



Working Paper No. 700

May 2021

An examination of energy efficiency retrofit scheme applications by low-income households in Ireland

Arya Pillai^{a,b}, Miguel Tovar Reaños^{a,b} and John Curtis^{a,b}

Abstract: This paper studies the determinants of why low-income households in Ireland abandon energy efficiency retrofit applications using administrative data from a targeted energy efficiency grant. By applying for the scheme the applicants overcome any financial barriers for undertaking retrofits and demonstrate their willingness to improve the energy efficiency of their dwellings. Hence this study contributes to the scarce literature on non-financial barriers preventing low-income households from undertaking energy efficiency retrofits. Contrary to previous findings, we find that the higher the number of retrofits to be implemented, the lower the probability of households abandoning their applications. We also find that planning to undertake retrofits such as ventilation, which can significantly improve the health and safety standards of the dwelling, is associated with a higher probability of abandonment. Both findings indicate the presence of key behavioural and informational barriers which prevent low-income households from fully comprehending the purpose or benefits of proposed energy efficient retrofits. Our findings also suggest that higher grant expenditure on dwellings with poor pre-works energy efficiency rating and on retrofits such as attic insulation and heating system upgrades may have the highest energy efficiency improvements per unit of expenditure. Within the constraints of limited budgets for retrofit grant supports, this research can inform the redesign of grant schemes to achieve the greatest aggregate improvements in residential building energy efficiency.

Key words: Energy efficiency, energy retrofits, retrofit intensity, vulnerable households, Abandonments JEL: Q38, Q41, Q48, H23

Corresponding author: arya.pillai@esri.ie

* Acknowledgements: This project has been funded by the Sustainable Energy Authority of Ireland under the SEAI Research, Development Demonstration Funding Programme 2019, Grant number 19/RDD/427. Funding and support was also provided by the ESRI's Energy Policy Research Centre, and Science Foundation Ireland (SFI) MaREI Centre for Energy, Climate and Marine (MaREI - 12/RC/2303).

a: The Economic and Social Research Institute, Dublin

b: Department of Economics, Trinity College, Dublin

1 Introduction

Apart from contributing significantly in the campaign against global warming, reducing energy inefficiency in the dwellings of low-income households can help break the cycle of poverty perpetuated by higher energy costs. Previous studies show that poorer households often forgo some life necessities such as food and medicines to cover high energy bills (Anderson et al., 2010; Raissi and Reames, 2020; Healy and Clinch, 2004). Buildings' energy efficiency can also affect physical and mental health and the well-being of residents (Campbell et al., 2014; European Parliament, 2016). Low adoption of energy efficiency retrofits by low-income households is attributed to four barriers: economic, informational, behavioural and, administrative (Sorrell et al., 2004, 2000; Raissi and Reames, 2020; European Parliament, 2016). The economic barriers include lack of savings and inability to obtain credit to upgrade inefficient appliances and infrastructure. Poorer households, in the face of uncertain future earnings, are also highly risk averse (Ozaki, 2011; Chen et al., 2017). Across many European countries, subsidies for the adoption of energy saving technologies is a core policy instrument to protect vulnerable households and overcome financial barriers for the adoption of these technologies (see Kyprianou et al., 2019). However, there are households who make a decision to engage in an energy efficiency retrofit free from financial constraints (i.e. have fully funded grant support) but abandon their retrofit applications due to non-financial barriers, which are often harder to identify. While the abandonment of energy efficiency scheme applications has already been investigated (see Collins and Curtis, 2017a), the abandonment of programs targeting vulnerable households has received little attention in the existing literature.

This study utilises an administrative dataset comprising application and processing information related to a targeted energy efficiency grant in Ireland. By applying for this scheme, low-income households overcome the financial barriers cited earlier. However, the abandonment of retrofit applications shows that significant barriers exist for low-income households even when financial barriers are eliminated. The main objective of this study is to better understand the factors associated with the abandonment of retrofit grant applications in the absence of financial barriers. Additionally, we quantify how improvements in building energy efficiency among low-income households are associated with retrofit measure type and building attributes.

Aside from financial constraints to the adoption of energy saving technologies, other barriers may prevent low-income households from undertaking retrofits. Behavioural and informational barriers may arise due to the lower educational status of many low-income households (Achnicht and Madlener, 2014; Abrahamse and Steg, 2011, 2009; Chen et al., 2017). Barriers can similarly be higher for low-income households considering their precarious employment conditions. Poorer households are often less aware of their energy consumption metrics and the potential savings which can be obtained from upgrading (Chen et al., 2017; Day and Gunderson, 2015). Many low-income households further fail to differentiate between maintenance costs and energy efficiency improvements (Chen et al., 2017; Poortinga et al., 2004). Lack of awareness about the support schemes available can be another important barrier in undertaking retrofits. In some cases, low-income households do not participate because a particular scheme may not be addressing their specific vulnerability (or they often misunderstand scheme eligibility conditions) (Raissi and Reames, 2020). Households may also forgo lengthy application procedures which are often

accompanied by disruptive practical arrangements needed for retrofits due to short-term practicalities (Raissi and Reames, 2020). Such hidden costs raise significant barriers to the adoption of energy efficiency measures. These barriers can be more significant in the adoption of retrofit measures which cause more disruption (Collins and Curtis, 2017a).

Previous research finds that energy efficiency retrofit grants can significantly improve energy efficiency in private dwellings (Collins and Curtis, 2017b; Hoicka et al., 2014). However, the literature is sparse in the case of grants specifically targeting low-income households. When it comes to the quantification of the savings attributed to programs that offer grants for the adoption of energy efficiency technologies to vulnerable households, Beagon et al. (2018) and Hernández and Phillips (2015), utilising data from Ireland and USA, find that participation in energy efficiency programs reduce energy consumption. In this study, we quantify improvements in energy efficiency metrics savings attributed to the programme and identify which retrofit type (i.e. insulation, ventilation etc) can bring the highest gains. In addition, we identify the dwelling types with higher potential for improvements.

2 Data and methodology

2.1 Data

This study utilises the administrative dataset consisting of the application and processing information related to the Better Energy Warmer Homes Scheme (BEWHS), which provides free energy efficiency upgrades to low-income households in Ireland. Scheme eligibility is confined to owner-occupier households that are recipients of at least one of six social welfare schemes targeting low-income households. Only dwellings built before 2006 can apply for the scheme. The scheme administrator, Sustainable Energy Authority of Ireland (SEAI), rather than the household applicant, decides the type of energy efficiency retrofit measures to be installed for each dwelling following a building energy audit. The scheme follows 4 main steps: application, energy survey, retrofit works, and post-works energy audit stages.

There are 35,395 unique applications (or dwellings) in the dataset used for this study. The raw data had 49,564 observations. This included cancelled applications (10,426) and entries with missing information (2,845). The cancelled applications are applications which are not eligible for the scheme and hence not relevant for this study and are therefore excluded. Also excluded are 898 applications made in the year 2020, as the natural conclusion of those applications was not available at time of data access. The dataset includes applications at various stages of processing, for example, those awaiting eligibility letters (early application stage) to those whose grant payments are processed (advanced post-works stage). An application is considered ‘abandoned’ when it’s status is listed as cancelled on the instruction of the homeowner or as those who cannot be contacted 30 days after a notice was issued by SEAI. There are 3,312 ‘abandoned’ applications in the dataset (9%). Descriptive statistics of these variables are provided in Table 1.

Table 1: Descriptive statistics

| Variable | Frequency | Proportion |
|---------------------------|---------------|---------------|
| Total applications | 35,395 | 100.00 |
| Application stage | | |
| Processing | 5,893 | 0.17 |
| Abandoned | 3,312 | 0.09 |
| Works completed | 26,190 | 0.74 |
| Person employed | 9,540 | 0.27 |
| Dwelling type | | |
| Apartment | 232 | 0.01 |
| House | 31,054 | 0.88 |
| Others | 4,109 | 0.12 |
| Year built | | |
| Before 1920s | 2,671 | 0.08 |
| 1920s-1930s | 2,677 | 0.08 |
| 1940s-1960s | 5,939 | 0.17 |
| 1960s- 1980s | 14,165 | 0.4 |
| 1990s - 2006 | 9,943 | 0.28 |
| Seasons | | |
| Summer | 7,142 | 0.2 |
| Autumn | 8,767 | 0.25 |
| Winter | 7,932 | 0.22 |
| Spring | 11,554 | 0.33 |
| Retrofit type dummy | | |
| Heating system | 3,145 | 0.09 |
| Wall insulation | 20,809 | 0.59 |
| Attic insulation | 22,971 | 0.65 |
| Lighting | 26,440 | 0.75 |
| Network costs | 1,508 | 0.04 |
| Ventilation | 29,170 | 0.82 |
| Miscellaneous | 18,778 | 0.53 |

The retrofit type categories in the data include heating system upgrades, attic insulation, wall insulation, network costs, ventilation, lighting and miscellaneous. The miscellaneous category includes retrofits related to draught proofing and hot water cylinder jacket installation. An indicator for seasonality is constructed to study the effect of the timing of an application on its advancement. Letter grades for Building Energy Rating (BER) ratings, from A (high energy efficiency) to G (low energy efficiency) is available for all properties pre-retrofit. The change in BER between pre and post energy efficiency retrofit denominated in $kWh/m^2/year$ is available for only a subset of applications (2,447 observations). A property’s BER is undertaken by SEAI’s registered BER assessors (SEAI, 2020). Summary statistics of these variables and other variables related to household and dwelling sizes are provided in Table 2.

Table 2: Summary statistics for indicators used in the study

| Indicators | Mean | SD |
|----------------------------------|---------|---------|
| Household size (count) | 2.27 | 1.47 |
| Duration of processing (months) | 0.13 | 0.47 |
| Dwelling size (sqm) | 115.14 | 49.18 |
| Retrofits per dwelling (count) | 8.58 | 3 |
| Change in BER (kWh/m2/year) | 68.59 | 133.29 |
| Grant amount (euros) | 4070.26 | 5761.83 |
| Grant amount by type of retrofit | | |
| Heating system | 357.85 | 1793.81 |
| Wall insulation | 1442.48 | 3959.97 |
| Attic insulation | 520.75 | 609.56 |
| Lighting | 14.27 | 10.82 |
| Network costs | 0.25 | 9.66 |
| Ventilation | 690.36 | 673.69 |
| Miscellaneous | 16.13 | 26.11 |

2.2 Methods

This study employs two separate analytical methods to study the two research questions. These are explained in the next subsections.

2.2.1 Method used for the analysis of abandonment of applications

The first objective of this paper is the determinants of why low-income households in Ireland abandon energy efficiency retrofit applications. We model the probability of abandonment as a function of dwelling, household and application processing related characteristics. The dependent variable in this case is a dummy variable indicating whether the application was abandoned by the applicant or not. The estimation method employed in this case is a logit regression. We follow the methodology employed by (Greene, 2003).

$$Pr(\text{Abandonment} = 1|Z_i) = f(\beta_0 + \beta_1 Z_i + u_i) \quad (1)$$

Z_i in this case refers to the matrix of household, dwelling and application related characteristics. Household related characteristics include household size and person employed dummy. Dwelling related characteristics include the year of construction, dwelling type and dwelling location. Application related characteristics include the total count of (planned) retrofit measures, duration of processing, year of application and dummy variables for retrofit type. β_0 and β_1 are the estimated parameters and u_i is the random error component. f is the logistic function. Since logit parameter estimates are difficult to interpret, odds ratios ($OR = e^\beta$) are calculated and the statistical significance is tested as different from $OR = 1$.

2.2.2 Method used for the analysis of post-works efficiency gain

Improvement in energy efficiency is modelled as a function of retrofit measures undertaken and dwelling characteristics. The dependent variable in this case is the change in energy rating (in kWh/m²/year), calculated as the difference between post-works and pre-works BER. A large positive value for the dependent variable indicates significant energy efficiency improvement.

$$\Delta BER = \beta_0 + \beta_1 Z_i + u_i \quad (2)$$

Z_i in this case relates to dwelling related characteristics and retrofit details. Dwelling related characteristics included are dwelling size, year of construction and dwelling type, while retrofit details include expenditure on each retrofit measure type.

3 Results

3.1 Factors affecting abandonment of applications

As mentioned in the data section, 9% of applications are abandoned. The dependent variable in this case is a dummy variable indicating whether an application was abandoned or not. The

results of regression analysis studying the factors affecting abandonment are presented in Table 3. Two versions of the model are estimated, with and without year and location controls. The justification behind this is to account for changes in the administration of the scheme over years¹. The common coefficients are consistent across both models. Model 2 with year and location controls is the preferred model for discussion since it has a lower Akaike information criterion (AIC), which is a measure of the goodness of fit of the model (Wooldridge, 2010). In addition to the odds ratios reported in Table 3, predicted probability estimates are reported in Table 4 to facilitate further discussion. Figure 1 plots some of the estimated predicted probabilities.

Model 2 in Table 3 shows that a larger number of (planned) retrofit measures, which is an indicator of retrofit intensity, reduces the probability of abandonment. The predicted probability of abandonment for a dwelling where only 1 retrofit measure is planned is 9 percentage points higher compared to a dwelling where 5 retrofit measures are planned (refer predicted probability estimates in Table 4). In contrast Collins and Curtis (2017a) find that higher retrofit intensity among more affluent households is associated with a higher probability of abandonment of applications to the retrofit subsidy scheme.

The probability of abandonment also varies by type of planned retrofit measure. Planning to undertake retrofit measures like attic insulation and ventilation is associated with a higher probability of abandonment. Ventilation retrofits increase the probability of abandonment by 6 percentage points, as shown in Table 4. It should be noted that retrofit type and intensity is decided by the grant administrator, not the grant applicant, and is based on technical criteria to maximise energy efficiency. There is also evidence that seasonality plays some role in abandonment; applications made in spring and winter have a higher probability of abandonment compared to other seasons (refer model 2 in Table 3). This is similar to the findings of Collins and Curtis (2017a). To summarise, undertaking a number of smaller measures is associated with a lower probability of abandonment, possibly attributable to lower levels of disruption for households.

Certain upgrades types, such as ventilation² or attic insulation have a higher probability of abandonment compared to a less intensive upgrade like lighting. Retrofits incorporating ventilation are more than 4 times more likely to be abandoned compared to retrofits without ventilation measures. Attic insulation retrofits are 2.1 times more likely to be abandoned compared to retrofits without attic insulation, whereas wall insulation retrofits are 0.6 times as likely to be abandoned compared to retrofits without wall insulation (as per Table 3). It is not clear why abandonment rates are higher in these instances but they maybe associated with installation disruption (e.g. emptying attic storage).

While the duration of application processing has a statistically significant association with the probability of abandonment in both models, our preferred model 2, shows that the effect has decreased across time (see Table 3). For the years 2015–2017 a higher duration of processing was associated with a higher probability of abandonment, however this effect disappears or reverses

¹ For instance, the type of retrofit activities prescribed by SEAI after 2018 have changed to include deeper retrofits activities (retrofits which bring a larger energy efficiency improvement) compared to the pre-2018 scheme administration.

² Ventilation related retrofit includes roof ventilation, wall vents, magnetic filtration device, mechanical extract vent, air tightness testing etc.

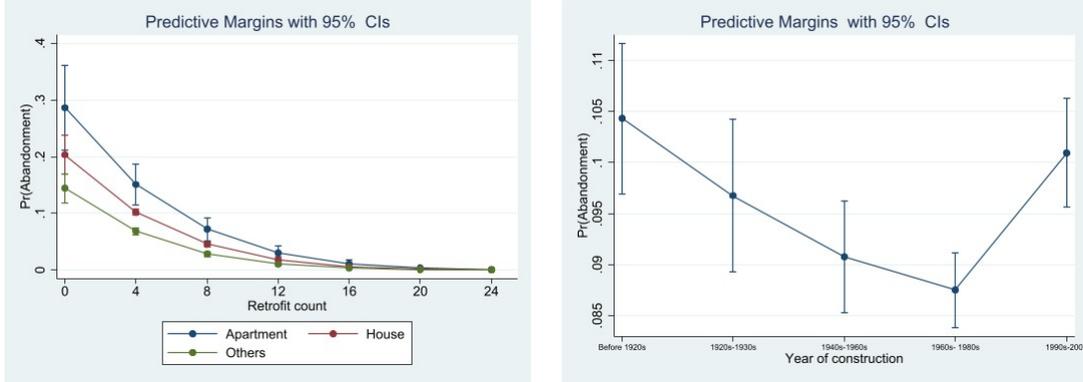
Table 3: logit regression for estimating factors influencing abandonment of applications

| | <i>Dependent variable: Abandonment dummy</i> | |
|----------------------------------|--|------------------------|
| | 1 | 2 |
| Retrofit count | 0.721*** (0.0187) | 0.732*** (0.0190) |
| Duration of processing (months) | 0.448*** (0.0284) | |
| Dwelling type (ref cat: Houses) | | |
| Apartment | 1.820*** (0.373) | 1.974*** (0.431) |
| Others | 0.499*** (0.0354) | 0.525*** (0.0390) |
| Household size | 0.846*** (0.0193) | 0.850*** (0.0202) |
| Person employed (ref cat: No) | 0.614*** (0.0422) | 0.615*** (0.0441) |
| Season (ref cat: Summer) | | |
| Autumn | 0.876* (0.0609) | 0.921 (0.0676) |
| Winter | 1.119 (0.0834) | 1.299*** (0.102) |
| Spring | 1.462*** (0.0896) | 1.703*** (0.112) |
| Year built (ref cat: 1990s-2006) | | |
| Before 1920s | 1.088 (0.0937) | 1.069 (0.0982) |
| 1920s-1930s | 0.893 (0.0806) | 0.920 (0.0888) |
| 1940s-1960s | 0.704*** (0.0535) | 0.813** (0.0668) |
| 1960s- 1980s | 0.714*** (0.0456) | 0.759*** (0.0520) |
| Retrofit type dummies | | |
| Heating system | 1.090 (0.151) | 1.077 (0.154) |
| Wall insulation | 0.715** (0.0935) | 0.658*** (0.0868) |
| Attic insulation | 2.291*** (0.263) | 2.108*** (0.245) |
| Ventilation | 5.023*** (0.646) | 4.142*** (0.542) |
| Network costs | 0.221*** (0.0396) | 0.247*** (0.0451) |
| Lighting | 0.0126*** (0.00133) | 0.0103*** (0.00112) |
| Miscellaneous | 1.763*** (0.147) | 1.686*** (0.142) |
| Duration*Year interaction | | |
| 2015 | | 1.654*** (0.169) |
| 2016 | | 2.025*** (0.352) |
| 2017 | | 3.704*** (0.515) |
| 2018 | | 1.050 (0.111) |
| 2019 | | 0.0169*** (0.00411) |
| Constant | 1.513*** (0.134) | 2.324*** (0.507) |
| Year-duration interaction | No | Yes |
| County dummies | No | Yes |
| Observations | 35,395 | 35,394 |
| AIC | 12460.25 | 11354.87 |

Standard error in parentheses; Odds ratios given in the table. *** p<0.01, ** p<0.05, * p<0.1

in later years. This could be attributed to efficiency improvements in the administration of the scheme with the passage of time. Table 3 shows that having at least one employed resident reduces the probability of abandonment by 2 percentage points. This can be linked to the evidence which supports the hypothesis that poorer socio-economic status results in higher informational barriers (Abrahamse and Steg, 2011). Households with fewer residents have a higher probability of abandonment compared to larger households. In Figure 1 we plot the predicted probabilities of abandonment that are attributed to retrofit intensity differentiated by dwelling types using the estimates from Table 3. In the first panel of Figure 1 the dwelling type of the applicants has a significant influence on the decision to abandon. Apartments show a higher probability of abandonment compared to houses. This result is consistent with Collins and Curtis (2017a), who argue that the barriers associated with retrofits in apartment buildings are greater than in other building types. Finally, dwellings built between 1940s and 1980s are between 0.7–0.8 times

Figure 1: Predicted probabilities of abandonment at various levels of retrofit count and year of construction



as likely to abandon their grant application compared to the reference category of dwellings built between the 1990s and 2006. There is no statistical difference in probability of abandonment of applications of earlier built dwellings (i.e. pre 1940s) compared to the reference category. Again, it is not clear why dwellings in the 1940s–1980s vintage though as illustrated in Figure 1, the maximum difference in predicted probabilities of abandonment across construction years is less than 2 percentage points.

3.2 Post-works efficiency gain

The pre-works energy rating was available for 2,447 observations only. The dependent variable in this case is the difference between pre- and post-works BER denominated in $kWh/m^2/year$. A large positive value for change in BER indicates significant energy efficiency improvement. The results of regression analysis, estimated by ordinary least squares (OLS), are reported in Table 5. The first model estimates energy efficiency improvement as a function of total expenditure on retrofits. The second model itemises expenditure by retrofit type, which illustrates how the benefit of efficiency improvements varies by expenditure across retrofit measure types. We control for dwelling characteristics including pre-works BER rating, year of construction, type and size of the dwelling.

As anticipated higher grant expenditure is associated with higher improvement in energy efficiency rating after controlling for the initial BER. Expenditure is measured in natural logarithms, meaning that the 22.09 coefficient (model 1, Table 5) can be interpreted as meaning that on average BER improves by $0.22 kWh/m^2/year$ for a 1% increase in grant expenditure. This shows that the scheme in general succeeds in improving the energy efficiency of the applicant dwellings. Properties with the lowest pre-works BER rating, labelled ‘G’, experience an improvement of $277 kWh/m^2/year$ in energy efficiency relative to the reference category of those with a ‘B’ BER, controlling for other attributes. The corresponding figure for ‘C’ rated properties is just $11 kWh/m^2/year$, though not statistically different than improvements experienced by ‘B’ rated properties. The coefficients estimates associated with ‘E’, ‘F’ and ‘G’ rated properties are all statistically significant, indicating greater levels of improvement among the least energy

Table 4: Predicted probabilities of abandonment at various levels of independent variables

| | Predicted probability | Standard error |
|--|-----------------------|----------------|
| Retrofit count = 5 | 0.081*** | 0.001 |
| Retrofit count = 1 | 0.166*** | 0.011 |
| Apartments (ref: House) | 0.036** | 0.010 |
| Household size (at 6) | 0.066*** | 0.003 |
| Household size (at 1) | 0.103 *** | 0.002 |
| Person employed (ref: unemployed) | -0.023*** | 0.003 |
| Season of application (ref: summer) | | |
| Autumn | -0.004 | 0.003 |
| Winter | 0.013*** | 0.004 |
| Spring | 0.026*** | 0.003 |
| Construction period (ref: pre 1920s) | | |
| 1920s-1930s | -0.007 | 0.005 |
| 1940s-1960s | -0.013** | 0.010 |
| 1960s-1980s | -0.016*** | 0.004 |
| 1990-2006 | -0.003 | 0.004 |
| Retrofit measures (ref: specified measure not installed) | | |
| Heating system upgrade | 0.003 | 0.007 |
| Wall insulation | -0.020*** | 0.001 |
| Attic insulation | 0.036*** | 0.005 |
| Ventilation retrofit | 0.06*** | 0.005 |
| Networks costs | -0.056*** | 0.005 |
| Lighting | -0.361 *** | 0.012 |
| Miscellaneous | 0.025*** | 0.004 |

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

efficient properties. This shows that the grant scheme is achieving the greatest energy efficiency improvements within the most energy inefficient properties, a finding consistent with other grant schemes (Collins and Curtis, 2017b).

Table 5: Regression results for energy efficiency improvements from retrofits

| | Dependent variable: Change in energy rating (OLS) | |
|--|---|----------------------|
| | 1 | 2 |
| Pre-works BER (ref cat: B) | | |
| C | 11.38 (21.60) | 18.52 (21.08) |
| D | 33.98 (21.73) | 41.49* (21.20) |
| E | 71.07*** (22.14) | 79.66*** (21.60) |
| F | 114.8*** (22.67) | 122.7*** (22.12) |
| G | 277.6*** (22.66) | 282.3*** (22.10) |
| Dwelling type | | |
| Apartment | -23.87 (25.52) | -21.56 (24.90) |
| Others | -4.289 (5.909) | -0.781 (5.767) |
| Dwelling size | -0.179*** (0.0524) | -0.0233 (0.0534) |
| Year of construction (ref cat: Before 1920s) | | |
| 1920s-1930s | 22.91* (12.98) | 21.27* (12.66) |
| 1940s-1960s | 9.368 (10.78) | 14.63 (10.51) |
| 1960s-1980s | 10.97 (10.10) | 15.09 (9.909) |
| 1990s-2006 | 18.88* (10.43) | 21.03** (10.27) |
| Log of total invoice amount | 22.09*** (1.996) | |
| Log of invoice amount by category | | |
| Heating system | | 12.08*** (0.904) |
| Attic insulation | | 2.347*** (0.802) |
| Lighting | | -8.265 (6.580) |
| Ventilation | | 0.719 (1.949) |
| Wall insulation | | 1.940*** (0.648) |
| Miscellaneous | | -5.440*** (1.082) |
| Constant | -149.5*** (28.59) | -3.852 (33.34) |
| Observations | 2,447 | 2,447 |
| R-squared | 0.489 | 0.515 |

Estimated coefficients are given in the table. Standard errors in parentheses
 *** p<0.01, ** p<0.05, * p<0.1

Model 2 in Table 5 considers grant expenditures across retrofit types. The highest improvement in energy efficiency per unit grant expenditure is associated with heating system upgrades, followed by attic insulation, followed by wall insulation. For heating system upgrades the model estimates says that a 1 percent increase in grant expenditure, on average, is associated with 0.12 $kWh/m^2/year$ improvement in BER rating. Coefficient estimates related to lighting and ventilation retrofits are not statistically significant. In the case of ventilation, the retrofits may reflect a necessity for health and safety purposes, rather than a measure that directly improves energy efficiency. The negative and statistically significant coefficient on the ‘Miscellaneous’ retrofit measure (-5.440) is unexpected. In practice expenditure on items such as draught proofing or insulation jackets on water cylinders would not lead to a deterioration in measured energy efficiency so the negative coefficient may possibly reflect omitted variable bias.

Irrespective of retrofit measure type, it should be noted that this analysis only considers quantitative energy efficiency improvements and other benefits such as those related to comfort and health are not considered. Further research is needed to measure and understand these non-energy benefits, including reduced condensation or better overall comfort (see Kerr et al., 2017).

4 Conclusion and policy implications

The multidimensional benefits of improving energy efficiency in the dwellings of low-income households can be significant to the lives of the dwellers and important to the emission reduction strategies of many nations across the world. Some of the most important barriers faced by low-income households towards energy efficiency include economic and informational barriers (Sorrell et al., 2000; Crandall-Hollick and Sherlock, 2018; Bird and Hernández, 2012). Even in the absence of these impediments, low-income households face significant difficulties in getting retrofits undertaken (Raissi and Reames, 2020; Reames, 2016). The programme considered in this study is a targeted initiative to improve energy efficiency of dwellings of vulnerable households. Since the scheme offers free retrofits for qualifying dwellers, participation in the scheme by such households should be high. However, we observe that 9% of eligible households abandon their retrofit application. This rate of abandonment is lower compared to abandonment rates in partially subsidised energy retrofit schemes such as Better Energy Homes Scheme by SEAI in Ireland with a 15% rate of abandonment (Collins and Curtis, 2017a). Making an application implies that the informational barriers are low and that occupants are motivated to have their homes retrofitted. The grant scheme itself obviates any financial barriers. Hence, we investigate the interrelationship between application abandonment and economic and dwelling related characteristics available within the administrative dataset associated with the grant scheme. We add to a sparse literature on energy retrofits in low-income or social housing, which is characterised by very small sample sizes (see for example Beagon et al., 2018; Hernández and Phillips, 2015). We find that the total number of (planned) retrofits measures plays an important role in determining the probability of abandonment. A higher retrofit intensity could be perceived as higher energy efficiency improvement by the applicants and hence this leads to a higher probability of them proceeding with the retrofits. A lower number of planned retrofit measures is associated with a higher probability of abandonment, which might be attributed to households perceiving fewer retrofit measures as having lower potential benefits. A higher measure intensity may not necessarily translate to a bigger improvement in energy efficiency since some of the retrofit activities undertaken are ancillary to the main retrofit. This finding is consistent with the literature on behavioural and informational barriers that there may be an inability to correctly assess the long term monetary and environmental benefits of retrofits (Chen et al., 2017; Day and Gunderson, 2015). Focusing on expanding the consulting and energy advice components of the schemes, particularly in the early stages, to clearly convey the benefits of energy efficiency retrofits to the occupants may help reduce abandonment rates, as found elsewhere (Achnicht and Madlener, 2014). Ramsden (2020) shows that advice related to energy efficiency is helpful to vulnerable households when the advice is provided in coordination between government and charities. Seasonality also plays a role in the abandonment of applications. Winter and spring applications have higher levels of abandonment compared to other times, which confirms findings in previous studies that disruption due to retrofits, especially in colder months, can be a deterrent to successful completion of retrofits (Collins and Curtis, 2017a). Simple practical measures during retrofit planning stage, such as the deferral of retrofit works, may be able to minimise abandonment associated with the season.

While it is important to assess the effectiveness of schemes like BEWHS in improving energy efficiency of low-income households, assessing the gains from the scheme as a whole requires com-

prehensive data on all multi-dimensional benefits the occupants may derive from the retrofits. In this study we focus on the effectiveness of the scheme in terms of energy efficiency improvements achieved by a subset of applicant households. The analysis shows that grant expenditure on retrofits delivers energy efficiency improvements but the magnitude of improvement varies depending on initial building energy efficiency, as well as retrofit measure types. The greatest value for money from grant expenditure occurs among dwellings with the poorest pre-works energy efficiency. Additionally, retrofits such as heating system upgrades also yield among the highest energy efficiency improvements. However, planned retrofits that comprise ventilation works are four times more likely to be abandoned compared to those without ventilation works. Ventilation retrofits are advised for health and safety reasons but such a high associated level of abandonment indicates that greater effort is necessary to convey to occupants the necessity and benefits of improved ventilation within homes. Aside from finance, a lack of comprehension in this area may represent the most significant barrier to households undertaking energy efficiency retrofits. Otherwise the analysis shows that from an energy efficiency perspective, the scheme is making a significant difference in the quality of dwellings of low-income households. Other benefits of the scheme, such as improve comfort and health outcomes, as well as lower energy costs are also likely to arise ([Hernández and Phillips, 2015](#)).

References

- Abrahamse, W. and Steg, L. (2009). How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? *Journal of economic psychology*, 30(5):711–720.
- Abrahamse, W. and Steg, L. (2011). Factors related to household energy use and intention to reduce it: The role of psychological and socio-demographic variables. *Human ecology review*, pages 30–40.
- Achtnicht, M. and Madlener, R. (2014). Factors influencing german house owners' preferences on energy retrofits. *Energy Policy*, 68:254–263.
- Anderson, W., White, V., and Finney, A. (2010). You just have to get by': coping with low incomes and cold homes. *Bristol: Centre for Sustainable Energy*.
- Beagon, P., Boland, F., and O'Donnell, J. (2018). Quantitative evaluation of deep retrofitted social housing using metered gas data. *Energy and Buildings*, 170:242 – 256.
- Bird, S. and Hernández, D. (2012). Policy options for the split incentive: Increasing energy efficiency for low-income renters. *Energy Policy*, 48:506–514.
- Campbell, N., Ryan, L., Rozite, V., Lees, E., and Heffner, G. (2014). Capturing the multiple benefits of energy efficiency. *IEA: Paris, France*.
- Chen, C.-f., Xu, X., and Day, J. K. (2017). Thermal comfort or money saving? exploring intentions to conserve energy among low-income households in the united states. *Energy Research & Social Science*, 26:61–71.

- Collins, M. and Curtis, J. (2017a). An examination of the abandonment of applications for energy efficiency retrofit grants in Ireland. *Energy Policy*, 100:260–270.
- Collins, M. and Curtis, J. (2017b). Value for money in energy efficiency retrofits in Ireland: grant provider and grant recipients. *Applied Economics*, 49(51):5245–5267.
- Crandall-Hollick, M. L. and Sherlock, M. F. (2018). Residential energy tax credits: Overview and analysis (updated). *Current Politics and Economics of the United States, Canada and Mexico*, 20(4):741–775.
- Day, J. K. and Gunderson, D. E. (2015). Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction. *Building and Environment*, 84:114–124.
- European Parliament (2016). Energy efficiency for low-income households. Accessed on 20th October, 2020 from [https://www.europarl.europa.eu/RegData/etudes/STUD/2016/595339/IPOL_STU\(2016\)595339_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2016/595339/IPOL_STU(2016)595339_EN.pdf).
- Greene, W. H. (2003). *Econometric analysis*. Pearson Education India.
- Healy, J. D. and Clinch, J. P. (2004). Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. *Energy Policy*, 32(2):207–220.
- Hernández, D. and Phillips, D. (2015). Benefit or burden? perceptions of energy efficiency efforts among low-income housing residents in New York City. *Energy research & social science*, 8:52–59.
- Hoicka, C. E., Parker, P., and Andrey, J. (2014). Residential energy efficiency retrofits: How program design affects participation and outcomes. *Energy Policy*, 65:594–607.
- Kerr, N., Gouldson, A., and Barrett, J. (2017). The rationale for energy efficiency policy: Assessing the recognition of the multiple benefits of energy efficiency retrofit policy. *Energy Policy*, 106:212–221.
- Kyprianou, I., Serghides, D., Varo, A., Gouveia, J., Kopeva, D., and Murauskaite, L. (2019). Energy poverty policies and measures in 5 EU countries: A comparative study. *Energy and Buildings*, 196:46 – 60.
- Ozaki, R. (2011). Adopting sustainable innovation: what makes consumers sign up to green electricity? *Business strategy and the environment*, 20(1):1–17.
- Poortinga, W., Steg, L., and Vlek, C. (2004). Values, environmental concern, and environmental behavior: A study into household energy use. *Environment and behavior*, 36(1):70–93.
- Raissi, S. and Reames, T. G. (2020). “If we had a little more flexibility.” perceptions of programmatic challenges and opportunities implementing government-funded low-income energy efficiency programs. *Energy Policy*, 147:111880.
- Ramsden, S. (2020). Tackling fuel poverty through household advice and support: Exploring the impacts of a charity-led project in a disadvantaged city in the United Kingdom. *Energy Research Social Science*, 70:101786.

- Reames, T. G. (2016). A community-based approach to low-income residential energy efficiency participation barriers. *Local Environment*, 21(12):1449–1466.
- SEAI (2020). Building energy rating. Accessed on December 1st, 2020 from <https://www.seai.ie/home-energy/building-energy-rating-ber/>.
- Sorrell, S., O'Maley, E., Schleich, J., and Scott, S. (2004). The economics of energy efficiency. cheltenham, uk, northhampton, ma.
- Sorrell, S., Schleich, J., Scott, S., O'Malley, E., Trace, F., Boede, U., Ostertag, K., and Radgen, P. (2000). Reducing barriers to energy efficiency in public and private organizations. *Science and Policy Technology Research (SPRU), University of Sussex, Sussex, UK*.
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.