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Does moving home affect residential heating decisions? Exploring heating fuel switching in Ireland

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ABSTRACT

Previous research finds that moving home can serve as a starting point for more sustainable living practices, specifically lower energy consumption. This research examines whether changes in occupancy or tenure at residential properties is also associated with decisions on overhauling a property's heating system. Properties are almost twice as likely to switch to gas from coal, oil or peat as the primary heating fuel when occupancy changes. The likelihood almost quadruples when there is also a change in tenure. Beyond occupancy and tenure, family size is the most notable occupant characteristic associated with a higher likelihood of switching to gas. In properties with six or more family members, and where occupancy changes, the likelihood of switching to gas is 7 percentage points higher than properties with 1–2 family members. The research extends the understanding of energy-related decisions associated with moving home and that property owners are more likely to invest in energy retrofits during this transitional period. Opportunities for designing policy supports, tailored to home-owners and landlords, but actively triggered by the registration of new tenancy leases or exchange of property deeds are discussed.

1. Introduction

In 2019 the EU updated its energy policy framework to facilitate the transition away from fossil fuels and to deliver on its Paris Agreement commitments for reducing greenhouse gas emissions [1]. Among the challenges for national governments is improving the energy efficiency and emissions performance of residential building stocks. Energy efficiency retrofits are neither the most frequent nor the most aspired to residential building renovations, with kitchen and bathroom renovations much more frequently undertaken [2,3]. Kitchen renovations are "something to dream about, make plans for and show to others", whereas some other types of renovation are typically made out of necessity rather than aspiration [2]. By contrast, energy-related retrofit projects are often framed in terms of overcoming technical problems, energy or cost savings, or return on investment but decisions to renovate may originate from deeper social or family issues [4–6]. Previous studies have suggested that life-course transitions (i.e. cohabiting, childbirth, relocation) can serve as starting point for more sustainable living practices and is potentially a promising area to encourage uptake of energy efficient behaviours [7–9]. In a case study of 10 Finnish families moving into new homes, Rinkinen and Jalas [10] find that ownership changes can lead to a major technical overhaul of the heating system, and that the public policy window to encourage retrofits extends beyond the point when occupants settle into their new home. Schaffner et al. [11] underline the importance of infrastructure or service based interventions to encourage new energy efficiency behaviours when families move into new homes. The roles of occupant behaviour and socio-economic factors have been extensively examined in the context of determining residential energy consumption. In a recent review article, Delzendeh et al. [12] note that while personal (physiological and psychological) parameters are taken into account in many studies of residential energy consumption, substantially fewer focus on both social and personal (socio-personal) factors. The social context of occupants' lives matters and is dynamically related to the nature of occupant's energy behaviour. One element of social context often overlooked is length of residency at a property. While occupants' tenure (i.e. private rental, social housing, owner-occupancy, etc.) is frequently associated with energy use behaviours, the formation of new energy practices are often activated at the time of moving into a new home [10], though such practices evolve with the passage of time [13]. In the context of energy modellers and researchers seeking to improve the calculation of energy consumption of buildings or of policy-makers

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seeking to influence energy consumption, a greater understanding of energy use and efficiency behaviours triggered by life-course transitions is desirable.

In a quantitative setting, Sonderegger [14] is among the first to examine the issue, finding that new occupants have lower mean gas consumption (and higher variance) compared to households with unchanged occupancy, controlling for the usual confounding factors. Following Sonderegger's methodology, van den Brom et al. [15] make similar findings for households in both The Netherlands and Denmark in the 2010–2015 period. Also with recent data, Cho [13] has similar findings; occupants that recently moved into a new property use less electricity (are more price sensitive) than residents who had lived in the same dwelling unit for 5 years or more. There are relatively few other studies that consider length of residency, which captures occupancy change, in explaining energy consumption [16–18] but the empirical evidence clearly suggests that there is a noticeable reduction in building energy use when new occupants move in. As the length of residency increases, energy consumption also increases, with Fogg [19] suggesting that this energy consumption pattern is related to the fact that new occupants are likely to be aware of their energy consumption and energy efficiency. It is this awareness that may trigger an overhaul of the heating system or investment in energy efficiency. The objective of this paper is to further investigate this hypothesis, expanding the analysis to consider the matter of tenure. New occupants in a dwelling may have greater awareness of energy consumption and energy efficiency within their new home but the nature of their tenure, i.e. whether they are owners or renters, is likely to impact the options available to undertake energy efficient behaviours.

2. Methods

2.1. Research question

Following the discussion on life-course transitions, this study has two related objectives. First, using a dataset from Ireland, establish whether moving home is a trigger for more sustainable living practices, as reflected in an overhaul of the new property's heating system. However, it is recognised that the driver of the heating system overhaul could be economic, i.e. lower costs, rather than an ambition to reduce emissions. Second, establish the extent to which the overhaul of the heating system is associated with property tenure. The *ex ante* hypothesis is that the trigger for overhauling the heating system is likely to be greater for owner-occupiers compared to renters (or equivalently for property owners that rent the dwelling). To undertake such an analysis we follow properties rather than households across time (i.e. 5 years) examining whether a change in the property's heating system observed at the end of the five-year period can be associated with changes in tenure or occupancy at the property. A standard logistic regression is used to examine this question.

The unit of analysis is dwelling-based, similar to Sonderegger [14], Cho [13] and van den Brom et al. [15]. Data observations relate to dwellings across two observation points, the census of population in 2011 and 2016. The observations relate to dwellings that are in existence in both periods, so any newly built properties between 2011 and 2016 are excluded. As a consequence of the exclusion of newly built properties, the analysis pertains only to heating system retrofits and not decisions surrounding heating system choice in newly constructed dwellings. The census of population includes a question on the primary heating system fuel. Fuel switching between censuses is used as a proxy for a heating system retrofit. Just over half of Irish households (51%) use the carbon-intensive fuels of either oil, coal or peat as their primary heating fuel and a further 34% rely on natural gas.[1] Renewable biomass (e.g. firewood, wood pellets) is the least carbon intensive heating fuel, followed by renewables generated electricity. These two energy sources are used for heating in 11% of households but there was a relatively modest transition to these fuels between 2011 and 2016. Households heated by biomass increased by 0.7% and electricity by just 0.3%. The greatest transition between fuels related to coal, peat, oil and natural gas. For the purpose of this analysis we examine the transition to natural gas, as the least intensive fossil fuel, to examine whether moving home can be considered as a trigger associated with more sustainable energy behaviours. While more sustainable energy behaviours may be the outcome, the motivation for the change may be economic related to lower household heating costs.

2.2. Data

Data for the analysis comprises anonymised building unit data on heating fuel, property attributes, and occupants' socio-demographic characteristics. Each observation represents a residential unit, for which information about tenancy, household and building characteristics, main fuel and location are available. The Central Statistical Office (CSO) of Ireland created the data file, which combines records from the 2011 and 2016 census of population and data on proximity of the natural gas network to dwellings. The dataset was originally created for the purpose of examining gas network connection and consumption. Matching census data for multi-property buildings (e.g. blocks of flats) with gas consumption data was not feasible, therefore most apartments were excluded from the dataset. In addition, buildings beyond 30 meters distance from the gas network were excluded, as the cost of gas network connection becomes prohibitive. Therefore, the dataset available for this analysis mostly comprises houses (detached, semi-detached, terrace) with relatively few apartments or flats (0.7%). Geographically the houses are located in cities and larger towns where network gas is available (i.e. within 30 metres of the gas network). The initial dataset comprises 466,929 observations. As the purpose of the study is to investigate heat fuel switching to gas, all the residential units with an existing gas connection in 2011 are excluded. The resulting dataset comprises observations on 110,419 properties. There is no obvious reason why the smaller sample of 110,419 properties, excluding properties already with gas connection, should materially impact the results associated with the primary research question of whether changing occupancy or tenure within a property is associated with a greater likelihood of retrofitting the property's heating system.

The main variables used in the analysis are reported in Table 1. The primary variable for analysis is a binary variable indicating whether the dwelling switched to natural gas as a heating fuel (*SwitchToGas*) between 2011 and 2016. Two key explanatory variables in the analysis are one indicating whether occupancy of the dwelling changed between 2011 and 2016, and a second indicating whether tenure of the occupants changed. The variable *NewOccupants* is a binary variable indicating new occupants in 2016, while *NewTenure* is a binary variable indicating whether the occupants' tenure of the dwelling switched from rental to ownership (with or without mortgage). The interaction of these variables allows the identification of four occupancy-tenure combinations, as shown in Table 2. The dataset does not objectively record changes in tenure or occupancy across the two years, rather records tenure and occupancy information independently across the two census years. The variables *NewOccupants* and *NewTenure* were created

[1] Source – 2016 Census of Population,https://www.cso.ie/en/census/census2016reports/

Table 1
Descriptive statistics of the variables (N = 110,419).

Variable	Description	Mean	Std. Dev.	Min	Max
SwitchToGas	If primary heating fuel switched to gas between 2011 and 2016 = 1, 0 otherwise	0.136	0.343	0	1
NewOccupants	If new occupants at property in 2016 compared to 2011 = 1, 0 otherwise	0.120	0.325	0	1
NewTenure	If new tenure at property in 2016 compared to 2011 = 1, 0 otherwise	0.027	0.161	0	1
Distance from gas network	0–15 metres	0.357	0.479	0	1
	15–20 metres	0.378	0.485	0	1
	20–30 metres	0.265	0.442	0	1
Central heating system fuel	No Central heating	0.036	0.185	0	1
	Oil	0.750	0.433	0	1
	Electricity	0.103	0.304	0	1
	Coal (including anthracite)	0.080	0.272	0	1
	Peat (including turf)	0.013	0.114	0	1
	Liquid Petroleum Gas (LPG)	0.007	0.082	0	1
	Wood (including wood pellets)	0.007	0.082	0	1
	Other	0.004	0.063	0	1
Year of building	Pre 1961	0.286	0.452	0	1
	1961–1990	0.599	0.490	0	1
	Post 1990	0.114	0.318	0	1
Number of rooms		5.759	1.65	1	18
House type	Detached house	0.232	0.422	0	1
	Semi-detached	0.482	0.500	0	1
	Terraced houses	0.279	0.448	0	1
	Flats	0.007	0.086	0	1
Tenure in 2011 (ref – owner with mortgage)	Owner occupier with mortgage	0.304	0.460	0	1
	Owner occupier without mortgage	0.528	0.499	0	1
	Private rental	0.109	0.311	0	1
	Social housing – public landlord	0.054	0.226	0	1
	Social housing – housing association landlord	0.005	0.069	0	1
Employment status	2011 Census reference person employed = 1, 0 otherwise	0.459	0.498	0	1
Family size	1–2 people	0.523	0.499	0	1
	3–5 people	0.437	0.496	0	1
	6 + people	0.040	0.196	0	1
Social class	Managers = 1, 0 otherwise	0.158	0.364	0	1
	Higher professionals = 1, 0 otherwise	0.059	0.235	0	1
	Lower professionals = 1, 0 otherwise	0.112	0.315	0	1
	Non-manual = 1, 0 otherwise	0.200	0.400	0	1
	Manual = 1, 0 otherwise	0.109	0.312	0	1
	Semi-skilled = 1, 0 otherwise	0.094	0.292	0	1
	Unskilled = 1, 0 otherwise	0.040	0.196	0	1
	Self-employed = 1, 0 otherwise	0.051	0.220	0	1
	Farmers = 1, 0 otherwise	0.004	0.065	0	1
	Agricultural workers = 1, 0 otherwise	0.003	0.057	0	1
	Other = 1, 0 otherwise	0.169	0.375	0	1
Age of census reference person	18–24	0.016	0.127	0	1
	25–34	0.093	0.291	0	1
	35–44	0.134	0.341	0	1
	45–54	0.206	0.405	0	1
	55–64	0.233	0.423	0	1
	65+	0.317	0.465	0	1

Table 2
Interpretation of interaction of two binary variables, *NewOccupants* and *NewTenure*

		NewOccupants	
		Yes	No
NewTenure	Yes	Prior rental property sold to new owner occupiers (N = 2,316)	Prior rental tenants are new owner occupiers (N = 643)
	No	New occupants but tenure unchanged. Tenure could be rental or owner-occupier (N = 10,974)	(Assumed) same occupants, same tenure (N = 96,486)

using data from the two census returns related to age of the reference person (for census enumeration purposes), age of the oldest and youngest household members, and household size. Household members should be 5 years older in 2016 compared to 2011. A household with the same size in 2011 and 2016, and with the reference person, the youngest and the oldest all being 5 years older in 2016 is assumed to be an unchanged occupancy. Deaths/departures or newborns of family members were considered as follows. A household with one less member in 2016 and where the reference person and the youngest person were 5 years older but the oldest member was less than 5 years older was assumed to be the same occupancy, with the death of a family member a potential explanation. Occupancy is also assumed unchanged with a change in the household reference person but other occupants unchanged. Such a household is identified when the reference person was different from 5 years older in 2016 compared to 2011 but the youngest member was 5 years older. A household with one member fewer in 2016 compared to 2011 where the reference person and the oldest member were 5 years older but the youngest member was less than 5 years old was assumed to be the same occupancy with a childbirth occurring in the inter-census period. Multiple changes within the same occupancy were too difficult to identify with the data available, for example, households with multiple births, deaths or departures from the residential unit. Such observations were classified as the default category of no change in occupancy, i.e. *NewOccupant* = 'No'.

2.3. Modelling approach and econometric analysis

The proposed methodological approach is to estimate the probability that the heating fuel used in a dwelling switched to gas, as a function of building and occupant characteristics using a logistic regression. The model specification is

$$Pr(SwitchToGas = 1) = P = \frac{e^{\beta X}}{1 + e^{\beta X}} \quad (1)$$

where X represents building or occupant characteristic variables and β is a vector of parameters for estimation. Direct interpretation of the estimates of β is difficult and instead odds ratios are reported, which are calculated as e^{β}. Marginal effects are also calculated, which show the change in probability of switching to gas as a heating fuel associated with a change in observed factor $z \in X$ [20]:

$$\frac{\partial P}{\partial z} = \beta_z P(1 - P) \quad (2)$$

2.4. Limitations

There are a number of limitations of the study, primarily related to the nature of the dataset. The first is that apartments and Flats are essentially excluded from the analysis meaning that any results about tenure or occupancy change cannot be assumed to hold for such properties. Another limitation relates to the fact that the dataset does not objectively capture changes in tenure or occupancy across the two years, rather a set rules were applied to identify relevant properties. Such rules are always subject to error and as noted earlier, multiple births/deaths/departures within the same occupancy were too difficult to identify. The impact of erroneously classifying properties as having unchanged occupancy is that the model results will be underestimates of the real association between occupancy change and heating retrofit. Excluding properties that had multiple births/deaths/departures rather than assuming a default category of no change in occupancy, would have introduced unknown sample selection issues. From a policy or energy modelling perspective the reported results can be regarded as lower-bound or conservative estimates of the impact of occupancy change.

3. Results

Regression models' estimates are reported in Table 4 for the main sample and two sub-samples. The sub-samples correspond to observations where occupancy changed between 2011 and 2016 (model (2) in Table 4) and observations where tenure changed (model (3)). The regressions on the sub-samples facilitate additional insight into which household attributes are associated with switching to gas as a primary heating fuel. In terms of model fit, the estimates have a McFadden's pseudo-R^2 in range of 0.20–0.23. Interpretation of the pseudo-R^2 is different from standard R^2 statistics, with values from 0.2–0.4 considered to have excellent fit characteristics [21]. The number of correctly classified observations, or Count R^2, are also high at 87% for the full sample and 74–76% for the sub-sample regressions.

3.1. Odds ratios

Odds ratios (e^{β}) are reported in Table 4 to facilitate easier interpretation and are accompanied with their associated standard error estimates. The two central explanatory variables in the analysis, *NewOccupants* and *NewTenure*, are strongly associated with households switching to gas as a primary heating fuel. New occupants in a property with the tenure type unchanged are 1.88 times more likely to switch to gas as the primary heating fuel compared properties where there was no change in occupancy or tenure between 2011 and 2016. Where there is both a change in occupancy and tenure the likelihood of switching to gas is 4.2 times higher than properties where there was no change in occupancy or tenure. For households where there is a change in tenure (e.g. rental to owner-occupied) but no change in occupancy, the likelihood of switching to gas is 1.09 times higher than the reference category (unchanged occupancy and unchanged tenure). In this instance the odds ratio is not statistically different from the reference category but this sub-group comprises just 0.6% of the total sample (see Table 2). Models (2) and (3) of Table 4 report estimates for the sub-samples conditional on either new occupancy or new tenure. The likelihood of switching to gas is 2.505 times higher where tenure changed, conditional on new occupancy, compared to no tenure change. There is a similar odds ratio of 2.360 associated with a change in occupancy conditional on new tenure. These odds ratio estimates are illustrated graphically in Fig. 1.

The tenure of the property in 2011 is also included as an explanatory variable to investigate if the original tenure is associated with different rates of switching to gas. Properties with mortgage-free owner-occupiers in 2011 are 0.7 times as likely to switch to gas relative to owner-occupiers with mortgages. Social housing properties, which amount to just 6% of the sample, are more likely to switch to gas relative to owner-occupiers with mortgages. An *ex ante* hypothesis that the likelihood of switching to gas is greater for owner-occupiers compared to renters (or equivalently for property owners that rent the dwelling) has mixed support. The logit coefficient for private rental tenure is statistically different from un-mortgaged owners ($\chi^2_1 = 5.07, p = 0.0243$) but compared to the reference category of mortgaged owners just outside 5% significance ($\chi^2_1 = 3.75, p = 0.0529$). In the sub-sample regressions where occupancy changed between 2011 and 2016 (Table 4, model (2)) the findings associated with tenure are even stronger. Private rental tenure is statistically different from the reference category of mortgaged owners ($\chi^2_1 = 10.94, p = 0.0009$), and un-mortgaged owners ($\chi^2_1 = 5.01, p = 0.0252$). In the case of social housing with a public landlord, switching to gas is 1.39 times more likely to occur compared to the reference category of mortgaged owners, while the odds ratio for tenants of housing associations is 1.0, though these estimates are not statistically different from each other ($\chi^2_1 = 0.41, p = 0.5207$). Public landlord's housing units are more likely to switch to gas compared to private rental units ($\chi^2_1 = 219.15, p < .0001$), mortgaged ($\chi^2_1 = 409.55, p < .0001$), and un-mortgaged properties ($\chi^2_1 = 82.39, p < .0001$). And likewise, housing associations' rental units are statistically more likely to switch to gas compared to private rental units, mortgaged, and un-mortgaged properties ($p = 0.0426, p = 0.0007, p = 0.0139$ respectively). So the *ex ante* hypothesis that the likelihood of switching to gas is greater for owner-occupiers compared to rental properties holds in the case of private rental properties but not social housing. The reason underpinning higher odds ratios in the case of social housing relates to a high reliance on coal/peat within the social housing stock. Within this dataset in 2011 36% of social housing units use either coal or peat for heating, compared to 8% for private rental, and owner-occupied properties.

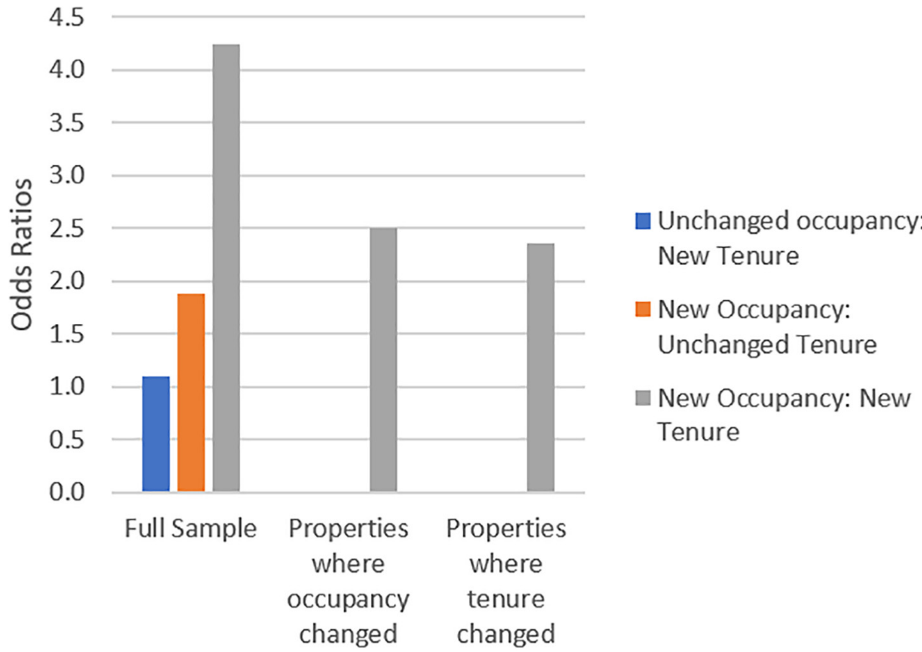

Fig. 1. Odds Ratios — New Occupancy and Tenure.

Over 15,000 (13.6%) properties in the sample switched to gas in the 2011–2016 period, with the largest share, at 45%, switching from oil followed by electricity (31%), coal (11%), and those with no central heating (8%). As shown in Table 3, using gas compared to other common home heating fuels is both cheaper and less polluting per unit energy, therefore, switching to gas could be advantageous to households, though there are additional capital costs associated with switching to gas that are discussed later. Although the motivation for switching fuels may be to reduce household heating costs, when households switch from coal, peat or oil to natural gas the outcome entails lower carbon emissions. Among the explanatory variables in the regressions are the central heating fuels used in 2011 relative to a reference case of no central heating. Controlling for other building and occupant attributes, properties fuelled by oil or coal in 2011 were less likely to switch to gas compared to the no central heating reference case. Given the low odds estimates for oil and coal, as well as, the high shares of properties switching from oil and coal, it suggests that factors other than the existing fuel (e.g. occupant attributes) are associated with the switch to gas. Properties fuelled with liquefied petroleum gas (LPG) are 2.7 times more likely to switch to natural gas relative to the reference case but this result is potentially an anomaly of data collection. In the dataset 53% of 740 properties fuelled by LPG in 2011 subsequently switched to natural gas but it is likely that many of these properties mistakenly reported or were unaware of the distinction of the two gas products (natural gas versus LPG) when completing their census return.

Table 3
Emission factors and fuel prices

Fuel	Emissions (g CO_2/kWh) (net calorific value)	Cost €/kWh
Gas	204.7	0.0723
Oil (kerosene)	257.0	0.0658
Electricity	482.8	0.2167
Solid Fuels (e.g. coal, peat)	357.0	0.0708

Source: [22].

A number of occupant characteristics are associated with the switch to gas as a primary heating fuel. The likelihood of switching to gas is lower where the census reference person, nominally the head of household, is aged 45 or above, though this is not the case in the sample conditional on a change in tenure (model (2)). Looking at social class categories, managers, professions, as well as those in the un-skilled professions are more likely to switch compared to manual workers. Households where the census reference person is employed in 2011 are marginally more likely to switch to gas compared to households where the reference person is not in employment. The occupant characteristic most highly associated with a switch to gas is family size. In the full sample (model (1)) families of 6 or more persons are 1.11 times more likely to switch to gas relative to 1–2 person families. The equivalent figure is 1.54 times when just considering properties where occupancy changed (model (2)).

3.2. Marginal effects

Marginal effects estimates are reported in Table 5, which are the change in probability, percentage point difference, associated with each right hand side variable in the regression models. Compared to odds ratios, the marginal effects help gauge from a practical perspective which impacts are most relevant. The difference in the magnitude of estimated marginal effects across the three subsamples is quite substantial, reflecting the large difference in proportion switching to gas: 13.6% for the full sample, 32% where occupancy changes, and 39.6% where tenure changed. In the full sample the probability of switching to gas is 7.1 percentage points higher among properties where occupancy changed between 2011 and 2016 compared to properties with unchanged occupancy. In the case of tenure change the difference is 2.4 percentage points. The marginal effects estimates conditional on either occupancy change or tenure change are very similar at 15 and 14 percentage points, respectively, relative to no change in occupancy or tenure. Fig. 2 illustrates these marginal effects estimates graphically.

Prior research established that the probability of connection to the Irish gas network declines with connection distance [23,22], though their estimates are not directly comparable with the cur-

Table 4
Regression models

Dependent variable: *SwitchToGas*	Full Sample		Properties where occupancy changed		Properties where tenure changed	
Models:	(1)		(2)		(3)	
	Odds ratio	Std err	Odds ratio	Std err	Odds ratio	Std err
NewOccupants : *NewTenure* (Ref. - No: No)						
No: yes	1.098	(0.075)				
Yes: No	1.882***	(0.113)				
Yes: Yes	4.24***	(0.387)	2.505***	(0.289)	2.360***	(0.250)
Distance from gas network (Ref.: less than 15 m)						
15–20 m	0.707***	(0.03)	0.606***	(0.037)	0.685***	(0.059)
20–30 m	0.52***	(0.043)	0.341***	(0.028)	0.491***	(0.072)
Heating system in 2011 (Ref.: no central heating system)						
Oil	0.237***	(0.046)	0.179***	(0.028)	0.25***	(0.027)
Electricity	1.081	(0.051)	0.833***	(0.05)	1.086	(0.279)
Coal (including anthracite)	0.618***	(0.051)	0.524***	(0.056)	0.69**	(0.121)
Peat (including turf)	0.414***	(0.106)	0.408***	(0.13)	0.278***	(0.141)
Liquid Petroleum Gas (LPG)	2.717***	(0.251)	4.775***	(0.987)	2.475*	(0.775)
Wood (including wood pellets)	0.669**	(0.136)	0.699	(0.251)	0.319***	(0.18)
Other	0.59***	(0.064)	0.562***	(0.08)	0.642	(0.277)
Year of building (Ref.: Before 1961)						
1961–1990	0.827*	(0.089)	0.92	(0.134)	0.759	(0.209)
Post 1990	1.997**	(0.443)	1.887	(0.598)	1.573	(0.615)
Number of rooms	1.089***	(0.01)	1.123***	(0.025)	1.167***	(0.047)
House type (Ref.:Detached houses)						
Semi-detached	1.104**	(0.047)	1.137**	(0.054)	1.061	(0.126)
Terraced houses	0.901	(0.069)	1.02	(0.09)	0.736***	(0.086)
Flats	0.227***	(0.033)	0.298***	(0.048)	0.117***	(0.036)
Tenure in 2011 (ref - owner with mortgage†)						
Owner without mortgage	0.702***	(0.023)	0.929	(0.132)		
Private rental	0.827**	(0.081)	0.75***	(0.065)		
Social housing - public	2.099***	(0.105)	1.396***	(0.099)	0.701***	(0.099)
Social housing - housing association	1.753	(0.485)	1.004	(0.319)	1.106	(0.282)
Employment status (reference person employed in 2011)	1.037**	(0.015)	1.087	(0.054)	1.243	(0.152)
Family size (ref - 1–2 people)						
3–5 people	0.989	(0.011)	1.244***	(0.067)	1.25***	(0.074)
6 + people	1.117***	(0.038)	1.545***	(0.093)	1.432**	(0.209)
Social class (Ref.: manual workers)						
Managers	1.218***	(0.049)	1.047	(0.144)	1.049	(0.125)
Higher professionals	1.285***	(0.086)	0.784*	(0.131)	0.971	(0.159)
Lower professionals	1.162***	(0.042)	0.798**	(0.092)	1.339*	(0.178)
Non-manual	1.123***	(0.036)	0.989	(0.074)	1.205	(0.212)
Semi-skilled	1.022	(0.033)	1.08	(0.086)	1.256	(0.205)
Unskilled	1.312***	(0.071)	1.289	(0.217)	1.427	(0.366)
Self-employed	0.988	(0.044)	0.983	(0.128)	0.952	(0.247)
Farmers	0.73*	(0.163)	0.696	(0.381)	0.6	(0.904)
Agricultural workers	1.161	(0.252)	0.957	(0.252)	0.53	(0.66)
Other	1.475***	(0.057)	1.277***	(0.069)	1.383	(0.254)
Age of census reference person (ref - 18–24)						
25–34	1.17**	(0.084)	1.031	(0.07)	0.885	(0.118)
35–44	0.994	(0.07)	0.998	(0.081)	0.873	(0.155)
45–54	0.702***	(0.066)	1.077	(0.068)	0.788**	(0.086)
55–64	0.685***	(0.047)	1.123	(0.083)	0.561***	(0.072)
65+	0.689***	(0.076)	1.079	(0.09)	0.658***	(0.108)
Constant	0.197***	(0.015)	0.521***	(0.086)	0.078***	(0.02)
County dummies	Yes		Yes		Yes	
Pseudo R-squared	0.2015		0.2144		0.2288	
AIC	70190		13135		3102	
BIC	70383		13285		3215	
ll	−35075.5		−6547.8		−1532.0	
Observations	110419		13288		2959	

Robust standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ and relate to tests of difference from 1. † The reference category in the regression in model (3) is rental properties. The sub-sample did not include any properties that were owner-occupied in 2011.

rent research. The distance decay effect is confirmed in the current study, finding that the probability of switching to gas declines as distance from the network increases, by 3.6 percentage points as distance increases from 0–15 metres to 15–20 metres and by 6.0 percentage points when the distance increases from 0–15 metres to 20–30 metres. The current research additionally finds that the distance decay effect is 2–3 times greater among properties where occupancy or tenure has changed (models (2) and (3)). The distance decay effect is likely associated with connection costs, of which there are two components. For most properties investigating the option of gas-fired heating, the largest cost of acquiring a gas service is the purchase and installation of a new gas boiler and associated domestic pipework, which typically will exceed €2000. The second cost is a network connection fee. For standard connections without a requirement for a gas mains extension, a flat-rate connection fee of €249.70 is levied for network connec-

Table 5
Logit marginal effects associated with property and household variables

	Full Sample		Properties where occupancy changed		Properties where tenure changed	
Models:	(1)		(2)		(3)	
	Marginal effect	Standard error	Marginal effect	Standard error	Marginal effect	Standard error
NewOccupants = Yes (ref - No)	0.071***	(0.005)			0.144***	(0.02)
NewTenure = Yes (ref - No)	0.024***	(0.007)	0.159***	(0.025)		
Distance from gas network (Ref.: less than 15 m)						
15–20 m	−0.035***	(0.004)	−0.087***	(0.011)	−0.068***	(0.016)
20–30 m	−0.061***	(0.006)	−0.172***	(0.011)	−0.124***	(0.023)
Heating system in 2011 (Ref.: no central heating system)						
Oil	−0.174***	(0.025)	−0.322***	(0.028)	−0.266***	(0.02)
Electricity	0.013*	(0.008)	−0.039***	(0.013)	0.016	(0.05)
Coal (including anthracite)	−0.074***	(0.014)	−0.135***	(0.022)	−0.073**	(0.034)
Peat (including turf)	−0.123***	(0.032)	−0.184***	(0.062)	−0.248***	(0.09)
Liquid Petroleum Gas (LPG)	0.195***	(0.019)	0.285***	(0.032)	0.162***	(0.051)
Wood (including wood pellets)	−0.063**	(0.031)	−0.075	(0.075)	−0.223**	(0.104)
Other	−0.08***	(0.017)	−0.121***	(0.028)	−0.088	(0.086)
Year of building (Ref.: Before 1961)						
1961–1990	−0.017	(0.011)	−0.013	(0.024)	−0.048	(0.05)
Post 1990	0.08***	(0.025)	0.11**	(0.053)	0.082	(0.069)
Number of rooms	0.008***	(0.001)	0.019***	(0.004)	0.027***	(0.007)
House type (Ref.:Detached houses)						
Semi-detached	0.009**	(0.004)	0.021***	(0.008)	0.01	(0.021)
Terraced houses	−0.009	(0.007)	0.003	(0.014)	−0.052**	(0.02)
Flats	−0.092***	(0.009)	−0.162***	(0.017)	−0.289***	(0.032)
Tenure in 2011 (ref - owner with mortgage)						
Owner without mortgage	−0.033***	(0.004)	−0.012	(0.024)		
Private rental	−0.018*	(0.01)	−0.047***	(0.015)		
Social housing - public landlord	0.092***	(0.008)	0.058***	(0.012)	−0.06**	(0.025)
Social housing - housing association landlord	0.067*	(0.038)	0.001	(0.053)	0.018	(0.045)
Employment status	0.003**	(0.001)	0.013*	(0.008)	0.038*	(0.022)
Family size (ref - 1–2 people)						
3–5 people	−0.001	(0.001)	0.035***	(0.008)	0.038***	(0.01)
6 + people	0.011***	(0.003)	0.072***	(0.01)	0.062**	(0.026)
Social class (Ref.: manual workers)						
Managers	0.018***	(0.003)	0.007	(0.022)	0.008	(0.02)
Higher professionals	0.023***	(0.006)	−0.038	(0.026)	−0.005	(0.027)
Lower professionals	0.013***	(0.003)	−0.035*	(0.019)	0.05**	(0.022)
Non-manual	0.01***	(0.003)	−0.002	(0.012)	0.032	(0.03)
Semi-skilled	0.002	(0.003)	0.012	(0.013)	0.039	(0.028)
Unskilled	0.025***	(0.006)	0.042	(0.029)	0.061	(0.046)
Self-employed	−0.001	(0.004)	−0.003	(0.021)	−0.008	(0.043)
Farmers	−0.025	(0.016)	−0.055	(0.08)	−0.081	(0.226)
Agricultural workers	0.013	(0.021)	−0.007	(0.042)	−0.1	(0.18)
Other	0.037***	(0.005)	0.04***	(0.009)	0.056*	(0.032)
Age of census reference person (ref - 18–24)						
25–34	0.018**	(0.007)	0.005	(0.011)	−0.022	(0.024)
35–44	−0.001	(0.008)	−0.000	(0.013)	−0.024	(0.032)
45–54	−0.035***	(0.011)	0.012	(0.01)	−0.042**	(0.02)
55–64	−0.037***	(0.009)	0.019	(0.012)	−0.099***	(0.019)
65+	−0.037***	(0.012)	0.012	(0.013)	−0.072**	(0.029)

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

tions up to 15 metres distance and increases by €51.32 per metre thereafter. If a connection necessitates a gas mains extension, which generally arises when the existing gas mains does not run perpendicular to the property seeking connection, network connection fees are higher. It is not surprising to find higher distance decay effects among properties where occupancy/tenure has changed, particularly where change in occupancy is due to purchase of the property, as moving home is typically associated with additional costs (e.g. mortgage/rent, moving, etc) and tighter budget constraints.

The odds ratio estimates indicate significant difference in switching to gas associated with property type or size (i.e. number of rooms). However, the marginal effect estimates are quite small from a practical perspective, being less than 1 percentage point for semi-detached or terraced houses relative to detached houses. For the sub-sample analyses, the marginal effect estimates are higher but still relatively low from a practical perspective. In the case of building age, the marginal effects estimates are relatively large, with properties built since 1990 8 percentage points more likely to switch to gas compared to pre 1960s properties. The effect is even higher among properties where occupancy has changed. Previous research has noted the high incidence of gas connections among properties built after 1990 reflecting strong marketing initiatives [24], however, the result here suggests that the trend has continued into the 2011–2016 period.

When looking at marginal effects associated with occupant characteristics for the full sample the estimates are all relatively low, the most notable of which is that properties where the census

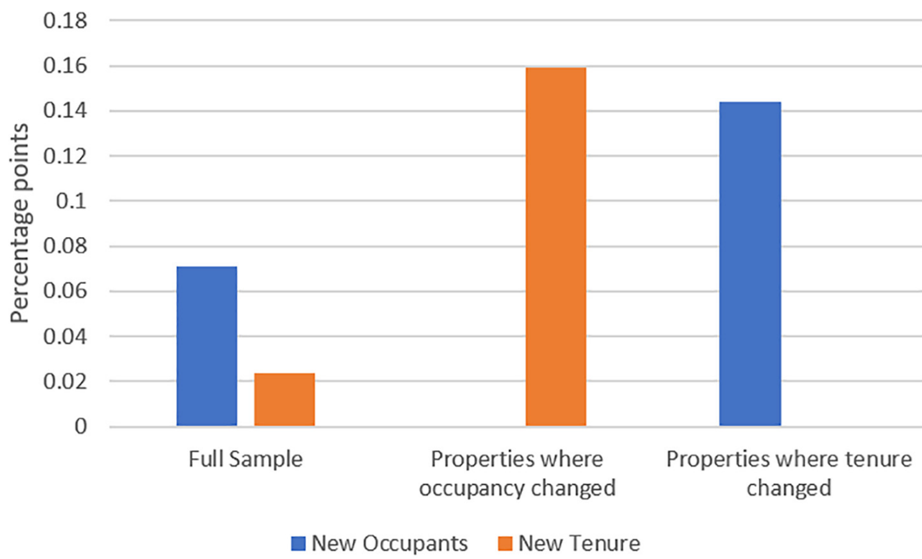

Fig. 2. Marginal effects — New Occupancy and Tenure.

reference person, nominally the head of household, is aged 45 or above. Such households are approximately 3.4 percentage points less likely to switch to gas compared to properties with 18–24 year old head of household. This result is not replicated when focusing on properties where occupancy changed but is replicated when focusing on properties where tenure changed. Again focusing on properties where occupancy changed, family size is strongly associated with whether a property switches to gas as a heating fuel. Relative to 1–2 person households, switching to gas is 3.5 percentage points more likely in the case of 3–5 member families, and 7.2 percentage points higher for even larger families. What is also notable is that the marginal effects associated with property size, as indicated by number of rooms rather than floor area, are much more modest. The number of family members rather than the size of property appears to be a key trigger in the decision to switch to gas heating.

4. Discussion and conclusion

This research attempts to establish whether moving home is a trigger for overhauling a property's heating system and the extent to which the overhaul of the heating system is associated with property tenure. Instead of data specifically on heating system overhaul we use switching to gas, as the least carbon intensive fossil fuel for domestic heating, as a proxy. On the first point there is clear evidence that switching to gas as a residential heating fuel and a change in occupancy are closely associated with each other, consistent with the findings of Sonderegger [14], van den Brom et al. [15] and Cho [13]. There is also evidence that a change in tenure is associated with switching to gas. Across all non-gas heated properties in 2011, within 30 metres of the gas network, the probability of a switch to gas in the 2011–2016 period is 7.1 percentage points higher for properties with new compared unchanged occupants. In the case of tenure change the marginal probability is +2.3 percentage points compared to properties with no tenure change. Conditional on occupancy change, the marginal effect associated with tenure change relative to no tenure change (and vice versa) is a 14–15 percentage point increase in the probability of switching to gas.

Research by Sonderegger [14] and Cho [13] finds that energy consumption is likely to change with new occupants in a property. The research here shows that there are wider energy impacts. First, the impact is not just related to energy consumption but entails a wider assessment of energy use within the home (i.e. fuel choice). The research explicitly examines whether properties switched to gas heating but implicit in that switch is a decision to invest in a property's heating system, possibly as part of a larger home renovation. This is consistent with the thesis that new occupants are likely to be more alert to energy efficiency and consumption levels within a property [19]. Second, the change in energy behaviour is associated with tenure as well as occupancy change. Properties where changes in both occupancy and tenure arise have the highest likelihood of switching to gas. Building on prior research on life-course transitions [7,8], the time-frame surrounding changes in property tenure and occupancy transitions could serve as a promising area to encourage uptake of energy efficient behaviours.

There is clear evidence that changes in occupancy and tenure trigger households to retrofit their heating systems. As noted in the discussion earlier on relative cost of fuels, the driver for fuel switching could be economic rather than due sustainability motivations, as natural gas is competitively priced relative to other fuels. In that instance, the more sustainable, lower emissions outcome is a side effect. Irrespective of motivations, it remains true that occupancy and tenure changes trigger households to upgrade their heating, which policymakers can exploit to encourage more sustainable outcomes. An additional challenge for policymakers would arise if the most carbon intensive fuels become substantially cheaper, however, carbon taxes can be adjusted to prevent such an outcome.

These findings have relevance for practitioners involved in climate and energy topics within the residential sector. Within the context of policy targets to improve the energy efficiency and emissions performance of residential building [e.g. 1] and also noting that energy efficiency renovations are relatively low priority among homeowners [2,3] the time period surrounding tenure and occupancy change are an opportunity to realise energy and emissions improvements. This research shows that energy renovations have a higher likelihood of occurring during this transitional period and therefore there may be a lower threshold to encourage homeowners to invest in energy retrofits at this time. Energy retrofit policy interventions specifically designed for and targeting properties where tenure or occupancy change should be considered. From Finnish research it is known that the policy window to encourage retrofits triggered by this transition covers an extended period of time and is not just the period immediately surrounding new occupants' arrival [10]. Three distinct cases with respect to changes in occupancy and tenure were highlighted in Table 2 and they potentially have very different underlying socio-economic and practical circumstances, that in turn need to be accommodated within policy initiatives. In some instances new occupancy follows the purchase of a property and in that situation new owner-occupiers may have short-term budgeting constraints that prevent immediate energy retrofits, so a longer window to avail of any policy support may be beneficial. However, a risk with open-ended supports is that energy retrofit investments can easily be deferred. A sunset clause on new retrofit supports specifically for new-occupants may inhibit such deferrals. Where new occupancy arises with a rental property, it is the landlord that makes energy retrofit decisions. In that situation the window for implementing a retrofit closes with the date of new occupancy (i.e. the retrofit is undertaken prior to arrival of new tenants) so the design of policy supports should differ from those assisting owner-occupiers. In both these cases of new occupancy, the time between old occupants departing and new occupants arriving is an opportunity to implement retrofit works without disturbing occupants, which evades an important barrier to energy retrofits, that of family disruption and inconvenience [25]. The case of new tenure but unchanged occupancy, possibly tenants of public housing acquiring the ownership of their home, does not include a vacancy period to implement retrofits and therefore presents challenges similar to properties with long-standing owner-occupiers.

Many climate and energy efficiency policy supports in the residential sector are voluntary, with homeowners opting-into avail of supports (e.g. retrofit grants). While such measures do encourage homeowners into action, the measures are passive in nature. With changes in occupancy and tenure it may be possible to actively engage with families during this transitional period to undertake an energy efficiency retrofit. Changes in occupancy and tenure involve either a new lease and registration of tenancy or exchange of property deeds. These events, plus the real estate agents and lawyers involved, could be utilised as a conduit to engage with property owners during these transitional periods. The engagement of real estate agents and lawyers may necessitate legislative underpinning but their involvement offers a timely means to refer property owners to relevant guidance and supports.

In addition to occupancy and tenure, this research highlights a number of other issues that may have relevance for the design of measures to encourage families to improve the energy and emissions performance of their homes. From a practical policy perspective there is no difference in the likelihood of switching to gas across house types (i.e. detached, semi-detached and terrace houses) nor house size (as measured by number of rooms rather than floor area). Additionally, while the most common pre-switch central heating fuels are oil, electricity and coal, when controlling for other property and occupant attributes these fuels are not associated with high odds ratios for switching, i.e. these fuels are not the defining characteristic associated with the switch to gas. Any policy initiative to encourage heating system upgrades that specifically targets or focuses on specific fuel types is not likely to be any more successful than initiatives focusing on other building or occupant attributes.

There is a substantially greater likelihood of switching to gas-fired heating in houses built since 1990, and among larger sized families. The fact that gas is more economical per unit energy compared to other fossil fuels, as noted in Table 3, combined with the fact that hot water demand is proportional to family size may be one potential explanation but this research is unable to provide further insight on why either larger families or houses built since 1990 are more likely to switch to gas. However, it is possible to say that the converse of these two categories (i.e. older properties, with small families) have a lower likelihood of upgrading their heating systems within the current policy environment and therefore special efforts, either via incentives or information/advertising, targeting these two categories may be necessary to increase heating system retrofits in these properties. More generally, a better understanding of the factors underlying these findings, including what motivates home-owners and landlords to makes these fuel-choice and retrofit decisions, is necessary to determine whether further policy supports can be developed to encourage residential heating retrofits.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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