UCL CENTRE FOR ADVANCED SPATIAL ANALYSIS

UCL

WORKING PAPERS SERIES

Paper 217 - Mar 20

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ISSN 1467-1298

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Centre for Advanced Spatial Analysis University College London Gower St London WC1E 6BT
Tel: +44 (0)20 3108 3902 casa@ucl.ac.uk www.casa.ucl.ac.uk

Delineating the spatio-temporal pattern of local authority house prices variation in England between 2009 and 2016

Bin Chi[1], Adam Dennett[1], Thomas Oléron-Evans[1], Robin Morphet[1]

[1] Centre for Advanced Spatial Analysis (CASA), University College London, UK

Abstract

Most spatio-temporal studies of house price in the UK are carried out at national or regional scale, but house prices differences could be better understood at finer spatial scales. Since England's house prices, standardised by the size of the property (£/m^2), have been shown to be somewhat clustered at local authority level and highly clustered at Middle Layer Super Output (MSOA) level, in the period 2009 to 2016, this research aims to further explore the nature of spatial and temporal variation in house prices at local authority level in England. Growth curve modelling offers a model-based description of the spatio-temporal patterns of local authority house price variation. This research explores local authority effects and three different time effects (quarter, half-year and year) on house price spatio-temporal variation. Results show that these three time effects are essentially identical and are extremely small, in comparison with local authority effects. Since annual effects provide the best fit, local authority annual house price trajectories between 2009 and 2016 are further explored. Local authorities with higher house prices in 2009 are found to have faster growing prices over the eight-year period than local authorities with lower house prices. Moreover, two clear geographic hubs of house price change over the period are observed, one centred on London, the other on Bristol.

Keywords: Local authority, house price variation, growth curve modelling, England

1. Introduction

A house is an immovable asset and its location is regarded as the most important determinant of its value (Downes, 2018; Kiel and Zabel, 2008). House prices in desirable locations are frequently too high to be affordable for people on average salaries and, in countries such as the United Kingdom, exhibit large spatial disparities (Hamnett and Reades, 2019). However, commentary on this spatial heterogeneity in the UK is often fairly crudely expressed through observations such as the "North-South divide". Regional house price spatio-temporal patterns and fluctuations have been well explored and historically conceptualised as a ripple effect spreading out from London and the South East across England. Indeed, it has been recognised that London and the South East have played a leading role in terms of spill-overs to other regions since 1969 (Cook, 2003; Cook and Watson, 2016; Hamnett and Reades, 2019; Meen, 1999; Stevenson, 2004), but little sub-regional analysis has appeared in the literature (Cooper et al., 2013; Gray, 2012). Our understanding of house price heterogeneity in the UK has been further limited with the majority of these regional house price analyses exploring the periods before the global financial crisis of 2008 – a time of great shock in the UK housing system.

Other criticisms of housing market research in the UK have been that attempts have not been made to link effects operating at different geographical or temporal scales (Cooper et al., 2013; Meen, 2001). Some more recent studies have begun to address this (Chi et al., 2020; Feng, 2016; Law, 2018; Orford, 2017), but only two have carried out this analysis nationally (Chi et al., 2020; Feng, 2016). Emerging from the work from Chi et al (2020), it has been shown that England's house prices, controlling for the size of the property (£/m^2), are found to be somewhat clustered at local authority level and highly clustered at Middle Layer Super Output Area (MSOA) level between 2009 and 2016. Accounting for property size reveals that this clustering is even more apparent than would be the case were just raw transaction prices examined, but gaps in our understanding still exist where the recent interacting influences of space and time on house prices are not fully understood.

The research in this paper overcomes these shortcomings and further explores house price variation in England at and below local authority level across different temporal scales, offering new observations on price variations across space and time. Two spatial scales (local authority and MSOA) along with three different time scales (quarter, half-year and year) are considered in this research. Our two aims are firstly, to understand the extent to which space and time influence house price variation in England and secondly to facilitate a deeper understanding of spatio-temporal changes using a growth curve modelling approach. In Section 2 we briefly review the previously observed price ripple effects in England. In Section 3, the study area and the data used are introduced. Section 4 presents the growth curve modelling approach used to model the spatio-temporal patterns of local authority house price variation, with the results show in Section 5. Finally, a summary and conclusions are drawn in Section 6, together with recommendations for future research.

2. Ripple effect studies in the UK

Regional house price trends in the UK have been previously likened to the ripples on a pond after a stone is thrown in (Cooper et al., 2013). The simile refers to the notion that house prices in one region affect house prices in other regions over a given time period (MacDonald and Taylor, 1993). Empirical studies exploring regional quarterly house price changes in the UK shows such a pattern, with London and the South East being the source of the ripple leading to eventual spillovers to other regions (Alexander and Barrow, 1994; Giussani and Hadjimatheou, 1991; MacDonald and Taylor, 1993; Meen, 1996). This phenomenon of interregional interactions has been well-identified in long-term house price change, especially in the period from 1968 to 2006. Regional house price studies after 2007 global economics crisis also reveal the similar ripple effect interregional interactions but with a more significant London effect (Cook and Watson, 2016; Hamnett and Reades, 2019).

Previous research on the ripple effect in the UK has used data aggregated by quarter or by year (Ashworth and Parker, 1997; Gray, 2012; Hamnett and Reades, 2019). Cooper et al (2013) attempted to use different time slices when producing aggregate house price indices at different spatial scales, but their approach does not enable a systematic understanding of the time effect on house price variation. A framework that systematically integrates England's house prices at different spatial and temporal scales does not exist limiting our understanding of the national housing market. This study builds on this previous research by investigating house price variation at and below the local authority spatial scale and three different time scales (quarter, half-year and year) for the time period after the economic crisis.

3. Study area and data

3.1 Study area

The study area is the whole of England, the largest country of the United Kingdom. It contains nine regions: the North East, the North West, Yorkshire and the Humber, the East Midlands, the West Midlands, the East of England, the South East, the South West and London. Administratively, England is divided into 326 local authorities, and these are further divided into 6791 MSOAs, units frequently used for the dissemination of demographic data from the decennial Census.

3.2 House price data

We use data on transaction price per unit floor area (£/m^2) – henceforth referred to simply as "house price (£/m^2)" – from a newly created house price dataset (Chi et al., 2019). The new data records 4,682,468 transactions sold at full market value in England between 2009 and 2016, representing 80% of the full market housing sales in the Land Registry Price Paid Dataset over the same period. Supplementary Material A displays the house price (£/m^2) density plots for prices below 15,000 £/m^2 over the full period from 2009 to 2016. House price (£/m^2) distributions in each year are seen to be positively skewed.

4. Methodology

The following analysis is divided into two stages with three methods employed. Firstly, a variance components model is used to explore the space and time effects on house price variance in England between 2009 and 2016, especially for three different time scales (yearly, half-yearly and quarterly). Secondly, growth curve models are used to present a model-based description of the spatio-temporal patterns of local house prices in England between 2009 and 2016. Choropleth mapping is used to represent the spatio-temporal patterns of England's local housing markets.

4.1 Variance components model

For geographical research, multilevel modelling is a useful statistical tool to model relationships that vary in space and over time (Jones, 1991). The variance components model is a multilevel model with no explanatory variables. In exploring house price variation, it offers a systematic tool to quantify variances over different spatial scales and time scales. Given the dataset described in Section 3.2, a three-level variance components model was built to systematically explore the spatial effect (i.e. local authority) and time effect on house price variance. This model is written as:

$$h_{igj} = \beta_0 + l_j + u_{gj} + e_{igj} \quad (1)$$

$l_j \sim N(0, \sigma_l^2)$

$u_{gj} \sim N(0, \sigma_u^2)$

$e_{igj} \sim N(0, \sigma_e^2)$

where h_{igj} refers to an individual house price (log scale) for the ith transaction at time period g in local authority j. The fixed term β_0, represents the overall mean house price over the complete time period, and l_j, u_{gj} and e_{igj} are the random terms of the variance components

model, representing respectively the residuals at local authority level, time period level and individual level. Residuals at each level are assumed to follow a normal distribution with zero mean and a constant variance. l_j measures the extent to which the mean house price in local authority j varies from the overall mean house price (β_0), u_{gj} measures the extent to which mean house price at time period g in local authority j deviates from mean house price in local authority j for the whole period (β_0). Residuals at the same level are assumed to be uncorrelated with each other, and residuals at different levels are also assumed to be uncorrelated.
The three level variance components model can also be extended to four levels to examine two location effects and one time-effect simultaneously. This is achieved by adding a new random term. House prices in England have been found to differ relatively little within the same MSOA for a given year over the period 2009 to 2016 (Chi et al., 2020). Given this, a four-level model was built to explore the extent of house price variation by local authority, MSOA and time. Equations are shown in equation 2:

$$h_{igkj} = \beta_0 + l_j + m_{kj} + u_{gkj} + e_{igkj} \quad (2)$$

$l_j \sim N(0, \sigma_l^2)$

$m_{kj} \sim N(0, \sigma_m^2)$

$u_{gkj} \sim N(0, \sigma_u^2)$

$e_{igkj} \sim N(0, \sigma_e^2)$

where h_{igkj} refers to an individual house price (log scale) i recorded during time period g in MSOA k and local authority j . β_0, l_j, σ_l^2 and σ_u^2 have the same meaning as in equation 1. The new random term m_{kj} is the MSOA level residual, which quantifies the extent to which the mean house price of MSOA k deviates from the mean house price in local authority j for the given period. The time level residual u_{gkj} quantifies the difference between the mean house price for a given time period (e.g. one year) in one MSOA and that MSOA's mean house price over the whole period. The individual residual (e_{ikj}) quantifies difference between any individual house price and the mean house price of the corresponding MSOA and time period.

In this four-level variance components model total house price variance is decomposed into four parts ($\sigma_l^2, \sigma_m^2, \sigma_u^2$ and σ_e^2), which represent the variance around the grand mean at the level of local authority, MSOA, time and individual (Jones and Bullen, 1993). The variance at local authority level (σ_l^2) measures house price differences between local authorities over the whole period; σ_m^2 is the MSOA level variance, measuring the price difference within-local-authority-between-MSOAs over the whole period; σ_u^2 is the residual variation at time level, which measures the time-to-time (e.g. year-to-year) differences within the same MSOA; σ_e^2 is the individual variance, measuring the house price variability for a given time period and MSOA. Variance partition coefficients (VPC) represent the percentage variance explained by a given level in the multilevel model using the four variance components (σ_l^2 , σ_m^2 , σ_u^2 and σ_e^2). It ranges from 0 to 1, with 0 signifying no between group differences and 1 signifying no within group differences. A higher VPC at a particular level indicates that a greater proportion of total variation is due to differences between the units at that level. The equation for VPC at local authority level is presented in equation 3, with equations for VPC at MSOA level (equation 4), time (equation 5) and individual level (equation 6).

$$VPC_l = \frac{\sigma_l^2}{\sigma_l^2+\sigma_m^2+\sigma_u^2+\sigma_e^2} \quad (3)$$

$$VPC_m = \frac{\sigma_m^2}{\sigma_l^2+\sigma_m^2+\sigma_u^2+\sigma_e^2} \qquad (4)$$

$$VPC_u = \frac{\sigma_u^2}{\sigma_l^2+\sigma_m^2+\sigma_u^2+\sigma_e^2} \qquad (5)$$

$$VPC_e = \frac{\sigma_e^2}{\sigma_l^2+\sigma_m^2+\sigma_u^2+\sigma_e^2} \qquad (6)$$

Three three-level variance components models were used to estimate the extent of the house price variability at local authority level, MSOA level and three different time scales, each considered by a different model. Level 1 is the individual residential properties. Level 2 is the time level but separately refers to three different time periods (quarter, half-year and year). Level 3 is MSOA level and level 4 is local authority level. The equations for these three models are listed in Table 1. A likelihood-ratio test is used to test the significance of the local authority effect and the time effect in Models 1, 2 and 3. The local authority effect is verified through comparison between the candidate models in Table 1 and their corresponding two-level variance components models, obtained by dropping the local authority level. The three different time effects are verified by means of three pairwise likelihood-ratio tests, comparing the candidate models with their corresponding two-level variance components models, obtained by dropping the given time level. Additionally, a likelihood-ratio test is used to identify which is the best fitted model in Table 1.

Table 1. The candidate three-level variance components models

Model	Equation
Model 1	$h_{iskj} = \beta_0 + l_j + m_{kj} + q_{skj} + e_{iskj}$
Model 2	$h_{imj} = \beta_0 + l_j + m_{kj} + hy_{mkj} + e_{imkj}$
Model 3	$h_{ikj} = \beta_0 + l_j + m_{kj} + y_{lkj} + e_{ilkj}$
Notes: h is the log scale of the house price (£/m^2). For example, h_{iskj} stands for the log of house price *i* in quarter period *s* in MSOA *k* in local authority *j*. β_0 is overall mean house price across the local authorities over the complete time period, l_j is the residuals at local authority level, m_{kj} is the residuals at MSOA *k* in local authority *j*, q_{skj} is the residual at time level in terms of quarter, hy_{mkj} is the residual at time level in terms of half-year period, y_{lkj} is the residual at time level in terms of year. e_{isj}, e_{imj} and e_{ikj} are stand for individual level residual.	

4.2 Growth curve modelling

Growth curve modelling generally uses a multilevel model with time as a predictor, to fit a trend in repeated-measures data over time and across different levels (Goldstein, 2010). Growth curve modelling has been effectively used in longitudinal studies when addressing questions about change (Singer and Willett, 2003; Steele, 2008; Zaninotto et al., 2009). While in house price analysis, house price can be treated as a "repeated measurement" for the same areas (Jones and Bullen, 1993). For example, individual transaction prices (level 1) are recorded for different local authorities (level 2). Such a basic two-level growth curve model can be represented formally using the following equation:

$$h_{ij} = \beta_0 + \beta_1 t_{ij} + l_j + e_{ij} \qquad (7)$$

$l_j \sim N(0, \sigma_l^2)$

$e_{ij} \sim N(0, \sigma_e^2)$

where h_{igj} is the individual house price (log scale) for the *i*th transaction in local authority *j*,

t_{ij} is the time (i.e. year) of the transaction i in local authority j. The natural logarithm of the response is used to deal with the technical problems of non-linearity and provides a meaningful interpretation of estimated slope parameter β_1. β_1 is the overall average slope, which is approximately equal to the overall percentage increases in England over the whole period (2009-2016) when it smaller than 0.25 (Tufte, 1974). β_0 is the overall mean, which is interpreted as the overall house price in England (2009-2016) in terms of a logarithmic scale. The fixed part in the multilevel model is $\beta_0 + \beta_1 t_{ij}$, the random part is $l_j + e_{ij}$. l_j and e_{ij} are the residuals. Residuals at a given level are assumed to follow a normal distribution with zero mean and constant variance. Moreover, residuals at the same level or different levels are assumed to be uncorrelated with one another.

In equation 7, all the local authorities in level 2 share the growth trend (β_1). However, growth curve modelling can permit this growth to vary between local authorities by adding a new random part $l_{1j} t_{ij}$. The new equation is:

$$h_{ij} = \beta_0 + \beta_1 t_{ij} + l_{0j} + l_{1j} t_{ij} + e_{ij} \quad (8)$$

$l_{0j} \sim N(0, \sigma_{j0}^2)$

$l_{1j} \sim N(0, \sigma_{j1}^2)$

$e_{ij} \sim N(0, \sigma_e^2)$

Here, h_{ij}, β_0, β_1 and e_{ij} have the same meaning as in equation 7. l_{0j} has the same meaning as l_j in equation 7. The new random term l_{1j} measures the extent to which the slope of local authority j deviates from the overall slope β_1. The random effects l_{1j} and l_{0j} are assumed to follow normal distributions with zero mean, variances σ_{j0}^2 and σ_{j1}^2 respectively, and covariance σ_{j01}. e_{ij} is also assumed to follow a normal distribution with zero mean and constant variance σ_e^2.

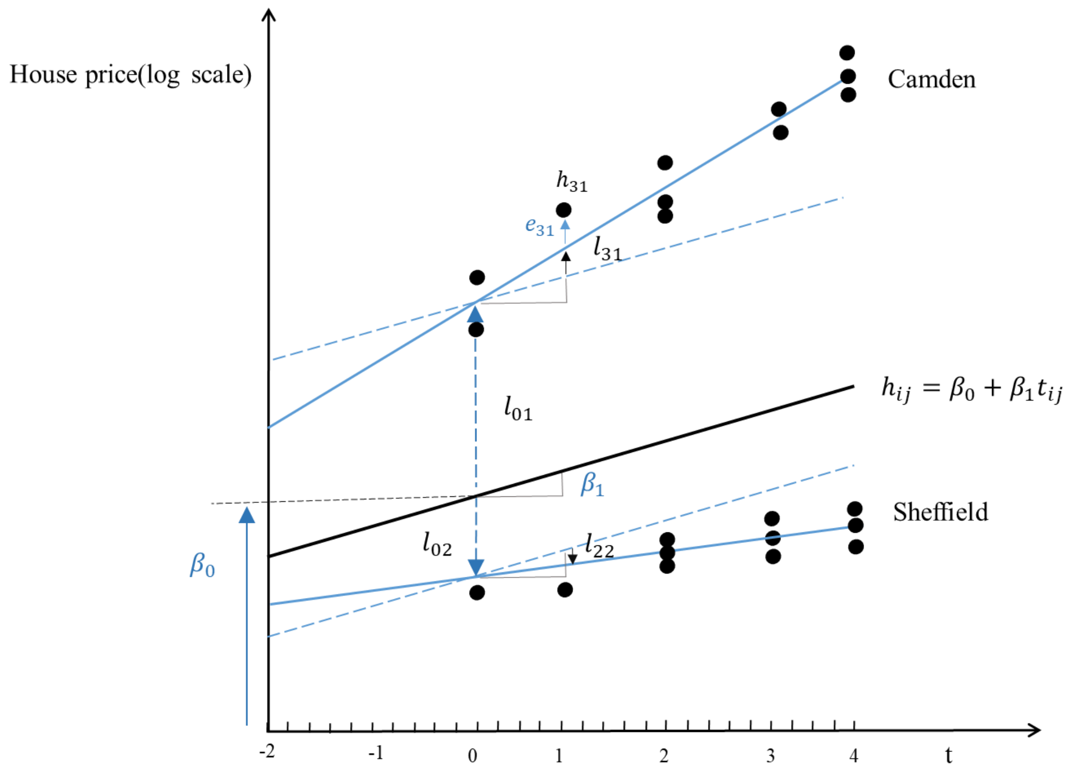

Figure 1 A graphical illustration of the two-level growth curve model in equation 8

Figure 1 provides a graphical illustration of equation 8 for 22 transactions in two local authorities (Camden and Sheffield) in England over five consecutive time intervals. Individual house prices are shown as black circles. β_0 is the intercept, which represents the grand mean house price (log scales) in England at time 0. β_1 represents the overall slope in England across the whole time period, which is approximately equal to the percentage change of the house price per square meter (Jones and Bullen, 1993; Tufte, 1974). $\beta_0 + l_{0j}$ measures the intercept for local authority j, and $\beta_1 + l_{1j}$ measures the house price (£/m^2) percentage change for local authority j. Camden has a larger intercept value ($\beta_0 + l_{01}$) than the mean house price in England (β_0) with a positive l_{01}, while Sheffield has a smaller intercept value ($\beta_0 + l_{02}$) than the mean house price in England with a negative l_{02}. The slope of Camden ($\beta_1 + l_{11}$) is steeper than the overall average slope line (the black line) by an amount l_{11}, while Sheffield has a slope ($\beta_1 + l_{12}$) which is smaller by an amount l_{12}. For the house price in Camden and Sheffield, a high intercept is associated with a steep slope. If this pattern holds when all local authorities are considered, the intercept-slope covariance will be positive and the group lines (the blue solid lines) will 'fan out'. e_{ij} measures house price differences for each individual *i* over the intercept (average local authority house price at time 0).

Given that house prices within the same MSOA are more similar than the house prices within the same local authority (Chi et al., 2020), we need to account for this by modelling the influence of MSOA as a random effect. Similar to the extension from equation 1 to 2, equation 7 and 8 can be extended to a three-level growth curve model by adding in a random term m_{kj}. Two models are listed in Table 2. In Models 4 and 5, Level 1 is individual, level 2 is MSOA level and level 3 is local authority level. A Likelihood-ratio test is used to compare Model 4 and Model 5 to determine which provides a better fit. If Model 5 fits the data better, local authorities in England reveal different house price growth curves compared with Model 4. The time variables (t_{ikj}) are centred at the beginning of year 2009 so that the estimated intercept has a meaningful interpretation (Raudenbush, 2002), as the estimated house price (log scale) in 2009. We refer to the estimated slope for each local authority in Model 4 and Model 5 as "estimated house price percentage change" (local authority slope, such as β_1 in Model 4 or $\beta_1 + l_{1j}$ in Model 5). We transform estimated intercept to its nature scale for each local authority (e.g. exponential $\beta_0 + l_{0j}$ in Model 2) and refer to it as the "starting-price".

Table 2. The candidate two-level growth curve models

Model	Equation
Model 4	$h_{ikj} = \beta_0 + \beta_1 t_{ikj} + l_j + m_{kj} + e_{ikj}$ $l_j \sim N(0, \sigma_l^2)$ $m_{kj} \sim N(0, \sigma_m^2)$ $e_{ikj} \sim N(0, \sigma_e^2)$
Model 5	$h_{ikj} = \beta_0 + \beta_1 t_{ikj} + l_{0j} + m_{kj} + l_{1j} t_{ikj} + e_{ikj}$ $l_{0j} \sim N(0, \sigma_{l0}^2)$ $l_{1j} \sim N(0, \sigma_{l1}^2)$ $m_{kj} \sim N(0, \sigma_m^2)$ $e_{ikj} \sim N(0, \sigma_e^2)$
Notes: h_{ikj} is the log house price (£/m^2) for transaction *i* in MSOA *k* belonging to local authority *j*. t_{ikj} is the year of the corresponding transaction. β_0 is overall mean house price across all local authorities between 2009 and 2016, β_1 is the slope, l_j or l_{0j} is the residual at level 3, m_{kj} is the residual at level 2, e_{ikj} is the residual at level 1. l_{1j} is the random slope at level 3.	

5. Results and discussion

Models 1 to 5 were run in MLwiN 3.03 (Charlton et al., 2019). All the results discussed below are based on the estimated values from these five multilevel models. Spatial maps are plotted in ArcGIS.

5.1 Local authority and time effects on house price variation in England (2009-2016)

The results of the four-level variance components models are listed in Supplementary Material B. Table 3 shows the VPC results of these three models. For all three models, the VPC at each level is exactly the same when rounding to 2 decimal places. There is no difference in the influence of time for the three different time scales (i.e. quarter, half-year and year) in England house price variance. Compared to the local authority and MSOA effects on the total house price variance, the time effect is very small (only accounting for 5% of total variance). Time is therefore treated as a fixed effect rather than a random effect in all subsequent analysis. Moreover, the deviance of Model 3 is smallest indicating that the annual time scale is the most appropriate. Therefore, subsequent analysis exclusively uses a one-year time scale.

Table 3 VPC statistic for Model 1, Model 2 and Model 3

Model 1		Model 2		Model 3	
Level	VPC	Level	VPC	Level	VPC
Local authority level	0.59	Local authority level	0.59	Local authority level	0.59
MSOA level	0.12	MSOA level	0.12	MSOA level	0.12
Quarter level	0.05	Half-year level	0.05	Year level	0.05
Individual level	0.24	Individual level	0.24	Individual level	0.24
Deviance	1,428,443	Deviance	1,338,665	Deviance	1,287,883

The VPC at local authority level is the greatest (0.59); this indicates that 59% of total house price variance (log scale) between 2009 and 2016 lies between local authorities. In other words, house price differences between local authorities in England are very large. Meanwhile, 12% of total house price variance lies between MSOAs within the same local authority. Of the remaining 29% of variance, only 5% is due to year difference.

5.2 Local authority house prices change between 2009 and 2016

Table 4 summaries the model results from Models 4 and 5. Owing to a large decrease in deviance between Model 5 and 4, the likelihood ratio test gives a near zero p-value. This suggests that Model 5 the data significantly better than Model 4, which reveals that local authorities' house price growth trends do vary across England.

Table 4 Model result of growth curve model[1]

Parameter	Model 4		Model 5	
	Estimate	S.E.	Estimate	S.E.
β_0 Intercept	7.5613	0.0237	7.5639	0.0199
β_1 (Year-2009)	0.0386	0.0001	0.0379	0.0013
σ_{l0}^2 between local authority variance	0.1806	0.0144	0.1262	0.0102
σ_{l01} Intercept-slope covariance	-	-	0.0061	0.0006

[1] Model 4 fits better than its corresponding three-level variance components model (deviance is 1964419) according to the likelihood ratio test. Also, since the variance in slope observed between MSOAs within the same local authority is quite small (0.0001), MSOAs were not modelled with random slope in subsequent work.

σ_{l1}^2 Slope variance	-	-	0.0006	0.0000
σ_m^2 between MSOA variance	0.0369	0.0007	0.0373	0.0007
σ_e^2 Individual variance	0.0789	0.0001	0.076	0.000
Deviance	1438463		1263077	

Covariance between the intercept and slope is 0.0061 in Model 5, suggesting a positive relationship between the local authority slope and intercept. In other words, house prices in expensive local authorities grew relatively faster than cheap local authorities between 2009 and 2016. Since the slope variance at local authority level is also positive (0.0006), a 'fanning out' of house price growth trends exists at local authority level in England over the period. Intercept variance (σ_{l0}^2) at local authority level is significantly larger than the slope variance (σ_{l1}^2), revealing a large difference in house prices in 2009 across local authorities and a very small difference in the overall house price percentage increase across local authorities.

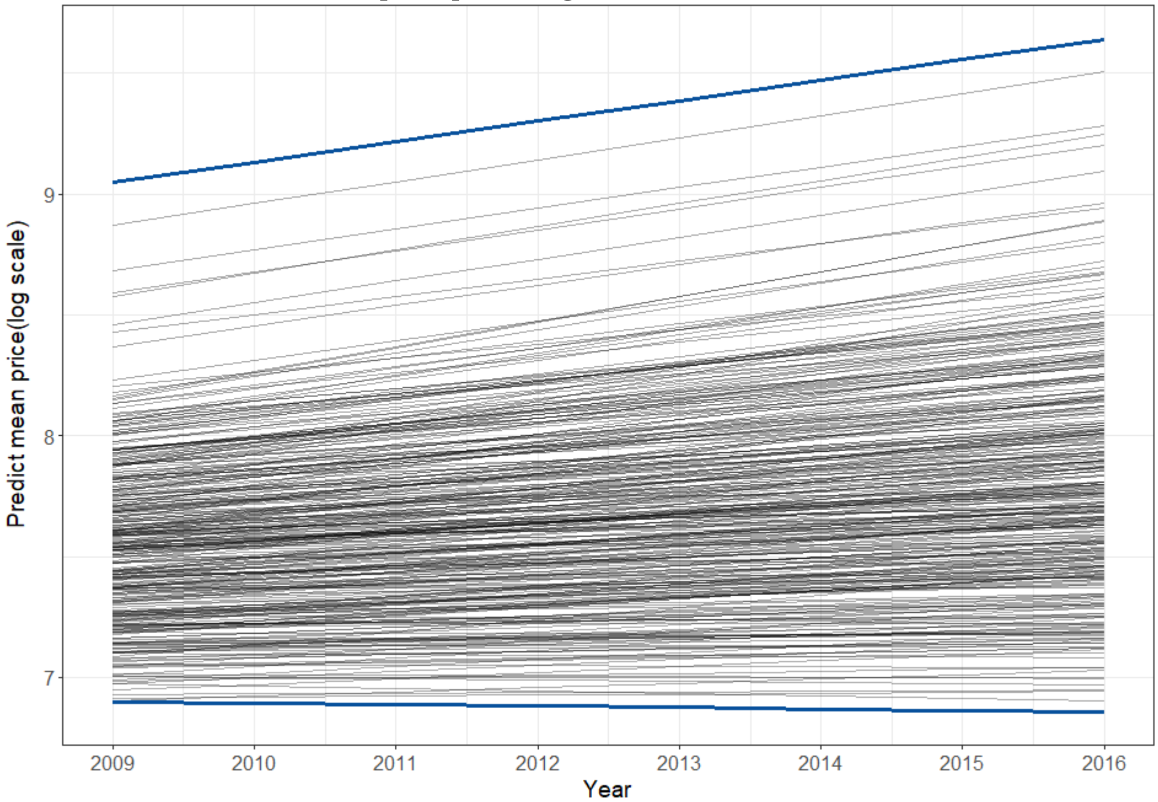

Figure 2 The "fanning out" of local house price growth trends across England

Figure 2 shows the estimated growth curves for each local authority in Model 5 and each line stands for one local authority. Figure 3 is created from Figure 2 by plotting the intercept and slope for each line. Each point stands for one local authority and is coloured by region. The black dashed lines indicate the intercept and slope for England's starting-price in 2009 and its overall house price percentage change between 2009 and 2016. The majority of local authorities in England show an increasing trend between 2009 and 2016; only 13 local authorities, in the North East, the North West and Yorkshire and the Humber, show a small decreasing trend over the same period. They are Hartlepool, Middlesbrough, Redcar and Cleveland, County Durham, Sunderland, Blackburn with Darwen, Blackpool, Allerdale, Carlisle, Eden, Burnley, Scarborough and Bradford.

The overall house price percentage increase in England between 2009 and 2016 is 3.79%. To better understand the differences in house price percentage increase at local authority level, supplementary material C provides similar plots separated by region. London has a higher percentage increase than that of England as a whole (the horizontal dashed line). All London's local authorities exhibited increases of greater than 6% between 2009 and 2016. Local authorities in the East of England and the South East exhibit moderate increases of between 2% and 8%. Moreover, while these local authorities are quite diverse in terms of house price percentage increase, the majority of them exhibit increases above that of England as a whole. Local authorities in the East Midlands, the South West and the West Midlands saw small increases at around the average level for England, between 2% and 6%. With the exception of Trafford, the remaining local authorities in the North West and Yorkshire and The Humber saw small percentage increases, below England's average. Local authorities in the North East saw only very small house price changes, generally below 2% and close to 0.

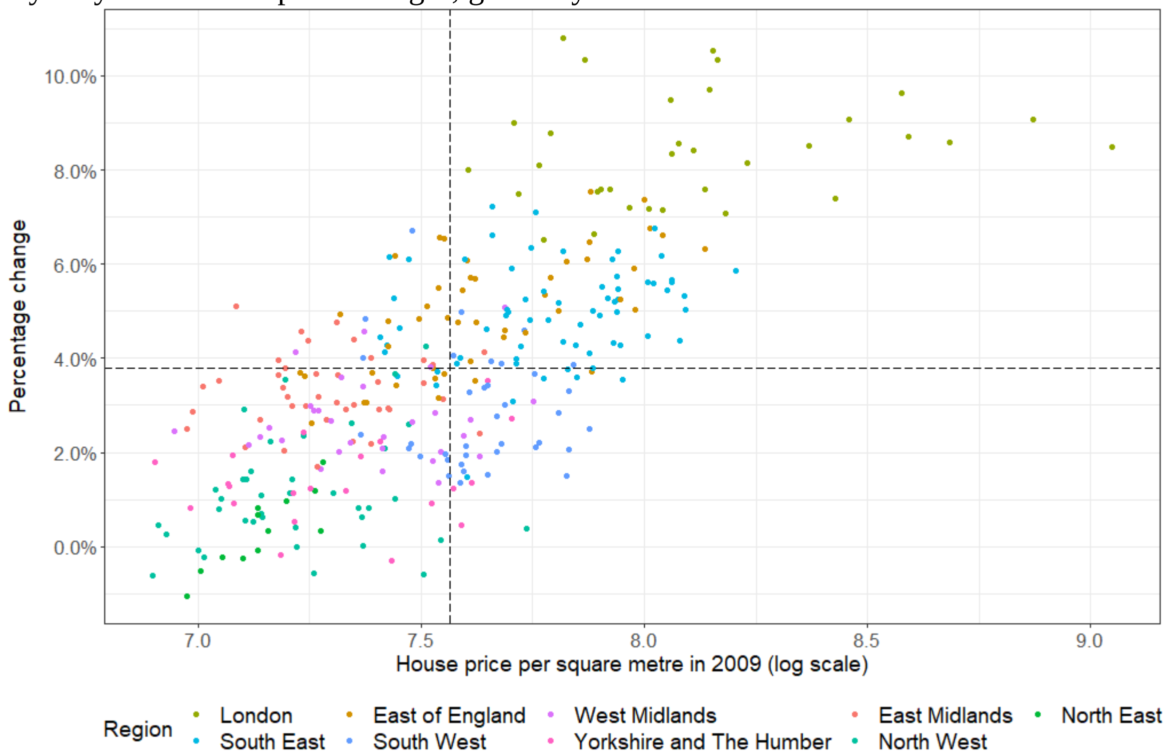

Figure 3 The relationship between estimated slope and intercept in Model 5

5.3 The spatial clustering pattern of local authority house prices in England

Figure 4 represents the spatial pattern of average house price percentage increase in England over our study period. Local authority house price percentage changes are sorted into 6 classes, corresponding to the vertical axis of Figure 3. There are two obvious gradient (ripple) patterns of percentage change at local authority level. One is centred on London and the other is centred on Bristol.

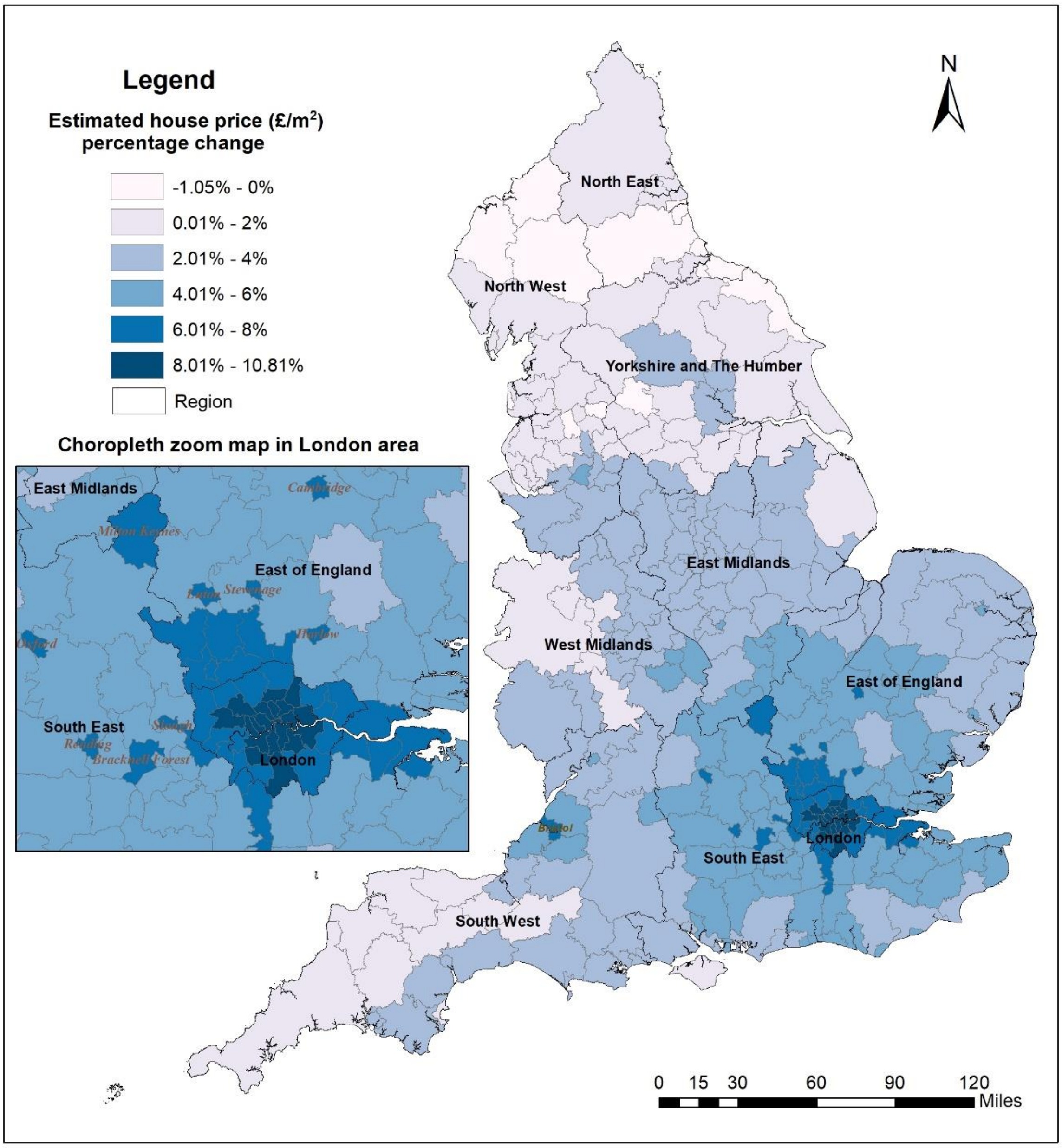

Figure 4 The spatial pattern of overall average house prices percentage change at local authority level

In London and its nearby housing market, house price percentage changes follow a kind of gradient radial pattern with high increases at the centre of London, decreasing as distance from the centre increases. However, nine local authorities (labelled on the inset map in Figure 4) display exceptional behaviour. These nine local authorities show a higher percentage increase (over 6%) compared to their neighbouring authorities and their travel time to London is around an hour. The underlying reasons that the housing markets of these nine local authorities differ from their neighbouring areas are likely to vary from case to case. One potential reason for the high percentage house price increases in Milton Keynes, Luton, Stevenage and Harlow could be their role as London commuter towns; these areas have a high proportion of people who work in London (Supplementary Material D).

Figure 5 represents the spatial pattern of the starting price at local authority level. Comparing the spatial patterns observed in the map of house price percentage increases (Figure 4) and that of starting-price (Figure 5), Luton, Stevenage and Harlow exhibit relatively higher percentage house price increases but relatively lower estimated mean house prices in 2009 compared to their neighbours. The reasons for the higher percentage increases in Oxford and Cambridge could be due to local green belt planning constraints or their status as prestigious university towns (Mace et al., 2016; Smith, 2017) within relatively easy commuting reach of London. Higher percentage house price increases in Reading and Bracknell Forest may be due to their technology industries and the fact that both are well-connected to London by both the M3 and M4 motorways, as well as fast rail links (Hodson, 2019; Holland, 2019; Osborne, 2016).

House price percentage change in and around Bristol exhibits another gradient radial pattern, with a high increase in Bristol and a decreasing percentage change away from the centre, as seen in Figure 4. Bristol is a tech hub for the electronics, creative media and aerospace industries (Card, 2014; Ismail, 2018). The pattern observed around Bristol may relate to commuting to work patterns, in the same way that the London effect appears to (Rae, 2017). Although these areas have high house price percentage increases, their starting-prices are not as high as those in London and its nearby housing market, as shown in Figure 5.

Considering the geography of the estimated starting-price at local authority level (Figure 5), house prices (in terms of the estimated mean house prices in 2009 at local authority level) display more complex patterns than would be suggested by the simplistic notion of a "North-South divide". In the south of England, 14 local authorities on the southeast coastline and southwest coastline have house prices under 2,000 £/m^2, relatively cheaper than nearby local authorities: Dover, Eastbourne, Gravesham, Hastings, Shepway, Medway, Swale, Thanet, Southampton, Gosport, Portsmouth, Weymouth and Portland, Havant and Torbay. Conversely, in the North of England, 5 local authorities display higher house prices than their neighbours, with house prices over 2,000 £/m^2: Derbyshire Dales in the East Midlands, South Lakeland in the North West, and Hambleton, Harrogate and York in Yorkshire and The Humber. Burnley in the North West and the City of Kingston upon Hull in Yorkshire and The Humber exhibit house prices below 1,000 £/m^2. The estimated mean house prices of all other local authorities in the North of England lie between 1,000 £/m^2 and 2,000 £/m^2.

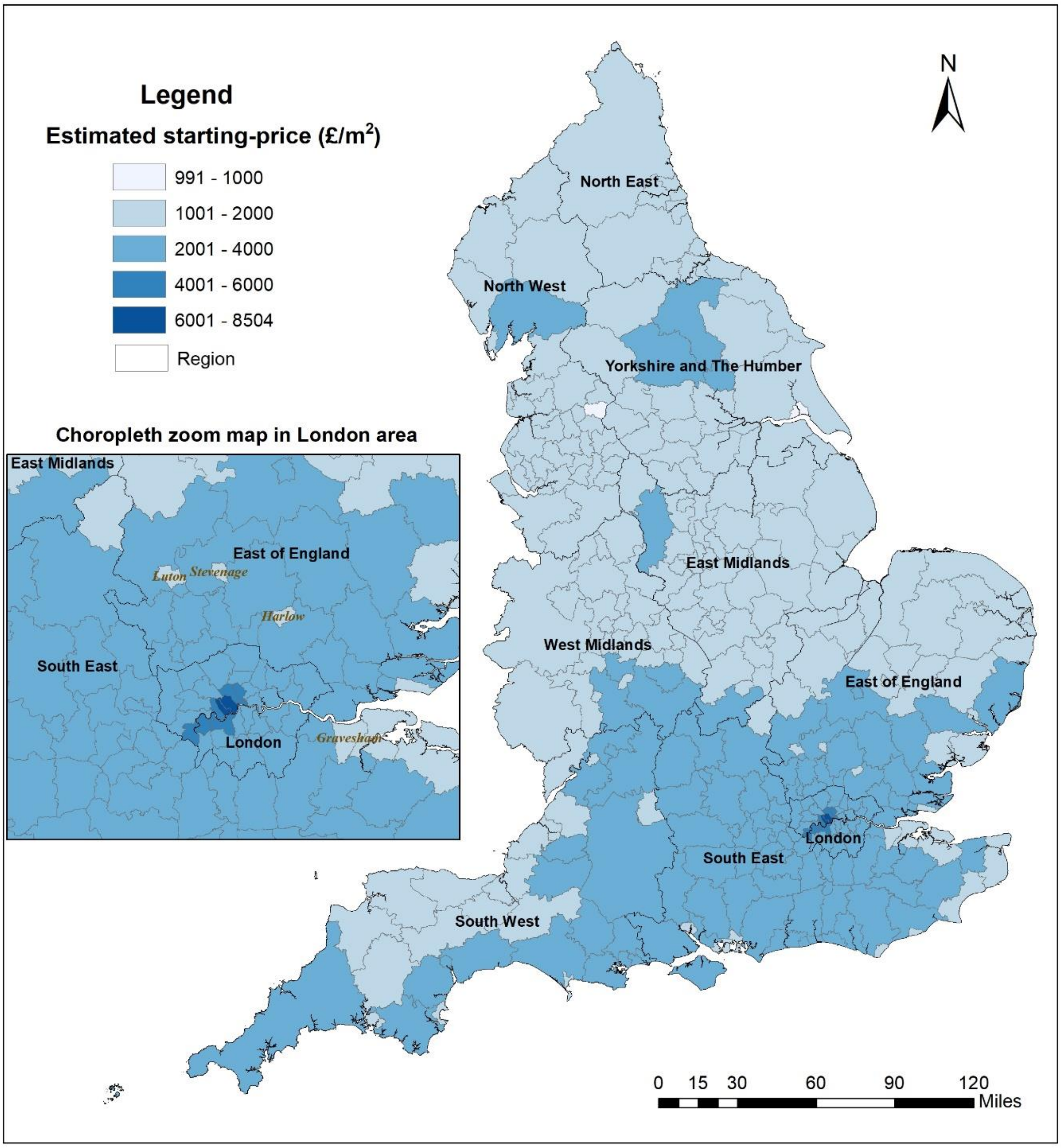

Figure 5 The spatial patterns of local authority starting-price in 2009

6. Conclusions

This research takes a first step in systemically exploring the spatio-temporal pattern of house prices (£/m^2) at local authority level in England between 2009 and 2016, something that has not previously been possible due to the absence of data normalised by total floor area. It contributes to house price variation research in three main ways: first, it investigates patterns of house price (£/m^2) variation in England across two spatial scales and three different time scales (quarter, half-year, year) between 2009 and 2016. Results reveal that the two spatial effects on house price variation are very much larger than any of the time effects. The local authority effect contributes 59% of total house price variance, with the MSOA effect within the same local authority contributing a further 12%. The time effect on house price variance is the same no matter which time scale is used (quarter, half-year, year) and is relative small enough to ignore compared to the two spatial effects. Second, since a one-year time scale has been found to fit the model best, annual house price trajectories in England were further investigated using growth curve modelling. Results demonstrate that those local authorities that had higher house prices in 2009 grew relatively faster over the eight-year period than cheaper local authorities. Third, similar to the house price "ripple effect" that has been observed at a regional level (Meen, 1999), house prices at local authority level also largely conform to this pattern. Local authorities in and around Bristol also show a small "ripple effect", centred on the city.

With a clear understanding of spatio-temporal patterns of local authority house price, we intend to extend this work through a more thorough exploration of key local factors such as property age, property type, plot size, land use structure, housing density and local physical and socio-economic environments (Hudson et al., 2018; Narayan and Narayan, 2011; Orford, 2017). Further research will focus on exploring how these different factors influence house price variation at local authority level between 2009 and 2016. Understanding the underlying mechanisms of house price variation in England at and below local authority will not only offer deeper insights into pressing housing inequality issues, but could also offer critical guidance on current housing and planning policy to solve issues of housing inequality.

Acknowledgements

The authors would like to thank Mrs Jane Galbraith, Dr Andrew Bell and Professor George Leckie for providing valuable guidance on growth curve model.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This research was funded by the China Scholarship Council (CSC No. 201708060184).

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Supplementary Material A

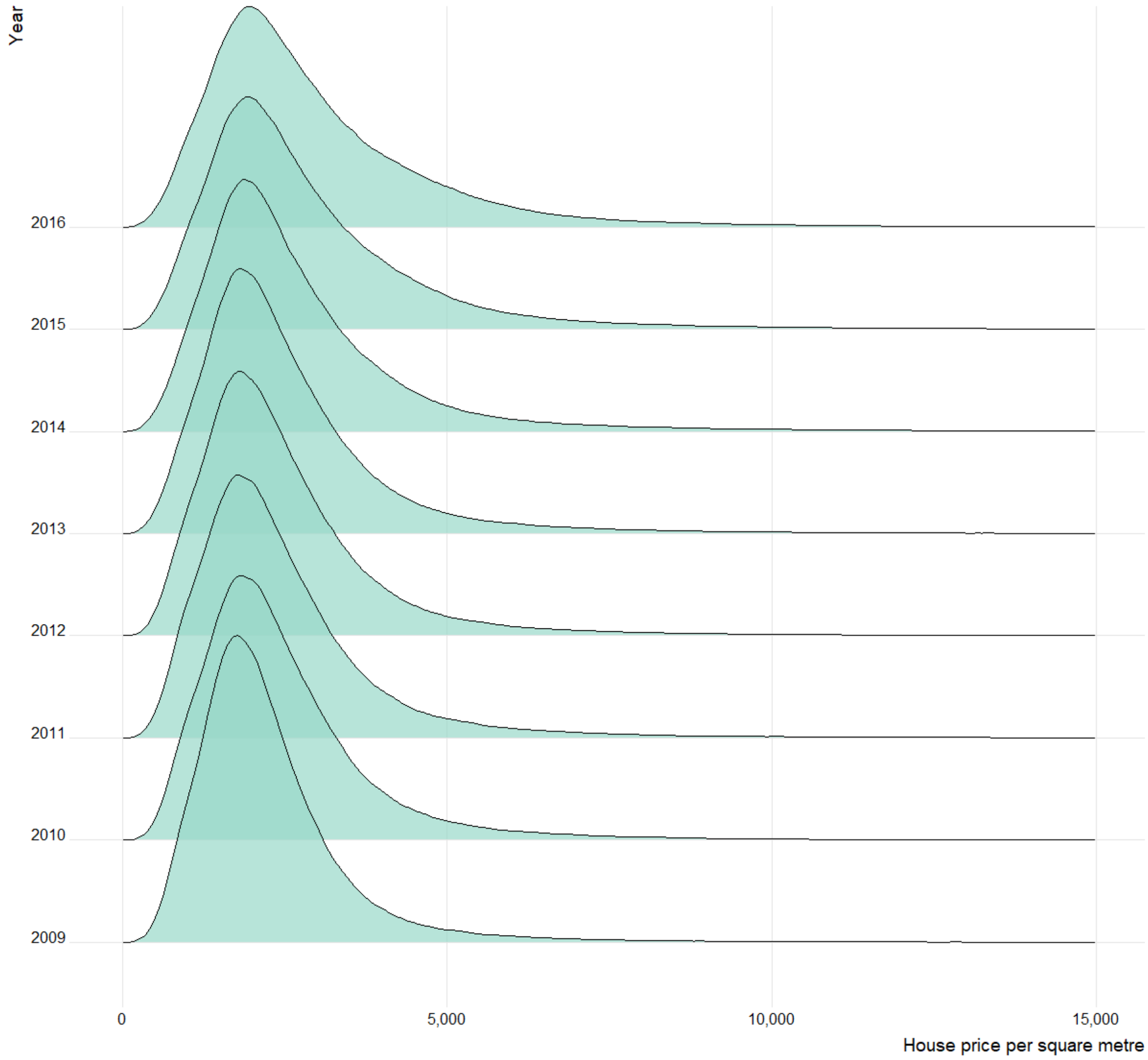

Figure A House price (£/m^2) density plots in England for the period from 2009 to 2016

Supplementary Material B

Table B Result of Models 1 to 3

Model 1			Model 2			Model 3		
Parameter	Estimate	S.E.	Parameter	Estimate	S.E.	Parameter	Estimate	S.E.
β_0 Intercept	7.6991	0.0235	β_0 Intercept	7.6980	0.0235	β_0 Intercept	7.6994	0.0235
σ_l^2 Local authority level variance	0.1770	0.0141	σ_l^2 Local authority level variance	0.1768	0.0141	σ_l^2 Local authority level variance	0.1771	0.0141
σ_m^2 MSOA level variance	0.0364	0.0007	σ_m^2 MSOA level variance	0.0361	0.0007	σ_m^2 MSOA level variance	0.0353	0.0007
σ_q^2 Quarter level variance	0.0140	0.0001	σ_{hy}^2 Half-year level variance	0.0142	0.0001	σ_y^2 Year level variance	0.0143	0.0001
σ_e^2 Individual level variance	0.0735	0.0000	σ_e^2 Individual level variance	0.0737	0.0000	σ_e^2 Individual level variance	0.0743	0.0000
Deviance	1428443		Deviance	1338665		Deviance	1287883	

Supplementary Material C

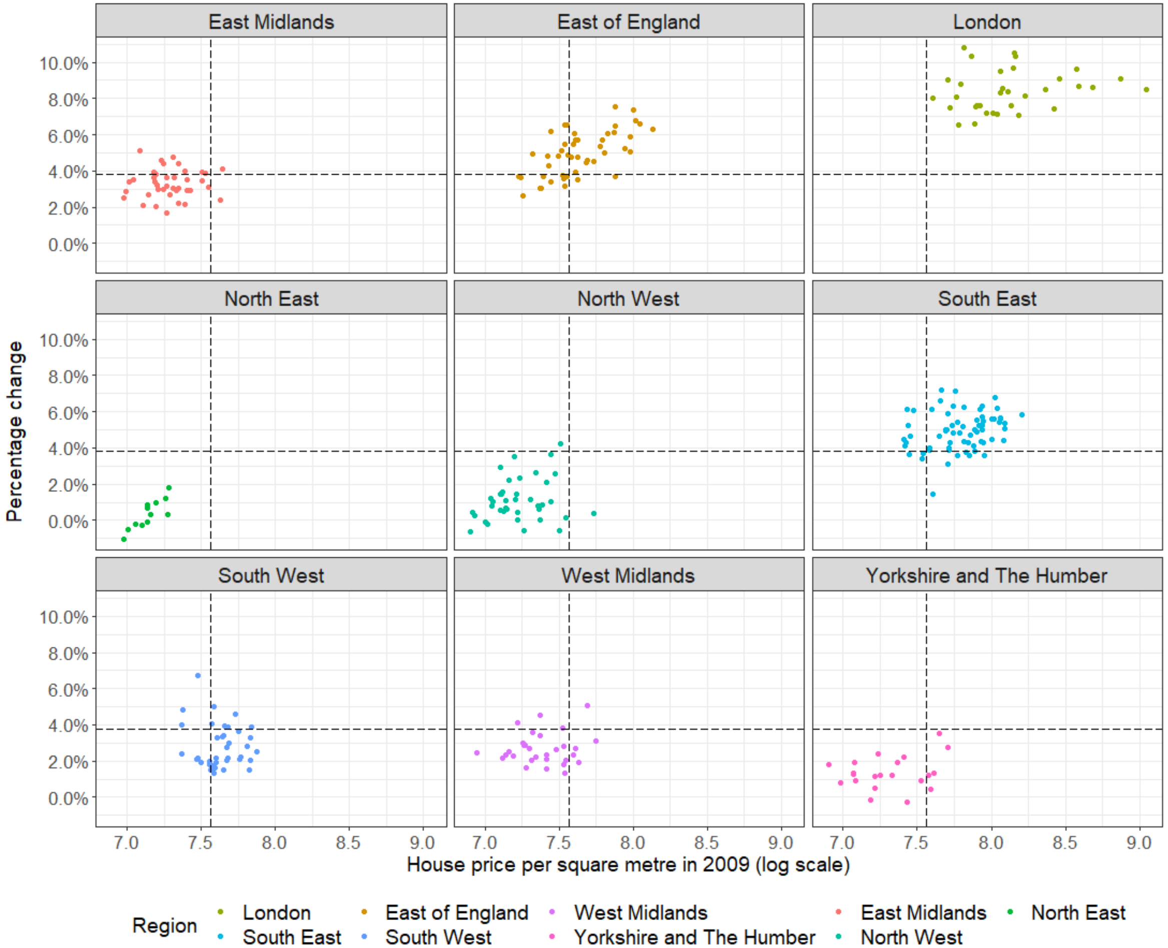

Figure C. The relationship between estimated slope and intercept in different region

Supplementary Material D

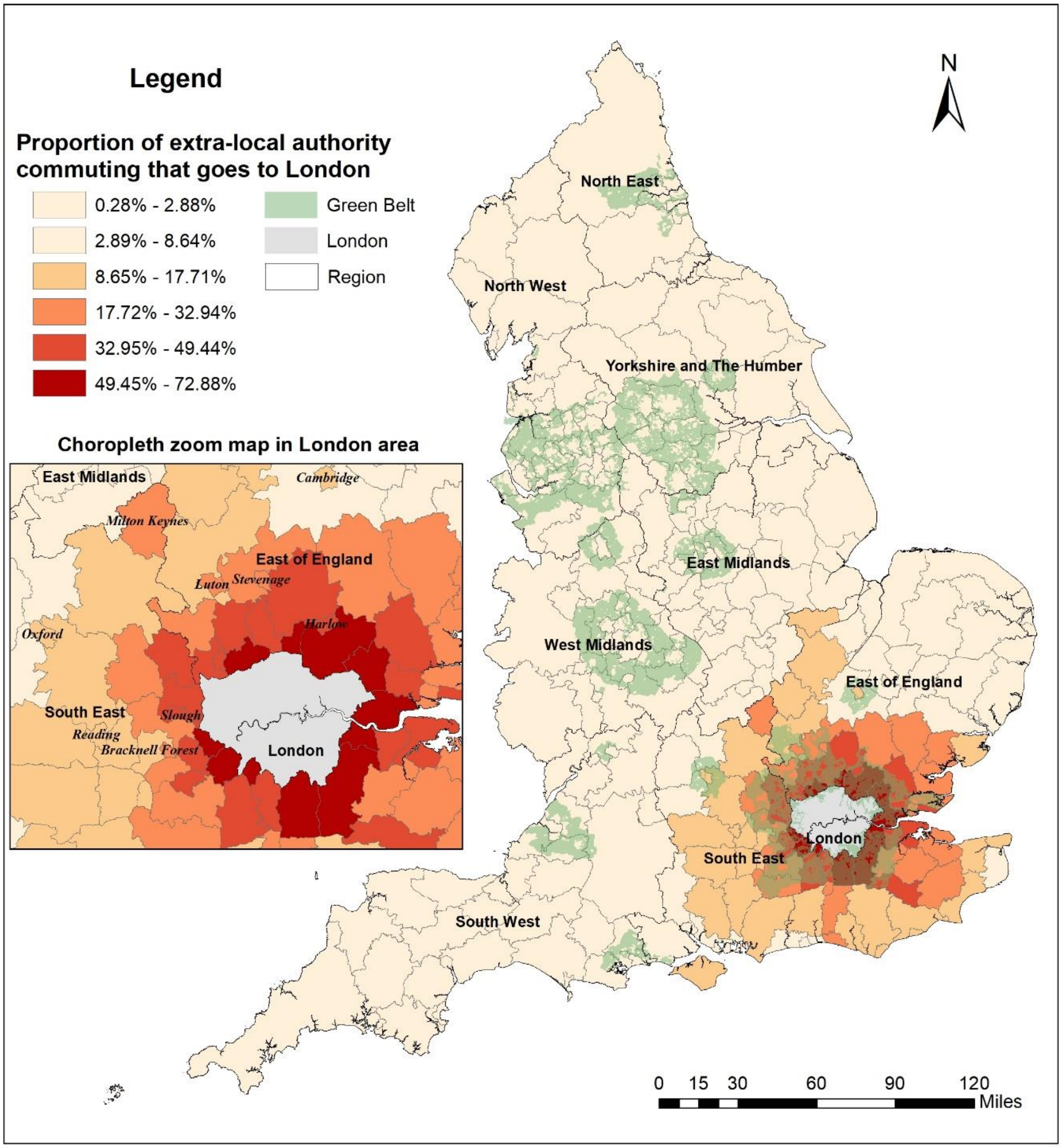

Figure D Percentage of outside travel to work in London against the total outside travel to work[2]

[2] Data for this map is aggregated travel to work data (Table WU03EW) in the Census 2011 at local authority unit and then treated all the local authorities in London as one unit. The proportion of extra-local authority commuting that goes to London refers to the number of people commuting outside of home local authority to work in London divided by the number of people commuting outside of home local authority to work.

Full contact details of authors

Bin Chi
Centre for Advanced Spatial Analysis, University College London, 90 Tottenham Court Road, London, W1T 4TJ Email: bin.chi.16@ucl.ac.uk

Adam Dennett
Centre for Advanced Spatial Analysis, University College London, 90 Tottenham Court Road, London, W1T 4TJ Email: a.dennett@ucl.ac.uk

Thomas Oléron-Evans
Centre for Advanced Spatial Analysis, University College London, 90 Tottenham Court Road, London, W1T 4TJ Email: thomas.evans.11@ucl.ac.uk

Robin Morphet
Centre for Advanced Spatial Analysis, University College London, 90 Tottenham Court Road, London, W1T 4TJ Email: r.morphet@ucl.ac.uk