0209)	(0.0124)
1991- 200	1.074***	0.367***
	(0.0194)	(0.0118)
2001 -	1.190***	0.399***
	(0.0213)	(0.0126)
Region (ref=GDA)		
County w/ City	1.271***	0.493***
	(0.0144)	(0.0091)
Border Midlands West	1.529***	0.561***
	(0.0164)	(0.0097)
South & East (ex. GDA)	1.379***	0.521***
	(0.0165)	(0.0098)
Apartment	-0.683***	-0.263***
	(0.0386)	(0.0250)
GDP (z)	-0.191***	-0.0717***
	(0.00840)	(0.0049)
Island	-1.683***	-0.647***
	(0.177)	(0.152)
Season (ref=Spring)		
Summer	-0.116***	-0.0344***
	(0.0167)	(0.0092)
Autumn	-0.0455***	-0.0104
	(0.0167)	(0.0091)
Winter	0.0928***	0.0306***
	(0.0157)	(0.0084)
Obligated Party (ref=private)		
ID 1	-0.449***	-0.217***
	(0.0617)	(0.0437)
ID 2	-0.825***	-0.600***
	(0.120)	(0.0954)
ID 3	-0.0140	-0.0317**
	(0.0254)	(0.0159)
ID 4	1.142***	0.366***
	(0.0560)	(0.0287)
ID 5	1.077***	0.3302***
	(0.129)	(0.0617)
ID 6	0.949***	0.362***
	(0.123)	(0.108)
Constant		0.123***
		(0.0083)

Standard errors in parentheses (*** $p<0.01$, ** $p<0.05$, *$p<0.1$)

Table 5: Estimated Marginal Effects on Retrofit Intensity

	Ordered Logit				Double-truncated Poisson
Number of Measures	1	2	3	4	
Scheme					
Scheme 2	-0.0499***	0.0365***	0.0129***	0.0004***	0.161***
Scheme 3	0.0049	-0.0038	-0.0011	-0.00003	0.0427***
Scheme 4	0.0631***	-0.0512***	-0.0115***	-0.0003***	-0.0837***
Scheme 5	0.133***	-0.112***	-0.0204***	-0.0006***	-0.3273***
Year of Build (ref=pre-1950)					
1951 - 1970	-0.133***	0.118***	0.0147***	0.00042***	0.281***
1971 - 1980	-0.191***	0.165***	0.0254***	0.0007***	0.4044***
1981 - 1990	-0.226***	0.191***	0.0340***	0.0010***	0.4765***
1991- 200	-0.219***	0.186***	0.0322***	0.0009***	0.462***
2001 -	-0.240***	0.201***	0.0379***	0.0011***	0.5045***
Region (ref=GDA)					
County w/ City	-0.278***	0.244***	0.0332***	0.0009***	0.618***
Border Midlands West	-0.323***	0.276***	0.0459***	0.0013***	0.7109***
South & East (ex. GDA)	-0.298***	0.259***	0.0382***	0.0011***	0.6553***
Apartment	0.135***	-0.113***	-0.0213***	-0.0006***	-0.3462***
GDP (z)	0.0350***	-0.0269***	-0.0078***	-0.0002***	-0.1264***
Island	0.343***	-0.307***	-0.0355***	-0.0010***	-0.7348***
Season (ref=Spring)					
Summer	0.0217***	-0.0169***	-0.0046***	-0.0001***	-0.0442***
Autumn	0.0084***	-0.0064***	-0.0018***	-0.00005***	-0.0135
Winter	-0.0168***	0.0126***	0.0040***	0.0001***	0.0397***
Obligated Party (ref=private)					
ID 1	0.0877***	-0.0721***	-0.0151***	-0.0004***	-0.2723***
ID 2	0.166***	-0.141***	-0.0238***	-0.0007***	-0.6898***
ID 3	0.0026	-0.0020	-0.0005	-0.00001	-0.0408**
ID 4	-0.172***	0.0928***	0.0771***	0.0026***	0.4822***
ID 5	-0.164***	0.0918***	0.0707***	0.0024***	0.4342***
ID 6	-0.149***	0.0881***	0.0590***	0.0019***	0.4759***

Significance of estimated coefficient *** $p<0.01$, ** $p<0.05$, * $p<0.1$

4.3 More Comprehensive Retrofits

We consider more comprehensive retrofits to be any retrofit comprised of two or more measures, excluding attic and cavity insulation retrofits. The logistic regression results are reported in Table 6 for models 3-5 and the estimated average marginal effects for these models are report in Table 7. The results of this model provide a different perspective to those of section 4.1 and 4.2, finding differing relationships between the explanatory variables and the probability of engaging in a more comprehensive retrofit, as opposed to a retrofit with more EEMs. We first discuss model 3, with models 4 and 5, which examine early adopter effects, discussed in detail in section 4.3.3.

4.3.1 Obligated parties

We find that all obligated parties are less likely to engage in more comprehensive retrofits, relative to private applications. Applications made via OP 3 and OP 6 are found to be only 3–4 percentage points less likely for more comprehensive retrofits than private applications. All other obligated parties, however, are found to be over 8 percentage points less likely to engage homes in more comprehensive retrofits, relative to private retrofits. This differs from our previous results in that those parties who appear to engage homes in more EEMs are more likely to be engaging homes in attic and cavity insulation retrofits than in a deeper retrofit. This indicates that obligated parties are not interested in trying to engage homes in the deepest possible retrofits but instead focus on certain types of retrofits, either boiler and heating controls or attic and cavity insulation retrofits.

4.3.2 Location and property type

In the previous results we found, unexpectedly, that newer homes were more likely to engage in retrofits with more EEMs. We now find a result more in line with prior expectations. There is an incremental downward pattern in the likelihood of applying for a more comprehensive retrofit moving across dwelling age from oldest to newest. Compared to pre 1950s properties, those built from 1951-1970 are 10.8 percentage points less likely to engage in a comprehensive retrofit, declining to 17.1 percentage points less likely for properties built from 2001 onward. This finding is consistent with the premise that greater energy savings potential exist in older properties and therefore greater returns are feasible from more comprehensive retrofits.

Regionally, applications from outside of the GDA are less likely to be comprised of deeper retrofits, particularly those in the Border Midlands West and other urban areas. Apartments are found to be more likely to engage in more comprehensive retrofits, being 4.7 percentage points more likely to engage in a deeper retrofit than houses. Seasonally, autumn and winter applications are less likely to be made for more comprehensive retrofits than applications made in either spring or summer, although the effect size is quite small at 2–3 percentage points. The positive coefficient on the GDP variable indicates that the likelihood of applying for grant aid for a more comprehensive retrofit increased with economic growth.

4.3.3 Scheme rule changes and early adopter effects

Over the lifetime of the BEH scheme, the likelihood of homes engaging in more comprehensive retrofits has fallen incrementally, with applications made during Scheme 5 being 5 percentage points less likely to apply for such a retrofit than those made during scheme 1. This effect is much smaller in magnitude than that found for number of EEMs reported in Table 5, signalling that the trend in intensity is due to the proportion of attic and cavity retrofits falling and the proportion of boiler retrofits rising, as shown in Figure 5. Nonetheless, this confirms a negative trend in retrofit depth.

Models 4 and 5 examine the presence of an early adopter effect, whereby those households who are more likely to engage in more comprehensive retrofits are also more likely to become engaged with the BEH scheme earlier than others. We estimate our model using a dummy variable for the first 12 months of the BEH scheme.[3] Models 4 and 5 show that an early adopter effect does appear to exist and that there are regional variations in the earlier adopter effect. Regionally, the early adopter effects is greatest in the South and East region.

5 Conclusion

To help meet Ireland's energy savings targets through improvements in energy efficiency, residential retrofits are required across much of the housing stock. The BEH scheme has been successful in helping over 160,000 homes engage in energy efficiency retrofits to October 2015. The improvement in the energy efficiency of Ireland's housing stock could be aided by increasing the intensity of the retrofits which are being undertaken. We examine

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[3] We selected 12 months as the length of the early adopter effect by estimating Model 4 with varying early adopter lengths. The estimated parameters on the dummy variables for any periods of greater than 12 months were not statistically significant effect.

Table 6: Likelihood of applications for more comprehensive retrofits

Model	(3)	(4)	(5)
Scheme			
Scheme 2	-0.0322	0.134***	0.135***
	(0.0219)	(0.0325)	(0.0326)
Scheme 3	-0.180***	-0.00747	-0.00979
	(0.0262)	(0.0362)	(0.0362)
Scheme 4	-0.217***	-0.0591	-0.0657*
	(0.0286)	(0.0367)	(0.0368)
Scheme 5	-0.561***	-0.435***	-0.439***
	(0.0781)	(0.0803)	(0.0804)
Year of Build (ref=pre-1950)			
1951 - 1970	-0.713***	-0.714***	-0.717***
	(0.0240)	(0.0240)	(0.0240)
1971 - 1980	-0.957***	-0.959***	-0.963***
	(0.0237)	(0.0237)	(0.0237)
1981 - 1990	-1.223***	-1.223***	-1.225***
	(0.0275)	(0.0275)	(0.0275)
1991- 2000	-1.317***	-1.316***	-1.315***
	(0.0253)	(0.0253)	(0.0253)
2001 -	-1.382***	-1.381***	-1.380***
	(0.0298)	(0.0298)	(0.0298)
Region (ref=GDA)			
County w/ City	-0.377***	-0.378***	-0.428***
	(0.0203)	(0.0203)	(0.0228)
Border Midlands West	-0.390***	-0.387***	-0.426***
	(0.0231)	(0.0231)	(0.0264)
South & East (ex. GDA)	-0.181***	-0.180***	-0.264***
	(0.0225)	(0.0225)	(0.0259)
Apartment	0.405***	0.406***	0.407***
	(0.0484)	(0.0484)	(0.0485)
GDP (z)	0.113***	0.120***	0.117***
	(0.0121)	(0.0121)	(0.0121)
Island	-0.115	-0.104	-0.107
	(0.240)	(0.240)	(0.240)
Season (ref=Spring)			
Summer	0.0609***	0.0390	-0.372***
	(0.0226)	(0.0228)	(0.0238)
Autumn	-0.217***	-0.262***	0.0403*
	(0.0236)	(0.0244)	(0.0228)
Winter	-0.327***	-0.374***	-0.258***
	(0.0229)	(0.0238)	(0.0244)
Obligated Party (ref=private)			
ID 1	-1.571***	-1.575***	-1.596***
	(0.173)	(0.173)	(0.173)
ID 2	-2.188***	-2.186***	-2.199***
	(0.307)	(0.307)	(0.307)
ID 3	-0.483***	-0.485***	-0.486***
	(0.0416)	(0.0416)	(0.0416)
ID 4	-1.374***	-1.380***	-1.361***
	(0.145)	(0.145)	(0.145)
ID 5	-1.149***	-1.158***	-1.143***
	(0.310)	(0.310)	(0.310)
ID 6	-0.300*	-0.304	-0.315*
	(0.182)	(0.182)	(0.183)
First 12 Months		0.229***	0.0320
		(0.0326)	(0.0452)
County w/ City*First 12 Months			0.242***
			(0.0493)
Bor. Mid. West*First 12 Months			0.195***
			(0.0541)
South & East*First 12 Months			0.357***
			(0.0524)
Constant	-0.588***	-0.724***	-0.684***
	(0.0279)	(0.0343)	(0.0349)

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

Table 7: Estimated Marginal Effects on the Propensity to Engage in a More Comprehensive Retrofit

Model	(3)	(4)	(5)
Scheme			
Scheme 2	-0.0034	0.0141***	0.0142***
Scheme 3	-0.0185***	-0.0007	-0.00090
Scheme 4	-0.0220***	-0.0058	-0.0064*
Scheme 5	-0.0505***	-0.0376***	-0.0379***
Year of Build (ref=pre-1950)			
1951 - 1970	-0.1084***	-0.108***	-0.108***
1971 - 1980	-0.135***	-0.135***	-0.136***
1981 - 1990	-0.159***	-0.159***	-0.159***
1991- 200	-0.167***	-0.166***	-0.166***
2001 -	-0.171***	-0.171***	-0.171***
Region (ref=GDA)			
County w/ City	-0.0398***	-0.0398***	-0.0393***
Border Midlands West	-0.0410***	-0.0407***	-0.0402***
South & East (ex. GDA)	-0.0204***	-0.0203***	-0.0203***
Apartment	0.0471***	0.0472***	0.0473***
GDP (z)	0.0115***	0.0122***	0.0119***
Island	-0.0112	-0.0101	-0.01040
Season (ref=Spring)			
Summer	0.0069***	0.0044*	0.004*
Autumn	-0.0224***	-0.0272***	-0.0268***
Winter	-0.0325***	-0.0374***	-0.0371***
Obligated Party (ref=private)			
ID 1	-0.0955***	-0.0957***	-0.0962***
ID 2	-0.109***	-0.109***	-0.109***
ID 3	-0.0429***	-0.0431***	-0.0431***
ID 4	-0.0893***	-0.0895***	-0.0889***
ID 5	-0.0807***	-0.0811***	-0.0804***
ID 6	-0.0284*	-0.0287*	-0.0297*
First 12 Months		0.0243***	0.0227***

Significance of estimated coefficient *** $p<0.01$, ** $p<0.05$, * $p<0.1$

energy efficiency retrofit depth in an attempt to identify whether certain households are more likely to engage in deeper retrofits, whether the introduction of bonus payments for more intense retrofits has had the desired effect, and whether obligated parties have had an effect on retrofit intensity. We examine two measures of retrofit depth, the number of retrofit measures undertaken, and the propensity to engage in what we have termed a more comprehensive retrofit. An ordered logistic regression and a double-truncated Poisson regression are used to analyse the number of retrofit measures undertaken, while a logistic regression is used to examine more comprehensive retrofits. These three modelling specifications are used to analyse Irish data with regard to energy efficiency retrofit depth.

The introduction of a bonus payment for more intense retrofits has not had, to date, the desired effect, with retrofit depth falling following the introduction of the bonus payment. Some obligated parties are found to be more likely to engage households in more retrofits measures, while others are more likely to engage in fewer measures, relative to private applications. All obligated parties are less likely to engage households in a more comprehensive retrofit compared to private household applicants. This is caused by differing strategies across obligated parties in attaining credits toward their residential energy reduction targets. A reconfiguration of the credit scheme for obligated parties could encourage more comprehensive retrofits. Rural homes are more likely to invest in more EEMs than urban homes, but less likely to engage in more comprehensive retrofits. This is likely due to the prevalance of construction characteristics of homes in rural versus urban areas, with more homes in rural areas built with cavity walls, allowing for more cavity insulation retrofits. Relative to older homes, newer homes are found to be more likely to engage in more EEMs but less likely to engage in more comprehensive retrofits. Apartments are less likely than houses to engage in more EEMs but more likely to engage in more comprehensive retrofits.

This is the first research that has examined residential energy retrofit intensity in an Irish context and reveals a number of policy implications. Most importantly, perhaps, retrofit intensity does not appear to be responsive to bonus payments for deeper retrofits and, as such, other policy tools should be used to boost retrofit depth. The overall aim of policy is to improve the energy efficiency of the Irish housing stock and other policy tools may be possible, such as targeted advertising in areas with higher proportions of homes found to be more likely to engage in deeper retrofits. For example, Aravena et al. (2016) found gains in energy savings to be one of the main determinants of making an energy efficient investment. If more information available to households engaging with the BEH scheme on the energy cost savings potential associated with more comprehensive retrofits, retrofit intensity might rise. As the SEAI already provides an indicative BER and estimated yearly energy cost of varying home types and ages, it may be possible to provide customised information to BEH applicants for different retrofit combinations.[4] This would potentially reduce uncertainty surrounding the returns to investing in an energy efficient retrofit. An alternative policy option might be the introduction of grant aid for household energy efficiency auditing. If households were able to have their home independently and expertly assessed, an energy efficiency advisory report, recommending a package of measures which would improve a home's energy efficiency may provide more clarity for home owners as to what is the most preferred combination of measures. The grant aid scheme examined by Gamtessa (2013), for example, included an energy audit prior to any energy efficiency works, which included a recommendation as to an optimal package of measures, although that research did not examine the proportion of the recommendations that were actually undertaken. Another policy option might be to add more energy efficient measures to the BEH scheme. For example, obligated parties may claim credits for window glazing, external door replacement, biomass boilers and heat pumps, among others. Were more options to be available to home owners, the intensity of retrofits might increase. While some of these measures are relatively inexpensive, their inclusion under the grant scheme could act as a nudging mechanism to encourage home owners to engage in more comprehensive and efficient retrofits. Improvements in depth may also be accrued via obligated parties, with incentives offered to parties who engage in deeper retrofits. While this may not be feasible in terms of credits offered, as these are calculated based on energy savings, other incentives could potentially be explored. A further market solution may also be possible, whereby independent third parties (or counterparties), who co-ordinate retrofits under the grant scheme charge a set commission to contractors, which could rise in line with retrofit depth, providing an incentive for these coordinating parties to engage homes in deeper retrofits.

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[4] A guide to building energy rating for homeowners (SEAI). Available onlne: `http://www.seai.ie/Your_Building/BER/Your_Guide_to_Building_Energy_Rating.pdf`

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	530	Exporting under Financial Constraints : Firm-level evidence from EU countries Gavin Murphy and *Iulia Siedschlag*
	529	Fisheries Management for different angler types *John Curtis and Benjamin Breen*
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