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SERC DISCUSSION PAPER **168**

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December 2014

This work is part of the research programme of the independent UK Spatial Economics Research Centre funded by a grant from the Economic and Social Research Council (ESRC), Department for Business, Innovation & Skills (BIS) and the Welsh Government. The support of the funders is acknowledged. The views expressed are those of the authors and do not represent the views of the funders.

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We thank seminar participants at the LSE/Spatial Economics Research Centre, American Real Estate and Urban Economics Association 2014 conference in Reading, Helsinki Government Institute for Economic Research, North American Meetings of the Regional Science Association, as well as Pat Bayer, Tom Davidoff, Piet Eichholtz, Hua Kiefer, Colin Lizieri, Sean Holly, Geoff Meen, Henry Overman, and Silvana Tenreyro for useful comments on earlier versions of this work. This research was initially developed to inform a leasehold enfranchisement case of a house in Central London, for which one of the authors acted as expert witness. The case (known as "Kosta v The Trustees of the Phillimore Estate") was first discussed at the Leasehold Valuation Tribunal in March 2013; the appeal was heard by the Upper Tribunal in June 2014. During the proceedings the data and the computer code were reviewed by the other expert witnesses of both sides. Any views expressed are solely those of the authors and cannot be taken to represent those of the Bank of England or its Monetary and Financial Policy Committees.

Abstract
Most housing transactions in London involve trading long leases of varying lengths. We exploit this feature to estimate the time value of housing --- the relationship between the value of a property and the length of time it will be owned for --- over the range 1-99 years. To do so, we compile a unique historical dataset from 1987 to 1992 to abstract from current institutional features of the UK system, for instance rights to extend leases that could confound our results. By applying hedonic techniques to these data we provide new evidence on how the market values leasehold properties. We find that the time value of housing over the range 1-99 is similar to an exponential shape, a finding that suggests sophisticated pricing behaviour in the London residential market. Digging deeper, however, we show that leasehold prices depart from this predictable pattern in a way that is consistent with a declining discount rate schedule.

Keywords: House prices, discount rates, historical data
JEL Classifications: G12; R30

1 Introduction

Leasehold contracts granting interests in real estate assets for a pre-defined length of time provide an alternative way to own property outside of perpetual, or freehold, ownership.[1] In some residential property markets – England and Wales, Hong Kong, and Singapore – tradeable long leasehold contracts make up a sizeable proportion of both housing stock and market transactions.[2] In England and Wales, where just short of two thirds of the population live in owner-occupied dwellings, as many as 1 million houses and 2 million flats are owned under long leases, around 40% of recent new build properties are leased, and leasehold transactions account for around a quarter of all residential sales each year.[3] Leaseholds are most commonly found where populations are highly concentrated—they account for around half of the sales in London and over four fifths of sales in Prime Central London, the highly urbanised core of central London that covers Mayfair, Chelsea and Kensington (Figure 1).

In this paper we exploit the residential lease system in England and Wales to estimate how market participants implicitly value variation in use rights over residential property assets. Our main focus is the relationship between transaction price and remaining lease length at the time of sale, frequently referred to as the unexpired term of the lease, in the London market. To conduct the analysis, we first compile a unique dataset of more than 8,000 historic house and flat sales in Prime Central London in the years 1987-1992. The historic nature of our dataset is important to our identification strategy since legal reforms in 1993 gave many leaseholders the right to extend their leases, whereas prior to 1993 very few owners of leases in Prime Central London had such rights and those that did can be isolated and dropped from our analysis. This ensures that our results are unaffected by the option value of extending or enfranchising a lease—most leaseholders exercise this option which is generally regarded as valuable. As well as unexpired term at the time of sale, our detailed dataset also allows us to identify critical details of ownership contracts – including whether the property is a freehold, a leasehold, or a leasehold sold with a share of the freehold – that are highly likely to have a material bearing on sales prices. The care we take to compile and refine our historic dataset, which we believe is unique in the literature, gives us confidence that we can make valid comparisons between properties in our data.

With these restrictions in place, we adopt a hedonic approach to identify separately the effect of variation in unexpired term on sales prices from other property, tenure, and

[1]Freehold ownership is also known as fee simple ownership

[2]Commercial real estate leases are also widespread, for example in the US and the UK, but are not covered here. See for example Mooradian and Yang (2002); Ball et al. (2012).

[3]DCLG Table FA1221 (S108): Household type by tenure, 2011-12; housing stock estimates from https://www.gov.uk/government/policies/helping-people-to-buy-a-home.

neighbourhood characteristics. The depth of our data means we can estimate individual dummies for all leases with a given unexpired term in the 1 to 99 year range rather than group observations together and thereby lose information. We take a number of steps to ensure that our results are robust. First, we take account of very specific localised variations in housing demand and supply factors through street fixed effects with the sheer size of our dataset in relation to the geographical size of the area making this a powerful approach. Next, by only comparing leaseholds with other leaseholds we can also rule out any influence from unobserved differences between leasehold and freehold properties. Finally, we estimate a variety of models which are designed to address concerns that omitted variables may be biasing our results. This procedure provides us with estimates of the discounts attached to all leases in the range 1 to 99 years against otherwise identical long leases.

Our main contribution is to reveal insights about the shape and the level of discounts in the London housing market, which we term the time value of housing, supplementing a nascent literature that uses residential tenure decisions to make inferences about long term discount rates (Giglio et al., 2014; Badarinza and Ramadorai, 2014). To facilitate a discount rate interpretation, our estimates are based on comparing flat sales. Because it will usually be impossible to redevelop flats to a higher density, this strategy gives us greater confidence that the implied relationship between price and lease length is less likely to be driven by variation in the value of the option to redevelop. We find that once we have partialled out other influences, sales prices of leasehold interests in the range 1 to 99 years in our sample broadly mirror predictions about the deterioration of prices of wasting assets drawn from finance theory. We argue that the shape of the curve we estimate demonstrates sophisticated pricing behaviour in the Central London market and provides strong support for rational and consistent pricing of assets in the London residential market. Using Galton (1907)'s terminology, the "wisdom of the crowd" in the London residential market appears to be strong. However, on closer inspection there appear to be material differences between the relationship implied by pure discounting and the observed relationship between lease term and prices. Although it is difficult to pin down exactly what drives our findings, our results are consistent with a declining schedule of discount rates.

In a recent study developed independently from our own research, Giglio et al. (2014) use data on freehold and leasehold properties in the UK and Singapore to estimate the discount rates applied to benefits that occur 100 or more years in the future. Their results are suggestive of very low long-run discount rates, around 2.5%. Differently from Giglio et al. (2014) and complementary to their work, we focus on discount rates between 1 and 99 years and, rather than emphasising the level of discount rates, we focus on the shape of these rates going from short- to long-run discounts. In terms of data, Giglio et al. (2014) use current transactions whereas we follow the approach of UK surveyors and tribunals (as laid out in Royal Institution of Chartered Surveyors (2009)) and study historical transactions when there were no leasehold extension or enfranchisement rights. In another recent contribution, Badarinza and Ramadorai (2014) use evidence from the UK First-Tier Tribunal—previously known as the Leasehold Valuation Tribunal (LVT)—to make inferences about the shape of the discount rate function in the UK. Using records of some 450 decisions on leasehold extensions and enfranchisements made from 1985, these authors contend that the discount rates implicitly adopted by tribunals are high and actually increasing with the length of the leasehold term. Since these decisions are based on the opinions of experts, LVTs provides a useful source of evidence against which market evidence can be compared. However, the complexities of the case law and statutory framework, as well as the small number of observations, inevitably create some uncertainty as to directly interpreting such evidence as discount rates.

We also highlight that our results should be of interest to many actual and would be participants in the housing market in England and Wales. A statutory right for leaseholders to extend their leases was first introduced in legislation in 1967 and then significantly widened in 1993. The legislation sets out a method to decide how much a leaseholder needs to pay to extend the lease or to purchase the freehold. The legislation, however, leaves the precise parameters to determine the premium unspecified, so in practice this is usually negotiated bilaterally between the leaseholder and the freeholder. One component of the valuation – known as relativity – is the ratio of the value of the lease at its current unexpired term to the value of the property if it were held on a freehold, but assuming no rights to extend or enfranchise are in place.[4] Because in practice leases are usually extended once unexpired term falls below 100 years, and since our estimates are historic, our findings are potentially related to this procedure.

2 Institutional Framework

2.1 Residential Leasehold in England and Wales

Since our aim is to identify precisely how leasehold tenure and lease length affect sales prices of properties, we begin by describing the residential leasehold system in England, which provides an alternative to the more widely studied home-ownership and rental forms of tenure (Henderson and Ioannides, 1983; Sinai and Souleles, 2005).[5] Conceptualising

[4] This follows guidance from Royal Institution of Chartered Surveyors (2009).

[5] A full account of the history of residential leasehold and its evolution lies outside the scope of this work. Interested readers are referred to McDonald (1969) who describes the origins of residential leasehold

tenure forms as distinct bundles of use, transfer, and contracting rights and obligations (Besley and Ghatak, 2009), the fundamental characteristic of leasehold ownership is that it grants the purchaser of the lease– the lessee or leaseholder – use rights for a long but finite period, commonly 99 or 125 years, known as the term of the lease. As such it lies between freehold home ownership (indefinite use rights) and renting (use rights for a short fixed period). As with freehold owners, leaseholders can gift or sell the asset (transfer rights) and mortgage or rent the property (contract rights).[6] Existing leasehold interests can then be bought and sold on the open market. When such a trade takes place, the buyer inherits the existing lease agreement in full, including the duration of the remaining use rights of the contract. This is known as the unexpired term of the lease and is simply the original term reduced by the elapsed time since the lease was granted.

In contrast to freehold ownership, leasehold ownership implies multiple interests in the same real estate asset since the seller of the leasehold – the lessor or freeholder – retains an interest in the asset beyond the initial sale.[7] Land rents, known as ground rents, are typically paid annually in accordance with a payment schedule agreed at the start of the lease and represent an income to lessors rather than a payment for services.[8] Failure to pay ground rents in accordance with the lease can result in forfeiture of the lease, although in practice this is rare. Lessors also commonly retain the right to veto redevelopment or alteration to the property by the leaseholder during the term of the lease. If a leaseholder does wish to redevelop, the freeholder will demand a premium which is subject to negotiation between the parties.

Nearly all flats in England and Wales are owned with leasehold contracts.[9] This

ownership in the granting of land, or ground, leases in feudal England. Under such arrangements, tenants would develop leased land, often to agreed parameters, and use it for the term of the lease with the land and buildings reverting to the land owner thereafter. McDonald (1969) suggests several reasons why this arrangement may have evolved, for example to enable management of the large fixed costs of providing services such as drainage, sea-defences, street lighting, and road construction. In many territories, some part of the public sector, or state, retains ultimate ownership of land underlying real estate in grants fixed length use of land in return for ground rent payments. Anglin et al. (2013) offer several possible reasons why a landowner may prefer a leasehold arrangement in the context of developing economies.

[6]Although technically the leaseholder cannot assign or sublet without the freeholder's approval.

[7]This interest – usually thought of as corresponding to the ownership of the ground beneath the real estate asset which has been leased – is known as the freehold interest, and can also be traded in secondary markets. Note the distinction between a freehold interest in a real estate asset and freehold ownership of an asset. The former implies that there is a lease over the property and there being two interests. The latter implies a single interest.

[8]In some cases ground rents are of a nominal amount, known as a peppercorn ground rent, or a fixed rent with no review. More often, ground rent payments are subject to review in intervals of 5, 10, 15, 21 or 25 years. The lease sets out how the ground rent is reviewed at the review date but according to Savills (2012) it is common for ground rents to either double, to increase by a fixed amount, to be rebased against the retail price index (RPI), or to be rebased against a percentage of the capital value of the underlying property at such times.

[9]A few flats are in fact held freehold, rather than share of freehold. These freehold flats will usually be the flat where the freeholder lives. They could have the right to receive ground rents from other leases

ownership structure provides a way to share costs for public goods when a single building houses more than one dwelling. For example, there may be a shared staircase or garden, and in large purpose built flats a lift and perhaps even a porter. In some cases the individual leaseholders collectively own the freehold interest while in other cases it is owned by a third party. The former is known as owning a leasehold with a share in the freehold. It effectively allows owners to extend their leases indefinitely and is therefore analogous to freehold ownership of houses in terms of the use rights it grants.[10]

2.2 Rights to Extend and Enfranchise a Lease

Prior to 1967, leaseholders in England and Wales had no rights over leased property assets at the end of the lease term such that the land and all buildings would revert to the lessor at this point. The lessor could then grant another lease or use the property themselves. The only option open to leaseholders that wished to retain ownership was to negotiate a new lease with the lessor, either before an existing lease expired or at the end of the lease term. A statutory right for leaseholders to extend their leases or to purchase the freehold, a process known as enfranchisement, was first introduced in legislation in 1967, granting rights to owners of leases on low value houses, defined on the basis of the property's rateable value, an assessment of the value of the property made for taxation purposes. In 1993 a subsequent Act widened the scope of rights to cover the vast majority of houses and flats.

The legislation sets out a method to decide how much a leaseholder needs to pay to extend the lease or purchase the freehold but leaves the precise parameters to determine the premium unspecified. In practice premiums are usually negotiated bilaterally between the leaseholder and the freeholder, often with the benefit of professional advice. If the leaseholder and freeholder can not reach an agreement, the leaseholder can 'hold over' and remain in the property paying a market rent. They also have the option of bringing a dispute to a statutory tribunal, where a panel of independent experts hear evidence and decide the premium payable following the statutory guidelines. Although direct data on the size of the market for lease extensions is difficult to come by, the activity of the Leasehold Advisory Service (LAS), a free advice service for leaseholders, provides an indirect measure. In 2012/13 LAS received more than 800,000 website visits and fielded more than 40,000 telephone or written queries with the second most common

in the building and, as described below, a stake in the residual interest as with other freehold interests.

[10] The owner of the freehold interest for flats usually provides management and maintenance services to the building on behalf of the leaseholder(s), recovering costs through a fee known as a service charge. This applies regardless of whether the block is owned leasehold of share of freehold. Although the incentives inherent in this principal agent relationship may differ across tenures, this is outside the scope of this research.

line of inquiry being lease extension (Leasehold Advisory Service Performance Statistics 2012/13 and Annual Report and Accounts 2012/13).

One component of the statutory valuation is the ratio of the value of the lease at its current unexpired term to the value of the property if it were held on a freehold. The legislation dictates that this ratio should be calculated assuming that the lease interest does not benefit from the right to extend or enfranchise, and to disregard any improvements the tenant has made to the property. This relationship is known as relativity. Outside of these assumptions, the legislation offers no guidance on what relativity looks like, how it should be calculated, and under what circumstances it should vary. As a result, relativity has been subject to intense debate since rights to enfranchise were introduced and a number of graphs of relativity have been complied and promoted by market practitioners. Valuers will pick and choose between these competing graphs when advising parties negotiating a lease, relying on decisions in tribunals and their judgment to choose appropriately. Some of the leading graphs currently in circulation for the Prime Central London (PCL) area are shown in Figure 2.

Several attempts have been made to standardise relativity. For example, as far back as 1999, the College of Estate Management (CEM) was commissioned to establish an evidence-based estimate of relativity. CEM analysed market data between 1997 and 1999 from the Valuation Office Agency, but was unable to find a discernible pattern in relativity. More recently, in *Arrowdell Ltd v Coniston Court (North)*, the Lands Tribunal expressed the hope the Royal Institution of Chartered Surveyors (RICS) may produce standard relativity graphs to be applied by all valuers, but the resulting RICS report merely collated existing relativities and concluded: "It has not been possible for the members of the Working Group to agree upon definitive graphs that could be used for this purpose."

One of the key difficulties has been to agree an appropriate evidential basis for generating a curve. Graphs typically rely on one of three types of evidence: open-market transactions of comparable properties, settlements of claims under the Acts, or past Tribunal decisions. Tribunals and practitioners have discussed extensively each type of evidence, finding drawbacks in each case. Graphs based on settlement evidence and past Tribunal decisions have been rejected widely.[11] Open market transactions have the potential to provide real world evidence about consumer valuations of lease term. However, graphs that use this kind of evidence rely on small and non-randomly selected data samples and

[11] A full discussion of the reasons for this are beyond the scope of this research - see Royal Institution of Chartered Surveyors (2009). Settlement evidence is thought to be defective because of the "Delaforce effect" - where one of the parties overpays to avoid the costs, delays, and uncertainties inherent in going to the Tribunal, and in any case may be self-perpetuating. Tribunal decisions reflect expert opinion, but, similar to settlements, decisions may be self-perpetuating.

enshrine *ad hoc* adjustments to individual property values in an attempt to ensure that properties are comparable (other than in the unexpired term of the lease). Moreover, decisions taken about the construction of sample, adjustments adopted, and line fitting methods to draw the graphs are not disclosed, and no information is provided to evaluate their statistical properties.[12] Beyond these issues, the vast majority of documented open-market transaction evidence is from after the 1993 Act, but the actual impact of the Act on prices is unclear, so this method necessitates an adjustment to strip out this effect for which there is little agreement or evidential basis.

3 Related Literature

3.1 Discount rates

Economic decisions involve trading off present and future costs and benefits. These trade-offs imply discount rates – the rate at which future costs and benefits are valued relative to those in the present – which can be either assumed from theoretical arguments or inferred from market prices or agents' decisions. How to conceptually and practically select an appropriate discount rate for policy making has been subject to longstanding deliberation.[13] In most circumstances costs and benefits accrue in close proximity, but in others such as pension financing, infrastructure investments, and environmental regulation, benefits may materialise only in the far-off future. The debates that followed in the wake of the Stern review (Stern et al., 2006) demonstrate that in such cases, the level and shape of the discount rate function can become of paramount concern in selecting the most appropriate policy response.

In this paper we aim to draw insights about discount rates that are revealed in housing markets. Our primary focus is the *shape* of the discount rate function, by which we mean the locus of points that traces out the relationship between the level of the discount rate and the time horizon under consideration. International discounting practices and the academic literature suggest the appropriate shape of the discount rate function for project evaluation is a live issue. Authorities in some countries including the UK, France, Norway and Denmark have recently adopted declining discount rate schedules. Her Majesty's Treasury (HMT) advises policy-makers in the UK to apply a discount rate of 3.5% to costs and benefits flows in the first 30 years of the project, 3% to flows in years 31

[12]In *Kosta vs The Trustees of the Phillimore Estates*, the Upper Tribunal wrote that '[the RICS graphs] have not been formally approved by RICS as providing definitive guidance on calculating relativity. Further the respondents have not called any evidence from any person with knowledge of the construction of any of these graphs who could explain for instance the nature of each input point on the graph and the spread between points [...]'.

[13]See for example Gollier (2012) for a flavour of some of the discussions

to 75, 2.5% to flows in years 76 to 125, with rates gradually falling to 1% for flows beyond 300 years (Treasury, 2003). In France, the schedule is 4% up to 30 years and 2% thereafter (Lebègue et al., 2005). At the same time, and despite encouragement from some commentators to follow suit (Cropper et al., 2014), other authorities including the Office of Budgetary Management (OBM) in the US guide policy-makers to use a constant discount rate across all time horizons.

The OBM schedule might be characterised as being in line with the conventional approach to discounting future cost and benefit flows. This method, widely known as exponential discounting, implies that a single rate is appropriate to discount all future flows regardless of how far into the future they take place, and that the present value of a future cost or benefit depreciates in a predictable way as the time horizon increases. While it has the benefit of operational simplicity and dynamically consistent preferences, researchers (e.g. Pearce et al. (2006)) have raised questions about whether these underpinning assumptions can be justified. This in part stems from theoretical research that demonstrates that discount rate schedules that decline over time can arise when incorporating uncertainty, either about the path of interest rates (Weitzman, 1998) or the state of the economy (Gollier, 2002), into decision making. This is supplemented by some empirical estimates of discount rate schedules usually derived from aggregate data — the yield on government bonds and the path of future interest rates, or by estimating the components of the Ramsey formula (see Cropper et al. (2014) for a review).

A large body of related empirical micro-research explores how individuals actually discount the future in practice. Much of the evidence is drawn from experimental studies that ask individuals to make choices over various alternatives distinguishable by the time pattern of their costs and benefits. These studies often — but not exclusively — find that individuals behaviour is consistent with a particular declining discount rate schedule known as hyperbolic discounting (Laibson, 1997). Hyperbolic discounting is associated with valuations that fall very rapidly over short time horizons, but then more slowly over longer periods. As such, it is often known as present bias.

3.2 Discount rates implied in housing markets

Housing markets arguably provide a good setting to estimate revealed discount rates given the importance of house purchases in overall household expenditure, the long-life nature of housing, and institutional features that provide variation in duration of widely traded housing assets. A recent literature attempts to exploit such features to estimate market discount rates over long horizons. Giglio et al. (2014) and Badarinza and Ramadorai (2014) are discussed in the introduction. Wong et al. (2008)'s findings are suggestive of a declining long-term discount rate in the Hong Kong leasehold market. In contrast, Gautier and Vuuren (2011) find no evidence of present bias in their study of ground leases in Amsterdam, and are unable to reject exponential discounting in favour of alternative discounting specifications.

This work typically approaches housing as an investment good and the pricing of leasehold contracts as an asset valuation problem. While a residential lease investment valuation could be approached in a number of ways, including option pricing (Grenadier, 2005) or partial interest (Asabere, 2004), the literature typically takes a net present value approach: a leasehold is valued as an annuity of maturity T and a freehold a perpetuity, with the underlying rental stream a function of property characteristics such as the size, condition, and location of the dwelling. In this set-up, the basic premise is that the relative discount for leasehold property of maturity t against a leasehold property of a different maturity s (or indeed a freehold property) can be interpreted as providing information about the discount rate between the maturities.

Despite an increasing number of empirical estimates, the conceptual interpretation of housing market discount rates and their applicability to policy making remains relatively unexplored]. Housing is an investment good but also produces a stream of housing services (Henderson and Ioannides, 1983) and houses purchased by owner occupiers may never deliver an investment return. As widely noted (see for example Arrow et al. (2013)) consumption and investment discount rates are likely to diverge in presence of market imperfections. In most markets owner-occupiers and investors will bid on the same property assets. As such, it may be inappropriate to rely on a purely investment interpretation of observed discount rates revealed in housing markets, especially in settings where owner-occupation dominates.

Besides this, characteristics of housing markets and tenure may confound a pure discounting interpretation of an association between price discounts and lease term. Assuming leaseholders have no rights over the leased asset value at the end of the lease, we propose three groups of factors may drive a wedge between otherwise identical properties' values: the *value of use rights*, *other term-varying factors*, and *term-invariant tenure factors*. The *value of use rights* is the present value of consumption and/or investment returns that flow from the asset. For an investment property, it is the present value of future rental streams, determined by (i) the cash value of rent (ii) the number of periods / length of use rights and (iii) the discount rate. With identical properties, the first factor drops out and it appears that by comparing sales prices and length of use rights provides direct information about the discount rate.

Solely concentrating on the value of use rights effectively disregards the possibility that *other term-varying factors* and *term-invariant tenure factors* may be present. The first group could include any factors which drive price differences between properties that are related to the term of the lease but do not arise simply because of discounting. The literature identifies at least two possible factors: the value of the redevelopment option (Capozza and Sick, 1991) and the effects of a rental externality (Henderson and Ioannides, 1983). The value of the option to redevelop the property is a function of the up-front costs of redevelopment and the increased rents that will result. Redevelopment option values can diverge even with identical properties: with a short lease and no claim over the residual value at the end of the lease, the value of the option to redevelop will be low relative to a long lease simply because there are few periods over which to recover capital costs. Moreover, by rolling time forward, following Henderson and Ioannides (1983)'s reasoning on the opportunity costs of renting and homeownership, we might find that the short lease property has been under-maintained relative to the long lease (i.e. the properties are no longer identical). This could manifest in short leases achieving lower prices in the market than simple discounting would imply.[14]

The latter group, *term-invariant tenure factors*, allows for any features that distinguish all freehold properties from all leasehold properties. This could include a range of observable characteristics, for example risks inherent in all lease contracts, or unobservable factors such as buyer preferences to hold freeholds. We also can not rule out that redevelopment option value and rental externalities also vary discontinuously between freehold and leasehold properties. For example, leaseholders often need permission to redevelop properties and may need to make a payment to do so. Moreover, Iwata and Yamaga (2009)'s empirical results for Japan suggest that leaseholders do under-maintain their dwellings relative to freeholders with expenditure on maintenance being 30% less in all leasehold properties and 20% less for long leaseholders. Our priors are that, all else equal, freeholds are generally more attractive to buyers than leaseholds so if this is coded as a freehold indicator, it will be non-strictly positive (the freehold trades at a premium to leases after controlling for length of use rights) although in our later empirical work we do not impose this to hold.[15]

[14]When considering *other term-varying factors*, Iwata and Yamaga (2009) and others suggest that a key consideration is the nature of leaseholders rights to claims over the residual asset at the end of the lease term. If a leaseholder can claim the full value of upgrades and maintenance work at the end of the lease then he is likely to act as a freehold owner would. With no residual rights, a leaseholder is less inclined to upgrade or maintain a leased property because higher rents that will accrue after the lease has expired will be lost. Intuitively, the length of the lease relative to the life of the upgrade should be important - for example a new boiler expected to last 25 years might be attractive to a leaseholder with 30 years unexpired term but less so to one with 10 years remaining. In related work, Dale-Johnson (2001) explore how contract incentives in leases, including those relating to residual claims over leased assets, may affect development incentives. Our aim is to empirically measure leasehold prices rather than consider development incentives, so these issues are not central to our paper.

[15]We also acknowledge the possibility that sorting and selection issues may play a role in driving an association between tenure or lease length and observed sales price. These issues could potentially cut across these groups of factors. Most obviously, the tenure of a property, i.e. whether the property is a freehold or a leasehold, may be correlated with observed or unobserved characteristics of properties.

This discussion serves to highlight potential difficulties in interpreting leasehold discounts as discount rates. There are at least *a priori* grounds to to think that leaseholds and freehold values may be systematically different. These can be avoided by only comparing leaseholds with other leaseholds, but even then we can not necessarily distinguish discounting from *other term-varying factors*. Barring an experimental research design, one approach is to attempt to control for these factors using observables characteristics. Controlling for the condition of the property, for example whether it has been recently redeveloped or refurbished, may mitigate concerns to some extent. In addition, houses are more likely to have redevelopment potential than flats, which in general can not be easily redeveloped so focusing only on flats may also be beneficial. We return to these issues in the final sections of the paper.[16]

4 Data

4.1 Context

In Prime Central London, the highly urbanised core of central London that covers Mayfair, Chelsea and Kensington, more than 85% of transactions are leasehold. We use a definition of Prime Central London provided by real estate agents operating in the London market. Our sample only includes properties that belong to the following postcode districts: SW1, SW3, SW5, SW7, SW10, W1, W2, W8, W11, W14.[17] A large proportion of the Prime Central London market has for 300 years been owned by a small number of private estates – including the Grosvenor, Cadogan, de Walden, Portman, Crown, Ilchester, and Phillimore Estates. These estates historically made extensive use of the leasehold tenure system to develop land in this area, maintaining some degree of control over development.

This could result if say, developers decided to keep the very best properties as freehold or vice-versa. Focusing only on leasehold properties, it is also possible that individuals with different time preferences may be attracted to bid on leasehold properties of different lengths.

[16]At first glance, the leasehold reforms in England and Wales described in the previous section would also seem to offer an alternative to mitigate these concerns since in principle they gave leaseholders a greater share in the residual value of the property. However, we are sceptical that the reforms granting rights to leaseholders offers a neat solution in this context because it is unclear whether these trades take place at market prices, not least because of the bi-lateral nature of negotiations, the complexity of the statutory valuation procedure, and the uncertainty surrounding the correct parameters to use in these valuations. In any case we strongly prefer attempts to estimate discount rates using data before the Act as this rules out the possibility that the value of the option to extend or purchase the lease may be driving differences in prices for leases of different lengths.

[17]Postcode districts correspond to the first half of British postcodes and, in London, they typically include 10,000–20,000 separate addresses.

4.2 Data source and sample construction

To undertake the empirical analysis we first create a dataset of transactions in the Prime Central London area for the period 1987 to 1992.[18] Our primary source of data is Lonres.com, a subscription service for real estate agents and surveyors working in the Prime Central London (PCL) area. Sale information in the Lonres sample have been provided by individual agents connected to the Lonres network.[19] In addition to the Lonres.com historical archives, we obtained access to the internal records of John D Wood & Co. (JDW), a real estate agency operating in the Prime Central London area. Sale prices in the JDW sample, which also starts in 1987, have been verified by agents.[20].

Before the two data sources are merged, suspected duplicate sales, when the address is the same and the second sales occurs after 90 days or less from the first sale, are dropped. Data points where street is missing or leasehold information is missing are dropped too.[21] In addition, for Lonres only, we merge in additional attributes extracted from the original sales brochures. To merge the two data sources we simply append the two data sources together. In order to avoid overlaps, we exclude Lonres data points coming from JDW offices, as these are likely to represent duplicates of data points already in the JDW records.

Once the two data sources are merged, we perform further data-cleaning operations. Because we use a street-fixed effect strategy, all transactions on streets with just one property in the dataset are dropped. We also drop enfranchisable houses from the sample. Following the 1967 Act, some low-value leasehold houses became enfranchisable, i.e. the leaseholder had the right to purchase the freehold of the property in exchange for a premium. Whether a house was enfranchisable or not depended on its rateable value, which we cannot observe directly in the data. We obtained from the relevant local authorities information that allows us to identify a list of houses which were enfranchisable at the time and were able to exclude them from the sample.[22]

One major consideration for the analysis is the selection of a time frame. The Leasehold Reform Act of 1993 introduced the right to extend leases. This represented a major

[18]Individual sale data before 1987 are extremely sparse and therefore of little use for econometric analysis.

[19]Historical data that predate the foundation of Lonres.com have been manually collected from the archives of real estate agencies. The sale ads have been scanned and put into the system, and the main variables (such as sale price and sale date) have been inputed into a table.

[20]These prices are likely to be correctly measured because agencies' commissions depend on them.

[21]We rename streets in the JDW data to match the format in Lonres. We modify or rename variables to make them consistent in both datasets before the merge. For instance, ground rent is a variable in Lonres.com but has to be extracted from textual descriptions of the property in the JDW data. Streets can sometimes be written differently, for example "Saint James's Gardens" is at times denoted as "St James Gardens".

[22]Rather than dropping enfranchisable houses, as a robustness check we also run the analysis including them but assigning a dummy. This had no material effect on results.

evolution of the leasehold system, which has had huge effects on the markets. In order to ensure that we estimate a pure leasehold term effect, and not any effects resulting from the option to enfranchise, we exclusively focus the analysis prior to this reform. We also exclude 1992 sales, because 1992 was election year in the United Kingdom and both main parties were proposing a reform of the leasehold system. Therefore, there is a slight chance the price of leasehold properties may have been influenced by the expectation of a reform.[23]

4.3 Descriptive statistics

As reported in the last column of Table 2, the final dataset has 8,184 records of unique sales. Of these, more than half are leaseholds with less than 100 years unexpired term. There are two groups of observations: Lonres and JDW records. For each group, we report the number of data points (houses and flats). Figure 3 shows the distribution of lease lengths in the sample: there are many data points for leases with 55–65 years left, for 85–100 years left, and between 120 and 125 years; there is a group of sales with leases between 950 and 999 years. The third column of Table 2 includes the main reference category of our analysis, namely freehold houses and share of freehold flats. Although share of freehold flats have a lease term,[24] it is critical to put them together with freehold properties. Their sale price includes a share of the freehold value of the building and, with it, the right to extend one's lease indefinitely.

All sale prices reported in the John D Wood & Co. archive are verified exchange prices. By contrast, only around 15% of Lonres data points have been verified against other data sources. Non-verified properties are equally found, in roughly the same proportion, both among freehold and leasehold properties,[25] and our hedonic regression contains a variable that flags non-verified properties.[26]

[23]As a robustness check, we also ran the analysis including 1992 sales and this did not change the results in a relevant way.

[24]These terms tend to be long. In our dataset, more than a third of share of freehold flats have a lease term longer than 945 years.

[25]Since we are estimating a ratio between freehold and leasehold prices, everything that equally affects both prices does not affect the estimation of this ratio. In other words, if leasehold properties are equally likely to have a non-verified price than freehold properties, the analysis should be unaffected. In Lonres records, the percentage of non-verified prices among leasehold properties with terms lower than 100 years is 88.09%. The percentage of non-verified prices among freehold properties and leasehold properties with a term of 100 years or more is 84.29%. The average discount between asking and final price (for properties with verified prices) is 4.85% for leasehold properties with terms shorter than 100 years and 4.01% for freehold properties and leasehold properties with terms of 100 years or longer. We also checked that, in the Lonres database, the percentage of non-verified properties stays roughly the same across leasehold of different lengths.

[26]Among verified sales in Lonres.com, the average difference between the asking price and the verified price is 4.48%. By including a variable that identifies non-verified sales, the statistical model is able to discount the price of those properties before including them in the computation of relativity. In any case,

Figure 4 shows the location of sales in the dataset and Figure 5 shows how observations in the dataset are spread across the different quarters between 1987 and 1991.

The attributes used in the statistical analysis can be grouped into primary, additional, and extracted attributes. *Primary attributes* are immediately available from the original data tables and include: HOUSE (whether the property is a house, as opposed to a flat), BEDROOMS (entered as a categorical variable; absent a floor area measure, this variable is a proxy for the size of the unit), SALE QUARTER, STREET (entered as fixed effect).

Additional attributes are also available from the original data tables: FLOOR LEVEL (this variable is coded similarly for the JDW and the Lonres datasets. The John D Wood & Co. dataset groups together all floors from the third upwards. The Lonres dataset always specifies the exact floor but I grouped all floors above the fourth together.), VERIFIED (for sales in the Lonres dataset, this variable indicates whether the sale price has been verified), MAISONETTE (indicates multi-level apartments), ONEROUS GROUND RENT (we define the ground rent as onerous when it is above 0.1% of the sale price)[27], and FREEHOLD FLAT.

Extracted attributes are not immediately available from the data tables but have to be extracted from unstructured text: DETACHED HOUSE, MEWS HOUSE, TWOORMORE BATHROOMS, GARDEN, COMMUNAL GARDEN, BALCONY, TERRACE, PATIO, RECENTLY REFURBISHED, IN NEED OF REFURBISHMENT, and PURPOSE-BUILT FLAT.

Using price per square foot instead of the sale price, as the dependent variable, reduces the total number of observations (John D Wood & Co. + Lonres) by more than a half. Hence, the analysis of price per square foot is just one of the several models that we estimate and we take its results as a robustness check rather than the main outcome of our analysis. By examining the dataset, we found no clear pattern regarding the presence of this information, i.e. expensive and less expensive properties, or big or small properties, are equally likely to have square footage recorded.

Table 2 contains the descriptive statistics of the dataset variables. The first column reports the count of data points for which the relevant variable is non-missing. *Primary attributes*, such as TYPE (whether the property is a house or a flat) or BEDROOMS, are never missing (i.e. count is 8,184). *Additional attributes*, such as VERIFIED, are also never missing. However, floor level information is not available for six properties, so the count is 8,178. *Extracted attributes* are available only for a subset of properties—in total, 7,476 data points. Finally, the third row shows that floor area (SQFT) is only available for

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we also ran our analysis only on verified properties and got similar estimates from the ones presented in this paper, albeit with a much smaller number of observations.

[27]This threshold (0.1% of the sale value) is commonly used by market practitioners to identify ground rents that are high enough to impact the transaction price. We experimented with other thresholds and did not find notable differences in results.

2,157 sales.

5 Empirical analysis

5.1 Methodology

We model the logarithm of the price of a leasehold property, held for t years, as follows:

$$p(t) = p(\infty) + \ln f(t), \tag{1}$$

where $p(\infty)$ is the price of a leasehold property held forever. The function $f(t)$ represents the discount associated with a given lease length as opposed to a property held forever. Our expectation is that $f(t)$ should satisfy $f(0) = 0$, $f'(t) > 0$, and $\lim_{x\to\infty} f(t) = 1$ indicating that a zero year lease has no market value, that all else equal more years on a lease makes the property more attractive, but that at some point very long but finite leases are equivalent to an infinite lease, reflecting the nature of discounting over very far-flung time horizons.

An earlier section noted the possibility of systematic differences in the pricing of freehold and leasehold properties. To recognise this, when we include both leasehold and freehold properties in the estimation we change equation (1) to:

$$p(t) = p(\infty) + \phi \text{ FH} + \ln f(t), \tag{2}$$

where FH is a dummy indicating freehold status and ϕ represents the price difference between leaseholds and freeholds that do not depend on the length of the lease. The rationale for this set-up is that we anticipate a 999-year lease may sell at a discount with respect to a freehold because of the obligations imposed on the leaseholder — for example payment of ground rents and service charges or limitations in the type of renovations and works that can be carried out on the property — although we are not prescriptive about the source of any difference and this indicator variable could also capture non-random selection of properties into freehold and leasehold tenure, buyer preferences, or other unobserved factors that drive systematic value differences between the property groups. When the property is a freehold $f(t) = 1$ and $\ln f(t) = 0$, as with very long leaseholds.

To estimate $\ln f(t)$ nonparametrically, we employ three methods: (1) leasehold buckets, (2) leasehold dummies, and (3) a semiparametric approach based on Yatchew (1997). The bucket method consists of dividing leasehold properties into several large groups according to their lease length and then estimating price effects associated with each bucket. The dummy method is identical but pushes the approach further so that each integer value of lease length up to 999 years (the highest in our data) takes a categorical variable:[28]

$$\ln f(t) = \sum_{t=1}^{999} \gamma_t \cdot d(t).$$

Our third estimation method is taken from Yatchew (1997). By sorting all the observations in ascending order with respect to t and differencing them, we take advantage of the fact that $\ln f(t') - \ln f(t)$ tends towards zero.[29] We can then use simple OLS to estimate a version of equation 1 that does not contain $f(t)$. In a second stage, we can apply common non-parametric estimation techniques to retrieve $f(t)$ from $\exp \hat{p}(t) = f(t)$, where $\hat{p}(t)$ is the property price predicted in the first stage.

To model the price of a property held forever we follow the literature on hedonic regressions (see Hill, 2012) and write:

$$p(\infty) = \alpha_j + X\beta + \lambda_s,$$

where α_j are street fixed effects, X are property attributes, and λ_s are quarterly dummies denoting the time of the sale (s).[30] The street fixed effects allow us to partial out location effects at a very granular level and may also help us partial out some unobserved housing attributes, for example where properties on the same street tend to share the same style and layout. We discuss general concerns about omitted variables in section 7. The appendix presents additional specifications for the models.

5.2 Results

Table 3 and Table 4 show the output of the hedonic regressions. Table 3 presents two specifications using the bucket approach. The first specification includes both freehold and leasehold properties whereas the second only includes leasehold properties. Table 4 presents two further specifications that focus only on leasehold properties and that improve on the bucket approach by using more granular information about lease term.

[28] To retrieve the true price discounts in each category the γ coefficients must be exponentiated. Jensen's inequality could cause the estimated discount to be larger than the actual discount, because an average of logarithms is not the same as the logarithm of an average. In practice, the consequences of Jensen's inequality are likely to be limited. We confirmed this by running our baseline regression on simulated data. The impact of Jensen's inequality on estimates was apparent only at the third or fourth decimal point.

[29] In practice, Yatchew (1997) suggests several degrees of differentiation, each of which is associated with optimal weights. In the estimation we use those weights.

[30] Repeat sales regressions are an alternative to hedonic models but they require a sample with a sufficient number of properties which have been sold twice. Since the current sample includes only the years from 1987 to 1991, the repeat sales regression would only include properties that sold twice within 5 years. The resulting sample would be small and potentially affected by selection bias, as property that sold often could be more likely of having been renovated.

The third specification (model 1 in Table 4) uses the dummy approach whereby a dummy is assigned to each lease length rounded to the nearest integer. The fourth specification (model 2 in the same Table) represents the first stage of the semiparametric approach.

Before turning to the leasehold discounts, we first examine other coefficients across the four models to demonstrate that the price associations for our controls are generally consistent across specifications and in line with general intuition. Coefficients represent the approximate percentage price increase or decrease associated with a 1-unit change in the relevant attribute. For instance, the first row in Table 3 shows that houses command a price that is roughly 20-25% higher than flats after controlling for the effect of all other attributes such as number of bedrooms and street. In both Tables we find that studios have a 30-40% discount with respect to one-bedroom properties, two-bedroom properties sell at a 35-45% premium with respect to one-bedroom properties (the baseline category); and flats on the lower ground floor have a 12-13% discount with respect to flats on the first floor (the baseline category). The coefficients on SaleQuarter are not reported in Table 3 and 4 for space reasons. When put together, these represent a mix-adjusted index of house prices in the Prime Central London area. We find our implied index is increasing in 1987–1989 and decreasing thereafter, a patten consistent with other historical indices such as the Nationwide regional house price index for London (see Figure A2 in the Appendix). The R-squared reported in the Tables show that these models are able to explain approximately 70-85% of the variation in house prices.

We now turn to the coefficients on the tenure variables. The first model in Table 3 is designed to test whether freehold properties trade at a premium to leasehold properties. Leaseholds have been divided into four buckets: those with leases below 80 years, between 80 and 99 years, between 100 and 124 years, between 125 and 900 years, and above 900 years. Choices over the boundaries for each group are inevitably arbitrary to some extent. Grouping leaseholds with less than 80 years together follows UK legislation which requires a different computation for the premium to be paid to enfranchise a lease when the lease reaches 80 years, presumably because the value of the lease is expected to decline rapidly after that. All the leasehold categories are significantly different from the baseline freehold group. Although the significance is only 10% for the two groups above 124 years, the size of the coefficients is consistent and, if put together, this whole group would be significantly different from the freehold baseline, a finding confirmed in unreported results. We interpret this specification as providing evidence of material pricing differences between freehold and leasehold properties which go beyond length of use rights (remaining leasehold years). In further specifications we concentrate solely on leasehold properties.

The second model of this Table, which excludes freehold properties, is designed to test whether we can identify price differences for long leasehold properties of different lease lengths. The baseline in this specification is composed of properties with leases longer than 900 years such that coefficients on the other buckets provide information about whether we can distinguish significant price differences between these very long leases and other leasehold groups. The coefficients for other leasehold categories are not significant except for the coefficient on leaseholds with less than 80 years, which is significant at the 10% level. These results suggest that in our setting long leaseholds of different lengths can not be statistically distinguished from other long leaseholds of a different length. We note that the results in Table 4 differ from those of Giglio et al. (2014) who find large and significant differences in discounts between long lease groups (above 80 years) of different maturities. Although we are unable to establish definitive explanations for these differences, it could be that these authors use data that come from a later period and which cover a much wider and heterogeneous geographical area; or, the differences could be due to other reasons.[31]

In subsequent models we sidestep decisions about how to group leaseholds together by using less parametric approaches that utilise the more precise information we have about lease term remaining. The first model in Table 4 shows the coefficients of the dummy model run on leasehold properties only. From this point on, we also drop houses from this analysis to focus purely on flats. Because it will usually be impossible to redevelop flats to a higher density, this strategy gives us greater confidence that the implied relationship between price and lease length is less likely to be driven by variation in the value of the option to redevelop than would be the case if we included houses in the analysis. Our main object of interest, the dummy coefficients, are not tabulated but are displayed—exponentiated—in the upper panel of Figure 6. These estimates indicate the discount associated with all leasehold flats of a specific lease length with respect to leasehold flats with 999 years remaining. The point estimates are shown as dots with the 95% confidence interval shown by the bars. The size of the errors associated with each leasehold group varies consistently with the histogram of Figure 3, with the smallest errors corresponding to leases groups that are computed from more observations. The second column of Table

[31]It should be noted that with leases over 80 years the premium for extending the lease or buying the freehold is often small, but the costs can be far greater. For instance a lease extension of an additional 90 years onto an existing lease of 90 years may cost circa £2,675 (£200,000 unimproved value with a fixed ground rent of £10 per annum). Inside London these professional fees may amount to £8,000 to £10,000 and even outside of London they may be around £5,000. Going to tribunal to determine the price is a lengthy process and one in which both sides must pay their respective costs, which may be substantial (even in case of victory). Whilst in theory the leaseholder has no obligation to extend the lease and therefore these costs should not depress the price of long-term leases, it should be noted some mortgage lenders require properties to be held on very long leases or share of freehold and therefore leaseholders will be forced to exercise this option (this option can be assigned to an incoming purchaser who will adjust their offer accordingly). Consequently, many in the market believe the costs of extending the lease may deter and actually depress relativity of long leases.

4 shows the coefficients from the first stage of the semi-parametric method and the lower part of Figure 6 plots the quality adjusted prices after the first stage ($\hat{p}(t)$ discussed in the previous subsection) against the unexpired term of the lease. Notwithstanding the fact that dummies and sale prices are slightly scattered around, the pattern of discounts is clearly similar across the two models. At face value the pattern of points seem to be broadly consistent with the pricing of assets that depreciate at a uniform rate, although from around 100 years it is more difficult to discern a clear shape. In the next section we demonstrate how these price discounts could be used to infer discount rates, and in the final section we discuss whether the assumptions needed to make such interpretation valid can be expected to hold and conclude.

6 Discounts and discount rates

As we outlined in an earlier section, observed price differences between otherwise identical leasehold properties could arise from differences in the *value of use rights* or from a range of *other term-varying factors*. In this section we disregard this latter group and proceed as if price differences related to the length of leases depend only on the former group, adopting Gordon (1959)'s simple constant discount rate model to illustrate how our estimated discounts could reveal information about discount rates. If the price of owning the property for one period is $P(1)$, then the price of owning the property forever is:

$$P(\infty) = \frac{P(1)}{R_\infty},$$

where R_∞ is the *net* discount rate applied with an infinite horizon. In turn, $R_\infty = r_\infty - g_\infty$, where r_∞ represents the *gross* discount rate and g_∞ the growth rate of $P(1)$ over time. For a property held for t years, we have that

$$P(t) = P(\infty)\ (\underbrace{1 - e^{R_t t}}_{f(t)}). \tag{3}$$

An important policy issue in the context of policy appraisal is whether the assumption that R_t is constant, i.e. $R_{t_1} = R_{t_2} = R$ holds, or whether it varies over the time horizon in question.

To demonstrate how residential leaseholds cold be used to shed light on this question, we return to Figure 6 that plots the exponentiated γ_t coefficients. These represent the price of leasehold property with an unexpired term of t years as a percentage of the price of a leasehold property with 999 years left and together define the shape of $f(t)$ in equation (3) above. In theory, $f(t)$ should always be smaller than 1 (i.e. $e^{-R_t t}$ is positive), and common sense dictates $\gamma_{t+1} \geq \gamma_t$ because a lease of longer unexpired term must cost at least as much as a lease on the same property with a shorter term (i.e. the derivative $f'(t) \geq 0$) but in practice, since we estimate the γ_t's in an unconstrained, nonparametric way, these conditions do not always hold. This can be seen in the upper half of Figure 6, where the points are scattered around and some estimates lie above the long lease line.

Before attempting to make inferences about discount rates we therefore begin by fitting a local polynomial through the estimated points, fine tuning the bandwidth of the polynomial within reasonable limits to make sure that conditions such as $f'(t) \geq 0$ and $\lim_{t\to\infty} f(t) = 1$ are satisfied.[32] Although the curves are fitted across the whole lease range, we focus on results for leases in the 1–100 years interval given our findings in the previous section. The results of this procedure are shown in Figure 7. The curve on the left-hand side of the figure is fitted through the points estimated by the model with dummies, weighting points by the number of sales at that specific lease length. The curve on the right-hand side is fitted through the quality adjusted sale prices obtained in the first stage of the semiparametric regression. Both curves are second-degree local polynomials with a bandwidth of 15 years on both sides and an Epanechnikov weighting scheme and in both cases confidence bands are represented by the grey areas around the curves.

We denote the polynomials drawn through the points the *time value of housing*. Eyeballing the Figure, it is evident that the curves behave in similar ways: they are increasing and remain below the line representing the value of 999-year leases (the horizontal line at 100). The shape of the curves provides our first major finding - that the pattern of discounts across lease term i.e. the *time value of housing* broadly resembles an exponential curve. In other words the pricing of leaseholds in our sample closely mirror predictions from basic finance theory about the pricing of deteriorating assets. We find this a striking result which we believe demonstrates sophisticated pricing behaviour on the part of participants in the Central London market and provides strong support for rational and consistent pricing of assets in the London residential market. Using Galton (1907)'s terminology, the "wisdom of the crowd" in the London residential market appears to be strong.

While this procedure provides our main broad-brush finding, this does not use all the information in our results since we effectively estimate a single discount rate using

[32] The choice of the baseline in the estimation of $f(t)$ could have an impact on coefficients. If, for some reason, 999-year leases (our baseline leasehold category) were randomly more expensive or cheaper than other properties, this would affect the estimated discounts.

As a robustness check, we also ran the analysis by using the average price of all leases between 100 and 999 years as the reference price of long leases ($p(\infty)$). Results were substantially unchanged. In any case, the main goal of this paper is the shape of the discounts, not their actual level. Therefore the choice of the baseline in this context is not critical to results.

all the dummies and in a sense overidentify the discount rate. In fact we are able to dig deeper into the shape of the discount rate function, using the predicted values of the polynomial curves to compute the discount rates at each point in the term range by solving for each R_t that corresponds to a pair $\{R_t, t\}$ in equation 3. The result is shown in Figure 8.[33] The left-hand side part of Figure 8 also contains the discounts derived from the original dummy estimates. Overall, and assuming that discounts are driven only by the term structure of discount rates, our results appear to be largely consistent with a declining discount rate schedule. Very short leases imply discount rates of around 5-6%, whereas long leases, close to 100 years left, imply discount rates between 3 and 4%. Two additional features are worth noting. The first is that both curves show a flattening or even a slight hump around 60+ years. Figure 7 shows that this is the year range where ratio between short and long leases flattens a bit and the curve asymptotically converges to 100. The second is that rates decline over the first 20 or so years of the lease term, in a pattern consistent with present bias. We discuss whether discount rates may be driving these patterns in the next section.

Before doing so, and although the main focus of this paper is the shape of discount rates rather than their precise level, we also note that we can use the net discount rates estimated above to derive an estimate of time preferences, i.e. the gross discount rates prevailing at the time of our analysis (1987-1992). The standard way of doing so is to use long-run real rent growth, as in Giglio et al. (2014). For the 1996-2012 sample, they find a real rent growth of 0.7% using the CPI component actual rents for housing (series D7CE) from the UK Office of National Statistics. This would imply a 0.7% upward shift of the dots in Figure 8. If one were to use real capital value growth instead of rental growth, gross discount rates would be between 6% and 9%.[34]

7 Discussion and conclusion

This paper presents estimates that describe the association between lease length and sales prices of flats in the London market, using historic data to abstract from the value of the option to extend the lease. Our dual objectives were to estimate the effect of lease length on property prices and to explore the extent to which the resulting estimates might be used to make inferences about discount rates. In this final section we discuss the empirical challenges we face, highlight how our results may be relevant to market participants, and

[33] This effectively solves for the constant discount rate that is applied to all years of a leasehold of a given term to make the discount consistent with a long lease. We are currently working on ways to evaluate the marginal discount rate associated with an additional lease year.

[34] According to Nationwide (`http://www.nationwide.co.uk/about/house-price-index/download-data`), real house price growth since 1978 in the UK has been 2.7%.

conclude. Absent an experimental research design, the major empirical challenge we face is the possibility that unobserved factors (e.g. property attributes) which are correlated with tenure and lease length drive price differences between properties and so bias our results.

We denote the aggregate effect of lease length on the sales price of a property as *the time value of housing*. This broad designation permits us to capture all price relevant variation that inherently depend on the length of the lease, which could include both the *value of use rights* and *other term-varying factors*. Outside of these factors, we do however aim to control for features of properties that are correlated with the length of the lease but do not inherently depend on it, say for example that short leases happen to be found in a particular geographical area, have particular property characteristics, or were sold at a particular time. A number of strategies are designed to neutralise these: we include an extensive list of variables in the hedonic regression, the street fixed effects are powerful in capturing time-invariant differences at the small-area scale, and quarterly dummies pick up any common time trends. Nevertheless, there may still might be unobserved heterogeneity *within* leasehold properties that is correlated with unexpired term. Naturally, one might expect the condition of a property to deteriorate as lease term declines which may result in a mechanical correlation between lease length and age of the property. Newly built properties, which we cannot observe in our data, may command a price premium relative to other properties. Where newly built properties are sold as leasehold, they will often be leased on 99 or 125 year leases, although not all 99 or 125-year leases are new built. Since we do not directly observe lease extensions nor the age of the property, we rely on proxies for the condition of the property, such as the variables InNeed and Refurbished.

Empirical work reported in the Appendix reports a number of additional specifications intended to demonstrate that our main results are robust to specification and sample changes. These include a model where we interact the street and quarter dummies to allow for street-quarter intercepts, which amounts to comparing only properties within the same street and sold in the same quarter. In practice, this reduces the effective sample size by a third but results remain broadly consistent as shown in Figure 6. Such an empirical strategy should also address concerns of spatial autocorrelation. In any case, an additional analysis of residuals confirms that spatial autocorrelation is not an issue in our data. In another model, we restrict the sample only to properties for which we know floor area. Again, this restriction does not materially affect our findings, even though the sample size is only around 2,000. Another, more general, consideration which speaks in favour of the internal validity of our estimates is provided by replicating our analysis only on subsets of our original dataset. We provide two such auxiliary analyses, firstly splitting the sample into the submarkets of Kensington vs Chelsea, and then separating out the boom period (1987-1988) vs the bust period (1990-1991) in our sample. The figures shown in the Appendix demonstrate that the same relationship between price and lease length broadly holds.

Although our main goal is to use these estimates to make inferences about discount rates, we first note that our findings about the time value of housing may be relevant to leaseholders in England and Wales who are considering purchasing a lease extension, and more indirectly to anyone considering buying or selling a leasehold property. This is because under the institutional framework for lease extension and enfranchisement in England and Wales, the relationship between lease length and property value, assuming no rights to extend a lease, is an important factor in determining the price required to purchase a lease extension or to enfranchise a leasehold property. Despite repeated calls to establish consensus on this issue, the shape of this relationship — referred to as relativity — remains fiercely contested by market practitioners and plays a major role in disputes between leaseholders and freeholders over lease extensions and enfranchisements. While a full-scale discussion of whether the methods we present above are appropriate for estimating relativity is outside the scope of this research, we do note that our findings — in common with several relativity curves currently used by market practitioners — are derived from pre-1993 data and so exclude any effect of the 1993 Act on property prices, making it credible that they bring valid evidence to this debate.[35]

We highlight two findings which are conspicuously different to the conventional wisdom prevailing in this arena. Firstly, Tribunals assume a price difference of 2% between a long leasehold and a freehold whereas our results imply much greater differences.[36] Second, the shape of the curves we fit diverge substantially from the curves in common use by practitioners. To visually illustrate these differences, we run a new specification designed to mirror the approach underlying most relativity curves, including houses as well as flats and freeholds as well as leaseholds. We then fit a curve to leasehold dummies

[35]Some commentators argue that it is impossible to use post-1993 sales to estimate relativity, for two reasons. First, most obviously, post-1993 sale prices are affected by the Act: buyers know they have the right to extend or enfranchise. Second, current prices are also affected by the existing relativity curves. Post-Act data is "tainted" and any attempt to adjust for the benefit of the Act will be subjective. It is impossible to estimate the benefit of the Act in current times because of a lack of counterfactual, i.e. non-enfranchiseable sales

The page in the RICS report dedicated to the Gerald Eve's curve says "[the graph based on pre-1996 data] has not been amended, because it is believed that the evidence that was available then is stronger than that which has emerged since 1996".

As specified in the Data section, we also exclude 1992 data to avoid any risk of *anticipation effects* on property prices. However, as a check, we run an additional analysis including 1992. Results are not substantially affected.

[36]The Upper Tribunal in *Erkman v Cadogan 2011* (paragraph 98) wrote: 'In our opinion the following range of relativities is appropriate: leases with unexpired terms of 100 to 114 years – 98%; 115 to 129 years – 98.5% and above 130 years – 99%'.

as in earlier results, plotting in Figure 9 the results alongside another 'relativity curve', derived from a set of 601 Tribunal decisions in the London region, compiled by real estate agency John D Wood & Co.[37] The differences evident between the curves lead us to suggest that lease extensions could result in transfers between leaseholders and freeholders that are out of kilter with market values (Badarinza and Ramadorai, 2014).

We finally turn to whether our estimates provide evidence about discount rates. In the previous section, we demonstrate that our estimates of the time value of housing can be used to compute discount rates using the simple Gordon discount rate model. First smoothing the data to eliminate noise, our first major finding is that as a first approximation, the pricing of leaseholds over the lease term range in our data broadly resembles an exponential curve. In other words, the pricing of leaseholds largely mirrors predictions from basic finance theory about the pricing of deteriorating assets. We suggest that this a striking result which we believe demonstrates sophisticated pricing behaviour on the part of participants in the Central London market.

An important issue in the context of policy appraisal is whether policy-makers should adopt discount rates that decline over the time horizon in question. To explore this, we next take the predicted value of the polynomial we fit through our estimates to compute the implied discount rate at each point of the lease term range in our data. Results are suggestive of a declining discount rate, both over the term of the lease as a whole and also present bias where rates are high for short term flows. At face value, these findings support the use of a declining discount rate function, as have been recently adopted in the UK and in France. However, a pure discount rate interpretation of our estimates relies on the assumption that the price–lease length relationship is purely driven by variation in the *value of use rights* rather than *other term-varying factors*. As regards this latter group, the literature points to the value of the redevelopment option and the effect of maintenance incentives as potential factors that may be related to the term of a lease but are separate from the value of use rights. We attempt to condition out these factors in two ways: controlling for observable measures of the condition of the property (InNeed and Refurbished) and by restricting analysis to flats only which are more difficult to redevelop than houses.

In conclusion, while our results are consistent with a declining discount rate schedule, we are unable to rule out that this shape arises due to other channels which we are unable to control for. Two features seem worthwhile of comment. Firstly, it seems plausible that value of the redevelopment option and the effect of maintenance incentives may bite most heavily for very short leases and a failure to adequately control for these factors

[37] The analysis was run by James Wyatt and the aggregate data is available at `http://www.johndwood.co.uk/r/surveyors/pdfs/publications/The_Pure_Tribunal_Graph.pdf`.

may explain why shorter leases are apparently discounted at a higher rate than longer leases.[38] Secondly, we find that at around 60 years, discount rates appear to flatten or even slightly increase. With the data at our disposal, it is difficult to point to a precise reason for this pattern; it might be due to financing restrictions on short leases (albeit, anecdotally, a high proportion of buyers in this area were not dependent on mortgage financing) or the fact that some freeholders were granting new leases of 60-65 years. We hope that future research will shed further light on these issues.

[38]It should be noted, however, that leaseholders have an obligation to maintain a property in good state. Failure to do so might trigger a dilapidation claim from the freeholder.

Table 1: Data points

Notes: Lonres.com is our main data source. Real estate agency John D Wood & Co. provided additional data for this paper. The table shows the number of sales in our dataset which belong to the following categories: leaseholds with unexpired term below 100 years, leaseholds with unexpired term above 100 years, and freeholds (including flats sold with a share of freehold). The average unexpired term for leasehold flats with more than 100 years to expiry is 307, whereas the median unexpired term is 124.

	Number of leaseholds < 100 years	Number of leaseholds ≥100 years	Number of freeholds or share of F/H	*Total data points in sample*
Lonres.com records				
Houses	525	9	1,109	1,643
Flats	3,353	906	236	4,495
John D Wood & Co. records				
Houses	116	2	888	1,006
Flats	605	428	7	1,040
Total	4,599	1,345	2,240	8,184

Table 2: Descriptive statistics

Notes: The table does not contain information on sale dates (described in Figure 5), sale locations (mapped in Figure 4), and lease length (see Figure 3). Price and floor area are the only continuous variables in the analysis; all other property attributes are dummy variables. Primary attributes, immediately available from the data sources, are nonmissing for all observations. Six flats are missing floor level information. Extracted variables are missing for a small part of the sample. Floor area is only available for approximately 2,000 data points (We haven't found any systematic correlation between the presence of the floor area variable and other attributes such as location or number of bedrooms).

	count	mean	sd	min	max
Price	8,184	403,140	412,064	25,000	9,000,000
Lease	8,184	.73	.45	0	1
House	8,184	.32	.47	0	1
Studio	8,184	.031	.17	0	1
1-Bedroom	8,184	.15	.36	0	1
2-Bedroom	8,184	.3	.46	0	1
3-Bedroom	8,184	.23	.42	0	1
4-Bedroom	8,184	.14	.34	0	1
5-Bedroom	8,184	.085	.28	0	1
6-Bedroom	8,184	.056	.23	0	1
7-Bedroom	8,184	.0088	.093	0	1
8-Bedroom	8,184	.0037	.06	0	1
9-Bedroom	8,184	.0012	.035	0	1
10-Bedroom	8,184	.00086	.029	0	1
11-Bedroom	8,184	.00037	.019	0	1
PurposeBuilt	8,184	.19	.39	0	1
Verified	8,184	.35	.48	0	1
OnerousGrRent	8,184	.1	.3	0	1
FH-Flat	8,184	.0015	.038	0	1
LwGr-Floor	8,178	.11	.31	0	1
Gr-Floor	8,178	.091	.29	0	1
1st-Floor	8,178	.11	.31	0	1
2nd-Floor	8,178	.098	.3	0	1
3rd-Floor (Lnr)	8,178	.067	.25	0	1
3rdOrMore Floor (JDW)	8,178	.032	.18	0	1
4th-Floor (Lnr)	8,178	.043	.2	0	1
5thOrMore-Floor (lnr)	8,178	.038	.19	0	1
Maisonette	8,178	.092	.29	0	1
Mews	7,476	.046	.21	0	1
Detached	7,476	.012	.11	0	1
TwoOrMore-Bathroom	7,476	.47	.5	0	1
Garden	7,476	.24	.43	0	1
Balcony	7,476	.2	.4	0	1
Terrace	7,476	.15	.36	0	1
Patio	7,476	.14	.35	0	1
CommunalGarden	7,476	.13	.33	0	1
Refurbished	7,476	.24	.43	0	1
InNeed	7,476	.078	.27	0	1
Sqft	2,157	1,380	1,229	157	22,000

Table 3: Hedonic regressions: Leasehold buckets

Notes: The baseline categories are flats, 1-bedroom properties, 1st floor. The first column displays the results of a regression including both leasehold and freehold properties. The next column refers to a regression with leasehold properties only. Both models have street and quarter fixed effects.

	(1) log(Price) Baseline: Freehold		(2) log(Price) Baseline: Lease ≥900	
House	0.255***	(0.040)	0.193***	(0.061)
Studio	-0.403***	(0.031)	-0.409***	(0.030)
2-Bedroom	0.354***	(0.015)	0.337***	(0.015)
3-Bedroom	0.650***	(0.021)	0.620***	(0.022)
4-Bedroom	0.864***	(0.029)	0.878***	(0.033)
5-Bedroom	1.057***	(0.040)	1.079***	(0.060)
6-Bedroom	1.235***	(0.048)	1.168***	(0.076)
7-Bedroom	1.253***	(0.077)	1.175***	(0.126)
8-Bedroom	1.282***	(0.203)	1.013***	(0.264)
9-Bedroom	1.301***	(0.231)	0.987***	(0.195)
10-Bedroom	0.734***	(0.198)		
11-Bedroom	1.835***	(0.374)	1.471***	(0.074)
PurposeBuilt	-0.004	(0.024)	-0.015	(0.026)
Verified	-0.079***	(0.013)	-0.087***	(0.016)
OnerousGrRent	-0.147***	(0.027)	-0.146***	(0.027)
LwGr-Floor	-0.119***	(0.024)	-0.126***	(0.024)
Gr-Floor	-0.032*	(0.020)	-0.035*	(0.020)
2nd-Floor	-0.082***	(0.016)	-0.080***	(0.016)
3rd-Floor (Lnr)	-0.108***	(0.021)	-0.107***	(0.021)
3rdOrMore Floor (JDW)	-0.118***	(0.027)	-0.111***	(0.027)
4th-Floor (Lnr)	-0.088***	(0.029)	-0.088***	(0.031)
5thOrMore-Floor (lnr)	0.022	(0.038)	0.022	(0.041)
Maisonette	-0.018	(0.022)	-0.027	(0.022)
Mews	0.097***	(0.034)	0.157*	(0.086)
Detached	0.395***	(0.122)	0.533**	(0.229)
TwoOrMore-Bathroom	0.116***	(0.013)	0.140***	(0.016)
Garden	0.048***	(0.014)	0.056***	(0.019)
Balcony	0.050***	(0.012)	0.056***	(0.013)
Terrace	0.065***	(0.014)	0.084***	(0.016)
Patio	-0.031**	(0.014)	-0.016	(0.021)
CommunalGarden	0.011	(0.018)	0.010	(0.020)
Refurbished	0.031***	(0.009)	0.029***	(0.011)
InNeed	-0.171***	(0.016)	-0.189***	(0.021)
FH-Flat	0.151	(0.117)	0.000	(.)
Lease <80	-0.195***	(0.029)	-0.104*	(0.058)
Lease [80,100)	-0.105***	(0.027)	-0.023	(0.049)
Lease [100,125)	-0.089***	(0.026)	-0.013	(0.049)
Lease [125, 900)	-0.066*	(0.035)	0.025	(0.062)
Lease ≥900	-0.081*	(0.048)		
Quarter (sale date)	✓		✓	
Street	✓		✓	
Observations	7476		5570	
R squared	0.825		0.784	

Standard errors in parentheses
clustered at the street level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Hedonic regressions: Model with dummies and semiparametric regression

Notes: Both columns refer to regressions which include only leasehold flats. The baseline categories are 1-bedroom, 1st floor. The first model has leasehold year dummies, one for each lease length. The second model represents the first stage of the Yatchew (1997) approach.

	(1) log(Price) Lease Flats		(2) log(Price) Lease Flats	
Studio	-0.424***	(0.033)	-0.376***	(0.041)
2-Bedroom	0.331***	(0.013)	0.378***	(0.036)
3-Bedroom	0.615***	(0.022)	0.650***	(0.039)
4-Bedroom	0.875***	(0.032)	0.848***	(0.039)
5-Bedroom	1.125***	(0.067)	1.048***	(0.049)
6-Bedroom	1.143***	(0.104)	1.040***	(0.098)
7-Bedroom	1.446***	(0.194)	1.318***	(0.196)
8-Bedroom	0.862	(0.550)	0.907***	(0.242)
PurposeBuilt	-0.027	(0.021)	-0.035*	(0.020)
Verified	-0.102***	(0.016)	-0.100***	(0.017)
OnerousGrRent	-0.115***	(0.018)	-0.130***	(0.018)
LwGr-Floor	-0.127***	(0.022)	-0.135***	(0.022)
Gr-Floor	-0.020	(0.018)	-0.019	(0.021)
2nd-Floor	-0.060***	(0.015)	-0.060***	(0.019)
3rd-Floor (Lnr)	-0.105***	(0.020)	-0.086***	(0.022)
3rdOrMore Floor (JDW)	-0.091***	(0.027)	-0.065**	(0.030)
4th-Floor (Lnr)	-0.086***	(0.026)	-0.066***	(0.024)
5thOrMore-Floor (lnr)	-0.004	(0.032)	-0.020	(0.027)
Maisonette	-0.019	(0.024)	-0.015	(0.021)
TwoOrMore-Bathroom	0.130***	(0.015)	0.128***	(0.012)
Garden	0.086***	(0.019)	0.094***	(0.017)
Balcony	0.083***	(0.011)	0.077***	(0.013)
Terrace	0.080***	(0.015)	0.091***	(0.015)
Patio	-0.012	(0.020)	-0.012	(0.018)
CommunalGarden	0.005	(0.017)	-0.003	(0.016)
Refurbished	0.017	(0.011)	0.020*	(0.011)
InNeed	-0.153***	(0.018)	-0.164***	(0.019)
Leasehold term	✓		✓	
Quarter (sale date)	✓		✓	
Street	✓		✓	
Observations	5164		5163	
R squared	0.815		0.650	

Standard errors in parentheses
clustered at the street level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 1: Fraction of leasehold and freehold sales, Land Registry 2010

Notes: The Land Registry contains all residential property sales in England and Wales since 1995. The dataset is available at `http://www.landregistry.gov.uk/market-trend-data/public-data`. The public version of the dataset only contains an indicator variable which labels properties as freeholds or leaseholds. For the main analysis of this paper, we use proprietary data from real estate agencies in Central London.

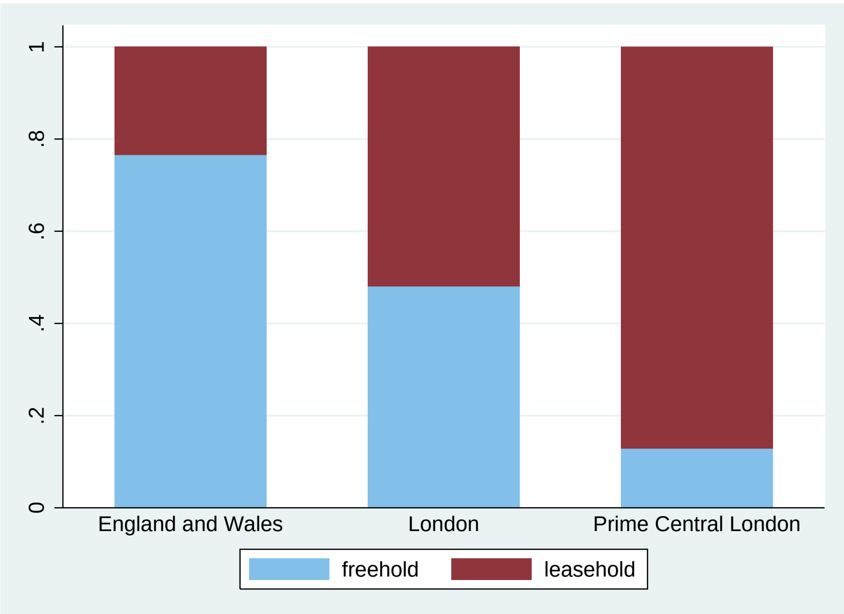
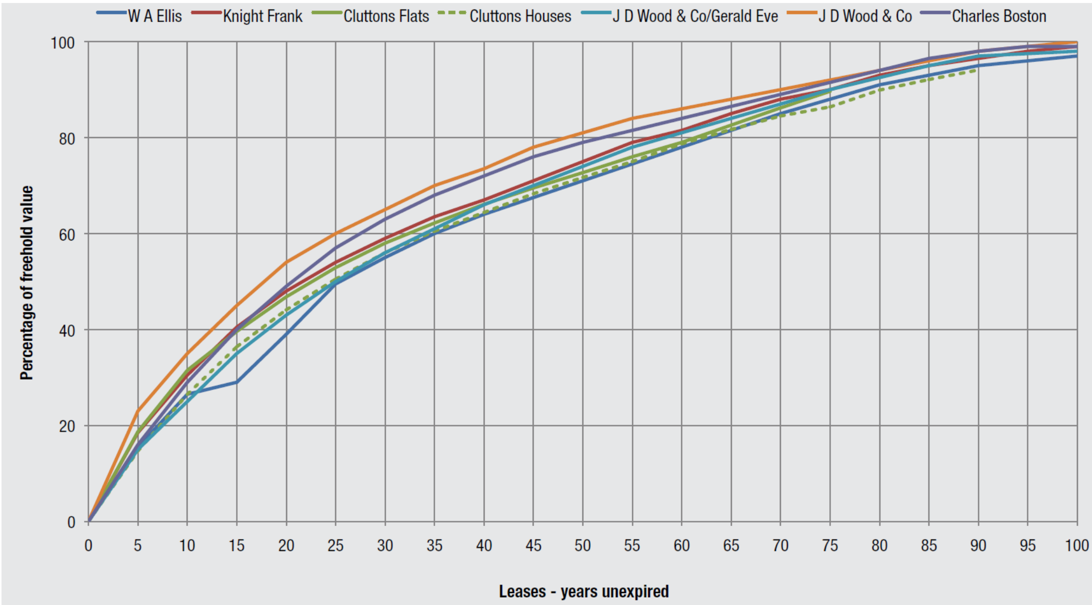


Figure 2: Practitioner Graphs of Relativity for Prime Central London



Source: Royal Institution of Chartered Surveyors (2009)

Figure 3: Leasehold observations by years remaining

Notes: The histogram include all leasehold observations in the sample, counted by length of the unexpired term. Freehold and share of freehold properties are not included. Bins are 5 years wide. There are 43 properties spread between 150 and 980 years of remaining term—they are not visualised in the histogram.

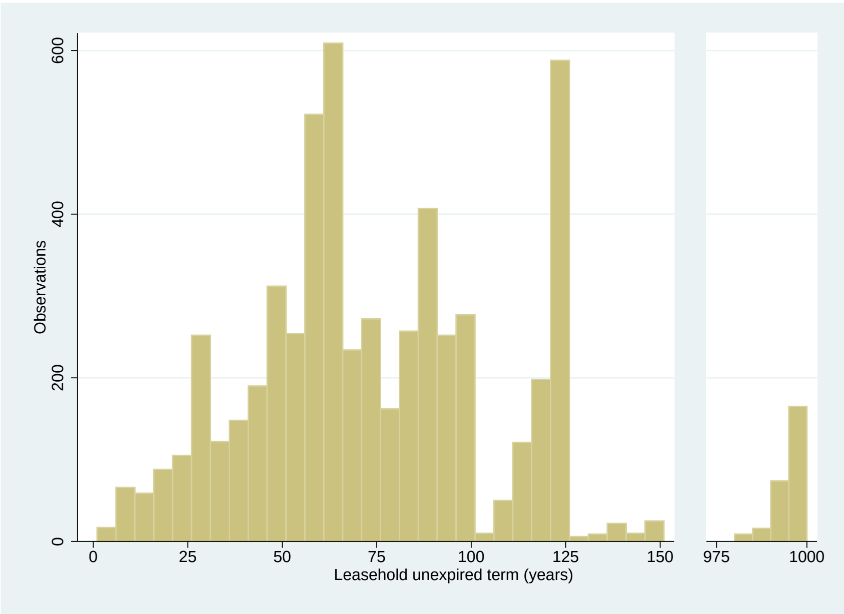


Figure 4: Location of sales

Notes: Addresses in the sample have been geocoded using Google Maps (`https://developers.google.com/maps/documentation/geocoding/`) and then mapped with R and the ggmap package.

Figure 5: Number of transactions per quarter

Notes: The pattern in sales well reflects the experience of market practitioners in that period and is consistent with national and local price indices. 1988 was a boom year, with real estate agents enjoying "high volumes, high prices, and high commissions". After that came a fall in the market in 1989, and the number of sales stabilised in 1990-1991.

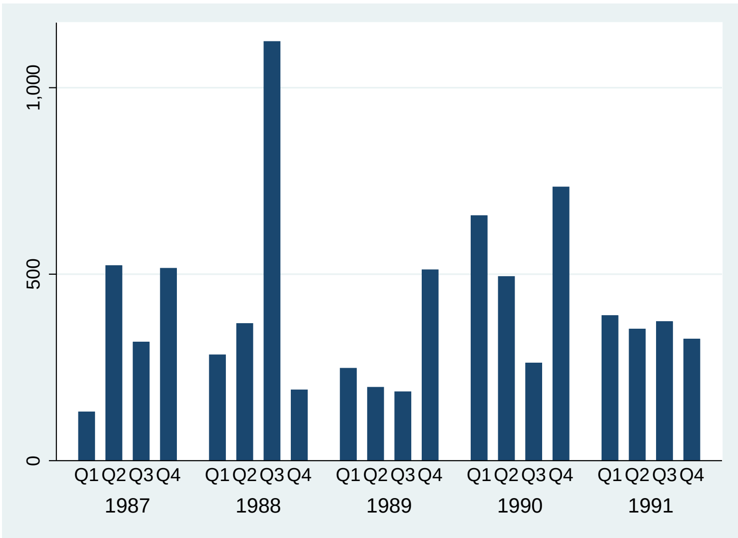


Figure 6: Dummy estimates and first stage of the semiparametric method

Notes: The upper chart represents the lease length dummy estimates for the model shown in the first column of Table 4. The charts also plot the 95% confidence bands associated with each coefficient. The dashed horizontal line represents the value of long leases and in this case represents the value of a 999-year lease.
The chart at the bottom is the scatter of quality-adjusted prices using the semiparametric approach.

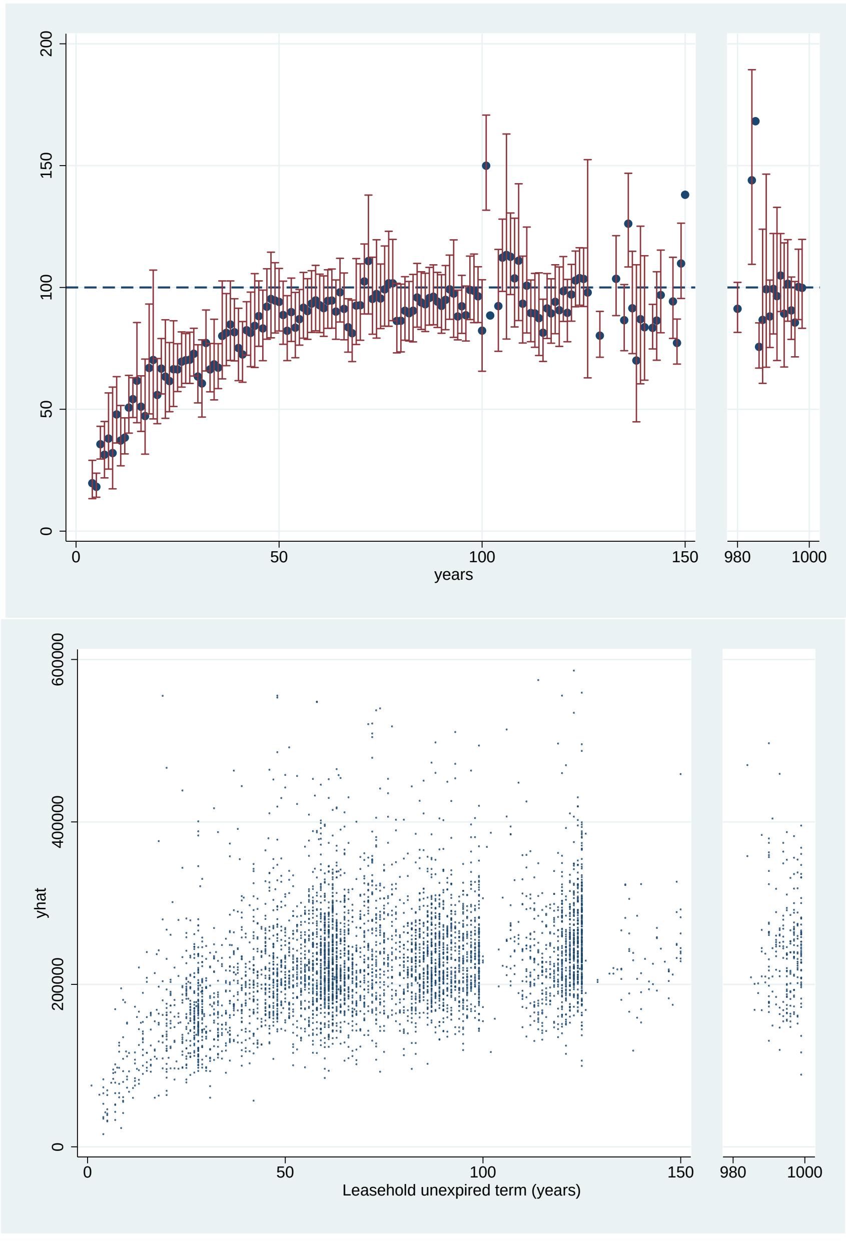


Figure 7: Smooth $f(t)$ function

Notes: The two charts show the second-degree local polynomials with a 15-year bandwidth on both sides fitted through the dots displayed in Figure 6. The two charts focus on the 1-100 year range. In the left-hand side chart, the dummy estimates are plotted as circles where the size of the circle is proportional to the number of observations for that specific lease length. The grey bands around them represent 95% confidence bands.

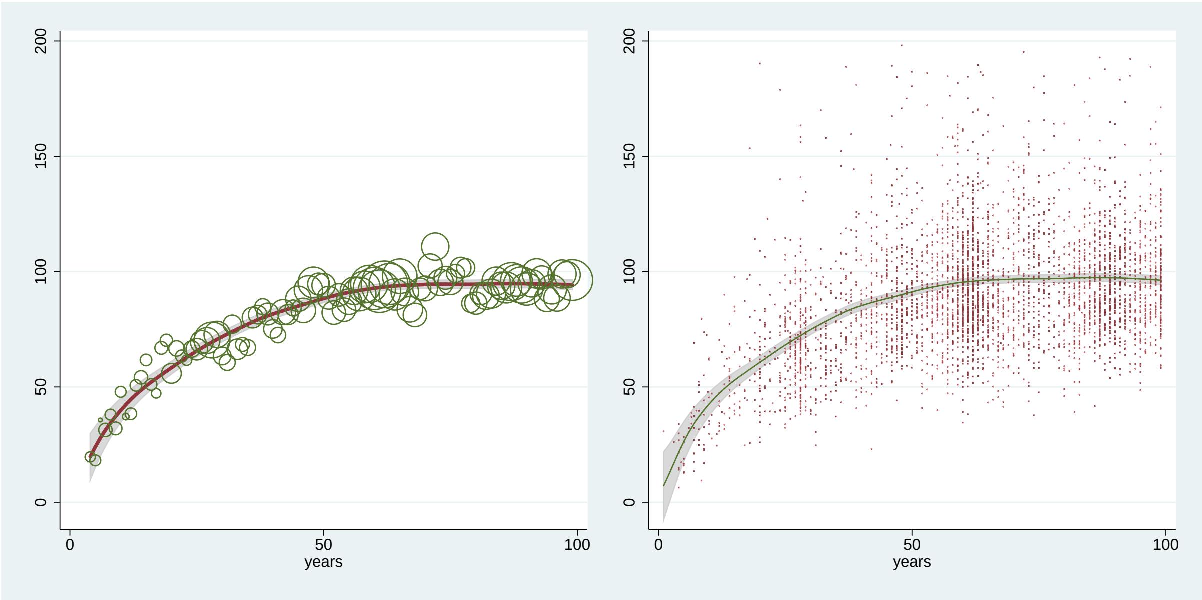


Figure 8: Implied discount rates

Notes: The two charts show the discount rates implied by the curves fitted in Figure 7. In the left-hand side chart, the discount rates implied by the corresponding individual dummy estimates are also plotted. As in Figure 7, circle size is proportional to the number of observations for that specific lease length. This Figure represents a leasehold flat v.s. leasehold flat analysis, significantly departing from the conventional basis for establishing relativity used by market practitioners, and is therefore inappropriate for use in this way.

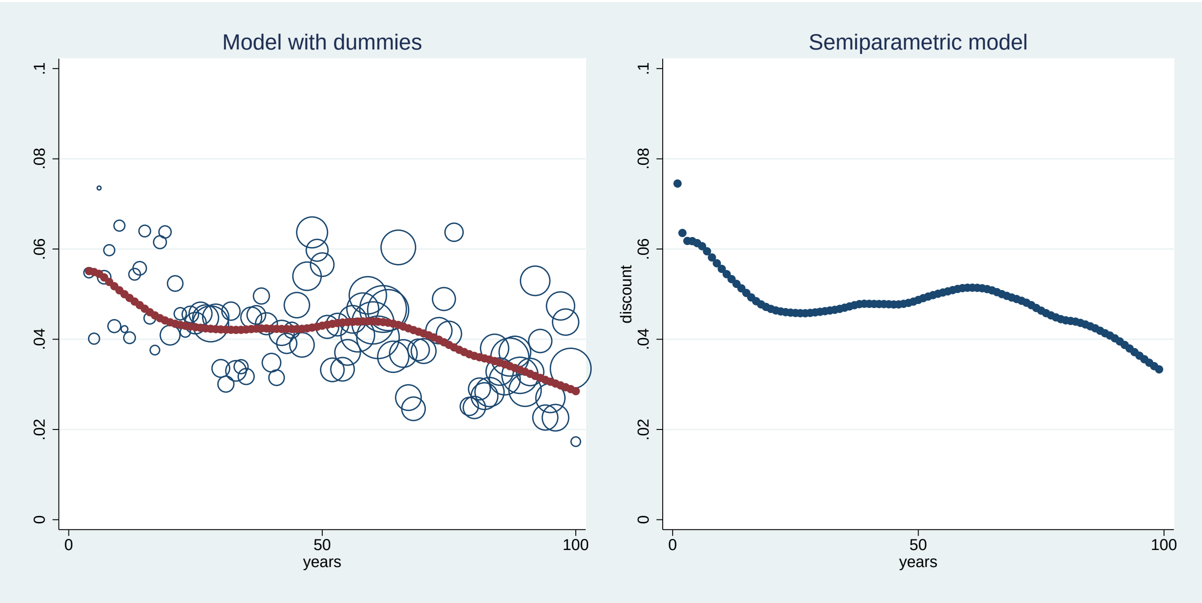
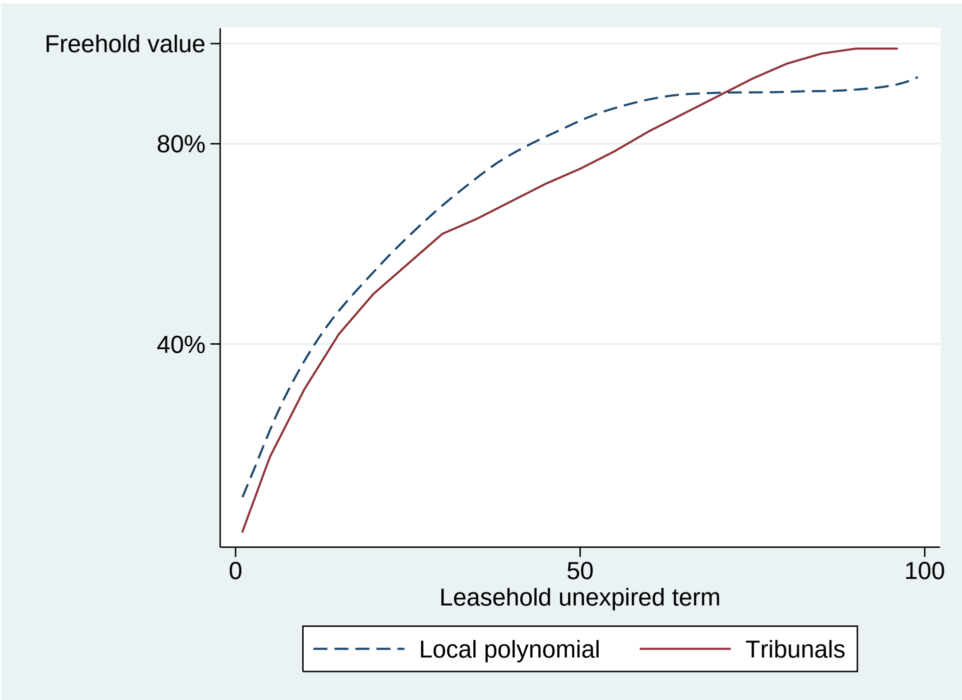


Figure 9: Paper's findings vs existing practice



Appendices

Table A1: Hedonic regressions: Additional regressions

Notes: The baseline categories are flats, 1-bedroom properties, 1st floor. The first column displays the results of a regression including quarter-street interactions as fixed effects to allow for specific local conditions in a given quarter. Since this specification automatically excludes quarter-street combinations where there are less than two sales, the reported number of observations drops by approximately 3,000. The second column refers to a regression run on price per square foot. The number of observations drops substantially because few properties have information on floor area. Interestingly, when including floor area the premium on houses (as opposed to flats) disappears.

	(1) log(Price)		(2) log(Price/Sqft)	
House	0.216***	(0.053)	-0.065	(0.108)
Studio	-0.420***	(0.050)	-0.135**	(0.054)
2-Bedroom	0.358***	(0.018)	0.086***	(0.021)
3-Bedroom	0.657***	(0.031)	0.158***	(0.031)
4-Bedroom	0.873***	(0.038)	0.220***	(0.048)
5-Bedroom	1.113***	(0.059)	0.333***	(0.082)
6-Bedroom	1.277***	(0.069)	0.393***	(0.125)
7-Bedroom	1.260***	(0.104)	0.285	(0.186)
8-Bedroom	1.627***	(0.219)	0.929***	(0.100)
9-Bedroom	1.366***	(0.220)	0.082	(0.176)
10-Bedroom	0.850***	(0.044)		
PurposeBuilt	0.013	(0.026)	-0.040	(0.025)
Verified	-0.066***	(0.018)	-0.062***	(0.022)
OnerousGrRent	-0.107***	(0.023)	-0.068***	(0.023)
LwGr-Floor	-0.136***	(0.032)	-0.198***	(0.029)
Gr-Floor	-0.026	(0.023)	-0.034	(0.025)
2nd-Floor	-0.067***	(0.022)	-0.030	(0.024)
3rd-Floor (Lnr)	-0.112***	(0.028)	-0.070***	(0.022)
3rdOrMore Floor (JDW)	-0.118***	(0.045)		
4th-Floor (Lnr)	-0.087***	(0.032)	-0.071**	(0.029)
5thOrMore-Floor (lnr)	-0.017	(0.041)	-0.019	(0.034)
Maisonette	-0.008	(0.032)	-0.113***	(0.031)
Mews	0.105*	(0.063)	0.128	(0.177)
Detached	0.402**	(0.185)	0.783***	(0.188)
TwoOrMore-Bathroom	0.096***	(0.016)	0.047***	(0.012)
Garden	0.083***	(0.018)	0.034	(0.030)
Balcony	0.058***	(0.016)	0.069***	(0.019)
Terrace	0.076***	(0.018)	0.068***	(0.020)
Patio	-0.006	(0.021)	-0.044	(0.029)
CommunalGarden	0.017	(0.021)	0.023	(0.015)
Refurbished	0.026**	(0.012)	0.014	(0.014)
InNeed	-0.142***	(0.023)	-0.158***	(0.023)
FH-Flat	-0.018	(0.170)	0.069	(0.100)
log(Sqft)			-0.316***	(0.035)
Leasehold term	✓		✓	
Quarter (sale date)	✓		✓	
Street			✓	
Street*Quarter	✓			
Observations	5098		2034	
R squared	0.892		0.722	

Standard errors in parentheses
clustered at the street level
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2: Results of the Pesaran (2004) cross-sectional dependence (CD) test

Notes: House prices are correlated across space and time and most of these correlations are accounted for by including the relevant explanatory variables. Even controlling for Street and SaleQuarter, there is the possibility of correlations between sales in a specific street and time period with sales in the same time period in another street. To check if this is the case, we look for correlations in the residuals: we compute the average residual for each street in each year and then measure the correlations between these residuals using all possible pairwise combinations of streets. To summarise all these pairwise correlations in one unique number, which allows us to determine whether these correlations are statistically significant, we use the method suggested by Pesaran (2004): we sum all the correlations and multiply the resulting number by $\sqrt{\frac{2T}{N(N-1)}}$, where T is the number of years (5) and N is the number of streets; I then compare the resulting number with the standard normal distribution. We run the test both within postcodes and across the entire sample, and find no statistically significant correlations. The table shows the values of the CD test in the first column, and the associated standardised probabilities in the second column. As a robustness check, we run the same tests on residuals obtained from a model with no controls and no streets (the last row of the table), and indeed find that, in this case, the sum of all correlations is statistically significant.

	CD statistic	Prob (N(0,1) < CD)
SW1	-0.530	0.298
SW10	0.099	0.539
SW3	0.369	0.644
SW7	0.264	0.604
W1	-1.527	0.063
W11	-1.120	0.131
W14	-0.349	0.364
W2	0.853	0.803
W8	-1.099	0.136
PCL	-0.401	0.344
PCL (no explanatory variables)	26.803	1.000

Note: Estimation uses only streets where all years have data points (SW5 does not have enough such streets)

Figure A1: Distribution of residuals

Notes: The left-hand side chart shows the distribution of residuals, which look normal around zero. The right-hand side chart plots the individual residuals against leasehold unexpired terms. Residuals and lease length do not appear to be correlated; we do not see systematically larger residuals for some lease lengths and smaller residuals for others.

Figure A2: Price index implied by hedonic regression (1990q1 = 100)

Notes: The chart plots the coefficients on quarterly dummies in the first model of Table 4, compared with the Nationwide price index for London. The period that goes from 1987 to 1989 was characterised by a boom and then the market stabilised. The price pattern is consistent with the quantity trend shown in Figure 5. The behavior of our index after the boom differs slightly from the one of the Natiowide index. This may be due to the different coverage of the two indices—Natiowide covers the whole London area whereas our observations only come from Prime Central London.

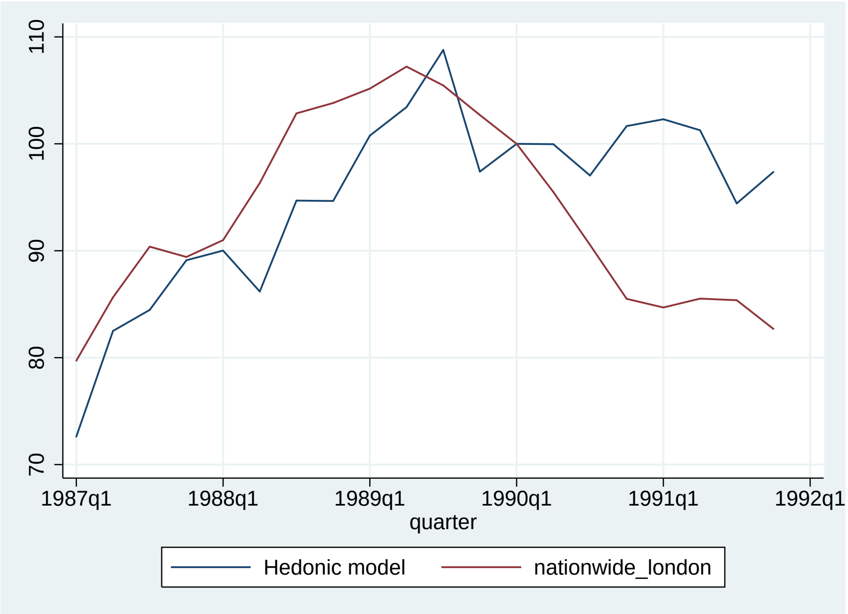


Figure A3: Smoothed $f(\textsc{yearLease})$ function, Kensington vs Chelsea

Notes: Most of the property sales in our dataset are located in an administrative area known as the Royal Borough of Kensington and Chelsea (this is the area populated by dots in Figure 4). The charts below replicate Figure 7 but only include the sales which have occurred in the Kensington neighbourhood (the first two charts) and the Chelsea neighbourhood (the last two charts). The number of observations per chart clearly diminishes, which makes the fitting curve (especially the local polynomial) less smooth. However, the general shape of the curve is preserved even at a smaller spatial scale.

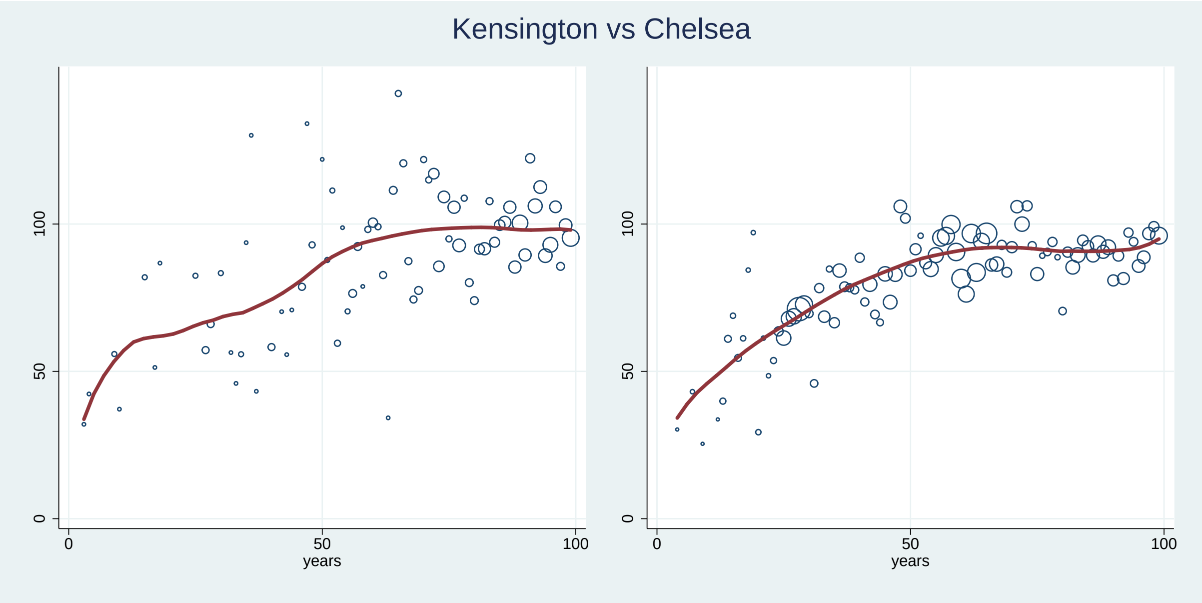
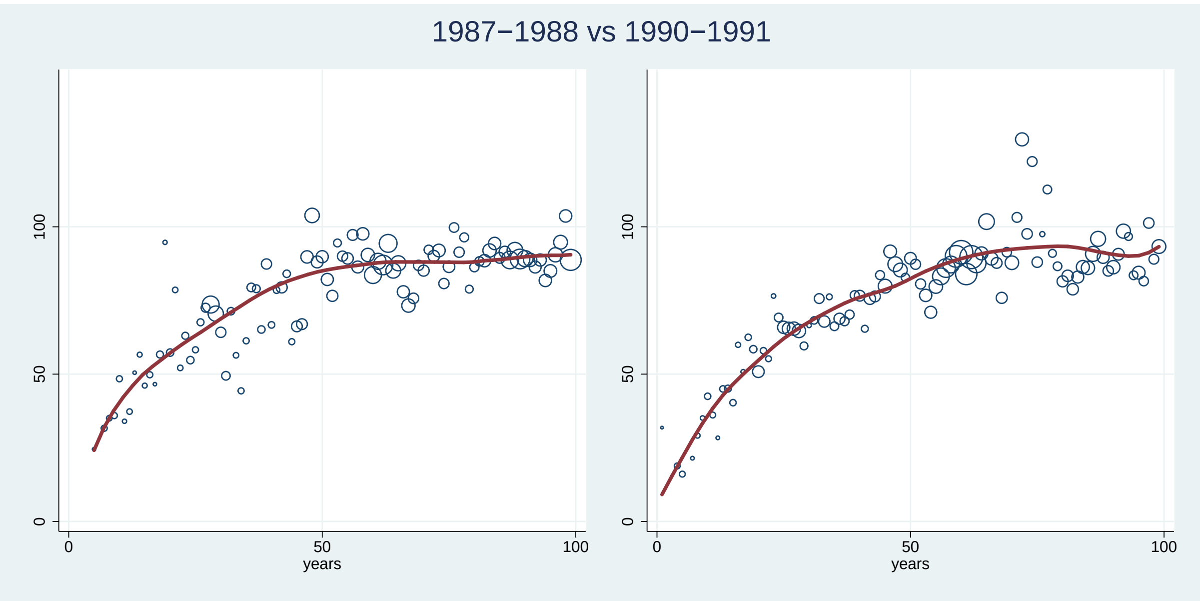


Figure A4: Smoothed $f(\text{YEARLEASE})$ function, boom period (1987-1988) vs bust period (1990-1991)

Notes: As the previous two figures in this appendix, this figure replicates Figure 7, this time comparing sales which occur in the first two years, 1987–1988 (in the first two charts), with sales which occur in the last two years of the sample, 1990–1991 (in the last two charts). The 1987–1988 was characterised by high sale volumes and growing prices, whereas the 1990–1991 saw flat volumes and prices (see Figures 5 and A2). As in previous figures, the analysis of subsamples does not produce significantly different results from those shown in the main part of the text and in Figure 7.



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SERC is an independent research centre funded by the Economic and Social Research Council (ESRC), Department for Business Innovation and Skills (BIS) and the Welsh Government.