A spatial perspective on the transition towards low carbon homes: evidence from the green deal

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Abstract

This paper aims to highlight the importance of environmental contexts in the pursuit of sustainability transitions by demonstrating the role local conditions play in the adoption of low carbon technologies. This aim is pursued by an empirical case study of the uptake of household energy assessments provided under the Green Deal energy policy of the United Kingdom. An analysis of uptake is presented which displays the spatial and temporal variation which has occurred throughout the lifetime of this energy policy. Through this illustration, it becomes apparent that uptake has occurred in a spatially heterogeneous manner, with certain areas of the United Kingdom exhibiting relatively high levels of adoption whilst others display comparatively low levels. A spatial regression model is specified to explain the observed spatial variation in uptake which draws attention to how the socioeconomic characteristics of the population, the attributes of the homes and the allocation of funding to local government condition the level of receptivity a particular area has to this energy policy. The findings of this analysis will likely prove of interest to the research community as evidence concerning the impact of spatial factors in energy transitions and to the policy community by demonstrating how spatial analysis can provide unique insights when evaluating the outcomes of energy policies.

Introduction

Achieving a successful transition to an environmentally sustainable energy system will be contingent on the widespread adoption of low carbon technologies amongst consumers. The adoption of these low carbon technologies tends to be framed in temporal terms, forecasting likely rates of uptake over given time periods. One issue which has attained less attention relates to how the adoption of these technologies will diffuse across space (Balta-Ozkan et al. 2015). Approaching the issue of low carbon technology adoption from a spatial perspective allows for insights to be generated concerning the impact that local conditions have on the diffusion of low carbon technologies specifically and the pursuit of sustainability transitions more generally.

The purpose of this paper is to illustrate how local contexts affect the level of activity surrounding low carbon technologies through an empirical case study which examines the spatial diffusion of the Green Deal household energy efficiency policy in the United Kingdom (UK). Specific focus is given to examining the ability of socioeconomic characteristics of the population and the attributes of the households to explain the observed spatial variation in uptake. Furthermore, the analysis evaluates how the allocation of funding to local government to enable the pursuit of local strategies stimulated uptake. This paper aims to shed light on the spatial processes at play in the diffusion of low carbon technologies and to demonstrate that the transition towards a sustainable energy system is unlikely to occur in a spatially uniform manner. Indeed, understanding the reasons why transitions are spatially heterogeneous will allow for future energy policy to be aware of the impact that local conditions can have on policy outcomes.

Background

The Green Deal represented a household energy efficiency policy implemented by the Department of Energy and Climate Change (DECC) in the UK. Mallaburn and Eyre (2014, p. 23) define the Green Deal as "a market-based, demand-led financial mechanism providing up-front loans for energy efficiency measures, which are repaid using the energy savings". The research presented in this paper concentrates on the uptake of Green Deal Assessments (GDAs) by households. Over the lifetime of the Green Deal, over 475,000 GDAs had been completed in England, which equates to approximately 2.1 % of the housing stock. These assessments involved the evaluation of the current energy profile of the household, leading to the production of an Energy Performance Certificate (EPC). The implementation of a GDA could be instigated by a householder requesting an evaluation by an accredited inspector or by an energy supplier recommending an evaluation to its customers due to the supplier's obligations to mitigate greenhouse gas emissions and fuel poverty (i.e. the Carbon Emissions Reduction Obligation and the Carbon Savings Communities Obligation). With this in mind, the spatial distribution of GDAs is likely generated through a mixture of demand pull and supply push activities. Table 1 reports the results of a market appraisal of GDAs undertaken by the DECC (2013), which indicates the principal reason for uptake is a desire to reduce household energy costs. With these considerations in mind, this paper utilises the uptake of GDAs as a proxy to measure the level of activity surrounding household energy efficiency retrofits.

Throughout the course of the Green Deal, the DECC made available a series of funding schemes to local government with the objective of enhancing Green Deal uptake (referred to as the Pioneer Places, Green Deal Communities and Core Cities schemes). Through its allocation of funding, the DECC implicitly recognised that knowledge of the local environment is an important issue in promoting the delivery of a successful energy policy, and that local government agents, with their familiarity of the population and existing housing stock, are well placed to pursue approaches tailored to the nuances of the local context. One of the contributions of the empirical case study of Green Deal uptake reported in this paper is to provide evidence regarding if the allocation of funds to local government to pursue their own strategies represents an effective means through which to promote the spatial diffusion of low carbon technologies.

Methodology

DATA SOURCES

The DECC released detailed information concerning the progression of the Green Deal (DECC, 2015a). As part of this, georeferenced data that notes the quantity of GDAs which have been conducted quarterly throughout the lifetime of the Green Deal (September 2013 to June 2015) have been reported across the 532 Westminster Parliamentary Constituencies (WPCs) of England. These data are the focus of the research reported in this paper. Additional data regarding the socioeconomic characteristics and household profiles of the WPCs are sourced from the 2011 census of England and Wales (Office of National Statistics, 2011), Her Majesty's Revenues and Customs' (2015) income data, the DECC's (2015b) National Energy Efficiency Database, the DECC's (2015c) fuel poverty estimates and the Office of National Statistics' (2016) records of house sales.

DATA PREPARATION

The data have been incorporated into a single dataset which lists the features of the WPCs inclusive of the number of GDAs conducted, socioeconomic characteristics, household attributes and funding allocations. This dataset has been spatially joined to a shapefile which contains the geographical layout of the WPCs of England (Office of National Statistics, 2013).

STATISTICAL ANALYSIS

The statistical analysis of the dataset progresses through three stages. The first stage of the analysis concentrates on a spatial and temporal depictions of the uptake of GDAs. A series of choropleth maps (i.e. variable maps) are presented which illustrate the spatial variation in the uptake of GDAs per 1,000 households across the WPCs of England at quarterly intervals between September 2013 and June 2015. To determine if any spatial dependence is present in the uptake of GDAs across the WPCs, spatial autocorrelation analysis is applied at both a global level, through the calculation of Moran's-I (Moran,

Table 1. Reasons stated by households regarding the decision to have a Green Deal Assessment conducted (multiple responses allowed).

Motivation	Percentage
To save money on energy bills	64.02 %
The assessment was free	58.01 %
To find out how to make the property more energy efficient	42.71 %
To reduce energy use for environmental reasons	28.71 %
To access the Green Deal finance and cashback initiative	16.70 %
Assessment was arranged by a landlord or local authority	15.34 %
The availability of cashback or discounts	13.35 %
Recommended by an energy company	13.32 %
Recommendation by an Energy Saving Advice Service	10.66 %
Recommendation by a friend or family member	9.67 %

1948), and at a local level, through the estimation of the Local Indicator of Spatial Association (LISA; Anselin, 1995).

The second stage of the analysis considers if WPCs located within local authorities that were recipients of central government funds have significantly higher levels of GDA uptake as compared to WPCs located within local authorities which did not receive such funds. Descriptive statistics are used to profile these recipient and non-recipient WPCs. Mann-Whitney-U tests are applied in order to determine if WPCs that received funding have a significantly higher level of GDA uptake compared to those WPCs that did not receive funding.

In the third stage, a log-log Spatial Durbin Model (SDM; Elhorst, 2014) is specified with the cumulative uptake of GDAs per 1,000 households as of June 2015 across the WPCs as the model dependent variable and measurements of the socio-economic characteristics of the population, the features of the households and the allocation of central government funding used as the independent variables. The SDM allows for the estimation of direct, indirect and total effects of the model independent variables. Direct effects measure the impact of an independent variable over the dependent variable in a particular area, indirect effects measure the impact of an independent variable over the dependent variable in neighbouring areas (i.e. a spatial spillover) and total effects measure the accumulation of direct and indirect effects. Thus, the SDM allows the analysis to consider how GDA activity is both effected by the environmental contexts directly present in a particular area and the wider environmental conditions present in neighbouring areas.

Results

SPATIAL-TEMPORAL ANALYSIS

Figure 1 illustrates the spatial dynamics in the uptake of GDAs across the WPCs of England between September 2013 and June 2015. A substantial range of uptake is visible. The WPC of the Cities of London and Westminster displays the lowest level of GDA uptake at 0,8 per thousand households in June 2015. The WPC of Nottingham South exhibits the highest level of uptake at 90,9 GDAs per thousand households. As the uptake of GDAs progresses through the observation period, the analysis indicates that WPCs in the North of England, especially surrounding some of the large conurbations in this region, represent areas with relatively high levels of adoption whereas the South East region appears to display comparatively low levels of uptake. During the last three observations (December 2014 to June 2015), the uptake of GDAs stabilises in terms of the rank order of WPCs. This stabilisation is largely due to the legacy of completed assessments, with new uptake not significantly altering the existing ranks of WPCs. One interpretation of this is that lead and laggard local markets for GDAs have been established in the time period where observations of uptake have been taken.

Whilst a significant degree of spatial variation in the uptake of GDAs is observable in Figure 1, the possibility exists that this variation is random in nature. The application of spatial autocorrelation analysis assists in determining if any degree of spatial organisation is present in the uptake of GDAs. The results of Moran's-I test of global spatial autocorrelation and the LISA analysis are displayed in Figure 2 for all of the observation points. In each instance, Moran's-I returns a statistically significant result (p-value < 0,001), indicating that the uptake of GDAs in a particular WPC tends to be related to the uptake of GDAs in the neighbouring WPCs. The LISA analysis provides additional information concerning the areas which seem to cluster around similar values (e.g. hotspots and coldspots of GDA uptake) and also WPCs which appear to be dissimilar to their neighbours, indicating the occurrence of spatial outliers.

From a visual inspection of the sequential LISAs, it is apparent that clusters of similar values (i.e. high-high and low-low) tend to be most prevalent, with the analysis identifying a series of coldspots (deep blue areas) and hotspots (deep red areas). Of particular interest is how these areas progress through the observation points. For instance, in the first observation point (September 2013), the North West of England is characterised as a large coldspot, implying that the WPCs contained within this region had a tendency to display low levels of uptake of assessments when the Green Deal was initially introduced. Over the course of the first four observations, this coldspot gradually reduced and can no longer be observed from September 2014 onwards. This result suggests that the North West of England was initially slow in its uptake of GDAs, but over the duration of the first year of the Green Deal it steadily converged to the national average. In terms of hotspots, a visual inspection of the sequential LISAs illustrates how the cities in the North (i.e. Liverpool, Manchester and Leeds) and the Midlands (i.e. Birmingham and Nottingham) of England established as lead markets for this energy policy.

FUNDING ANALYSIS

Throughout the course of the Green Deal, the DECC made available three different rounds of funding to local authorities intended to accelerate uptake of the policy (i.e. the Pioneer Places, Green Deal Communities and Core Cities schemes). This section evaluates whether WPCs that received funding are significantly different in terms of their uptake of GDAs as compared to WPCs that did not receive funding. The results of the analysis are presented in Table 2 which notes a series of descriptive statistics as well as the results of the Mann-Whitney U tests. In terms of the Pioneer Places funding, no significant difference in the uptake of GDAs is observed between those WPCs which are located in local authorities that received funding and those which did not receive funding. For the Green Deal Communities and Core Cities funding, significant differences in the uptake of GDAs are observed, with those WPCs which are located in local authorities that received funding tending to display higher levels of uptake compared to those WPCs which did not receive funding. This finding is consistent with expectations and indicates that the allocation of funding under the Green Deal Communities and Core Cities schemes may have increased the uptake of GDAs.

REGRESSION ANALYSIS

The results of the SDM are reported in Table 3. A number of significant direct, indirect and total effects are identified in the model. In terms of the direct effects, the variables measuring the proportion of the population under the age of 35, cohabiting with children, the mean personal incomes of the population, the mean number of residents per households, the proportion of households classified as EPC grade C or above as well as the presence of local funding in the form of the Green Deal

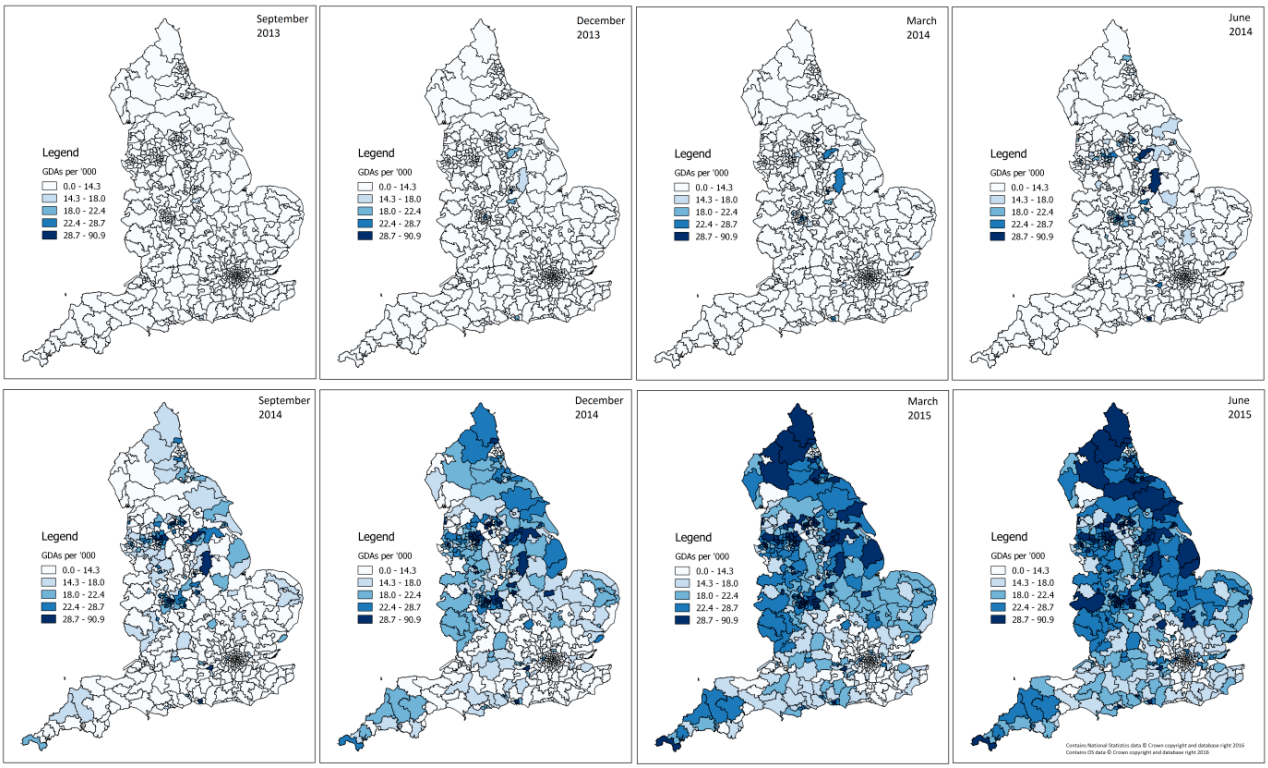

Figure 1. Choropleth maps illustrating the level of Green Deal Assessments (per 1,000 households) conducted across the Westminster Parliamentary Constituencies of England quarterly from September 2013 to June 2015.

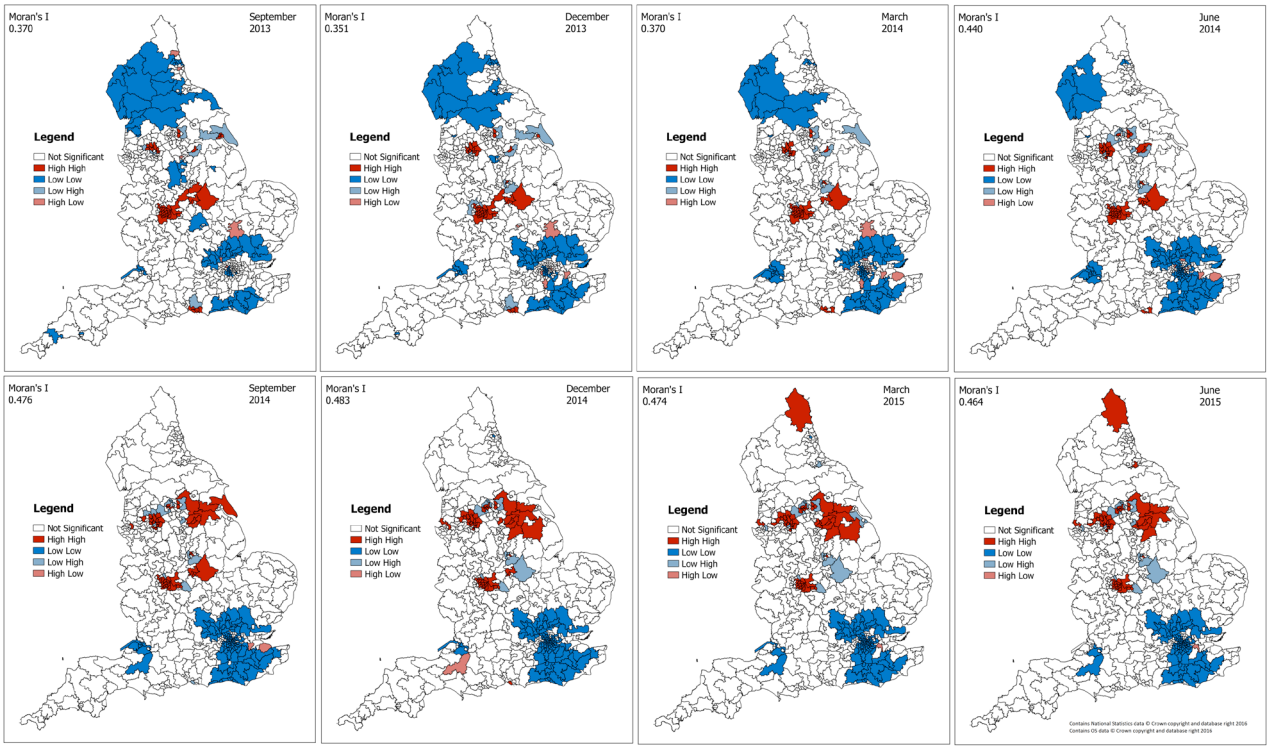

Figure 2. Local indicator of spatial association analysis for Green Deal Assessments (per 1,000 households) across the Westminster Parliamentary Constituencies of England quarterly from September 2013 to June 2015.

Table 2. Descriptive statistics and Mann-Whitney U test results for the Green Deal Assessments (per 1,000 households) as of June 2015 across the three funding allocations.

	Mean	Std. Dev.	Min.	Max.
Pioneer Places (U = 11,006, p-value = 0,136)				
Recipient (n = 67)	21,533	7,431	4,500	39,000
Non-recipient (n = 371)	20,527	8,888	0,800	73,900
Green Deal Communities (U = 6,579, p-value = ,020)				
Recipient (n = 45)	25,839	13,222	9,500	68,300
Non-recipient (n = 371)	20,527	8,888	0,800	73,900
Core Cities (U = 3,250, p-value < .001)				
Recipient (n = 28)	28,460	12,840	11,800	64,000
Non-recipient (n = 371)	20,527	8,888	0,800	73,900

Communities and Core Cities all represent significant factors. This implies that variation in these variables within a particular WPC significantly effects the GDA activity within that particular WPC. In terms of indirect effects, the variables measuring the proportion of the population that have attained a university degree, that are self-employed, the mean personal incomes of the population and the proportion of households classified as detached all represent significant factors. These findings indicate that variation in these variables in neighbouring WPCs affects GDA activity in a particular WPC. To scrutinise the intuition of these findings, consider the positive indirect effect of the variable measuring the proportion of households classified as detached. It is likely that areas with relatively large proportions of detached households have experienced higher levels of household energy efficiency activities in the past, due to these properties being more conducive to retrofits (e.g. having authority over roofs and exterior walls). Due to this, mature supply chains for energy efficiency retrofits may have developed in the vicinity of areas with relatively large proportions of detached households. Thus, the observation of an indirect positive effect between the proportion of detached households and GDA activity could be the result of these mature supply chains motiving higher levels of GDA activity. In terms of total effects, the variable measuring the proportion of house sales per annum holds a negative association with GDA activity.

The introduction of the spatial lag of the uptake of GDAs in the SDM allows for the analysis to consider if GDA activity itself exhibits spatial spillovers. The spatial lag is significant (Beta: 0,510), indicating that the uptake of GDAs in particular WPCs are effected by the levels of uptake in neighbouring WPCs after accounting for the effect of socioeconomic, household and funding characteristics. A number of possible reasons may underpin this observation. One interpretation of is that householders are observing the level of GDA uptake in their vicinity and this is effecting their level of uptake. In this sense, there could be an imitation effect present, whereby households tend to mimic the behaviour of other households which they have a close proximity to. Alternatively, the significance of the spatial lag of GDA uptake could indicate the presence of knowledge spillover, whereby the experiences of households in one spatial unit are communicated to those in their vicinity and produce an increase in uptake in neighbouring spatial units. Both of these interpretations are plausible but would require additional empirical research with adopters in order to determine if either imitation effects or knowledge spillovers are present.

Conclusions

To date, evaluations of the diffusion of household low-carbon technologies have occurred predominately in an aspatial manner. Assessments of such issues as household uptake of energy efficiency technologies have tended to overlook the geographical issues at play which condition how such technologies are received. Through the empirical case study reported in this paper concerning uptake of GDAs, the analysis brings to light the importance of environmental conditions in energy transitions.

The analysis commences with relatively simple illustrations for the spatial and temporal variation in the adoption of GDAs. These illustrations demonstrate that activity surrounding household energy efficiency retrofits has a substantial spatial variation, with some areas displaying higher levels of activity than others. Whilst on the surface this may seem like an obvious finding, it can have a number of important implications on further reasoning. Most apparent of these is that the diffusions of low carbon technologies amongst households are unlikely to occur in a spatially uniform manner. The results of the spatial autocorrelation analysis demonstrate that certain regions of England appear to be gravitating around similar levels of uptake, indicating the existence of lead and laggard local markets. With the uptake of GDAs having occurred in a spatially heterogeneous manner, the next issue to consider is why this has happened.

The results of the regression analysis provide insight on this issue and indicate that local environmental conditions appear to significantly affect the uptake of GDAs. These conditions have been separated into three factor groupings which are effecting uptake in a direct manner (i.e. local conditions effecting local uptake) and an indirect manner (i.e. neighbouring conditions effecting local uptake). The first of these groups relates to the socioeconomic profile of the population, which is linked to the capabilities and desires of citizens to adopt technologies. For example, the variable measuring the proportion of the population who are in the under 35 years old, cohabitating and with children lifestage has a positive direct effect on the uptake of GDAs. One interpretation of this finding is that the establish-

Table 3. Spatial Durbin Model estimates of direct, indirect and total effects of socioeconomic characteristics, household attributes and local funding availability over the adoption of Green Deal Assessments (per 1,000 households).

Variable	Direct		Indirect		Total	
	Mean	T Stat	Mean	T Stat	Mean	T Stat
Socioeconomics						
% Cohabiting under 35 with Child (ln)	0,241**	2,2496	0,3549	1,0101	0,596	1,5465
% University Qualification (ln)	-0,0347	-0,349	0,8807**	3,2604	0,846**	3,0659
% Self Employed (ln)	0,1142	1,139	-0,8576**	-3,2874	-0,7434**	-2,6958
Median Personal Income (ln)	-0,667**	-3,0368	-1,2203**	-2,3814	-1,8874**	-3,3398
% Fuel Poverty (ln)	0,044	0,3286	-0,3618	-1,6571	-0,3178	-1,5039
Household						
% Detached (ln)	0,0797	1,6487	0,2534**	2,4938	0,3331**	3,413
% Terraced (ln)	0,0346	0,6196	-0,0387	-0,269	-0,0041	-0,0284
Mean Number of Residents (ln)	1,3087**	3,4452	-0,9999	-1,0069	0,3087**	0,3024
% House Sales per Annum (ln)	-0,1709	-1,4698	-0,3831	-1,5372	-0,554**	-2,1577
% Owned with Mortgage (ln)	-0,1212	-0,8933	0,3433	1,0225	0,2221	0,6082
% No Central Heating (ln)	0,0277	0,4799	0,0796	0,8044	0,1072	1,2659
% EPC Grade A–C (ln)	-0,2606**	-3,0299	-0,1604	-0,7025	-0,421	-1,7015
Funding						
Pioneer Places [A]	0,0425	1,1488	-0,0957	-0,8751	-0,0533	-0,466
Green Deal Communities [A]	0,1556**	3,6268	0,1479	1,4561	0,3035**	2,9445
Core Cities [A]	0,157**	2,2595	-0,1967	-1,0543	-0,0396	-0,2237
Spatial Interaction						
Spatial lag of GDAs (ln)	0,510**					
Model Fit						
R^2 (adjusted)	0,733					
Log-likelihood	2,414.467					

*: p-value < 0,01

ment of a family represents a stage in which households have a heightened propensity to consider investing in energy efficiency. The second category relates to the attributes of the homes present within an area, which is linked to the application environment for the technology. For example, the variable measuring the proportion of the housing stock classified EPC grade C or above has a negative direct effect on the uptake of GDAs. This finding is quite intuitive, as areas that already have relatively high levels of household energy efficiency are less suited to GDA activity. The third category relates to the availability of funding to local government, which enables local agents to support the adoption of technologies. For example, the variables measuring the allocation of funds under the Green Deal Communities and Core Cities schemes have positive direct effects over the uptake of GDAs. This result implies that the provision of resources to allow local agents to pursue strategies which are tailored to the specific circumstances of the areas (such as conducting street-by-street assessments of the housing stock to identify opportunities) can promote household energy efficiency activity.

More generally, the results of the case study indicate that different areas are likely to possess different transition capacities to adopt low carbon technologies. Understanding why these different capacities are present represents the first stage in developing spatially aware policies. National level policy frameworks can have built in flexibilities which acknowledge the importance of environmental conditions and allow local approaches to be developed that respond to the circumstances of particular areas. For instance, communication budgets to raise awareness of the energy policy could be targeted according to the tenure of households. In areas with high owner-occupier rates, a letterbox leaflet distribution could be optimal but would likely prove ineffective in areas with high renting rates, where a focused approach to estate agents and leasing unions would be more suited. Additionally, understanding that transition capacities are unlikely to be spatially uniform can be useful in policy monitoring and evaluation by allowing the setting of targets to account for the particular conditions which may constrain or promote uptake across different spatial contexts. For instance, the expectations for uptake in an area which has a relatively low proportion of cohabiting couples under the age of 35 with children, high levels of personal income, a high proportion of household sales and a high proportion of homes classified as EPC grade C or above (all factors which significantly effect

GDA uptake) could be set lower than an area with the opposite conditions for these metrics. In order for such post-hoc assessments to occur, governments will need to ensure that accurate spatial data is collected and made publicly available throughout the course of future energy policies.

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