Climbing the property ladder: An analysis of market integration in London property prices*

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December 2016

Abstract

We investigate the long-run convergence of house prices across the London boroughs based on a pairwise unit root probabilistic testing procedure. In sharp contrast to the earlier literature, we employ a dataset that distinguishes between four different types of property in each borough. Using a quarterly dataset that spans from 1995 to 2014, we find evidence in favour of long-run convergence thereby suggesting that the great majority of London borough house prices are driven by a single common stochastic trend. In a further contribution, we offer new insights through analysing the determinants of long-run convergence, by considering the role of geographic proximity, type of accommodation, and amenities (quality of life).

JEL Classification: C2, C3, R1, R2, R3.

Keywords: Pair-wise, house prices, cointegration, convergence.

*We gratefully acknowledge the helpful comments and suggestions made by seminar participants at the Universidad del Rosario (Bogotá), conference participants at the 2016 meeting of the New Zealand Association of Economists, and three anonymous referees. The usual disclaimer applies. Corresponding author: M.J.Holmes (holmesmj@waikato.ac.nz); J.Otero (jesus.otero@urosario.edu.co); T.Panagiotidis (tpanag@uom.gr).

1 Introduction

Housing is a durable consumption good that is immobile and is frequently used as collateral for loans. When commenting on the state of the national economy and setting U.K. interest rates, the Bank of England pays close attention to the state of the domestic housing market. However, there is considerable value in understanding how relative regional house prices behave over time.[1] Not only do they have the potential to influence relative regional economic activity, but also the affordability of housing, relocation costs and labour mobility between regions. Following the early work by Meen (1999), it has been argued that shocks to regional house prices "ripple out" across the economy. While the idea of a ripple effect may rely on factors such as spatial patterns in the determinants of house prices, migration, equity transfer, and spatial arbitrage, it also requires some notion of a degree of long-run convergence, or existence of a long-run equilibrium relationship, between regional house prices. However, the literature to date can only offer mixed evidence that long-run equilibrium or cointegrating relationships between all regional house prices actually exists; see e.g. Holmes and Grimes (2008) and Abbott and De Vita (2012), and references therein.

While there is a relatively extensive literature that explores inter-regional house price convergence, there have been far fewer studies that explore intra-regional convergence. With this context in mind, we focus on house price convergence involving the 32 administrative divisions of London, which are defined as boroughs.[2] An analysis of house price convergence within London is of considerable interest. In terms of other European cities, London is of great significance vis-à-vis size, economic importance and as an inward

[1]For a review on the interaction between house prices and the macroeconomy see Leung (2004), Goodhart and Hofmann (2007) and Meen (2016). Ball (1973) is one of the earliest studies on relative house prices.

[2]The City of London is not considered in the analysis because it is not officially a London borough. In addition to this, we encountered data limitations for this administrative area that will be described later on.

source of migration to both EU and non-EU citizens. Within the UK, the importance of London in terms of both population and national economic activity is also well known. London and the South East of England are considered as the source of house prices shocks that ripple out across the rest of the economy; see, for instance, Holly et al. (2011) for an analysis using impulse response functions that allow for spatial dependence.

Among a small number of studies that conduct intra-regional house price analysis, Hamnett (2009) shows that there has been a limited catching up process with some of the highest rates of price inflation in the lowest priced boroughs, and vice versa. The author here argues that spatially displaced demand from the expensive boroughs may help to explain price rises in the cheaper boroughs. Abbott and De Vita (2012) investigate the long-run convergence of district-level house prices in Greater London using a pairwise approach. They find no overall multidistrict long-run convergence across London boroughs. Indeed, Abbott and De Vita identify evidence of district-level segmentation of house prices in Greater London.[3]

Our investigation is intended to deepen our understanding of house price co-movement across the boroughs of London. The stationarity of house price differentials is used as an indicator of long-run intra-city house price convergence, based on a tendency for house prices to not necessarily be equal, but instead move together over time.[4] In other words, do shocks to relative house prices have a permanent effect, or are the effects more short-lived

[3]Wabe (1971) was one of the early studies that examined the factors that influenced house prices in London. It is interesting to note that this (very early) regression analysis employed 93 observations and central heating emerged as the most important characteristic that could affect the price of a house in London. This was followed by proximity to the green belt and the time and the price of the journey. The floor area measured in square feet was found not to be significant.

[4]Our time frame for the notion of 'long run' spans two decades of quarterly data. Although there does not appear to exist a threshold in the literature, Otero and Smith (2000) report Monte Carlo simulation results which indicate that when testing for the existence of long-run equilibrium relationships, it is preferable to use data collected over a long period of time, rather than a large number of observations gathered over a much shorter period.

such that house price differentials are restored? In this respect, authors such as DiPasquale and Wheaton (1996) argue that although one might expect house prices across all locations to rise and fall with a market's fortune, the relative price of more desirable locations compared to less desirable ones perhaps changes very little in the long-run. Indeed, Glaeser and Gottlieb (2009) highlight that house prices represent the interaction of supply conditions and the desire to live and work in certain locales. Factors such as labour and capital mobility may be important, but the influence on housing markets of the movement of people and firms can be complex. Models of spatial equilibrium argue that house prices can vary according to differences in planning rules and amenities (congestion, crime levels, public transportation, schools, weather, etc.). Regional house price interactions may occur from the gradual dissemination of information across space following any shock. In an efficient market, we might expect all regions to react at the same time to a common shock. However, there are many reasons why lags may arise in the case of housing. Consequently, our empirical analysis specifically addresses whether or not the expected general stability of relative prices (or property price premiums) is a generalised phenomenon throughout the boroughs of London.

In the spirit of the earlier studies by Holmes et al. (2011) on inter-state house price convergence in the US, Abbott and De Vita (2012) on intra-borough house price convergence in London, and Holmes et al. (2015) on intra-city price convergence in Paris, our empirical analysis is based on Pesaran (2007) who employs a probabilistic unit root testing procedure applied to all house price differentials within London. Our study also contributes towards an ongoing debate addressed by earlier studies, such as Pollakowski and Ray (1997), as to whether house price relationships between contiguous regions are any stronger than between non-contiguous regions. The verdict on this remains open and we enrich the debate by considering the role of geographic separation between the boroughs as a factor that helps explain the existence of long-run equilibrium relationships involving bivariate house price differentials.

Building upon the earlier work of Abbott and De Vita (2012), we use a highly detailed database in that we distinguish between the prices of different types of dwellings, namely detached houses, flats, semi-detached houses and terrace houses. This is in marked contrast to the typical employment of a single aggregate house price index for each borough. Such a distinction is clearly important when thinking in terms of a property ladder because it allows us to capture the fact that when agents are deciding to purchase real estate of a certain price range, they not only take into account the type of property but also they consider the location of their prospective purchase. In other words, the heterogeneity of the housing market is captured by examining all available buying options.[5]

Whether or not house prices drift apart within London has implications for relative affordability, labour mobility, labour mismatch, commuter times, and potential localised house price bubbles. Essentially, these are issues relating to economics, financial stability and well-being. The potential policy implications that arise from this are in terms of measures such as transport policy to address commuting issues, house building to address affordability, incentives for employment to be offered in cheaper areas, and financial measures to address potential bubbles. Employing a disaggregated dataset enables us to reflect on the extent to which long-run price convergence is more or less likely across these property types. Given that housing affordability has been a key issue of concern, borough price convergence or divergence is of potential interest to policymakers with an eye on long-term affordability.

[5] In an empirical application to hedonic prices in Paris, Baltagi and Bresson (2011) estimate panel seemingly unrelated regressions with both spatial lag and spatial error components to three types of flats. These authors pay special attention to the heterogeneity and spatial variation in housing prices across districts. Nemov et al. (2016) demonstrate the different behaviour of houses against flats in Norway and reveal the importance of heterogeneity in the housing market.

To summarise, our paper possesses two salient features with respect to the existing literature. First, in terms of employing a highly disaggregated dataset. The second feature of our paper is that in an extension to testing for long-run convergence, we also examine the drivers that determine the likelihood of finding long-run convergence. We not only take into account the role played by the type of accommodation under consideration (heterogeneity), but also a range of factors related to amenities or quality of life such as education standards, crime rates, population densities and income levels.

The paper proceeds as follows. Section 2 outlines our econometric modelling approach. Section 3 describes the data. Section 4 examines long-run house price convergence. Section 5 investigates the determinants of house price convergence. Section 6 concludes.

2 Econometric methodology: A brief review

Our econometric modelling approach draws upon the work of Pesaran (2007), who develops a pair-wise approach to analyse stochastic convergence across a large number of cross section units. We adapt and extend this pair-wise approach to the analysis of house prices in the boroughs of London. Stochastic convergence involves applying unit root/stationarity tests to investigate the order of integration of prices relative to a reference (or an average) price level, and as a result the outcome of the tests depends on the choice of that reference price. This is regardless of whether unit root/stationarity tests are applied in a time series or panel contexts. In sharp contrast to this, the pair-wise approach that we adopt in this paper requires testing the order of integration for all possible pairs of prices and, in doing so, does not involve what can be a problematic choice of a single reference unit with respect to which all house price differentials are computed.

As indicated before, the aspect that characterises our empirical analysis is the availability of price information for four different types of properties. A household might aspire towards moving from a semi- to a detached house. However, such a move within a borough may be infeasible on the grounds of cost. Therefore, the household might consider moving to a different borough that has a more accessible price for detached housing. Allowing for other factors that might include distance, amenities and so on, a process of arbitrage will contribute towards different house prices across different boroughs converging. Of course, it is certainly possible to simplify the analysis by aggregating prices within each borough and proceeding with the application of the pair-wise approach, as undertaken by Abbott and De Vita (2012) also for the boroughs of London. While such an aggregate approach can provide valuable insights, one can further exploit the underlying heterogeneity across property types (see Nemov et al. (2016)), and so allow for consideration of all purchase possibilities that are available to individuals.

In line with Pesaran (2007), we let p_{it}^k be the observed house price series of property type k in borough i at time t. Here the superscript k refers to detached houses (d), flats (f), semi-detached houses (s) and terrace houses (t); in turn, the subscript $i = 1, ..., 32$ denotes the number of boroughs, while $t = 1, ..., T$ is the number of time observations. To apply the pair-wise approach to the study of the price differentials of all property types, let us denote p_{it} as the set that comprises the prices of detached houses, flats, semi-detached houses and terrace houses in all 32 London boroughs at time t; that is, $p_{it} = (p_{it}^d, p_{it}^f, p_{it}^s, p_{it}^t)$, where $p_{it}^k = (p_{1t}^k, ..., p_{32t}^k)$ and $k = d, f, s, t$. Overall, p_{it} consists of $N = 32 \times 4 = 128$ prices. Next, let us define all possible price differentials as $p_{ijt} = p_{it} - p_{jt}$, where $i = 1, ..., N-1$ and $j = i+1, ..., N$. The important aspect to bear in mind is that p_{ijt} permits the examination of all the arbitrage opportunities that are available to the individual. Indeed, if one considers for instance detached (d) and semi-detached (s) houses in boroughs 1 and 2, so that $p_{it} = \left(p_{1t}^d, p_{2t}^d, p_{1t}^s, p_{2t}^s\right)$, then the corresponding price differentials that can be computed are $\left(p_{1t}^d - p_{2t}^d\right)$, $\left(p_{1t}^d - p_{1t}^s\right)$, $\left(p_{1t}^d - p_{2t}^s\right)$,

$\left(p^d_{2t} - p^s_{1t}\right)$, $\left(p^d_{2t} - p^s_{2t}\right)$ and $\left(p^s_{1t} - p^s_{2t}\right)$. Overall, the total number of price differentials that can be calculated amounts to $(128 \times 127)/2 = 8128$. Consequently, the application of this modelling strategy not only allows us to study the possibility of spatial integration within the prices of different types of dwellings, but also between them.

The pairwise approach then proceeds by investigating the order of integration of all $(N(N-1)/2)$ price differentials p_{ijt}, with the purpose of identifying those that appear to behave as stationary processes (that is, those that are bounded). Notice that finding a stationary price differential based on two non-stationary house price series is equivalent to stating that there is cointegration between the two prices, and that the cointegration vector is equal to $[1, -1]'$ so that the two prices move in tandem in the long-run. The cointegration vector thus plays the role of a long-run equilibrium relationship such that prices may deviate from it in the short run, but not by an ever growing amount since arbitrage opportunities are expected to act so as to restore equilibrium. The existence of cointegration does not necessarily lend support to the view that in the long run prices are the same, but simply that they move together over time in the same proportion.[6]

To implement the pairwise approach we consider the application of the augmented Dickey and Fuller (1979) and the Leybourne (1995) unit root tests, denoted ADF and $\text{ADF}_{\max}$ respectively, to each time series p_{ijt}. As is well-known, the ADF test is a regression-based procedure which, in its simplest form, involves testing the null that the first order autoregressive coefficient in a first order autoregressive equation is equal to one (where this simple setup can be suitably generalised to deal with the presence of deterministic components in the data and/or serial correlation). The $\text{ADF}_{\max}$ test, in turn, is based on the maximum ADF test statistic that results from applying the ADF test to both the forward and reversed realisations of the

[6]See also Carlino and Mills (1996) for an early application on the study of output convergence.

data. Next, we define the indicator function z_{ij} which is equal to one if the corresponding unit-root test is rejected at significance level α, and zero otherwise. Pesaran (2007) studies the fraction of the $N(N-1)/2$ differentials for which the unit-root hypothesis is rejected, and proposes a test statistic given by:

$$\bar{z}_{ij} = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} z_{ij}. \tag{1}$$

Previous pair-wise studies of house price convergence by Holmes et al. (2011) and Abbott and De Vita (2012), as well as applications of the pair-wise approach in other contexts such as Pesaran (2007), Nourry (2009) and Le Pen (2011), focus on computing the fraction of rejections $\bar{z}_{ij}$. In this paper, however, we progress our investigation further by also examining all individual cointegration outcomes, z_{ij}, with the purpose of identifying the variables, if any, that increase or decrease the likelihood of cointegration.

We begin by considering the factors that are expected to affect the probability of long-run convergence between pairs of property prices into three groups, namely those that refer to geographic separation between boroughs and location; those that are related to amenities and quality of life; and those that are concerned with the type of housing. The first group of factors include two measures of the geographic separation between boroughs which are based on distance and travel time, as well as indicator variables related to whether or not pairs of boroughs are part of inner or outer Greater London.[7] In this case, we are interested in examining whether a shorter distance (less travel time) is associated with an increase in the likelihood of cointegration. Indeed, it seems reasonable to assume that shorter distances (travel times)

[7] It is well known that high house prices in the south-east have forced many people out of the capital and into longer commutes. In the London Borough of Tower Hamlets, 79% of the working population live in another borough: fewer than 500 live and work in the borough itself. Figures taken from "Commuting is now a fact of life. We just need to make it less awful" by Dawn Foster; published in The Guardian, April 28, 2016.

between districts may facilitate arbitrage mechanisms that bring house prices into line. In line with previous work by Pollakowski and Ray (1997) and others, we also contribute to the existing literature as to whether house price relationships between contiguous regions are any stronger than between non-contiguous regions.

As to the second group, we include variables that reflect amenities and quality of life differences across boroughs. In doing so, we test the hypothesis that the more similar are any two boroughs with respect to amenities and quality of life, then the more likely is the probability of finding cointegration between their house prices. The inclusion of education standards follows earlier views expressed on the linkages between house prices and education standards. For example, Gibbons and Machin (2006) point out that school quality is capitalised in UK house prices if access to schools is rationed by residential location. More specifically, they find that test-score-based school performance significantly increases property prices, but only the best one in ten schools generates higher than average prices close by, and that prices are higher close to popular, over-capacity schools. Additional insight is offered by Cheshire and Sheppard (2004) who provide evidence on the complex and subtle ways in which housing markets capitalise the value of local public goods such as school quality, and suggest that this is highly nonlinear. In addition to this, Fack and Grenet (2010) provide evidence supporting the view that housing prices in Paris increase as the performance of public and private schools improves.

Another variable of potential importance is crime which enters the analysis with the intention of capturing security conditions in the boroughs. Furthermore, we also include population density motivated by the idea that it can serve as a measure of demand pressure and also as an indirect measure of supply shortage.[8] When the population density is high, it may be an in-

[8]To obtain a more direct measure of relative supply across the boroughs, we also collected data from the London Datastore to compute the ratio between the number of houses

dication that the land endowment is very limited and thus the possibilities to augment the supply of housing are constrained.

The amenity variables included in the second group of factors are considered as differentials in absolute terms. This is because we are interested in whether increased differences between the boroughs lead to a lower probability that their respective house prices are cointegrated. As a result of this, in all cases the sign on the estimated coefficient is expected to be negative if the degree similarity of amenities between boroughs is a positive driving force behind house price convergence.

However, in assessing the impact on the likelihood of cointegration, one might also in fact regard the signs on the income and amenity coefficients as being indeterminate. Positive income differentials across city pairs, which are related to productivity and wage differentials, should attract flows of workers thus pushing up housing demand and in turn house prices. When we consider amenities, an increase in crime (education quality) in borough i relative to borough j might discourage (encourage) flows of workers into i thereby reducing (increasing) housing demand in i relative to j. Moreover, crime is a negative attribute that is expected to adversely impact on house prices. For the sake of argument, assume that high- and low-crime boroughs respectively have low and high house prices. The absolute crime differential will increase if, say, (i) there is a general decrease in crime that is skewed towards the low-crime/high house price areas, or (ii) there is a general increase in crime that is skewed towards the high-crime/low house price areas. What happens to relative house prices can depend on the respective borough elasticities of house prices with respect to crime. We may then ask under what circumstances will scenario (i) be associated with a greater likelihood of cointegration? This will more likely occur if the high-crime/low house areas have the greater (absolute) elasticities of house prices with respect to crime

and the number of households. However, this variable was not found to be statistically significant and for this reason is not included in the analysis.

and so the house price differentials will narrow. In the case of (ii), relative prices will narrow with a greater likelihood of cointegration if it is the low crime/high house price boroughs characterised by the greater elasticities.

Lastly, regarding the factors related to the type of housing, these are captured through the use of indicator variables for the different types of properties. These variables enter as control variables, and there is no clear expectation as to the signs on the estimated coefficients. The motivation for including these variables is because the stationarity of pair-wise differentials in house prices may be more or less likely between the same as opposed to different house types. Housing transactions involving movements up or down the property ladder might involve relocation from one borough to another on the basis of the same type of property. Of course, it could be that relocating to a different borough involves purchasing a different type of property.

3 Data

We use HM Land Registry data by borough and by property type for each house sale in London from 1995 to 2014.[9] Overall, the database contains more than 2.5 million observations on prices based on housing transactions, which are used to construct quarterly time-series on the median price (in pounds sterling) paid for detached houses, flats, semi-detached houses and terrace houses in the 32 boroughs that comprise London (although real estate agents may be tempted to push the advantage of an end terrace, these properties are not usually viewed as fully equivalent to a semi-detached house). The sample period runs from 1995q1 to 2014q4, for a total of $T = 80$ time observations. Although London is officially divided into 32 boroughs and the City of London, the latter is not included in our analysis because of insufficient data to construct the time series for the prices of detached houses,

[9] Unless otherwise stated, the data used in our empirical analysis were downloaded from the London Datastore at `http://data.london.gov.uk`.

semi-detached houses and terrace houses. Indeed, 6,262 out of the 6,323 transactions that occurred during the period of analysis (that is, just over 99%) refer to flats located in the City of London. In sharp contrast to this, the corresponding number of transactions for detached, semi-detached and terrace houses amount to only 6, 1 and 54, respectively.[10] In addition to this, for the City of London there are also difficulties in terms of the availability of data on the determinants of house price convergence; for example, the Office for Standards in Education, Children's Services and Skills (Ofsted) reports excludes the City of London on account of the limited number of schools. For the purposes of the econometric analysis, we require a consistent run of data for each borough over the time period. In doing so, data availability limits the extent of heterogeneity that we can capture in the London housing market. From a microeconomic perspective, we are not able to control for differences in the size of buildings, their quality, and the exact location, etc.[11] Indeed, there are potential differences within boroughs that would be interesting to examine insofar administrative borders that might not fully represent the border of specific "housing" areas, specific streets within a borough that behave different to other areas and so on.

The price series are in logarithms, and so the price differentials used in the econometric exercise are in percentage terms; see the figures in Appendix A, which also include the median property price in London as a measure of the overall development of property prices over time. Visual inspection of the time series plots in these figures suggest that within each property type the price series are non-stationary and tend to move together over time, so that there could be support for the hypothesis of price cointegration not only across boroughs, but also across property types. Another feature that is apparent from the graphs is the higher variability exhibited by prices of de-

[10]In the very few quarters where no transactions occurred, the missing observations for the specific property type were obtained using linear interpolation.

[11]There are studies such as Meier and Rehdanz (2016) that address these differences much further.

tached and semi-detached houses (particularly in the upper segment of price scale), compared with the prices for terrace houses. As to flats, the higher variability of prices is more frequently observed in the lower and intermediate segments of the price scale.[12]

Let us now turn to the data concerning the potential drivers of convergence. For geographic separation it was first necessary to estimate the geographic coordinates (that is, latitude and longitude) of the population-weighted centroids of the London boroughs. Once the coordinates are available, we employ the Stata programme `osrmtime` developed by Huber and Rust (2016), which uses the Open Source Routing Machine software based on Open Street Maps, to determine the shortest route by car between any two pairs of geographic coordinates, and calculate the corresponding optimal distance (in metres) and optimal travel time (in seconds). The resulting measures of optimal distance and optimal travel time between boroughs i and j are denoted $ldist_{ij}$ and $ldur_{ij}$, respectively, where the prefix l indicates that they are considered in logarithms.[13] Although $ldist_{ij}$ and $ldur_{ij}$ are both car-based commuting measures which offer consistency across all boroughs, we also consider the average number of tube stations in each pair of boroughs as a measure of public transport connectedness (bearing in mind that there some boroughs which do not have tube stations); the resulting variable is denoted $uground_{ij}$.

Regarding location, we account for the possibility of boroughs being part of inner and outer Greater London, by means of the dummy variables $inner_{ij}$ and $outer_{ij}$, respectively. The variable $inner_{ij}$ is set equal to 1 when both i and j refer to the prices of properties located in inner boroughs, and 0

[12]For example, during the study period the standard deviation of detached and semi-detached house prices in the borough of Kensington and Chelsea is 0.928 and 0.756, respectively, as opposed to 0.622 for terrace houses and 0.535 for flats.

[13]The results produced by the software `osrmtime` reflect the fact that the distance (duration time) through the road transportation network between i and j, is not necessarily the same as that between j and i; thus, in the econometric analysis we use the simple average between the two distances (duration times).

otherwise, and a similar definition is employed for the variable $outer_{ij}$.[14] It is worth appreciating the distribution of property type by borough. Figure 1 displays the relative importance of flats in the inner boroughs (on average 77%) followed by terrace houses (on average 22%). In contrast, in the outer boroughs the percentages accounted for by flats, terraced and semi-detached houses amount to approximately 38, 33 and 22%, respectively. Since flats and terraced housing might be regarded as the least heterogeneous forms of housing, one might regard substitutability across the inner boroughs as potentially higher. The estimated coefficients on $inner_{ij}$ and $outer_{ij}$ are expected to be positive, reflecting an increase probability of finding cointegration when the two boroughs in a pair are both part of inner (outer) Greater London.

The quality of education is measured through the percentages of pupils attending good or outstanding primary and secondary schools in borough i in 2013, as taken from the Ofsted Annual Report 2012-2013, which we respectively denote as $peduc_i$ and $seduc_i$.[15] These two variables are used to compute the differentials $peduc_{ij} = |peduc_i - peduc_j|$ and $seduc_{ij} = |seduc_i - seduc_j|$.

Crime corresponds to the average rate of recorded offences per thousand of population over the financial years 1999/2000 to 2014/2015 (the source of the data is the Metropolitan Police Service, through the London Datastore). Here, relative crime conditions are measured by $crime_{ij} = |crime_i - crime_j|$, where $crime_i$ and $crime_j$ denote the crime rates in boroughs i and j, respectively. For the empirical analysis we consider four crime rates, namely that of "criminal damage", "violent crime", "burglary", and "all recorded offences".[16] Gibbons (2004), for instance, finds that "criminal damage" is

[14] See the note to Figure 1 for the list of inner and outer boroughs.

[15] Ofsted classifies schools as outstanding (grade 1), good (grade 2), requires improvement (grade 3) and inadequate (grade 4), depending on the overall effectiveness of the education provided in the school. The evaluation process involves judgement on aspects that include the behaviour and safety of pupils at the school, the quality of teaching in the school, the achievement of pupils at the school, and the quality of leadership in and management of the school; see Ofsted (2015, p.33).

[16] All recorded offences comprise violence against the person, sexual offences, robbery, burglary, theft and handling, fraud or forgery, criminal damage, drugs and other notifiable

the only type of crime that affects property prices in London.

For demographic influences we consider $lpopd_{ij} = |lpopd_i - lpopd_j|$, where $lpopd_i$ and $lpopd_j$ indicate the logarithms of the average population density (per hectare) over the years 2001 to 2014 in boroughs i and j, respectively. As an illustration, Figure 2 plots the average household size by borough based on data extracted from the 2011 Census. Here it is interesting to see that smaller household sizes tend to be concentrated in the inner boroughs, precisely where flats represent a much larger share. Larger household sizes are observed in the periphery of the city (most especially in the western and northeastern boroughs).

Economic conditions are measured by $linc_{ij} = |linc_i - linc_j|$, where $linc_i$ and $linc_j$ denote the logarithm of the average median income of tax payers over the tax years 1999/00 to 2012/13 in boroughs i and j, respectively. These data were retrieved from the HM Revenue and Customs Survey of Personal Incomes, through the London Datastore.

Finally, we consider the dummy variables $detach_{ij}$, $flat_{ij}$, $semi_{ij}$ and $terrace_{ij}$. Here, $detach_{ij} = 1$ when both i and j refer to the prices of detached houses (0 otherwise), and similarly for the other property types.

It is important to appreciate that there are other borough-level factors that could be relevant in terms of influencing flexibility in a market which would affect the relative price differential and so likelihood of long-run convergence. Such factors include regulatory stringency over land use, infrastructure, car dependency, the presence or absence of natural amenities, net population flows across boroughs, racial diversity and income diversity; for a historical perspective see Meen et al. (2016). These factors cannot all be operationalized. However, we do include a measure of borough housing supply (likely to be inversely related to regulatory stringency over land use), a measure based on borough underground station access (inversely related

offences. Criminal damage includes vandalism, graffiti and arson.

to car dependency), and relative population density (related to population diversity). Of these three measures, borough housing supply was not found to be statistically significant, and was therefore omitted from the subsequent probit analysis. In relative terms, natural amenities are less likely to have changed dramatically over the study period.

4 Long-run house price convergence

Because we are interested in price differentials, rather than price levels, the use of data in nominal or real terms, the latter obtained after deflating using a national (or even city level) deflator, makes no difference to the results. The top and bottom panels of Table 1 summarise the absolute and relative frequencies of stationary relative prices. The first four rows in each panel present the (absolute and relative) frequencies based on all the differentials that can be constructed using the prices of only detached houses, only flats, only semi-detached houses and only terrace houses (that is, 496 price pairs in each case). In turn, the next six rows in each panel present the corresponding frequencies based on all the relative prices that can be computed using couples of property types, namely detached houses and flats, detached and semi-detached houses, and so on (that is, 1024 price pairs in each case). Overall, the total number of price differentials that can be calculated with the 128 price series under consideration is 8128, as presented in the last row of each panel.

To produce Table 1, the ADF and $\mathrm{ADF}_{\max}$ unit root tests were performed at the 5 and 10% significance levels, the optimal lag length was chosen using the Schwarz information criterion (SIC), allowing for a maximum of 6 lags, and a borough-specific trend term was included in the test regression if it was statistically significant at the 5% significance level. From an economic perspective, the inclusion of the time trend (if significant) is intended to serve the purpose of picking up effects associated to relative changes in amenities between boroughs.

The results presented in Table 1 illustrate that at the 5% significance level, the ADF test yields a rejection frequency of 99.2% for detached houses only, indicative that the overwhelming majority of price differentials are stationary. For semi-detached houses the associated rejection frequency is also considerably high, i.e. 75.2%, while for flats and terrace houses the corresponding percentages are 45.2 and 39.7%, respectively. Although at first sight these results may not appear surprising, in the sense that they involve homogeneous property types, higher relative frequencies of stationary price differentials are also observed when examining couples of different property types. For instance, if one looks at the ADF test at the 5% level, the results for detached and semi-detached houses, detach and terrace houses, and detach houses and flats reach relative frequencies of rejection of 94.7, 88.7 and 85.2%, respectively. The smallest relative frequency of stationary price differentials is observed for terrace houses only, with 39.7%, although this is certainly not a negligible percentage. Overall, 5690 out of the 8128 price differentials (that is, 70%) are found to be stationary when using a significance level of 5%. In all cases higher relative rates of rejection are obtained when the more powerful $\mathrm{ADF}_{\mathrm{max}}$ unit root test is used for inference. The lowest proportion remains the one observed for terraced houses and the highest for detached houses.[17]

The results described above highlight that, at least in the case of London, the finding of long-run co-movement of property prices tends to be more prevalent when allowance is made for the type of dwelling. Indeed, results not reported here indicate that when one constructs quarterly time series on the median price (in pounds sterling) paid for all four property types in the

[17]When one includes the price series of flats in the City of London in the computation of the percentages of stationary price differentials, the results are largely unaffected. For example, using the ADF test at the 5% significance level the relative frequency of rejection for all price differentials is 69.7% (compared to 70% in Table 1), while for flats the corresponding rejection frequency is 44.9% (compared to 45.2% in the same table)

32 boroughs that compose London, then 37.1% (i.e. 184 out of the 496 price differentials) are stationary based on the ADF test at the 5% level. This relative frequency compares very favourably with the 36% value reported by Abbott and De Vita (2012) for the London boroughs, also using the ADF test at the 5% level, and where the optimal number of lags is determined using SIC.[18]

Figure 3 displays the geographic pattern of spatial integration in the boroughs of London, where the darker purple areas indicate those boroughs with rejection rates greater than 75%, based on the $\mathrm{ADF}_{\mathrm{max}}$ unit root test at the 5% significance level, and therefore more long-run convergence with other London boroughs. In turn, the lighter purple areas show those boroughs with rejection rates between 50 and 75%. Overall, this figure reveals that the highest degree of long-run house price co-movement tends to occur in the boroughs located in the central part of the city. This figure provides the motivation to ask ourselves if it is possible to formulate and estimate a model with the purpose of identifying the variables or drivers that are expected to have an effect on the likelihood of finding cointegration between pairs of property prices.

Lastly, in an attempt to provide a more complete view of the property market in London, we examine whether or not similar developments can be observed in the case of private sector rents. To address this issue, we collected annual data on this variable (measured in pounds per week) for the London boroughs over the period 1997 to 2015, which corresponds to $T = 19$ time observations for each borough (the source of the data is the Valuation Office Agency through the London Datastore). Using the ADF test at the 5 and 10% significance levels, the percentages of stationary private rents

[18] The small discrepancy in the results may be explained by the fact Abbott and De Vita (2012) use a shorter sample period (1996q1 to 2009q2), and also include the City of London along with the other 32 boroughs of London. It ought to be remembered that because of data availability, we were not able to obtain prices series for detached, semi-detached and terrace houses in the City of London.

differentials are respectively 26.9 and 37.3%, that is much lower than the corresponding fractions obtained for the house price series. However, these results ought to be interpreted with caution because the number of time observations is small, and the private rents series are an aggregate measure of the four property types (and as such do not take into consideration the inherent property heterogeneity). In terms of future research, house price to rent ratios would probably give us some insights into testing for house price bubbles across London boroughs.

5 Determinants of house price convergence

In this section we estimate a binary (probit) model to find the variables that are expected to have an effect on the likelihood of z_{ij} being equal to one (or zero), that is whether or not pair-wise differentials in house prices are stationary (or non-stationary). To do this, it is important to bear in mind that ideally one would need to assemble a consistent database of the relevant explanatory variables across all 32 London boroughs over the sample period of interest. However, in some instances data availability prevent us from calculating the average value of a variable during the totality of the study period, but only in some specific years. Thus, caution must be exercised when interpreting the effects because potential variations in levels over the whole time span may have not being accounted for.

Table 2 reports the marginal effects when the binary outcome z_{ij} is modelled based on the $\mathrm{ADF}_{\max}$ at the 5% significance level.[19] The models in this table differ in that they use travel distance (left) and travel duration time (right), both in logarithms, as measures of geographic separation between boroughs. Furthermore, Model 1 denotes the unrestricted specification where

[19] Qualitatively similar results are obtained when z_{ij} is defined based on the ADF test. Although the results of the probit analysis are not intended to be causal, but rather correlational, an exogeneity test was supportive of our specification and is available upon request.

all the potential drivers described earlier (including the interaction between the amenity variables with proximity) are included as potential determinants, while Model 2 corresponds to a more parsimonious specification that excludes insignificant regressors, namely the dummy variable for outer boroughs, and the proxy variable for the quality of secondary education. Overall, the binary regression models tell the same story. With regards to the factors related to distance or location, a shorter distance (travel duration time) between the boroughs concerned increases the likelihood of property price integration by 8 (6.6) percentage points, and similarly when both boroughs are being part of interior or inner Greater London. As to the factors related to the type of housing, the models reveal that the probability of long-run convergence between pairs of property prices is higher on account of pairs of detached and semi-detached housing, rather than pairs of flats and pairs of terraced houses. For instance, in the model that uses travel distance the probability of stationarity decreases by 21 and 27 percentage points when one only considers pairs of flats and terrace houses, respectively, while for pairs of only detach and semi-detached houses the probability increases respectively by 27.6 and 5 percentage points. If flats and terraced housing are relatively homogeneous compared with semi- and detached housing, this finding could be viewed as counter-intuitive if homogeneity is associated with substitutability and price convergence. However, semi- or detached house price differentials are much larger across boroughs when compared with flats or terraced housing. With this in mind, significant short-run increases in semi- or detached house price differentials are less likely to be as sustainable in the long-run. This might account for price convergence being more likely for these types of housing. Lastly, regarding factors related to amenities or quality of life, the likelihood of integration in property prices increases for smaller pairwise differences in primary education standards, population densities and income levels. Our findings suggest that disparate rather than similar crime rates between boroughs are more likely to drive house price convergence. Following our earlier discussion, this finding is consistent with the view that the high-crime/low house price areas have greater (absolute) elasticities of house prices with respect to crime. Gibbons (2004) for instance compares the maps for crimes and burglaries with the distribution of property prices in London, and finds that the highest price districts are in the west, while high-density crime areas are in the east. A formal assessment of whether the high-crime/low house prices exhibit greater (absolute) elasticities is, however, beyond the scope of the paper and therefore left as avenue for future research.

6 Concluding remarks

In this paper we have uncovered evidence supporting the view that long-run property price convergence is present across the London boroughs insofar as price differentials are stationary and prices therefore move in tandem. This co-movement of property prices within regions has important implications for relative affordability and labour mobility. In reaching this finding, we have conducted a probabilistic test of convergence based on the unit root testing of all pair-wise house price combinations. In contrast to the existing literature, however, our findings are based on the employment of a richer dataset that explicitly distinguishes between four types of dwelling. By not relying on a single house price measure for each borough, this has enabled us to capture the heterogeneity of the London property market.

While we acknowledge the need to interpret our findings with caution due to potential bias introduced by omitted variables, there is evidence that the probability of finding long-run convergence between any two boroughs is inversely related to the geographic separation (measured through the optimal travel distance and optimal travel time) between them, as well as differences in amenities and quality of life such as considerations based on education, population densities and income levels; public transport connectedness, on the other hand, is found to be directly related. Disparate rather than similar crime rates between boroughs, a negative attribute, are more likely to drive house price convergence. With regard to the unresolved issue concerning the role of geographic separation in house price relationships, our findings are consistent with the view that property price relationships are likely to be stronger between contiguous than non-contiguous boroughs. Finally, we find that the highest proportion of unit root rejections emerges when we consider pairs of semi- and detached as opposed to pairs of flats or terraced houses.

We can reflect on policy implications that might arise from our findings. In our sample, the cheaper properties within each borough are terraced housing and flats and are therefore most relevant to the affordability issue for lower income households. Across boroughs, we find that convergence is less likely for these housing types. This implies relative divergence and therefore potential for relative affordability to worsen. Looking at the earlier presentation of the data, this policy issue is particularly relevant to the inner-London boroughs that are characterised by a high proportion of terraced houses and flats. Policy measures aimed at addressing the relative affordability of cheaper housing should therefore be strongly borough-focused. Further to this, it is desirable to bring crime rates down. If it is also desirable to ensure that borough house prices do not drift apart, then crime rate reductions in high crime/low house price areas are likely to make cointegration between borough house prices less likely with the prospect of borough house prices drifting further apart. This potential conflict in objectives may lead policymakers to carefully assess priorities.

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Table 1: Absolute and relative frequencies of stationary price differentials

p_i	p_j	ADF		$\text{ADF}_{\max}$		
		5%	10%	5%	10%	Pairs
Absolute frequency:						
Detach	Detach	492	493	493	494	496
Flats	Flats	224	262	254	289	496
Semi-detached	Semi-detached	373	389	393	412	496
Terrace	Terrace	197	224	222	251	496
Detach	Flats	872	903	901	938	1024
Detach	Semi-detached	970	980	979	990	1024
Detach	Terrace	908	927	922	941	1024
Flats	Semi-detached	602	665	642	712	1024
Flats	Terrace	415	483	445	540	1024
Semi-detached	Terrace	637	678	677	723	1024
All	All	5690	6004	5928	6290	8128
Relative frequency:						
Detach	Detach	0.992	0.994	0.994	0.996	
Flats	Flats	0.452	0.528	0.512	0.583	
Semi-detached	Semi-detached	0.752	0.784	0.792	0.831	
Terrace	Terrace	0.397	0.452	0.448	0.506	
Detach	Flats	0.852	0.882	0.880	0.916	
Detach	Semi-detached	0.947	0.957	0.956	0.967	
Detach	Terrace	0.887	0.905	0.900	0.919	
Flats	Semi-detached	0.588	0.649	0.627	0.695	
Flats	Terrace	0.405	0.472	0.435	0.527	
Semi-detached	Terrace	0.622	0.662	0.661	0.706	
All	All	0.700	0.739	0.729	0.774	

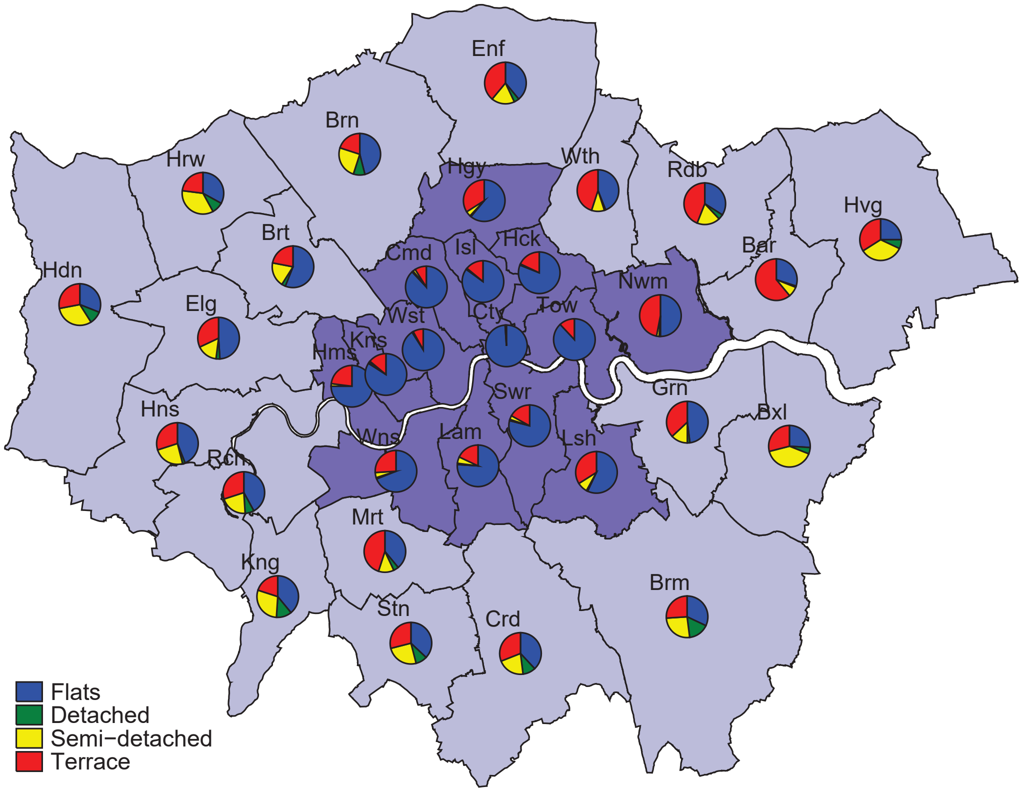
Note: The unit root tests include a linear trend if it is statistically significant at the 5% level. The number of lags of the dependent variable in the test regression is selected using the Schwartz information criterion with $p_{\max} = 6$ lags. The critical values for the ADF test are based on Cheung and Lai (1995). For the $\text{ADF}_{\max}$ test, the critical values are based on Otero and Smith (2012). Relative frequencies are calculated with respect to the row totals.

Table 2: Determinants of stationarity price differentials (ADF_{max} 5%)

	Using travel distance				Using travel duration time			
	Model 1		Model 2		Model 1		Model 2	
Variables	dy/dx	(s.e.)	dy/dx	(s.e.)	dy/dx	(s.e.)	dy/dx	(s.e.)
ldist	-0.081	(0.013)	-0.078	(0.012)				
ldur					-0.066	(0.013)	-0.066	(0.013)
detach	0.276	(0.007)	0.276	(0.007)	0.277	(0.007)	0.277	(0.007)
flat	-0.212	(0.021)	-0.212	(0.021)	-0.212	(0.021)	-0.212	(0.021)
semi	0.053	(0.018)	0.053	(0.018)	0.052	(0.018)	0.052	(0.018)
terrace	-0.273	(0.020)	-0.273	(0.020)	-0.273	(0.020)	-0.273	(0.020)
inner	0.113	(0.017)	0.107	(0.016)	0.114	(0.016)	0.113	(0.015)
outer	0.012	(0.014)			0.002	(0.014)		
peduc	-0.002	(0.001)	-0.002	(0.001)	-0.003	(0.001)	-0.003	(0.001)
seduc	0.000	(0.001)			0.000	(0.001)		
cdamage	0.007	(0.003)	0.007	(0.003)	0.006	(0.003)	0.006	(0.003)
violence	0.002	(0.001)	0.002	(0.001)	0.003	(0.001)	0.003	(0.001)
burglary	0.004	(0.002)	0.004	(0.002)	0.004	(0.002)	0.004	(0.002)
lpopd	-0.055	(0.017)	-0.062	(0.014)	-0.069	(0.016)	-0.069	(0.014)
linc	-0.342	(0.046)	-0.347	(0.046)	-0.325	(0.046)	-0.326	(0.045)
uground	0.005	(0.001)	0.005	(0.001)	0.004	(0.001)	0.004	(0.001)
Obs	8128		8128		8128		8128	
LR test	777.3	[0.000]	774.3	[0.000]	765.6	[0.000]	763.6	[0.000]

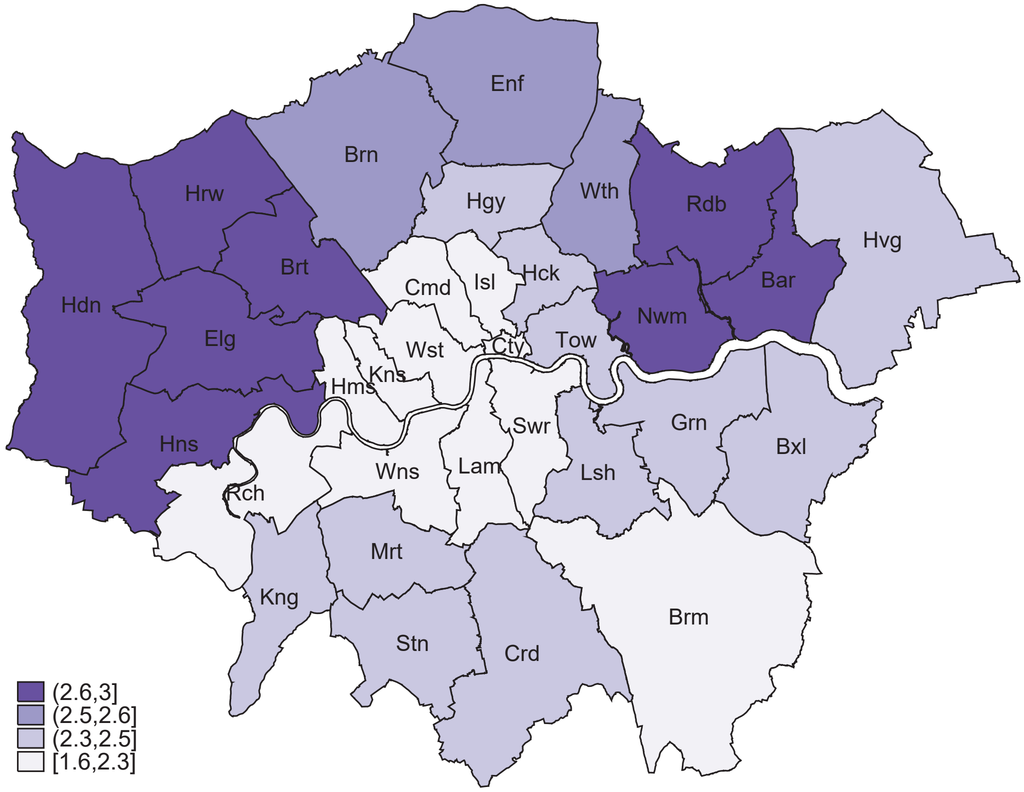
Note: Standard errors are heteroskedasticity consistent. dy/dx denotes marginal effects. Numbers in [•] are the probability values of the diagnostic test statistics.

Figure 1: Distribution of property type by borough



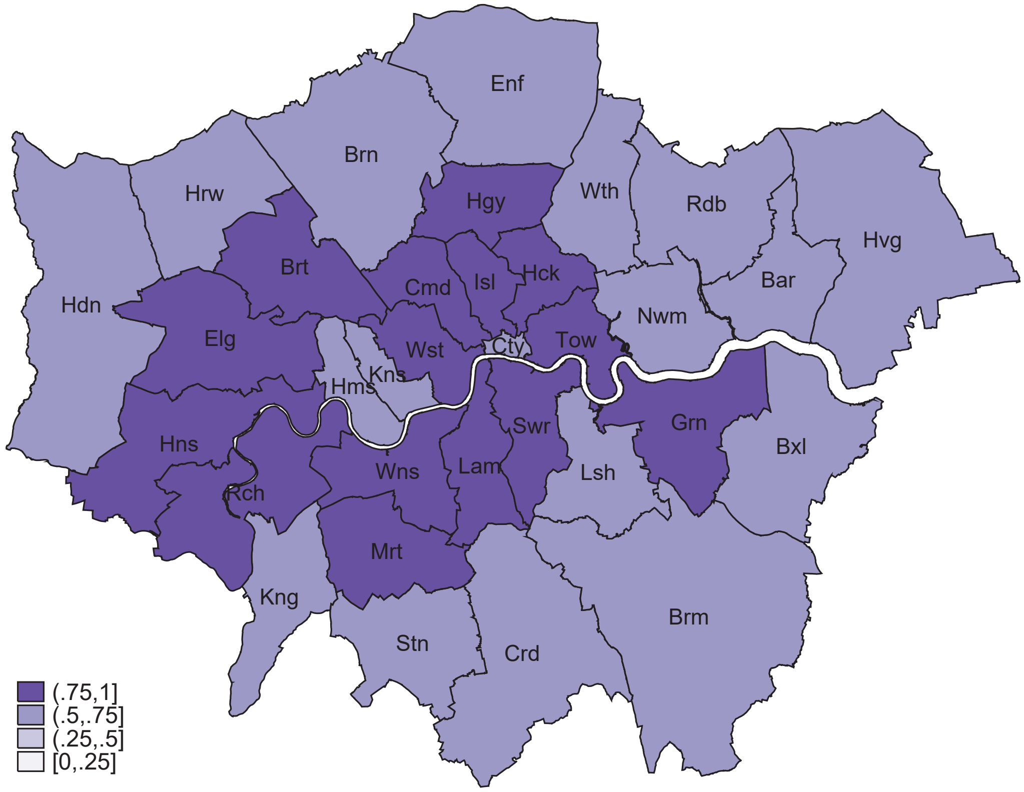
Note: The darker purple area denotes inner boroughs: Camden (Cmd), Hackney (Hck), Hammersmith and Fulham (Hms), Haringey (Hgy), Islington (Isl), Kensington and Chelsea (Kns), Lambeth (Lam), Lewisham (Lsh), Newham (Nwm), Southwark (Swr), Tower Hamlets (Tow), Wandsworth (Wns) and Westminster (Wst). The lighter purple area denotes outer boroughs: Barking and Dagenham (Bar), Barnet (Brn), Bexley (Bxl), Brent (Brt), Bromley (Brm), Croydon (Crd), Ealing (Elg), Enfield (Enf), Greenwich (Grn), Harrow (Hrw), Havering (Hvg), Hillingdon (Hdn), Hounslow (Hns), Kingston upon Thames (Kng), Merton (Mrt), Redbridge (Rdb), Richmond upon Thames (Rch), Sutton (Stn) and Waltham Forest (Wth). The City of London (Cty) is not officially a London borough. The percentages are calculated using property counts from the London Datastore as at 31 March 2014.

Figure 2: Average household size by borough



Note: The data on the number of persons per household were extracted from the 2011 Census, Table H01UK. Borough abbreviations are in Figure 1.

Figure 3: Proportion of stationary house price differentials

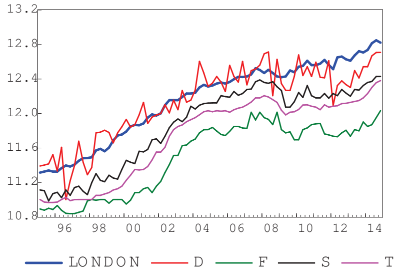


Note: The purple scale indicates the proportion of stationary house price differentials for each borough, including the City of London, based on the ADF_{max} test at the 5% significance level. Borough abbreviations are in Figure 1.

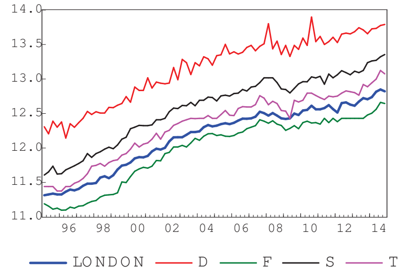
A Time-series of quarterly property prices

This appendix presents the plots of the (logarithm of the) quarterly prices of detached houses (D), flats (F), semi-detached houses (S) and terrace houses (T) in each borough. As a measure of overall price development, the median property price in London is also included in each figure.

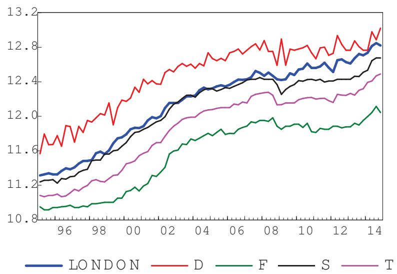
Figure A.1: London boroughs and London



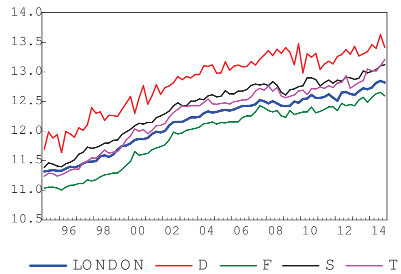
(a) Barking and Dagenham



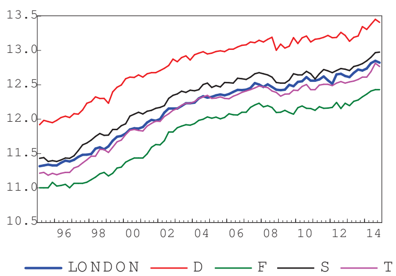
(b) Barnet



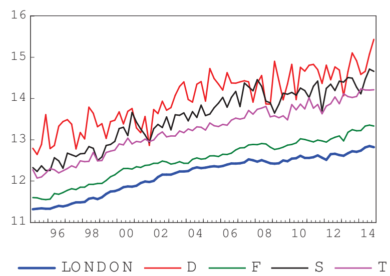
(c) Bexley



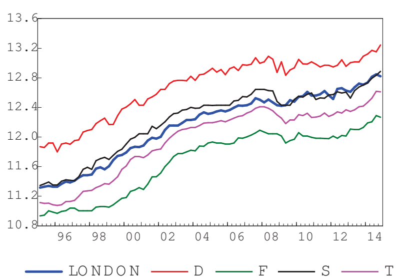
(d) Brent



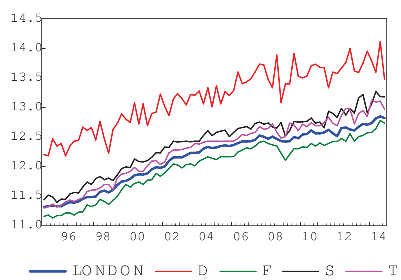
(e) Bromley



(f) Camden

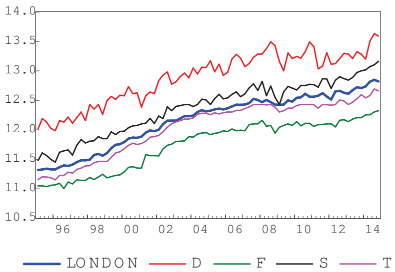


(g) Croydon

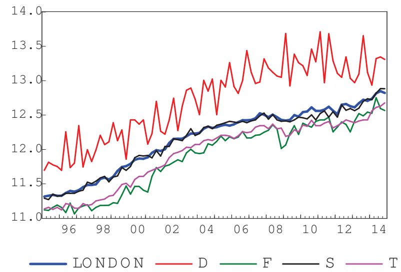


(h) Ealing

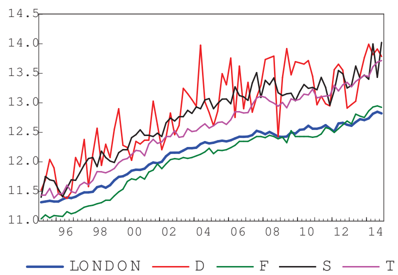
Figure A.2: London boroughs and London



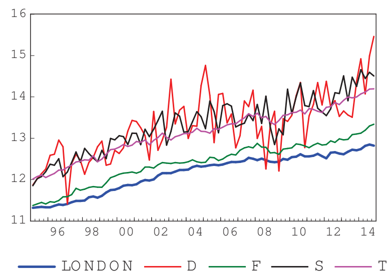
(a) Enfield



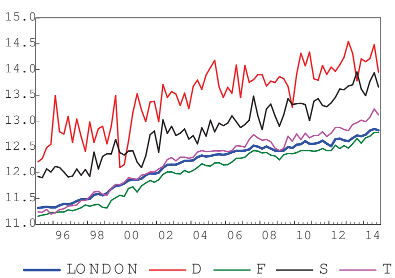
(b) Greenwich



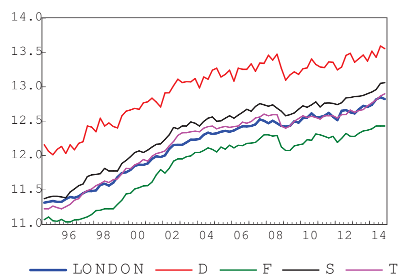
(c) Hackney



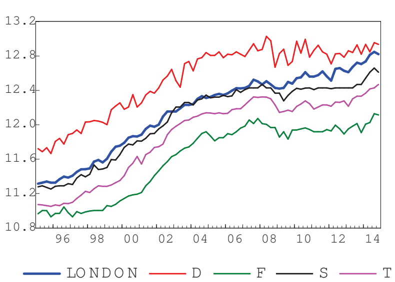
(d) Hammersmith and Fulham



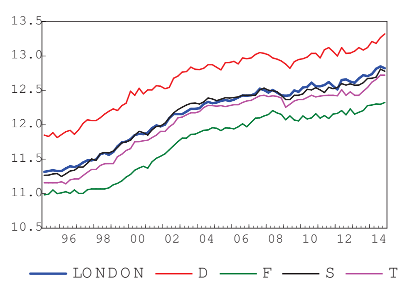
(e) Haringey



(f) Harrow

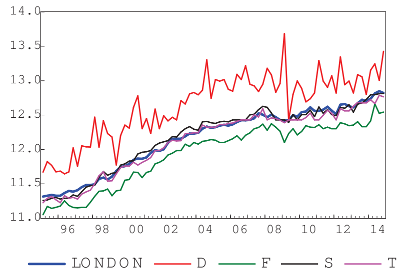


(g) Havering

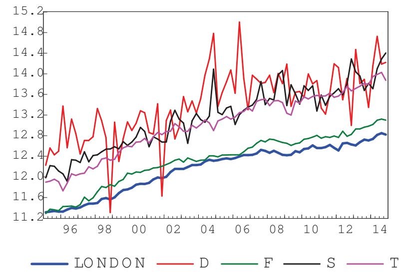


(h) Hillingdon

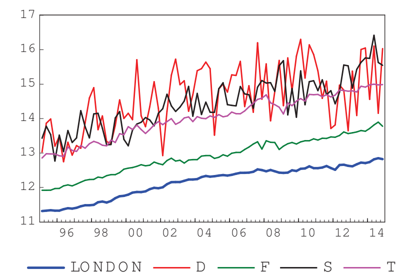
Figure A.3: London boroughs and London



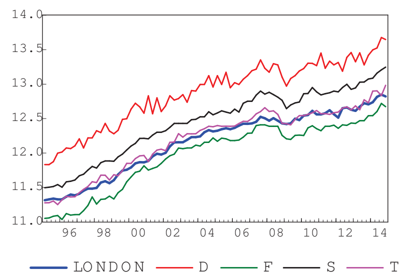
(a) Hounslow



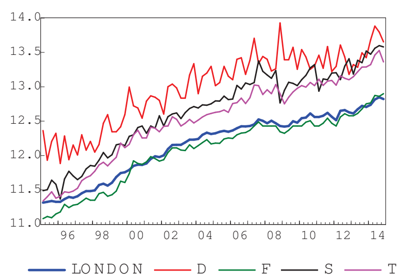
(b) Islington



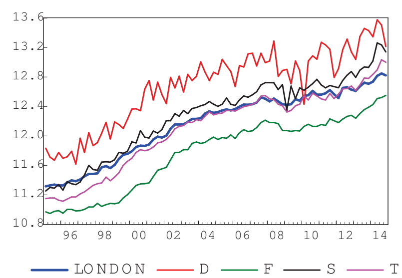
(c) Kensington and Chelsea



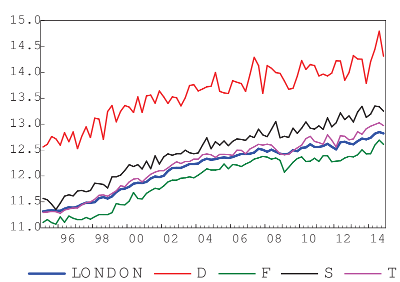
(d) Kingston upon Thames



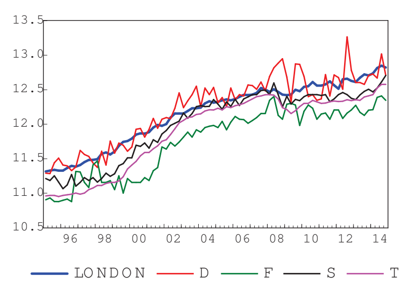
(e) Lambeth



(f) Lewisham

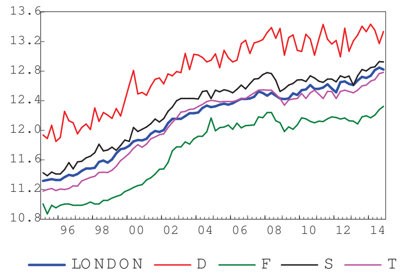


(g) Merton

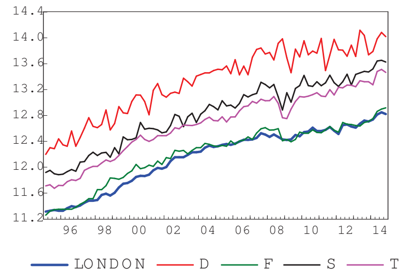


(h) Newham

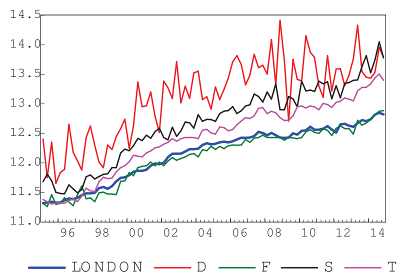
Figure A.4: London boroughs and London



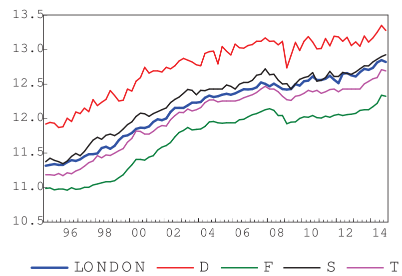
(a) Redbridge



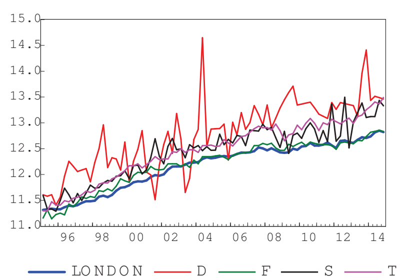
(b) Richmond upon Thames



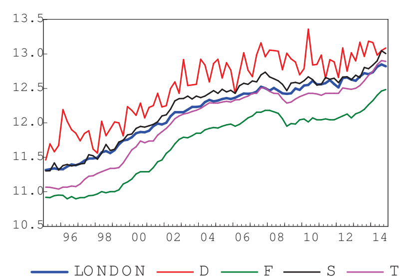
(c) Southwark



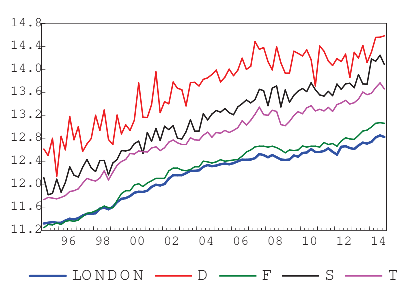
(d) Sutton



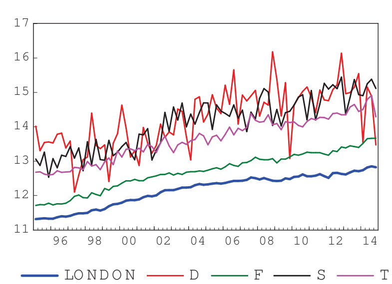
(e) Tower Hamlets



(f) Waltham Forest



(g) Wandsworth



(h) Westminster