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Do people or buildings matter more in predicting domestic energy consumption?

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Abstract

To understand the importance of and interaction between household and building characteristics in predicting domestic energy consumption, we analyse Energy Performance Certificates (EPCs) along with a host of consumption drivers. Particularly, we exploit a large sample of English dwellings drawn from the National Energy Efficiency Database (NEED) to show that property type, age, size and the main fuel used for heating play an important role in explaining the variation in gas and total energy consumption. Energy efficiency improvements including loft insulation, cavity wall insulation and new efficient boiler installation are also found to be associated with lower gas and total energy consumption. Additionally, the regression results from this sample suggest that socio-economic characteristics in the form of deprivation at local area level have a significant bearing on gas and energy consumption of dwellings. In the second sample, observations from the English Housing Survey are used to incorporate socio-economic characteristics at household level, energy prices and weather conditions into the analysis. We find households` composition, income, age and employment status to be important drivers of gas used for space heating which is also found to vary with gas prices and meteorological observations in the form of heating degree days. More importantly, the EPC rating of a dwelling is documented to be a powerful predictor of consumption level. Particularly, favourable EPC rated properties are associated with lower consumption levels, suggesting that the energy performance expressed by the EPC translates into savings on fuel costs in terms of lower energy consumption.

Keywords: *Environmental Regulation, Energy Efficiency, Residential Energy consumption, Asymmetric Information, Signalling and Microeconometric*

JEL Classification: Q4, D8, C5

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1. Introduction

In situations that involve a high degree of uncertainty, information becomes a commodity as identified by Arrow (1962) and demonstrated by Spence`s (1973) Model of Education. Hence, market participants are often incentivised to find ways to elucidate information. Investors with high quality assets must find ways to *signal* the quality of their assets to extract premiums and buyers in the market need to *screen out* low-quality assets from high-quality ones despite not being able to directly and fully observe the quality characteristics. For instance, in the case of the real estate market, potential investors are often unable to directly verify intrinsic green attributes of a property and must rely on incoming information from the market place in the form of eco-labels. The uncertainty caused by the presence of asymmetric information represents a crucial barrier to unlocking greater *green investments in* the real estate market. Yet, recent experiments of eco-labelling of buildings offer ample opportunities to overcome this specific form of market failure in the real estate market by providing transparent information on energy efficiency. The acquisition costs of a label vary for different types of properties depending on their existing level of energy efficiency. Hence, developers and homeowners can exploit the information given by eco-labels to hedge against risks by weighing the potential premiums to be gained from inhabiting, selling or letting a favourable eco-labelled property against the costs of investing in retrofit measures yielding such labelling. On the other hand, green investors, renters and homebuyers are likely to form beliefs about the relationship between the eco-label and the intrinsic or actual energy performance of the property and can then discriminate properties according to their ratings. This will, in turn, increase the demand for energy efficient properties and provide economic incentives for homeowners and developers alike to invest in green construction and retrofits yielding enhanced energy performance. Yet, this hypothesised link between the eco-label of a property and its actual energy consumption is largely untested. For instance, the Energy Performance Certificates (EPCs) of buildings as adopted into national legislation by a number of EU states including the United Kingdom only specifies the intrinsic energy performance of a building based on its design, installations and fabric. However, actual energy consumption is not only determined by the physical energy efficiency characteristics of a building but includes socio-economic factors such as households' income, size and dwelling usage patterns. The complexity of predicting actual energy consumption compared to the relatively simple EPC evaluation, may cast doubt over the actual cost efficiency of a property in operation and may create uncertainty among investors leading to discounting of the information conveyed by the EPC (see Fuerst et al, 2015 for a detailed discussion).

This paper investigates whether the EPC labelling can serve as a *credible signalling* device in the real estate market by drawing on the theoretical proposition that an investor or a homeowner with an energy efficient property can distinguish herself by using the property's energy performance rating to signal the actual energy costs in operation. More so, energy efficiency is likely to be reflected in the market pricing of properties, but only if the intrinsic energy efficiency of the dwelling as revealed by the market in the form of energy performance rating is credible and accurately estimated (Brounen et al, 2012). To verify this hypothesis, the study presented here investigates the main factors driving energy consumption in English dwellings with the emphasis on whether EPC rating of a dwelling is a major determining factor of energy consumption. By using two unique micro-economic data of English dwellings and households, it is shown that energy consumption of a dwelling is by and large determined by socio-economic characteristics, building characteristics, energy prices and weather conditions. Interestingly, the EPC rating of the dwelling is also found to be an important predictor of energy consumption. Particularly, 13 % of the variation in gas consumption and 8 % of the variation in total energy consumption is explained by the EPC bands alone. Likewise for a sample of English households, 12% of the variation in gas used for space heating is found to be explained by the EPC bands alone.

2. Energy Performance Certificates (EPCs) and determinants of domestic Energy consumption

In recent years, the uptake of green investments in the real estate market has accelerated due to technological progress, favourable public opinion and strong policy commitment (Eichholtz et al 2013). Numerous studies report that the built environment offers a great potential for greenhouse gas reduction and that investment in sustainability of buildings and in the green features of their operations can have a substantial impact on their market value (see the Australian Bureau of Statistics, 2008; Brounen and Kok, 2011; Cajias and Piazolo, 2013, Hyland et al, 2013 and Fuerst el al 2015). Rising energy costs are also envisaged to increase the private profitability of investment in energy efficiency in buildings provided investors are able to hedge against energy price volatility in the future (Eichholtz et al 2013 and Kahn 2009). To promote sustainability in the built environment, many countries have thus introduced compulsory eco-labels in which building legislations mandate compliance with minimum environmental standards. In the European Union, the Directive on the Energy Performance of Buildings which came into effect from 2007, requires all member States to implement Energy Performance Certificates (EPCs) for buildings. The prime purpose of the EPC is to increase investments in energy efficiency by addressing the issue of imperfect information. That is, EPC is a market-based environmental rating scheme which is intended to inform about the intrinsic energy performance of a building in order to aid the decision-making process in the real estate market. When a residential property is built, sold or rented out, the owner or developer is required to make an EPC available to the potential buyer or renter. The EPC places properties on a scale from A to G, with more than half of English dwellings rated D.

In a study of the UK housing stock, Kelly et al (2012) found a correlation between dwellings' energy efficiency as expressed by the Standard Assessment Procedure (SAP) and their energy demand. In this study, Kelly et al (2012) also discuss the two basic methods used in different EU countries in the calculation of building performance; the estimation method based on the physical features of the dwelling and the consumption based method using actual energy consumption data, respectively. In the UK, the SAP estimation method is used to produce the EPC rating to allow for comparability across dwellings and for retrofit diagnostics to be carried out. However, an important question arises; does a property in the highest rating class (A or B) consume less energy relative to a property in a lower rating class? Although this is implicitly assumed in the certification of buildings, there is a lack of empirical evidence supporting or refuting such claim. This is largely attributed to the lack of comprehensive data sources due to the relative infancy of the EPCs regulation. Henceforth, in this paper the emphasis is to investigate the reliability of EPCs in reflecting the energy efficiency of the dwellings in terms of lower energy consumption. However, in order to conduct such study, a better understanding of the determinants of household energy consumption is required.

Notwithstanding its importance, the determinants of energy consumption are still understudied, particularly at a household level. One of the first micro-econometric studies to be published, Baker et al (1989), adopted a conditional demand approach accounting for socio-economic characteristics of households to model energy demand in English dwellings. By using a random sample of 50,000 households pooled from 12 consecutive years of the

UK`s Family Expenditure Survey, they conclude that households` characteristics and energy prices have significant bearings on the forecasting of electricity and gas consumption in English dwellings. Drawing on these findings, Druckman & Jackson (2008) cite dwelling type, tenure, household composition and rural/urban location to be important determinants of household energy consumption. Interestingly, they also examine specific neighbourhoods with contrasting levels of deprivation based on the Index of Multiple Deprivation in England and they report differential patterns of consumption. A more recent study by Brounen et al (2012) on energy consumption of Dutch dwellings suggest that physical building features and socio-economic characteristics of households are crucial determinants of domestic energy consumption. Notably, the influence of age, sex, number of children, marital status and income profiles on per capita gas and electricity consumptions are documented. In a separate specification, dwellings characteristics such as dwelling type, vintage class, number of rooms and size are also found to be significant determinants of households' per capita gas and electricity consumptions. Yet, unlike Druckman & Jackson (2008), gas and electricity prices are not accounted for.

In one of the studies closely related to the research presented in this paper, Rehdanz (2007) uses a cross-sectional data to examine the determinants of energy used for space heating and hot water supply for a sample of households in Germany. Socio-economic characteristics of households, building characteristics and energy prices are found to important, despite the lack of controls on variation in weather conditions. This study is complemented by Meier & Rehdanz (2010) who also adopt a conditional demand approach pioneered by Baker et al (1989) to incorporate socio-economic and building characteristics into the energy demand analysis. Particularly, a panel study of English households covering many years and involving more than 64,000 observations is used to show the significant bearings of socio-economic characteristics in determining residential energy consumption. It is also suggested that in order to design target-oriented policy measures, a clear understanding of the impact differences between types of household is required. Furthermore, this is the first study to account for the variation in weather conditions and price variation over time on energy expenditure for space heating. Notably, energy expenditures are found to vary positively with the number of heating degree days per year. Despite its strengths, a few limitations of the study prevail. Firstly, the focus is on expenditures on general energy consumption as opposed to energy used for space heating in kWh. Similarly, heating expenditure per room as opposed to the more preferable option of space heating per square metre is used as the dependent variable. Building vintage or construction year which is considered to be a key determinant of energy consumption in dwellings is also excluded from the analysis due to data unavailability.

In contrast to the aforementioned literature, the study presented here applies proprietary data sources to gain a better understanding of determinants of energy consumption in English dwellings by specifically linking this to the Energy Performance Certificates (EPCs) as a signal of energy efficiency. To our knowledge, there is only one very recent empirical study (Curtis & Pentecost, 2014) that links eco-labelling of dwellings to energy expenditure let alone to actual gas or electricity consumption. The analysis in this study starts by first examining the impact of building characteristics and socio-economic characteristics (at an area level) as well as the various EPC classifications on weather-adjusted metered gas and energy consumptions of dwellings. Additionally, drawing on a cross sectional sample of English households, socio-economic characteristics at the individual household level, regional meteorological observations and energy prices over time are incorporated into the analysis to study gas used for space heating.

3. Data

The standard methodology for investigating the determinants of energy consumption is a conditional demand analysis. The underlying premise is that the impact that each feature has on energy consumption needs to be controlled for to allow for a consistent estimation. The primarily dataset applied to construct the regression analysis presented in this study is the recently released National Energy Efficiency Data-framework (NEED) administrated by the UK`s Department of Energy and Climate Change. This data framework is a panel data combining weather adjusted metered gas and electricity consumption readings of dwellings with information on a wide array of quality characteristics for each dwelling including physical building characteristics, energy efficiency retrofits installed in the dwelling and socio-economic factors at neighbourhood level as well as information on the EPC rating of each dwelling in the sample. The sample used is made up of observations from approximately three million properties in England with a valid EPC logged from 2010 onwards obtained using random sampling. The dataset comprises of all dwellings with valid recorded electricity reading as well as dwellings with average annual gas consumption between 3000 kWh and

50,000 kWh (domestic gas consumption of the majority of households in the UK is within this threshold).

Furthermore, in order to entrench socio-economic factors, energy prices and weather conditions into the analysis, a complementary data set is used. A sample database of the English Housing Survey (EHS) refined with information on energy prices and data on weather conditions in the form of number of heating degree days is constructed to examine energy used for gas space heating in English dwellings. The EHS is a continuous cross sectional survey administrated by the Department for Communities and Local Government (DCLG) and it compiles information on households` housing conditions and energy efficiency in English dwellings. The EHS consists of three components: a household interview conducted with a sample of 13,300 households per year and a physical inspection by qualified surveyors of a subsample of 6,200 dwellings per year. For the purpose of this study, a sample of households drawn from the 2012 Fuel Poverty series compiling various socio-economic characteristics is used. Information on EPCs was only collected between April 2011 and March 2013 and verified for 502 households. In order to avoid unobserved heterogeneity in the sample, this rather modest sample size relative to the NEED sample is used. Next, information on annual gas prices obtained from the International Energy Agency (IEA) is added to the EHS sample. Gas prices of the years of the fieldwork (2011-2013) were converted into pence per kWh. The average gas price was 4.10 pence per kWh in 2011, 4.50 pence per kWh in 2012 and 4.70 pence per kWh in 2013. Turning to weather conditions, the number of regional heating degree days on annual basis is matched to the respective regions in England, to obtain an average of annual heating degree days per region. Heating degree day (HDD) is a relative measurement created to estimate the demand for energy required to heat a dwelling to an acceptable temperature. This is an important factor as gas for space heating tends to vary according to weather conditions. The base temperature of the HDD is an outside temperature of 15.5 Celsius. In England, this benchmark is usually considered to be the base temperature in which a dwelling does not need heating. Table 1 describes variables included in the regression analysis of EHS sample.

Table 1: Description of variables included in the regression

Variable	Description
Income	Logarithm of gross annual household income.
No of People 60 plus	Number of seniors in the household
Age of oldest household	Age of the oldest person in the household
No of workless people	Number of unemployed people in the household
No of disabled people	Number of disabled or long-term ill people in the household
Household`s size	Logarithm of number of people in the household
Single male	Dropped and used as the reference
Single Female	Unity if the household is a single female, zero otherwise
Lone parent with child(ren)	Unity if the household is a lone parent with child(ren), zero otherwise
Couple	Unity if the household is a couple, zero otherwise
Couple with child(ren)	Unity if the household is a couple with child(ren), zero otherwise
Multi_person	Unity if the household is a multi-person household, zero otherwise
Floor area	Logarithm of floor area of the dwelling in square metres
Yrbuilt x	Vintage class of the dwelling, unity for the respective class or zero otherwise
Terraced	Unity if the dwelling is Terraced, zero otherwise
Semi-detached	Unity if the dwelling is semi-detached, zero otherwise
Detached	Unity if the dwelling is detached, zero otherwise
Bungalow	Unity if the dwelling is bungalow, zero otherwise
Flat	Dropped and used as a reference
Owner-occupied	Unity if the dwelling is owner-occupied, zero otherwise
Council/RSL owned	Unity if the dwelling is owned by the council or a housing association, zero otherwise
Privately-rented	Dropped and used as a reference
Central-heater	Unity if the dwelling has a central heater, zero otherwise
Full double glazing	Unity if the dwelling is entirely double glazed, zero otherwise
City/urban	Unity if the dwelling is located in the city or an urban centre, zero otherwise
Suburban	Unity if the dwelling is located in a suburban, zero otherwise
Rural area	Dropped and used as a reference
No of heating degree days	Average number of annual heating degree days (varies across time and region)
Gas prices	Logarithm of annual gas prices in pence per kWh
EPC = A/B	Unity if the EPC rating of the dwelling is A or B, zero otherwise
EPC = C	Unity if the EPC rating of the dwelling is C, zero otherwise
EPC = D	Dropped and used as a reference
EPC = E-G	Unity if the EPC rating of the dwelling is E, F or G, zero otherwise

4. Empirical Analysis

The OLS regression model for the NEED sample takes the following form:

$$\overline{E_i} = \alpha_i + \beta\overline{X_i} + \varepsilon_i \quad (1)$$

In equation (1), $\overline{E_i}$ is the average total energy or gas consumption in kWh between 2008 and 2012 for dwelling i. α_i is the intercept. Xi is a vector of explanatory building characteristics, socio-economic area variables and the region the dwelling is located in and β is the respective vector of parameters to be estimated. ε_i is a stochastic disturbance term taking the form of a normal distribution with a mean of zero and a variance of σ^2.

The identifying equation with full variable list is then given by the following regression:

$$lnE_i = \alpha_i + \beta_1 main\ heating\ fuel_i + \beta_2 vintage\ class_i + \beta_3 \sum_{n=1}^{N} dwelling\ type_i + \beta_4 \sum_{n=1}^{N} floor\ area\ band_i + \beta_5 CW_i + \beta_6 CWI_i + \beta_7 LI_i + \beta_8 Boiler_i + \beta_9 \sum_{n=1}^{N} EPC_i + \beta_{10} \sum_{n=1}^{N} IMD_i + \beta_{11} \sum_{n=1}^{N} Region_i + \varepsilon_i \quad (2)$$

In equation (2), depending on the specification, lnEi is the natural logarithm of average total energy consumption or average gas consumption for a given dwelling in the sample. Main heating fuel is unity if gas is the main fuel used to heat the dwelling and zero otherwise. Vintage class represents period of construction; pre-1930, 1930-1949, 1950-1966, 1967-1982 and post-1983. Dwelling type indicates the type of the property; detached, semi-detached, end-terraced, mid-terraced, bungalow and flat. Floor area band accounts for dwelling`s size in square metres; 1-50, 51-100, 101-150 and Over 151. CW is a dummy variable equal to unity if the dwelling has a cavity wall construction or zero otherwise. Likewise, CWI, LI and Boiler are binary variables equal to unity if the dwelling has cavity wall insulation, loft insulation and a new efficient boiler installed or zero otherwise. EPC is a vector of dummy variables controlling for the EPC rating of the dwelling; A/B, C, D and E, F, and G. Rating of D is the average EPC rating in England and is thus omitted and used as the reference rating. Index of Multiple Deprivation (IMD) accounts for dummy variables for neighbourhood’s attributes likely to reveal households` income profiles, usage behaviour and other specific characteristics linked to individual households. The Index of Multiple Deprivation is a weighted aggregation of seven domains of neighbourhoods` profile: income, employment, Health deprivation and Disability, Education Skills and Training, Barriers to Housing and Services and Crime and Living Environment. Households are assigned to five groups (quintiles) based on the neighbourhood they live in. Households in the 20 per cent most deprived neighbourhood are in the bottom quintile (IMD-1) and households in the 20 per cent least deprived neighbourhood is in the top quintile (IMD-5). Lastly, the region vector locates the dwellings in the sample to their respective regions in England; North East, North West, Yorkshire and the Humber, East Midlands, West Midlands, East of England, London, South East and South West.

Furthermore, we recognise that space heating relates most closely to the building itself. We, therefore, specify energy used for gas space heating as a function of the EPC bands along with a long list of other factors likely to affect energy use. This specification is more comprehensive than the one used for the above NEED sample as further independent variables including heating degree days, gas prices and socio-economic characteristics at the household level are incorporated into the analysis. Also, unlike the specification in most other studies, logarithm of energy used for gas space heating is used as the dependent variable; this is preferred to using for example, an energy expenditure function. It is, also, methodological desirable to use both energy used for gas space heating per square metre of floor area as well as total gas usage as dependent variables relative to consumption per number of rooms or per head.

The following cross sectional regression is constructed:

$$G_i = \alpha_i + \beta_1 S_i + \beta_2 B_i + \beta_3 T_i + \beta_4 A_i + \beta_5 W_i + \beta_6 P_i + \beta_7 E_i + \beta_8 Y_i + \beta_9 R_i + \varepsilon_i$$

Where

G_i Logarithm of energy used for gas space heating /per square metre
S_i Socio- economics characteristics
B_i Building characteristics
T_iTenure
A_iNature of area

W_i Weather conditions
P_i Gas prices
E_i EPC ratings
Y_i Year of fieldwork
R_i Region
ε_i Error term

Table 2 shows the results of six separate estimations of the relationship between average gas consumption and a list of characteristics for dwellings on the gas network. All models yield statistically significant coefficients at the 1% level of confidence. The base model (Model-1) isolates the effect of the EPC rating of a dwelling on its average annual gas consumption without any controls and moderators. Models 2 and 3, further control for building characteristics and existing energy efficiency features. Next, Model-4 introduces socio-economic characteristics at area level in the form of the Index of Multiple Deprivation into the regression analysis. Model-5 controls for the full list of factors considered including regional differences. Although the base model explains only about 13% of the variation in gas consumption, as we add further factors into the analysis, there is a clear progression as the predictive power of the model increases. Particularly, depending on the specification, Models 2-5explain approximately 42-44% of the variation in gas consumption. Interestingly, in Model-6, the importance of controlling for the energy ratings of dwellings is further highlighted by the fall in the explanatory power upon modelling gas consumption as a function of a long list of variables while dropping the EPC bands from the regression. This drop in explanatory power implies that the overall EPC conveys predictive information about actual gas consumption that are not contained in the main individual components that enter the EPC assessment. This may be due to additional minor criteria that are not part of our regression model (for example, whether a conservatory exists) or, more importantly, the signalling value of the overall EPC rating.

Turning to the estimated impacts of the various EPC classifications, dwellings with an EPC rating in the highest class band (A/B) is found to have 48.2% lower gas consumption relative to the national average of D-rated dwellings. This estimate falls to approximately 16.4% when controls for physical characteristics, energy efficiency features, socio-economic characteristics and regional variations are introduced in Model-5. Next, in comparison to D-rated dwellings, dwellings in the C classification are estimated to have 25.1% lower gas consumption in the base model and 9.4% in Model-5 with the full list of controls. Contrary, E and F rated homes are found to consume 17.2 % and 22.7% more in gas in the base model in comparison to D-rated dwellings. These estimates are adjusted to 8.1% and 8%, respectively, in Model-5 controlling with the full list of controls. Remarkably, dwellings in the worst rating class (G) are predicted to consume 15.6% less gas relative to D-rated dwellings in the base model and 3.5% lower gas consumption in Model-5. This abnormality could theoretically be explained by the "pre-bound effect" in that there appears to be a gap between estimated energy performance revealed by the respective EPC rating and the actual energy consumption measured in the above regression, see Sunikka-Blank and Galvin (2012) for a detailed discussion of the pre-bound effect.

By examining the effects of the various control variables in the regression analysis of Table 2, the type of fuel used in the dwelling is found to be an important contributor to average annual gas consumption. Where gas is the main fuel used to heat the dwelling, the estimated gas consumption is found to increases by 27-29%. Model-6 excluding the EPC bands adjusts this estimate to 24%. Next, with increasing building vintage class, there is a corresponding reduction in gas consumption. This could be due to lower levels of energy efficiency in older homes or perhaps improvements in construction technology after the -oil-crisis in the late 1970s. For instance, dwellings constructed post-1982, are predicted to have between 6% and 7% lower gas consumption relative to dwellings built between 1967 and 1982. The size of a dwelling is also observed to be a significant determining factor of gas consumption. In comparison to dwellings in the average floor area band in England (51-100 square metres), dwellings in the floor area class of 0-50 square metres are estimated to range from 23% to 24% lower gas consumption depending on the specification. Dwellings in the largest floor area class (above 151 square metres) are predicted to consume between 57% and 58% more gas in comparison to dwellings in the average floor area class. This suggests that larger homes with possibly more inhabitants are likely to require more energy to heat. Likewise, with increasing detachment i.e. from semi-detached homes to detached ones etc., gas consumption is predicted to increase. For instance, in line with expectations, detached homes are found to have between 38% and 42% higher gas consumption relative to flats. This is not surprising as Ewing and Rong (2008) found evidence of households inhabiting detached homes consuming 54% more in energy for heating. Depending on the specification, Mid-terraced dwellings are estimated to have only approximately 9-12% higher gas consumption in comparison to flats. These variations in gas consumption by property type are likely to reflect the amount of heat-loss surface area.

Furthermore, consistent with Hong et al`s (2006) findings, energy efficiency retrofits in the form of cavity wall insulation, loft insulation and a new efficient boiler are somewhat observed to reduce average gas consumption in dwellings.  In contrast, in Models 3-5, with increasing neighbourhood`s profile as defined by the Index of Multiple Deprivation, there is a slight increase in gas consumption. This suggests that households inhabiting the least deprived neighbourhoods (IMD-5) are more likely to have more energy-driven appliances and may also have a different saving behaviour in comparison to households in average neighbourhoods (IMD-3). In Models 4 and 5, regional variations in gas consumption are controlled for and observed to be significant. For instance, dwellings in South West England are found to consume 18% less gas than dwellings in North East. This variation is likely to be linked to difference in weather and prices between the two regions.

Table 2: Prediction of gas consumption

Log(gas consumption in kWh)	**Model-1**	**Model-2**	**Model-3**	**Model-4**	**Model-5**	**Model-6**
EPC = D vs:						
EPC = A/B	-0.482***	-0.183***	-0.179***	-0.175***	-0.161***	
EPC = C	-0.251***	-0.106***	-0.101***	-0.098***	-0.094***	
EPC = E	0.172***	0.088***	0.082***	0.081***	0.082***	
EPC = F	0.227***	0.0865***	0.079***	0.078***	0.080***	
EPC = G	-0.156***	-0.028***	-0.034***	-0.031***	-0.033***	
Main heating Fuel = Gas vs other		0.282***	0.281***	0.279***	0.268***	0.227***
Vintage class = 1967-1982 vs:						
Vintage class = pre-1930		0.121***	0.097***	0.102***	0.105***	0.148***
Vintage class = 1930-1949		0.115***	0.105***	0.111***	0.094***	0.119***
Vintage class = 1950-1966		0.056***	0.055***	0.061***	0.058***	0.068***
Vintage class = post-1982		-0.060***	-0.068***	-0.072***	-0.071***	-0.112***
Floor area = 51-100 m^2 vs:						
Floor area = 1-50 m^2		-0.244***	-0.243***	-0.239***	-0.232***	-0.245***
Floor area = 101-150 m2		0.286***	0.285***	0.279***	0.275***	0.280***
Floor area = above 150 m2		0.580***	0.577***	0.569***	0.561***	0.560***
Dwelling type = Flat vs:						
Detached		0.379***	0.394***	0.378***	0.418***	0.483***
Bungalow		0.272***	0.288***	0.275***	0.314***	0.371***
Semi-detached		0.231***	0.243***	0.236***	0.269***	0.314***
End-terraced		0.175***	0.185***	0.184***	0.217***	0.260***
Mid-terraced		0.091***	0.097***	0.097***	0.127***	0.146***

Log(gas consumption in kWh)	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Wall construction = Cavity wall vs other			-0.034***	-0.035***	-0.014***	-0.029***
Cavity wall insulation vs none			-0.009***	-0.008***	-0.009***	-0.019***
Loft insulation vs none			-0.017***	-0.015***	-0.013***	-0.013***
New efficient boiler vs none			-0.022***	-0.022***	-0.020***	-0.034***
IMD = 3 vs:						
IMD1				-0.022***	-0.037***	-0.046***
IMD2				-0.006***	-0.016***	-0.020***
IMD4				0.016***	0.017***	0.020***
IMD5				0.039***	0.046***	0.051***
Region= North East vs:						
North West					-0.052***	-0.053***
Yorkshire					-0.024***	-0.024***
East Midlands					-0.077***	-0.075***
West Midlands					-0.059***	-0.054***
East of England					-0.075***	-0.074***
London					0.052***	0.057***
South East					-0.080***	-0.079***
South West					-0.190***	-0.192***
Constant	9.508***	8.913***	8.950***	8.944***	8.978***	8.980***
Adj.R2	0.13	0.417	0.419	0.421	0.435	0.408
N	3,082,231	3,082,231	3,082,231	3,082,231	3,082,231	3,082,231
BIC	3,799,138	2,559,190	2,551,501	2,537,630	2,461,156	2,609,151

*Significance at the 0.10, 0.05, and 0.01 levels are marked *, **, and *** respectively.*

Table 3 presents regression estimates of the bearings of various characteristics on average total energy consumption for dwellings in the sample. Again, all coefficients are all statistically significant at the 1% level of confidence. The base model (Model-7) capturing only the impact of the EPC bands explains about 8% of the variation in total energy consumption. Similar to table 2, as building characteristics, energy efficiency features, socio-economic factors at a neighbourhood level and regional differences are accounted for, the explanatory power of the model increases. In the Model-7, dwellings in the highest rating class (A/B) are estimated to have approximately 49.4% lower energy consumption in comparison to D-rated dwellings. This is similar to the estimate for gas consumption in Table

2. C-rated dwellings are predicted to have 22.8% lower energy consumption relative to average D-rated dwellings. Whereas, below average rated dwellings in the E and F classifications are found to consume 11.9% and 8.8% more in total energy. Interestingly, the worst energy performing dwellings (G) are found to have 9.4% lower total energy consumption relative to D-rated dwelling. In Model-11 with the full list of controls, the impacts of the various classifications are adjusted down. In comparison to D-rated dwellings, 30.4% lower energy consumption for A or B rated dwellings, 13.2% lower energy consumption for C-rated dwellings, 6.4% higher energy consumption for E rated dwellings and 1.9% higher energy consumption for F rated dwellings are documented. Again, the impact of G-rated dwellings is not as straightforward as 7.6% lower energy consumption is found. The effects of all the other coefficients in Table 3 resemble the results in Table 2.

It is also worth noting that some factors that are part of the EPC calculation still show up as highly significant when included in the above regression. Particularly, the estimation of the EPC rating will vary according to standardised assumptions about heating patterns and geographical location as well as the in-built energy efficiency features of the building. This enables dwellings to be compared on a like for like basis. The estimated energy-use displayed by the EPC is thus likely to differ from the actual energy consumption presented here. For instance, the EPC rating assumes a standard heating pattern of 9 hours each weekday and 16 hours a day at the weekend, and that the living area is heated at 21°C and the remainder of the dwelling at 18°C. This is likely to be different to the actual heating pattern of households. More importantly, the energy-use displayed in the EPC assumes that the number of people living in the dwellings is proportional to the floor area which is then used to estimate the hot water usage. All these issues suggest that perhaps the EPC rating reflects the intrinsic energy-performance features of the physical object of the building itself, as opposed to the dynamic and continuous processes of building operation.

Table 3: Prediction of overall energy consumption (electricity plus gas)

Log (Energy consumption in kWh)	Model-7	Model-8	Model-9	Model-10	Model-11	Model-12
EPC = D vs:						
EPC = A/B	-0.494***	-0.318***	-0.318***	-0.313***	-0.303***	
EPC = C	-0.228***	-0.140***	-0.140***	-0.136***	-0.132***	
EPC = E	0.119***	0.066***	0.066***	0.063***	0.065***	
EPC = F	0.088***	0.018***	0.018***	0.016***	0.019***	
EPC = G	-0.094***	-0.078***	-0.077***	-0.078***	-0.076***	

Log (Energy consumption in kWh)	Model-7	Model-8	Model-9	Model-10	Model-11	Model-12
Main heating Fuel = Gas vs other		-0.076***	-0.078***	-0.075***	-0.052***	-0.016***
Vintage class = 1983-1996 vs:						
Vintage class = pre-1930		0.040***	0.036***	0.040***	0.055***	0.118***
Vintage class = 1930-1949		0.103***	0.102***	0.108***	0.098***	0.148***
Vintage class = 1950-1966		0.036***	0.037***	0.046***	0.049***	0.082***
Vintage class = 1967-1982		0.005***	0.005***	0.010***	0.013***	0.039***
Vintage class = post-1996		0.011***	0.009***	0.010***	0.014***	-0.060***
Floor area = 51-100 m^2 vs:						
Floor area = 1-50 m^2		-0.172***	-0.172***	-0.170***	-0.166***	-0.179***
Floor area = 101-150 m2		0.256***	0.256***	0.250***	0.245***	0.249***
Floor area = above 150 m2		0.418***	0.417***	0.409***	0.400***	0.393***
Dwelling type = Flat vs:						
Detached		0.205***	0.207***	0.189***	0.235***	0.306***
Bungalow		0.125***	0.128***	0.115***	0.160***	0.221***
Semi-detached		0.151***	0.153***	0.142***	0.182***	0.235***
End-terraced		0.110***	0.111***	0.108***	0.143***	0.195***
Mid-terraced		0.060***	0.061***	0.058***	0.090***	0.120***
Wall construction = Cavity wall vs other			0.005***	0.008***	-0.011***	-0.005***
Cavity wall insulation vs none			-0.012***	-0.013***	-0.014***	-0.007***
Loft insulation vs none			-0.017***	-0.015***	-0.012***	-0.012***
New efficient boiler vs none			-0.040***	-0.040***	-0.040***	-0.042***
IMD = 2/3 vs:						
IMD = 1				-0.025***	-0.029***	-0.038***
IMD = 4				0.004***	0.007***	0.010***
IMD = 5				0.060***	0.069***	0.075***
Region= North East vs:						
North West					-0.007***	-0.007***
Yorkshire					0.001	0.001
East Midlands					-0.040***	-0.038***
West Midlands					-0.012***	-0.006***
East of England					-0.023***	-0.023***
London					0.088***	0.093***
South East					-0.010***	-0.010***
South West					-0.124***	-0.130***
Constant	8.930***	8.832***	8.830***	8.815***	8.791***	8.652***
Adj.R2	0.08	0.2321	0.2324	0.2347	0.2442	0.2282
N	6,307,002	6,307,002	6,307,002	6,307,002	6,307,002	6,307,002
BIC	9,736,732	8,593,830	8,591,483	8572216	8,493,457	8,625,372

*Significance at the 0.10, 0.05, and 0.01 levels are marked *, **, and *** respectively.*

Table 4 presents regression results of the effects of various characteristics on energy used for gas space heating for a cross section of English dwellings. Given the many control variables used, various diagnostics are conducted. Firstly, the regression results are tested for multi-collinearity using the Variance Inflation Factor (VIF). This investigation led to the exclusion of the independent variable on the number of children in the household as it was found to have a VIF significantly greater than 10. Including this variable into the regression also caused unstable coefficients and widely inflated standard errors. More importantly, robust regressions are used to weigh the observations differently based on how well behaved they are. It is also worth mentioning that only two households inhabit G-rated dwellings and for robustness reason these observations are excluded from the regression analysis in Table 4.

The base models of Table 4 (Model-13 and Model-15) only account for the various EPC bands; these models yield several statistically significant coefficients at an acceptable confidence level and explain approximately 12% of the variation in gas used for space heating per square metre and 19% of the variation in total gas consumption, respectively. As we introduce further factors into analysis, the predictive power increases to 73% in Model-14 and 44% in Model-16. This is an improvement from Meier and Rehdanz (2010), who explain less than 30 % of gas expenditure for a panel of English dwellings. In Model-13, while controlling for several factors, households inhabiting dwellings in the highest energy performance class (A/B) are estimated to use approximately 50% lower gas for space heating per square metres relative to households living in D-rated dwellings. The coefficient of households inhabiting C-rated dwellings has the expected sign but is insignificant in Model-13. On the other hand, households inhabiting E-rated dwellings are predicted to use 26.9% more in gas for space heating relative to households living in D-rated dwellings. Whereas, those living in F- rated dwellings are found to consume 40.5% more in gas used for space heating in comparison to households living in D-rated dwellings. More importantly, upon controlling for socio-economic characteristics, weather conditions and gas prices in Model-14, estimates for A/B and C rated dwellings are significantly readjusted. Particularly, 20.6 % lower gas consumption is documented for households living in A or B rated dwellings and 10.1 % lower gas consumption for households in C-rated dwellings. These figures are close to the findings in Table 2, generated using the NEED data of approximately 3 million properties. The remaining coefficients for households living in E and F rated dwellings in Model-14 are found to be insignificant. In Models 15 and16, upon modelling EPC classifications and controls against total gas used for space heating across the whole dwelling, the impacts of the various EPC ratings are found to vary somewhat relative to Models 13 and 14.

Turning to the other drivers of gas consumption, the coefficients on average regional gas prices and regional weather conditions are found to be significant at an acceptable level of confidence. In Models 14 and 16, regional gas prices appears to be negatively linked to gas consumption with a 1% increase in regional gas prices entailing a 0.72% lower gas used for space heating per square meters and 1.2% lower gas usage across the whole dwelling. This is consistent with Meier & Rehdanz`s (2010) finding that households` expenditure on gas is sensitive to gas prices. Next, an additional day of the annual number of regional heating degree days is predicted to increase households` gas consumption per square metres by 0.03% and by 0.002% for gas usage across the whole dwelling, respectively. These negligible impacts of heating degree days confirm the common observation that a dwelling`s energy-use for space heating varies with weather conditions. Considering socio-economic households` characteristics, several factors are controlled for including, income, unemployment, disability, age, household composition and the number of persons in the household. For instance, a 1% increase in total household income is estimated to increase overall gas used for space heating across the whole dwelling by 14.5%. Next, an additional unemployed person in the household is found to increase gas consumption per square metre by 2.8%, perhaps suggesting that workless people are more likely to spend more time at home and would thus consume more energy for space heating. The age of the oldest person in the household is also associated with 1% higher gas used for space heating per square metre.

Furthermore, larger household size has been found to increase total energy consumption while reducing per-capita consumption (Estiri, 2014 and O'Neill & Chen, 2002). Since consumption is measured in square metres and large households tend to live in larger houses with more space per capita, lower heating intensity per square metre is reported in Model-15 and higher gas consumption across the whole dwellings in Model-16. Interestingly, this may also reflect that the impact of household size on gas consumption varies by household composition. For instance, relative to a single male living alone, lone parents with one or more children are predicted to have 33.4% higher gas usage for space heating per square metre while couples with one or more children are estimated to use 42.7% more in gas for space heating. , This reinforces Brounen et al`s (2012) finding that families with children consume more energy for heating than other households. Couples without children are found to have 30.1% higher gas consumption per square metre relative to a household consisting of a single male. In other words, the presence of a second person in the household adds roughly one third to a dwelling's gas consumption. Interestingly, multi-person households are also found to consume 33.3% more in gas for space heating relative to a single male living alone, suggesting that the presence of children is associated with higher gas consumption beyond the level expected from a pure increase in the number of inhabitants of a dwelling. The coefficient of single female household is insignificant.

Turning to physical characteristics of dwellings, in line with previous findings, an additional bedroom is estimated to increase gas consumption per square metre by 28.7% (see Hirst et al., 1982). Intuitively, building vintage is positively and significantly linked with gas consumption. For dwellings built pre- 1965, higher gas consumption is observed relative to dwellings built between 1965 and 1980. Whereas, dwellings built post- 1980 are modelled to consume relatively lower gas for space heating. The lowest gas consumption is observed among dwellings constructed post-2002. These new built dwellings are likely to be constructed to a higher energy efficient standard and are estimated to consume approximately 49% lower gas relative to dwellings built between 1965 and 1980 in Model-14. These findings suggest that policy measures should continue to focus on insulation standards in addition to socio-economic characteristics in reducing domestic fuel usage.

A significant negative relationship exists between dwellings located in urban centres and their respective gas consumption in comparison to dwellings located in rural areas, possibly reflecting an Urban Heat Island effect (Thumin and White, 2008) which causes urbanised areas to be warmer under identical weather conditions leading in turn to somewhat lower heating requirements.

Table 4: Regression results of the effect of various characteristics on energy used for gas space heating for a sample of English households drawn from the EHS.

	Model-13 Log of gas usage per sqm	**Model-14** Log of gas usage per sqm	**Model-15** Log of total gas usage	**Model-16** Log of total gas usage
EPC = D vs:				
EPC = A/B	-0.496***	-0.206***	-0.536***	-0.163*
EPC = C	-0.137	-0.101*	-0.254***	-0.062
EPC = E	0.269**	0.069	0.193*	0.122
EPC = F	0.405**	0.090	0.387***	0.216*
Log Household`s size		-0.344***		0.211***
No of unemployed people		0.028**		
Log income		0.016		0.145***
Household = single male vs				
Single Female		-0.001		
Lone parent with child(ren)		0.334*		
Couple		0.301*		
Couple with child(ren)		0.427*		
Multi_person household		0.333*		
Age of oldest person		0.091***		
Log(Floor area)		-0.999***		0.006
No of bedrooms		0.287***		
Vintage class = 1965-1980 vs:				
Pre 1850		0.542***		0.289
1850 -1899		0.467***		0.377***
1900 – 1918		0.483***		0.474***
1919 – 1930		0.274***		0.354***
1931 – 1944		0.366***		0.380***
1945-1964		0.141*		0.108
1981 – 1990		-0.008		-0.009
1991 – 1995		-0.005		-0.046
1996 – 2001		-0.305***		-0.347**
2002 or later		-0.490***		-0.468***
Type of Area = Rural vs				
City/urban Area		-0.170*		
Suburban		-0.064		
No of heating degree days		0.0003***		0.0002*
log(gas prices)		-0.722*		-1.196**
Constant	5.018***	5.515***	9.451***	3.439*
R2/Adj.R2	0.12	0.73	0.19	0.44
N	500	500	500	500
BIC	1112	660	886	799

*Significance at the 0.10, 0.05, and 0.01 levels are marked *, **, and *** respectively. Dwelling type, tenure, whether the dwelling is fitted with a central heater, whether the dwelling is fully double glazed, the field collection year of the data and the home region of households are all found to be insignificant and excluded from Table 4 for the sake of space.*

5. Conclusion

This paper set out to investigate whether domestic energy consumption is mainly driven by building or household characteristics or a combination of factors from these two categories. More specifically, we tested whether the Energy Performance Certificate (EPC) which assesses the intrinsic energy efficiency of a building regardless of household profiles and characteristics is a reliable predictor for actual energy consumption observed in these dwellings. To this end, we estimated the determinants of heating consumption including socio-economic characteristics at area level, building characteristics and energy efficiency features of dwellings as well as EPC classifications. The base models with no controls suggest 48.2% lower gas consumption and 49.4% lower total energy consumption for dwellings in the highest EPC classification, A/B, relative to the UK average of D-rated dwellings. Upon controlling for a long list of factors influencing consumption levels, gas consumption is adjusted to 16.4% lower and total energy consumption to 30.4% lower in comparison to consumption levels of average rated dwellings. Next, C-rated dwellings are estimated to have 25.1% lower gas consumption in the base model and 9.4% in the model with the full list of controls compared to D-rated dwellings. These dwellings are also predicted to consume 22.8% less in total energy in the base model and 13.2% lower total energy consumption upon introducing controls into the analysis. Turning to poorly rated dwellings, E and F rated homes are found to consume 17.2 % and 22.7% more in gas in the base model relative to D-rated dwellings. When controlling for the full set of variables, these estimates are adjusted down to 8.1% and 8%, respectively. Similarly, these dwellings are predicted to consume 11.9% and 8.8% more in total energy in the base model and 6.4% and 1.9 % higher total energy consumptions when controlling for building characteristics, energy efficiency installations and socio-economic characteristics at area level. Interestingly, the worst energy rated dwellings in the G classifications are predicted to consume 15.6% less gas and 9.4% less total energy in comparison to D-rated dwellings. These figures are adjusted down to 3.5% and 7.6% lower gas and total energy consumptions upon controlling for the full list of factors considered. This puzzling result may indicate the existence of the "pre-bound effect". That is, a discrepancy between predicted energy usage standards and actual metered energy consumption in dwellings. This term is linked to earlier identification of a "rebound effect", in which households inhabiting dwellings retrofitted to a high energy efficient standard choose to consume more energy. Neither of these theoretical propositions can explicitly be tested in this study. Nonetheless, since the various EPC classifications can be used as proxies for energy efficiency, the above regression results appear to show that households living in G-rated dwellings consume considerably less energy than predicted given their performance rating. Consistent with Sunikka-Blank and Galvin`s (2012) insights, the findings reported in this study challenges the prevailing policy practice focusing purely on technical innovations and by doing so over-estimating the benefits of energy efficiency retrofits and the rate of pay-back of retrofit investments. Future research in the field should also consolidate the pre-bound effect with the budget-consciousness among families living in energy inefficient homes.

In addition to the above analysis, an attempt is made to examine gas specifically used for space heating. In this complementary analysis, a sample drawn from the English Housing Survey is exploited to incorporate socio-economic characteristics at household level, energy prices and meteorological observations into the analysis. Consistent with previous results, dwellings in the highest EPC classification are predicted to have lower energy used for gas space heating relative to average D rated dwellings, despite controlling for a host of households` characteristics, energy prices and weather conditions. On contrary, in all specifications, poorly EPC rated dwellings are predicted to have relatively higher consumption levels. In summary, the empirical results presented in this study are consistent with the theoretical hypothesis that green homeowners and investors can potentially use the EPC labelling as a *credible signalling device* to extract premiums associated with green assets in the real estate market. Green investors and homebuyers are, on the other hand, better informed to price and discriminate residential properties according to their EPC ratings. These findings also shed more light on preliminary results from Ireland which report that the eco-label of a building is directly linked to its energy expenditure (see Curtis & Pentecost, 2015).

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