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No-Bubble Condition: Model-free Tests in Housing Markets
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ABSTRACT

We test for the existence of infinitely-lived bubbles in housing markets by directly measuring failures of the pricing condition requiring the present value of infinite-maturity payments to be zero. This condition is central to workhorse models of bubbles. In the U.K. and Singapore, property ownership takes the form of either leaseholds or freeholds. Leaseholds are finite-maturity ownership contracts with maturities often exceeding 700 years; freeholds are perpetual contracts. The price difference between long-maturityleaseholds and freeholds reflects the present value of the freehold after leasehold expiry, thus directly measuring the no-bubble condition. We find no evidence of infinitely-lived bubbles.

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Market efficiency, and in particular the existence of bubbles, is one of the fundamental debates in finance (Fama, 2013; Shiller, 2013). The workhorse model of bubbles is based on a failure of the so-called "no-bubble condition" that requires the present value of a payment occurring infinitely far in the future to be zero. In this paper, we call this financial claim the "bubble claim," and denote its price by B_t. The no-bubble condition requires:

$$B_t = \lim_{T \to \infty} E_t[\xi_{t,T} P_T] = 0, \tag{1}$$

where $\xi_{t,T}$ is a model-implied discount factor between date t and T, and P_T is the price of the asset at time T, so that $B_t \equiv E_t[\xi_{t,T} P_T]$ is the present discounted value of the claim to the asset at time T. Theories about this type of bubble provide a sharp null and alternative hypothesis: $B = 0$ if there are no bubbles, and $B > 0$ if there is a bubble. $B > 0$ is a bubble, because it implies a positive price today for a claim that postpones payments indefinitely and, therefore, has zero fundamental value.

This type of bubble has received widespread attention in the theoretical literature, with classic papers by Samuelson (1958), Blanchard and Watson (1982), Tirole (1982, 1985) and Froot and Obstfeld (1991); however, empirical evidence on its existence has remained elusive. The natural test for this type of bubble is to verify whether infinite maturity claims do, in fact, have zero or positive present value. This direct test, however, has been impossible to conduct, because we normally do not observe traded claims to payments that only occur at (even approximately) infinite maturity. We generally either observe prices of claims to cash flows at all horizons (e.g., equities), or prices of claims to cash flows for finite, but relatively short, horizons (e.g., bonds).[1] Due to the challenges with measuring the price of extremely long-run financial claims, the literature has resorted to indirect model-dependent tests of bubbles, thus incurring the *joint hypothesis problem*: every test of a bubble is a joint test of the presence the bubble in the data and the validity of the model applied by the econometrician.[2]

A connected literature has tried to rule out the bubble based on theoretical grounds (Tirole, 1982; Milgrom and Stokey, 1982; Santos and Woodford, 1997), arguing that it is inconsistent with infinitely-lived agents' optimization or backward induction, or has provided necessary conditions for the existence of the bubble (Tirole, 1985) that have subsequently been tested in the data (Abel et al., 1989). Despite these efforts, the theoretical and

[1] For example, the U.K. government has issued some perpetuities, but the longest finite-maturity bond that could be used to back out the equivalent zero-coupon price has a maturity of only 40 years, a horizon unsuitable to approximate the infinity limit required by the theory.

[2] Both sides of the debate on the efficient market hypothesis agree on this fundamental difficulty. Shleifer (2000) remarks: "The dependence of most tests of market efficiency on a model of risk and expected return is Fama (1970)'s deepest insight, which has pervaded the debates in empirical finance ever since."

empirical debate on this type of bubble is still ongoing (Farhi and Tirole, 2012) and, inspired by the recent financial crisis and housing boom-bust cycle, this type of bubble has received renewed attention in the macroeconomics and real estate literatures (Caballero and Krishnamurthy, 2006; Arce and López-Salido, 2011; Martin and Ventura, 2012, 2014; Giglio and Severo, 2012; Gali, 2014).

We provide direct tests for infinitely-lived bubbles by exploiting a unique feature of residential housing markets in the U.K. and Singapore, where property ownership takes the form of either very long-term leaseholds or freeholds. Leaseholds are temporary, prepaid and tradable ownership contracts, often with initial maturities of 999 years, while freeholds are perpetual ownership contracts. The price difference between leaseholds with extremely long maturities and freeholds for otherwise identical properties captures the present value of rental income starting at leasehold expiry, and thus provides an estimate of the price of the bubble claim, B_t. We focus on leaseholds with remaining maturities greater than 700 years, which reasonably approximate the infinite limit of the theoretical literature. Our empirical strategy has the advantage of being *model free*. Since we focus on bubbles associated with failures of the terminal condition, we do not have to assume a model for the fundamental value of the claim B_t: all models agree that such value is zero. In addition, our direct test of the no-bubble condition does not require us to derive indirect, model-implied sufficient conditions for the existence of the bubble.

Our empirical analysis is based on proprietary information on the universe of property sales in the U.K. and Singapore between 1995 and 2013. These data contain information on transaction prices, leasehold terms and property characteristics such as location and structural attributes. We estimate the bubble component by comparing the prices of leaseholds with maturities between 700 years and 1,000 years to the prices of freeholds across otherwise identical properties. We use hedonic regression techniques to control for possible heterogeneity between leasehold and freehold properties. We find that extremely long leaseholds are valued identically to otherwise similar freeholds. Our results, therefore, show no deviations from the no-bubble condition in these markets. We find this to be true even during time periods and in geographic regions when people argued that housing bubbles were likely to be present (e.g., U.K. in 2007 or 2013, or Central London).

Given our empirical finding that the no-bubble condition held remarkably well during the recent housing boom and bust in the U.K. and Singapore, it is important to emphasize that our empirical set-up is, if anything, biased toward finding a bubble. The obvious concern, in fact, is that even very long maturity leasehold contracts might be less valuable than freehold contracts for reasons unconnected to their finite maturity. For example, the possibility of a “full ownership premium" based on psychological preferences or contractual restrictions, such as covenants, that could reduce the flow utility of a leaseholder relative to a freeholder, would bias our tests toward finding a bubble. Such concerns are discussed in detail in Giglio, Maggiori and Stroebel (2013), who estimate sizable price discounts for short(er) maturity leaseholds compared to freeholds.[3] Since these concerns would only make the current analysis conservative, we do not review them in detail. One possibility that might bias our hedonic regressions toward finding no bubbles would be if leasehold properties had higher unobserved quality than freehold properties. However, we find this to be unlikely, since houses with extremely long leaseholds appear to be of worse average quality on all observable characteristics (i.e., they are older, smaller and have fewer bedrooms and bathrooms).

We focus on infinitely-lived bubbles because they are an important workhorse model of bubbles in finance and macroeconomics, and because we can offer a clear test for such bubbles; our paper and test methodology are silent on the possible presence of bubbles with finite horizon. Similarly, our paper focuses only on residential real estate because the institutional set-up in the U.K. and Singapore provides a clear test of the theory of this type of bubbles; we are silent on the possibility of bubbles in other assets. Nevertheless, residential real estate has been the subject of enormous bubble-related attention because of its recent boom-bust cycle. The top panels of Figures 3 and 4 show the behavior of real house prices in the U.K. and Singapore. Both countries experienced strong increases in house prices from the late 1990s to 2007, a pronounced reversal during the financial crisis 2007-2009, and a renewed boom after that. These periods have often been described to exhibit a housing bubble. The Figures also plot a "bubble index," constructed by counting the number of references to "real estate bubbles" in major newspapers. For both countries, this index generally increased with house prices, spiking particularly in 2013. Similarly, a sizable academic literature has speculated about the presence of bubbles in housing markets over this period (Case and Shiller, 2003; Himmelberg, Mayer and Sinai, 2005; Glaeser, Gyourko and Saiz, 2008; Piazzesi and Schneider, 2009; Glaeser, Gottlieb and Gyourko, 2010; Arce and López-Salido, 2011; Mayer, 2011; Glaeser and Nathanson, 2014; Nathanson and Zwick, 2014). We conclude that while our focus on the housing market of Singapore and the U.K. gives the best chances of detecting a bubble in the data, our results show that no infinitely-lived bubble was actually present.

[3]While Giglio, Maggiori and Stroebel (2013) use a similar empirical setting, the focus of that paper is entirely different. That paper estimates the term structure of discount rates over horizons of 100-200 years, and does not study bubbles. The question of the term structure of discount rates is irrelevant for testing the presence of bubbles, which is the focus of this paper. Due to differences in sample availability of leaseholds and freeholds this paper mainly focuses on houses, while the other paper focuses on flats.

1 Theoretical Review and Empirical Tests

The theoretical literature on bubbles is vast and richly varied.[4] The focus of this paper is on a particular type of bubble whose existence is associated with a failure of the terminal condition of the asset valuation equation. Consider an asset that pays dividend D_t in each period and denote its price at time t by P_t. If ξ_{t+T} is a valid stochastic discount factor for this asset, we have:

$$P_t = E_t[\xi_{t,t+1}(P_{t+1} + D_{t+1})],$$

the price today equals the present discounted value of the price and dividend tomorrow. Applying a recursive argument and the law of iterated expectations, we obtain:

$$P_t = \sum_{s=1}^{\infty} E_t[\xi_{t,t+s} D_{t+s}] + B_t, \qquad B_t \equiv \lim_{T \to \infty} E_t[\xi_{t,t+T} P_{t+T}]. \tag{2}$$

where we have defined $\xi_{t,t+s} \equiv \prod_{j=0}^{s-1} \xi_{t+j,t+j+1}$, so that $\xi_{t,t+s}$ is the stochastic discount factor between period t and $t+s$. The price of the asset is decomposed into the fundamental value, i.e. the present discounted value of dividends, and the bubble component B_t. The absence of a bubble requires that $B_t = 0$, independently of the model-specific discount factor (ξ) or asset under consideration. If instead $B_t \neq 0$, there exists a bubble.[5] If present, the bubble evolves according to $B_t = E_t[\xi_{t,t+1} B_{t+1}]$.

The classic bubble that relies on the failure of the terminal condition is the infinitely-lived rational bubble of Blanchard and Watson (1982) and Froot and Obstfeld (1991): the failure occurs because the bubble grows faster than the discount rate applied to the asset, which in these models is assumed to be a constant rate of return.[6] There has been a critical literature verifying the theoretical conditions under which a bubble of this type can arise. For example, standard neoclassical theories rule out this bubble because it is inconsistent with the optimization problem of an infinitely-lived representative agent or inconsistent with backward induction in a finite horizon setting (Santos and Woodford, 1997). In settings with asymmetric information, the "no-trade theorems" also preclude the existence of this bubble (Tirole, 1982; Milgrom and Stokey, 1982).

These theoretical challenges have inspired a literature that has subsequently shown how the bubble can occur in economies with combinations of overlapping generations,

[4] See Brunnermeier and Oehmke (2013) and Shleifer (2000) for reviews.

[5] In what follows, we focus on the case $B_t > 0$, because a negative bubble can be easily ruled out if there is free disposal of rents. Nonetheless, our test would detect negative bubbles if they were present.

[6] These models are a particular case of equation (2) in which $\xi_{t,t+s} = R^{-s}$, and R is the gross expected rate of return on the asset.

incomplete markets, and financial frictions (Tirole, 1985; Kocherlakota, 1992, 2008).[7] This theoretical literature reaffirmed the theoretical plausibility of this type of bubble as an equilibrium phenomenon, and recent contributions have imported this bubble into macroeconomics to study its effects on the accumulation of capital as a store of value, and the consequent possibility of dynamic inefficiency due to over-accumulation (Caballero and Krishnamurthy, 2006; Martin and Ventura, 2012, 2014; Giglio and Severo, 2012; Farhi and Tirole, 2012; Gali, 2014).

The recent theoretical literature has focused on one notable necessary condition for bubbles to occur on assets, such as real estate, that are in positive supply: the bubble cannot grow faster than the rate of growth of the economy. Intuitively, if the bubble were to grow faster than the economy, it would eventually overtake the entire wealth of the economy, as long as wealth and output are cointegrated and, therefore, grow at the same rate in the long run. While this restriction rules out bubbles that grow too fast, it cannot exclude the possibility of bubbles that grow at a lower rate in the long run. In addition, the literature has shown that bubbles can exist (and grow at a low rate) even on assets that, on average, have high returns, for two main reasons. First, the bubble does not have to have the same expected rate of return as the asset it pertains to; hence, it is quite possible that even for a risky asset, such as housing, the rate of return of which is higher than the growth rate of the economy, its bubble component is relatively safe and grows at a lower pace.[8] Second, in an economy with frictions, the rate of return on the asset can be higher than the rate at which the bubble grows, further de-linking the growth rate of the fundamental and bubble component of prices. Indeed, Farhi and Tirole (2012) show that even in a deterministic economy the marginal product of capital can be high, due to frictions that prevent its equalization with the risk-free rate, while the bubble on capital grows at the risk-free rate of return. These results do not overturn the necessary condition for the existence of a bubble derived by Tirole (1985), namely that the long-run growth rate of the bubble should be less than that of the economy, but they restore the theoretical case for bubbles by showing that such condition could easily be satisfied in realistic set-ups.

While $B_t > 0$ is a sufficient condition for the existence of a bubble, it is not a necessary condition. It is possible to generate bubbles that do not require a failure of the terminal condition. In fact, an interesting literature has created models of bubbles that can occur

[7]This work builds on earlier contributions of Samuelson (1958) and Diamond (1965) regarding the value of fiat money and government debt. See also: Scheinkman and Weiss (1986); Woodford (1986, 1990); Miao and Wang (2011).

[8]This is the case, for example, in Gali (2014)'s economy, where the bubble is attached to capital, a risky asset with a positive risk premium, but the bubble itself is purely idiosyncratic and therefore earns the risk-free rate of return.

even in finite horizons (Allen, Morris and Postlewaite, 1993; Abreu and Brunnermeier, 2003; Scheinkman and Xiong, 2003; Hong, Scheinkman and Xiong, 2006, 2008; DeMarzo, Kaniel and Kremer, 2008). In this paper, we only focus on the workhorse infinitely-lived bubble, not only because it remains a benchmark and popular case, but also because we can provide a clean testing ground for its existence. Our tests, and this theoretical review, are silent on other type of bubbles whose presence in the data remains an open question for future research.

Similarly, our tests are for infinitely-lived bubbles but do not distinguish between rational and irrational or behavioral bubbles. If $B_t > 0$, there is a bubble, but it could be either rational or irrational. While in the theoretical literature rational bubbles are most often associated with failures of the terminal condition, behavioral bubbles could in principle generate a similar failure. On the other hand, $B_t = 0$ does not imply the absence of behavioral bubbles, as pointed out in the previous paragraph, or even rational bubbles.[9]

1.1 Existing Empirical Tests

The empirical literature on bubbles is vast but, despite the notable research effort, also largely inconclusive. In their recent survey of the literature on bubbles, Brunnermeier and Oehmke (2013) emphasize that "*identifying bubbles in the data is a challenging task. The reason is that in order to identify a bubble, one needs to know an asset's fundamental value, which is usually difficult to measure.*" We have already highlighted in the introduction that by focusing on bubbles that require a failure of the terminal condition our tests are model independent – all infinite-horizon models that preclude bubbles agree that the bubble claim should have zero value.

However, even the literature that also focuses on the infinitely-lived bubble has been plagued by a number of econometric or interpretational issues. Rather than reviewing each paper in detail,[10] we focus on the main difference between our approach and that of the previous literature. Previous tests focused on *indirect* measures of a failure of the no-bubble condition by: testing the cointegration between prices and some transformation of current dividends (Diba and Grossman, 1988*a*), imposing a structural model of the present discounted value of dividends (Shiller, 1981), or testing model-implied necessary conditions for the existence of a bubble (Abel et al., 1989). Given the dependence of the

[9] The distinction between rational and behavioral bubbles can be blurry and depends on the exact definition adopted by each author. Here we only stress the difference between bubbles that manifest themselves as a failure of the terminal condition and other types of bubbles that can occur even in finite horizon set-ups.

[10] See Flood and Hodrick (1990) for a complete survey of the econometric difficulties in the previous literature. See also: Flood and Garber (1980); Diba and Grossman (1988*b*); West (1987).

results on the different assumptions imposed in each case, these tests – while influential – were overall inconclusive. For example, Evans (1991) shows that the cointegration test of Diba and Grossman (1988*a*) may fail to detect bubbles that periodically collapse, Merton (1987) highlights that Shiller (1981)'s test is sensitive to the specification of the appropriate fundamental model, and Farhi and Tirole (2012) show that the dynamic-inefficiency conditions tested in Abel et al. (1989) are no longer necessary for the existence of bubbles in the presence of financial frictions.[11] Our approach, as explained in detail in the next section, differs from the previous papers because we *directly* measure deviations from the no-bubble condition.[12]

A different, but complementary, approach in the literature has been to document deviations from arbitrage and interpret such mispricing in the light of bubble theory.[13] For example, Lamont and Thaler (2003) document that the Palm/3Com carve-out during the height of the internet boom led to mispricing in the shares of Palm and 3Com that is hardly attributable to fundamental differences. The authors offer an interpretation based on an irrational premium for internet stocks at the time. Similarly, Xiong and Yu (2011) document that warrants on Chinese stocks traded at prices inconsistent with the value of the underlying replicating portfolio, the fundamental value, which they argue to be zero due to the extreme out-of-the-money nature of the warrants. The authors offer an explanation based on the "resale-option value" theory of bubbles in the presence of heterogenous beliefs and short sale constraints (Scheinkman and Xiong, 2003). Our approach is complementary, because we focus on a different type of bubble, because we consider failures of the no-bubble condition rather than tests of irrationality theories in finite time, and because we focus on an aggregate asset class, real estate, that constitutes a large fraction of household portfolios rather than individual securities. Finally, a vast and interesting literature pioneered by Smith, Suchanek and Williams (1988) has tested for bubbles in experimental settings. We differ from this literature by analyzing market prices of traded assets with both finite and infinite maturity.

To sum up, bubbles associated with failures of the terminal condition are a workhorse model in finance and macroeconomic theory, and theoretical restrictions to rule them out have been shown to not be binding in practice. Yet, direct empirical tests to verify their existence in the data have been lacking, because of the difficulties of observing market

[11] Geerolf (2014) finds, using new data, more favorable evidence for dynamic inefficiency of advanced economies, and links it to the empirical plausibility of asset bubbles.

[12] Our test also differs from the predictability test for bubbles suggested by Cochrane (2011) because we test the existence of a bubble directly in the level of an asset price. Cochrane's test focuses on whether the bubble accounts for any variation in price-dividend ratios over time and therefore cannot rule out the existence of a bubble that accounts for a constant, and possibly sizable, fraction of the asset price.

[13] The mispricing is generally assumed to persist due to limits to arbitrage (Shleifer and Vishny, 1997).

prices for cash flows at approximately infinite horizons. Our contribution is to provide the first such test.

2 Direct Test of No-Bubble Condition

In this section we describe our empirical approach to directly estimating the value of the bubble claim, B_t, and the institutional setting of the U.K. and Singapore housing markets that we exploit to do so. The next section discusses our data and presents the empirical results.

2.1 Institutional Setting

Residential real estate ownership in both the U.K. and in Singapore comes in two forms: permanent ownership, called a freehold, and long-duration, temporary ownership, called a leasehold. A leasehold is a grant of exclusive possession of the property for a clearly defined, temporary period of time during which the tenant has the right to exclude all other people from the property, including the freeholder (Burn, Cartwright and Cheshire, 2011). In the U.K., common initial leasehold maturities are 99, 125, 150, 250 and 999 years. In Singapore, initial lease lengths are either 99 or 999 years. During the life of the leasehold, the lessee is entitled to similar rights as a freeholder would be, including the right to mortgage and rent out the property. Leaseholds and freeholds are also treated equally for tax purposes. Unlike for commercial leases, the vast majority of the costs associated with a residential leasehold come through the up-front purchase price; annual payments, the so-called "ground rents," are small to non-existent, and do not significantly affect the prices paid for leaseholds. Leasehold properties are traded in liquid secondary markets, where the buyer purchases the remaining term of the lease. Once the leasehold expires, the ownership reverts back to the freeholder.[14,15]

[14] In the U.K., the set of freeholders is widely varied, and includes aristocratic estates, the Church of England, Oxford and Cambridge colleges, the royal family as well as large private corporations. In Singapore, by far the largest freeholder is the government of Singapore, represented by the Singapore Land Authority (SLA). In the U.K., the Leasehold Reform Act 1967 has provided owners of houses with the right to extend the lease. Lease extensions are by and large irrelevant to our study of leases that have unexpired terms of more than 700 years. It is also possible for the leaseholder to buy the underlying freehold (a process called enfranchisement), but we do not observe these transactions in our data. Such lease extensions and enfranchisements entail significant costs, including those for engaging a valuer and a solicitor. In Singapore, no statutory right to lease extensions or enfranchisements exist.

[15] One might be concerned about a number of factors that could differentially affect the flow utility of leasehold and freehold properties. In particular, leasehold contracts may contain covenants that can affect their valuation. Giglio, Maggiori and Stroebel (2013) provide empirical evidence that covenants are unlikely to affect leasehold prices. Section 2.4 discusses not only covenants but also other potential factors that could

2.2 Empirical Test

This setting is uniquely suited to directly testing the no-bubble condition, since it allows us to estimate the present value of a claim to rents occurring at extremely long horizons (e.g., $T > 700$ years). Let us define by P_t the price of the freehold contract at time t and by P_t^T the price of the leasehold contract with maturity T at time t. The freehold is the claim to the infinite stream of rents generated by the property, while the leasehold is the claim to the rents for the first T years.[16] A simple algebraic substitution shows that $P_t - P_t^T = E_t[\xi_{t,t+T} P_{t+T}]$; intuitively, the difference in value between a freehold and a T-maturity leasehold is the present value of the claim to rents starting T years from today and extending to the infinite future, i.e. the present value of the claim to the freehold T years from now.

We focus on maturities of the leasehold in excess of 700 years, a horizon sufficiently long to well approximate the infinity limit of the terminal condition:

$$P_t - P_t^T \approx B_t = \lim_{T\to\infty} E_t[\xi_{t,t+T} P_{t+T}], \qquad \text{for } T > 700 \text{ years.}$$

We can test whether the no-bubble condition, Equation (1), holds on average by testing whether the discount of extremely long leases compared to freeholds is zero. To make the interpretation of the discount easier we standardize this price discount by the price of the freehold: $Disc_t^T \equiv \frac{P_t^T}{P_t} - 1$. Then, $-Disc_t^\infty$ is the fraction of the current price of the asset (the freehold) that is due to the bubble. We correspondingly formulate our null hypothesis of no-bubbles as: $Disc_t^T = 0$ for $T > 700$ years.

Intuitively, a horizon between 700 and 999 years is sufficiently long to approximate the infinite limit of the no-bubble condition. We (informally) quantify the approximation error, by considering the simple Gordon growth environment (Gordon, 1982) where the dividends of the asset grow at rate g and are discounted at a constant rate r. It is then a matter of algebra that $Disc_t^T = -e^{-(r-g)T}$. In the absence of a bubble, even a very low net discount rate of 1% would only imply discounts of -0.09% and -0.001% at 700 and 900 years, respectively. A net discount rate $(r-g)$ of 1% is much lower than the values normally estimated in the literature, which has estimated average housing returns r to be above 6% and rent growth g to be below 1%, leading to a more plausible calibration of $r-g$ above 5%.[17] This confirms that our horizon is sufficiently long for the approximation to

in principle reduce the attractiveness of extremely long leaseholds.

[16] We will assume in the theory that the leasehold and the freehold have identical cash flows, the only difference being the horizon of ownership. Section 2.4 shows that this assumption is validated in the data and further explores its robustness.

[17] See for example Flavin and Yamashita (2002) and Favilukis, Ludvigson and Van Nieuwerburgh (2010).

hold well, even in the presence of very low net discount rates. Finally, Pástor and Veronesi (2003) point out, in the context of internet stocks, that market valuations might appear bubbly, despite the absence of bubbles, if there is sufficient uncertainty about growth prospects, with the possibility of having $r - g$ close to 0 in the long run. As will become clear, this possible confounding effect is not a concern for our estimates because we find valuations to not be consistent with the presence of a bubble, presumed or otherwise.

2.3 Data

Estimating the relative price of leaseholds and freeholds is potentially challenging because the underlying properties are heterogeneous assets, and we do not observe the same properties transacting both as leaseholds and as freeholds. Therefore, to estimate $Disc_t^{\infty}$, we need to compare different properties that are either freeholds or leaseholds. Since leasehold and freehold properties could differ on important dimensions such as property size and location, comparing prices across properties requires us to control for these differences. To do so, we use hedonic regression techniques (Rosen, 1974), which allow us to consider the variation in price over time and across contract type for different properties while controlling for key characteristics of each property.

2.3.1 U.K. Residential Housing Data

We obtained transaction-level administrative data on all residential housing sales between 1995 and 2013 from the England and Wales Land Registry.[18] The data include the price paid, whether the property is a flat or a house, information on the type of property (detached, semi-detached or terraced), the full address, and a "new construction" indicator. In addition, the Land Registry has provided us with an indicator of whether the transaction was for a freehold or a leasehold property, as well as information on leasehold characteristics such as origination date and lease length.[19] For a large subset of properties,

Giglio, Maggiori and Stroebel (2013) show the term structure of housing discount rates to be downward sloping and find a long horizon net discount rate of 1.9% to be consistent with housing data. This discount rate is consistent, in the absence of bubbles, with zero leasehold discounts at horizons greater than 700 years.

[18]In contrast to Giglio, Maggiori and Stroebel (2013), in this paper we do not constrain ourselves to the period following 2003. Land Registry data for leaseholds with shorter duration, between 80 and 150 years, is subject to potential concerns before 2004 related to inconsistent recording of lease extensions. In this paper we can use data back to 1995, since extremely long leaseholds are unlikely to be subject to these concerns even before 2004. This is because extensions and changes in the contract are rare for extremely long leases. All our results are robust to using only data post-2003.

[19]We exclude transactions for properties for which we observe both a freehold and a leasehold transaction. This is because it is unclear whether transactions of the freehold cover the rents after leasehold expiry or the infinite flow of rents. In addition, when the same person purchases both the freehold and the leasehold, it is unclear what the division of price between the two titles captures.

we have obtained proprietary information on property characteristics such as the number of bedrooms, bathrooms, and the size, age and condition of the property. These are collected by Righmove.co.uk from "for sale" listings and other data sources. We observe a full set of hedonic characteristics for approximately 52% of the properties transacting since 1995.

We focus on houses in the U.K., because this market is dominated by freeholds and extremely long leaseholds, whereas the market for flats is dominated by shorter leaseholds. Given that our focus is on the difference between extremely long leaseholds (with 700 years or more of remaining maturity at the time of transaction) and freeholds, Table 1 provides key summary statistics for these two types of contracts in the U.K. sample. Our final dataset contains more than 7.6 million house transactions between 1995 and 2013 for which we observe a full set of hedonic characteristics.

Panel A of Table 1 reports the mean, median and standard deviation of the log price, the number of bedrooms, the number of bathrooms, the age of the property and property size for extremely long leaseholds and freeholds in the U.K. house sample. The third column reports the average difference between the two contract types (Δ). Extremely long leaseholds are, on average, smaller than freeholds in all dimensions, and they are associated with older buildings; overall, they are cheaper. The last column shows the average difference in each characteristic between extremely long leaseholds and freeholds, conditional on the fixed effects we use in our hedonic regression (3-digit postcode $\times$ transaction year $\times$ property type). Once we control for spatial and temporal heterogeneity, extremely long leaseholds and freeholds are much more similar, with all the differences in means economically small, though statistically significant.

Overall, about 4.65% of our transaction sample of houses consists of extremely long leaseholds, 94.3% are freeholds, and the rest are short leaseholds. Figure 1 plots a heatmap of the share of transactions that occur for extremely long leaseholds across 3-digit postcodes. A white postcode indicates an area with no extremely long leasehold transaction; a black postcode indicates an area where 2% or more of the transactions are for extremely long leaseholds. While 1% or 2% may seem a small number, it is large enough to provide us with good identification, given the large size of our dataset. While we find transactions of extremely long leaseholds everywhere in the U.K., there is a clear concentration in the North of England (around Manchester and Liverpool) and the South-West. Importantly, there are several postcodes in Greater London with a nontrivial fraction of extremely long leaseholds; some of our analysis will focus exclusively on this area, depicted in Figure 2.

2.3.2 Singapore Residential Housing Data

We have obtained transaction-level administrative data for all private residential transactions in Singapore from the Urban Redevelopment Authority. We observe approximately 379,000 private market arms-length transactions between 1995 and 2013. For each transaction there is information on the transaction price and date, the lease terms, property characteristics and the precise location of the property. Panel B of Table 1 provides an overview of the extremely long leaseholds and freeholds in our sample. As in the U.K., unconditionally leaseholds tend to be cheaper than freeholds; in Singapore, they are on average slightly larger and younger. The absolute difference between leaseholds and freeholds in terms of observable characteristics is economically small, with and without controlling for our set of fixed effects (5-digit postcode $\times$ transaction year $\times$ property type). Approximately about 6.6% of our sample consists of extremely long leaseholds, 47.7% of freeholds; the remaining transactions are shorter leaseholds.

2.4 Testing the No-Bubble Condition: Aggregate Results

We study the difference in price between extremely long leaseholds and freeholds by estimating the following hedonic regression for the U.K. and Singapore:

$$log(Price_{i,p,h,t}) = \alpha + \beta ExtremelyLongLease_{i,t} + \gamma Controls_{i,t} + \phi_p \times \xi_h \times \psi_t + \epsilon_{i,p,h,t} \quad (3)$$

where the unit of observation is a transaction i of a property of type p in postcode h at time t. The variable $ExtremelyLongLease$ is an indicator of whether transaction i is a leasehold with more than 700 years remaining – the excluded category in the regression is freeholds. The coefficient β captures the log-discount of extremely long leaseholds relative to otherwise similar freeholds. We control for average prices in a property's geography by including property type (ϕ_p) by postcode (ξ_h) by time of sale fixed (ψ_t) effects. For the U.K., we use 3-digit postcodes. For Singapore, we use 5-digit postcodes. In Singapore, we also interact the fixed effects with whether the property is a "land" or "strata" title.[20] We control for various characteristics of the property using standard hedonic variables.[21]

[20] Land title properties occupy land that is exclusive to the owner (e.g., a detached house), whereas a strata title comprises units in cluster housing (e.g., an apartment). Owners of strata properties enjoy exclusive title only to the airspace of their individual unit. The land that the development is built on is shared by all the owners of the project, based on the share of the strata title unit owned by each owner.

[21] For both the U.K. and Singapore, we control for the size and age of the property in a flexible way by including dummy variables for 50 equally sized groups of these characteristics. In addition, for the U.K. we include as controls: number of bathrooms, bedrooms, property condition, whether there is parking, whether the property is new, and the type of heating. In Singapore, we instead include the number of units in the development. Finally, we include transactions of short leaseholds (with less than 300 years remaining) in our sample, properly controlling for the lease length remaining at the time of the transaction

Standard errors are clustered at the postcode level.

Tables 2 and 3 report the results for the U.K. and Singapore, respectively. Our preferred specification, reported in the first column of each table, uses transaction year in the fixed effects ψ_t. For both the U.K. and Singapore, there is no significant difference between the price of a 700+ year leasehold and that of a freehold. While standard errors are larger for Singapore where we have fewer data, for the U.K. the discount is a precisely estimated zero. Columns (2) and (3) of each table use transaction quarter and month, respectively, to account for time fixed effects ψ_t; results are robust to these variations. The remaining columns of each table explore robustness to features specific to each country.

For the U.K., we explore whether the discount (that, in the first three columns, is estimated using our full sample of England and Wales) is different in different geographic areas. In particular, in column (4), we estimate the discount for the postal district of London. We find the discount economically small (-1.7%) and statistically indistinguishable from zero. In column (5) we further zoom into Prime Central London (PCL), defined as the areas of Mayfair, Knightsbridge, Belgravia, Chelsea and Kensington. This area has experienced particularly significant run-ups in prices over the past decade, and is often described in the media to exhibit the features of a housing bubble (The Guardian, 2013). Even in this geography, we find the price difference between extremely long leaseholds and freeholds to be indistinguishable from zero (and, indeed, even slightly positive). However, the small number of house transactions in London, particularly in PCL, diminishes our statistical power.

For Singapore, in column (4) we restrict the sample to private buyers (as opposed to the public authority, the Housing and Development Board), and in columns (5) and (6) we restrict the sample to the two types of title, "land" or "strata". In all cases, the estimates of the discount of extremely long leaseholds relative to freeholds are economically small and statistically insignificant.

When estimating leasehold discounts using hedonic regressions, one might be worried about other factors that may affect the observed discounts and that are not fully captured by our hedonic regressions. Since, as shown in Section 2.3.1, freehold houses are somewhat better on all observable characteristics, it is unlikely that they are sufficiently worse on the unobservables to mask a possible bubble. Indeed, several unobservable factors may actually reduce the value of leaseholds, and thus imply a discount relative to freeholds that may resemble a bubble. These include financing frictions, covenants, differential liquidity, differential marginal buyers, and, more generally, any unobserved

as in Giglio, Maggiori and Stroebel (2013). We include short leaseholds in our sample – even though they are not the focus of this paper – to maximize power, since they help identify the hedonic coefficients and the fixed effects. All results are robust to excluding them.

factor that could differentially affect the flow utility of leasehold and freehold properties. These alternative explanations for observed discounts are discussed in detail in Giglio, Maggiori and Stroebel (2013). Here, we do not explicitly consider these alternative explanations, because they are either irrelevant for long leaseholds (for example, financial frictions only affect very short leaseholds), or, to the extent that they might affect extremely long leaseholds, they would *reduce* their value relative to freeholds, and therefore would push against our result of finding no difference in the two prices.[22]

One final consideration is the statutory right, present in the U.K. but not in Singapore, of the leaseholder to purchase the underlying freehold. Such optionality would not affect our results if such purchases happen at market prices, make our results conservative if they happen above market prices, and bias our results toward finding no bubble if they happen at below market values. This latter case could, for example, occur if the prices of enfranchisements that may be enforced through courts in the U.K. were low relative to households' true valuation, despite the requirements of the Leasehold Reform Act 1967 that courts focus on market values.[23] However, since such enfranchisements generate significant fixed costs (including direct financial costs for valuers and solicitors), involve negotiations which may protract for years, and entail some legal uncertainty,[24] the price impact of court-induced enfranchisements is likely to be small. In addition, no right to leasehold enfranchisement exists in Singapore, yet we find similarly small to non-existent price differences between extremely long leaseholds and freeholds.

2.5 Testing the No-Bubble Condition: Time Series

We conclude that there is no evidence in our data supporting the presence of infinitely-lived bubbles. Of course, the tests reported in Tables 2 and 3 are evidence that *on average* the prices of freeholds and extremely long leaseholds are very close to each other. It is possible that a bubble in the housing market might have originated only late in the

[22] Purchases of property in the U.K. are subject to a transaction tax (stamp duty). The tax applies equally to freehold or leasehold purchases. The tax schedule is progressive: for example, a purchase of a property up to £125,000 is tax exempt, while a purchase of a property between £125,001 and £250,000 is taxed at 1% of the *total* purchase price. This tax schedule potentially makes shorter term leases more attractive because for similar properties a shorter, and thus cheaper, leasehold might avoid incurring the higher tax bracket. Since the brackets are very wide, this would be unlikely to have a large average effect.

[23] The Leasehold Reform Act 1967 establishes that if leaseholder and freeholder cannot agree on the appropriate price paid for a lease extension or enfranchisement, they can appeal to a government-run leasehold valuation tribunal (LVT) – and, since July 2013, the First-tier Tribunal (Property Chamber) – with the power to set the prices. It is extremely hard to compare the prices of enfranchisements to the market value of the underlying properties, because the underlying properties are not being transacted at the time of enfranchisement.

[24] For example, the Leasehold Reform Act 1967 grants landlords the right to resist tenant's claim to the freehold or an extended lease of a house where he intends to redevelop it or to occupy it as his own home. In addition, the cost of going to court can easily run into the tens of thousands of pounds.

sample, or even originated and then collapsed within our sample period. Therefore, the bubble may only being present for a short period of time, and thus be undetectable when looking at an average over 20 years.[25] As a more stringent test, Figures 3 and 4 report the discounts in the U.K. and Singapore estimated separately for each year (bottom panels). While our statistical power decreases and standard errors increase, both figures show that there is no evidence of a bubble at any point in time between 1995 and 2013 in either country, because the extremely long leasehold discount is never significantly different from zero. For the U.K., we can rule out with 95% confidence that the bubble term B_t was more than 2.5% of the value of the freehold in any year between 1995 and 2013.

This latter time series test is of particular interest because it shows the absence of an infinitely-lived bubble even at the peak of the housing market in 2007, after years of strong house price growth. The top panels of Figures 3 and 4 show the time series of the real price indices of the U.K. and Singapore together with a "bubble index" constructed from newspaper article mentions of real estate bubbles. The Figures show that the fast increase in house prices in the two countries was accompanied (and partly followed) by a large increase in the mention of house price bubbles in newspapers.[26] Indeed, many commentators directly ascribed the run-up in house prices before the financial crisis to the presence of a large bubble in this market (Case and Shiller, 2003; Caballero and Krishnamurthy, 2006; Gali, 2014). Glaeser and Nathanson (2014) review the debate on housing bubbles and point to a number of models that could rationalize the price dynamics due to (combinations of) search frictions, heterogenous beliefs, and rational bubbles. Within models of real estate bubbles, the closest theoretical paper to our empirical tests is Arce and López-Salido (2011) that develops an infinitely-lived rational bubble model of real estate prices. In contrast to this view, we find no evidence of this type of bubble, precisely where and when we would most expect to see it.[27]

[25] Within theory models the origin of bubbles remains unclear and bubbles are often assumed to be present at the start of the model rather than arise endogenously. Similarly, within many models, a bubble cannot arise again after it has exploded. In our empirical work, we take the agnostic view that the bubble might only have been present for a temporary period in our data.

[26] For the U.K., the "bubble index" counts the number of times the phrases "real estate bubble" and "U.K." appear in the 11 largest U.K. newspapers. For Singapore, it counts the number of times the phrases "real estate bubble" and "Singapore" appear in the world's most widely-circulated English-language newspapers and periodicals. The data source is ProQuest.

[27] As emphasized in Section 1, while our paper does empirically rule out the presence of an infinitely-lived bubble in the real estate market, it is silent on the presence of other type of bubbles that are for example the focus of Glaeser, Gyourko and Saiz (2008), Piazzesi and Schneider (2009) and Nathanson and Zwick (2014). A number of papers have provided theories of the boom and bust in house prices that do not rely on infinitely lived bubbles. For example, Burnside, Eichenbaum and Rebelo (2011) explicitly exclude explosive solutions of the asset pricing recursive equation. Other explanations focus on the role of mortgage credit availability, in particular for lower-income households (Mian and Sufi, 2009; Landvoigt, Piazzesi and Schneider, 2012).

3 Conclusion

We provide a direct test for the existence of housing bubbles that rely on violations of the terminal condition in asset valuation. We exploit the heterogeneity in ownership contracts for real estate in the U.K. and Singapore, which feature both infinite maturity ownership (freehold) and temporary ownership (leasehold) for a very large but finite number of years. If a bubble based on a failure of the standard no-bubble condition were present in these housing markets, it would affect the price of the freehold but not that of the extremely long leasehold. Empirically, we find that after controlling for observable characteristics of the properties, the two contracts sell for identical prices. This result holds in every year in our sample (1995-2013), and directly implies that bubbles that violate the terminal no-bubble condition were not present in these housing markets.

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Table 1: Summary Statistics

Panel A: U.K.

	700+ Leaseholds			Freeholds			Δ	SE	Δ FE	SE
	Mean	Median	Std	Mean	Median	Std				
Log Price (£)	11.26	11.29	0.71	11.70	11.74	0.73	-0.44	0.03	-0.01	0.01
Bedrooms	2.74	3	0.79	3.01	3	0.87	-0.26	0.02	-0.10	0.01
Bathrooms	1.16	1	0.44	1.30	1	0.58	-0.14	0.01	-0.02	0.00
Age (years)	66.6	71	43.26	58.12	50	48.75	8.47	1.32	-2.75	0.92
Size (m^2)	101.5	93	55.52	112.8	100	58.17	-11.26	0.77	-5.04	0.51
N		353,309			7,167,253					

Panel B: Singapore

	700+ Leaseholds			Freeholds			Δ	SE	Δ FE	SE
	Mean	Median	Std	Mean	Median	Std				
Log Price (SG$)	13.97	13.89	0.53	14.02	13.92	0.63	-0.05	0.04	0.02	0.07
Age (years)	4.47	0	7.41	5.20	0	8.79	-0.75	0.33	0.23	1.12
Size (m^2)	175.5	134	147.3	173.1	129.0	197.1	2.72	6.19	3.84	6.36
N		26,197			174,126					

Note: Table shows summary statistics for the U.K. transaction sample (Panel A) and the Singapore transaction sample (Panel B). For each of our key hedonic characteristics, we show the mean, median and standard deviation separately for extremely long leaseholds and freeholds. We also show the average difference between extremely long leaseholds and freeholds (Δ), and the average difference after controlling for the fixed effects in the hedonic pricing regressions (Δ FE). For each type of contract we report the sample size (N). All standard errors are clustered at the postcode level.

Table 2: U.K.: Impact of Lease Type on Prices

	(1)	(2)	(3)	(4)	(5)
700+ Year Leasehold	0.001	0.001	0.001	-0.017	0.009
	(0.005)	(0.005)	(0.005)	(0.026)	(0.062)
Fixed Effects	PC × Y × Prop	PC × Q × Prop	PC × M × Prop	PC × Y × Prop	PC × Y × Prop
Controls	✓	✓	✓	✓	✓
Sample	England & Wales	England & Wales	England & Wales	London	PCL
R-squared	0.883	0.886	0.887	0.892	0.871
N	7,602,276	7,602,276	7,602,276	285,281	52,336

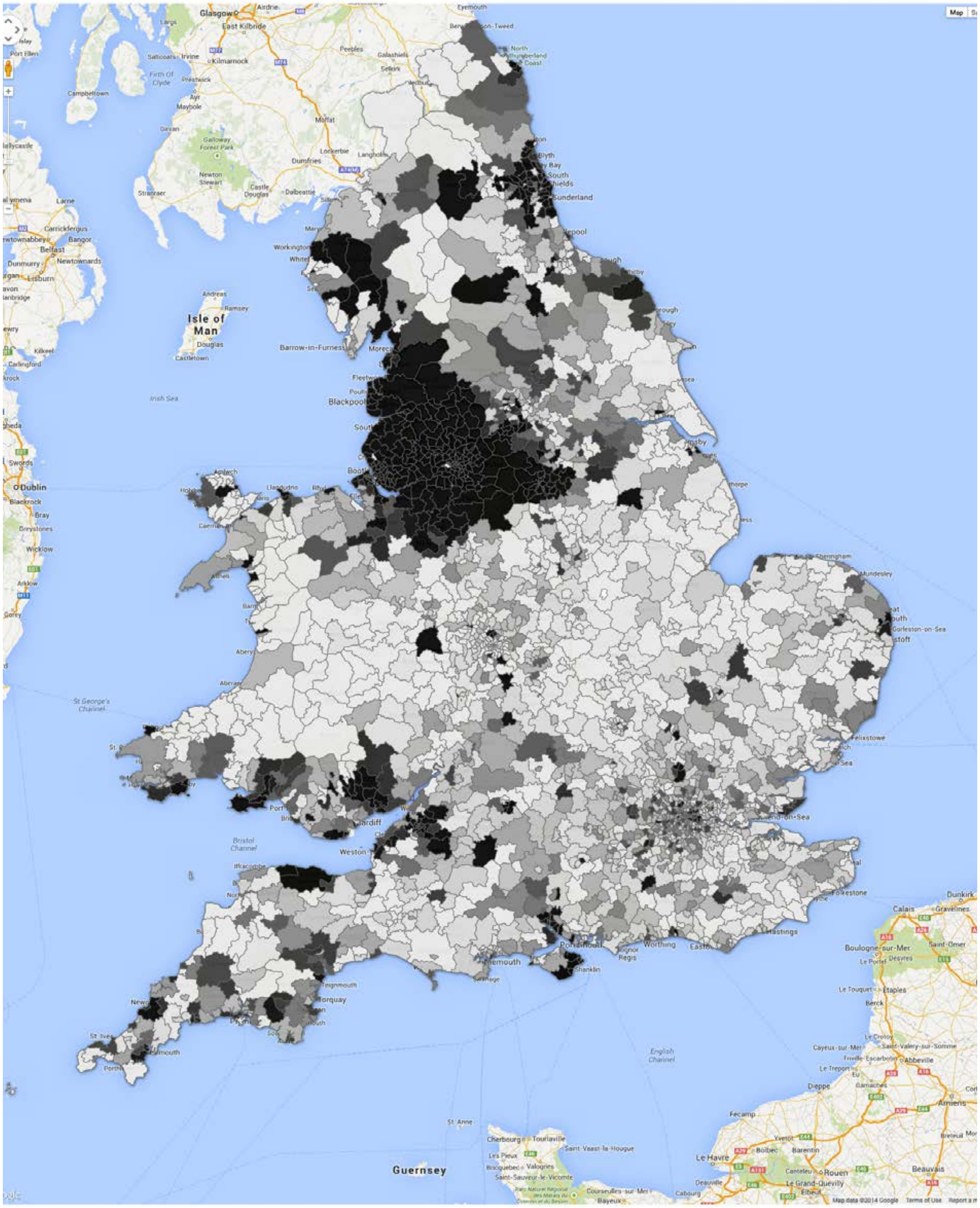
Note: Table shows results from regression (3). The dependent variable is the log price paid for houses in England and Wales between 1995 and 2013. We include fixed effects at the 3-digit postcode by transaction date by property type (detached, semi-detached, terraced) level. In columns (2) and (3) the transaction date is the transaction quarter and month, respectively, in the other columns the transaction year. In columns (1) - (3) we focus on on all transactions in England and Wales, in column (4) in the postal district of London, and in column (5) in Prime Central London (PCL). We control for property size, the number of bedrooms and bathrooms, property age, property condition, whether there is parking, and the type of heating. Standard errors are clustered at the 3-digit postcode level. Significance levels: * ($p<0.10$), ** ($p<0.05$), *** ($p<0.01$).

Table 3: Singapore: Impact of Lease Type on Prices

	(1)	(2)	(3)	(4)	(5)	(6)
700+ Year Leasehold	-0.012	-0.010	-0.007	-0.009	-0.012	-0.008
	(0.035)	(0.034)	(0.039)	(0.039)	(0.035)	(0.054)
Fixed Effects	PC × Y × Prop × Title	PC × Q × Prop ×Title	PC × M × Prop × Title	PC × Y × Prop × Title	PC × Y × Prop	PC × Y × Prop
Controls	✓	✓	✓	✓	✓	✓
Sample Restriction	·	·	·	Private Buyer	Strata Only	No Strata
R-squared	0.967	0.977	0.979	0.966	0.964	0.959
N	378,768	378,768	378,768	220,044	333,684	45,084

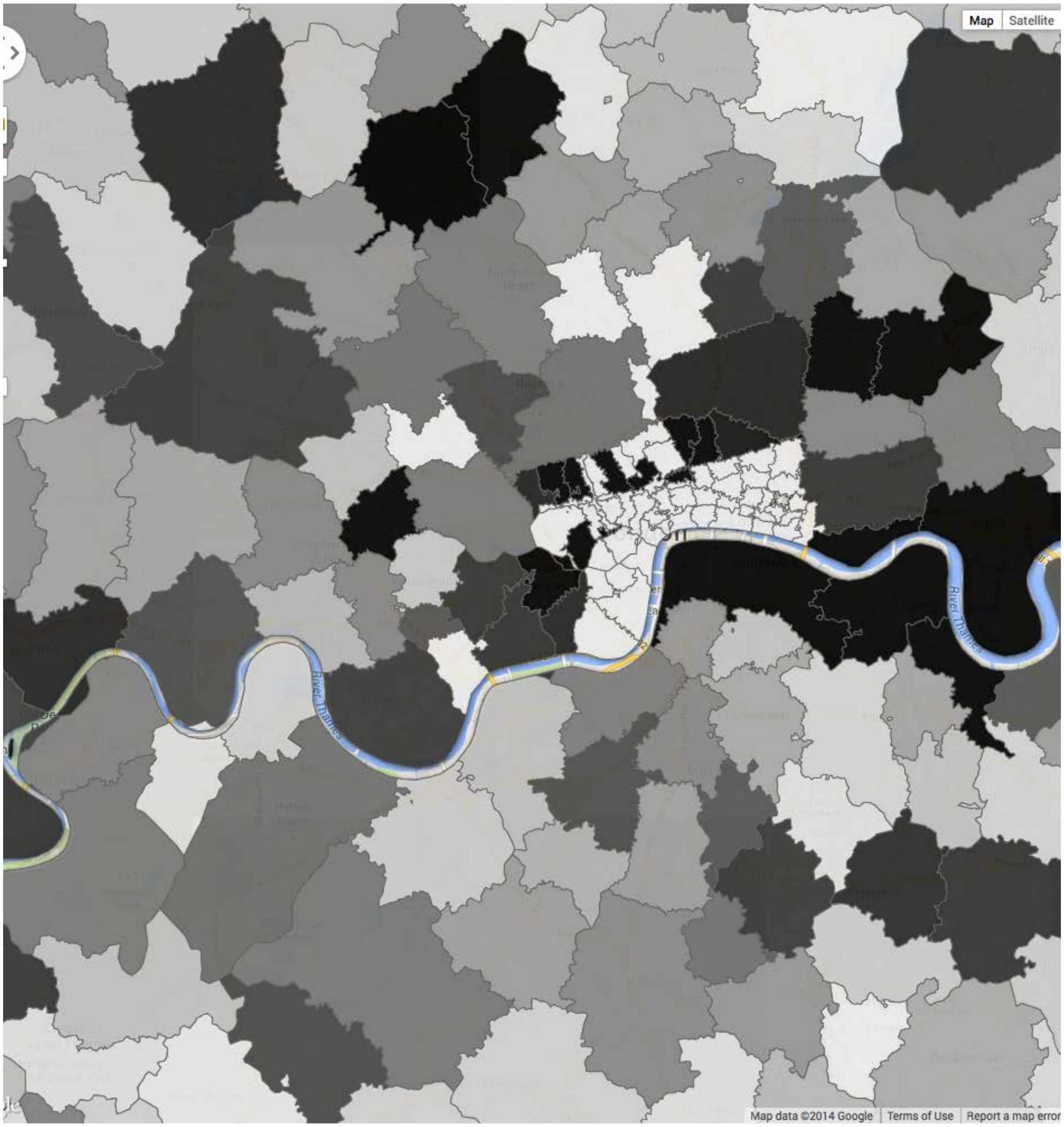
Note: Table shows results from regression (3). The dependent variable is the log price paid for properties sold by private parties in Singapore between 1995 and 2013. We include fixed effect at the 5-digit postcode by property type (apartment, condominium, detached house, executive condominium, semi-detached house and terrace house) by title type (Strata or Land) by transaction date level. In columns (2) and (3) the transaction date is the transaction quarter and month, respectively, in the other columns the transaction year. In column (4) we only focus on properties that were bought by a private individual (and not the HDB). In columns (5) and (6) we conduct the analysis for Strata and non-Strata titles separately. We control for property age, property size and the total number of units in the property. Standard errors are clustered at the 5-digit postcode level. Significance levels: * ($p<0.10$), ** ($p<0.05$), *** ($p<0.01$).

Figure 1: U.K. Sample - Distribution of 700+ Year Leaseholds



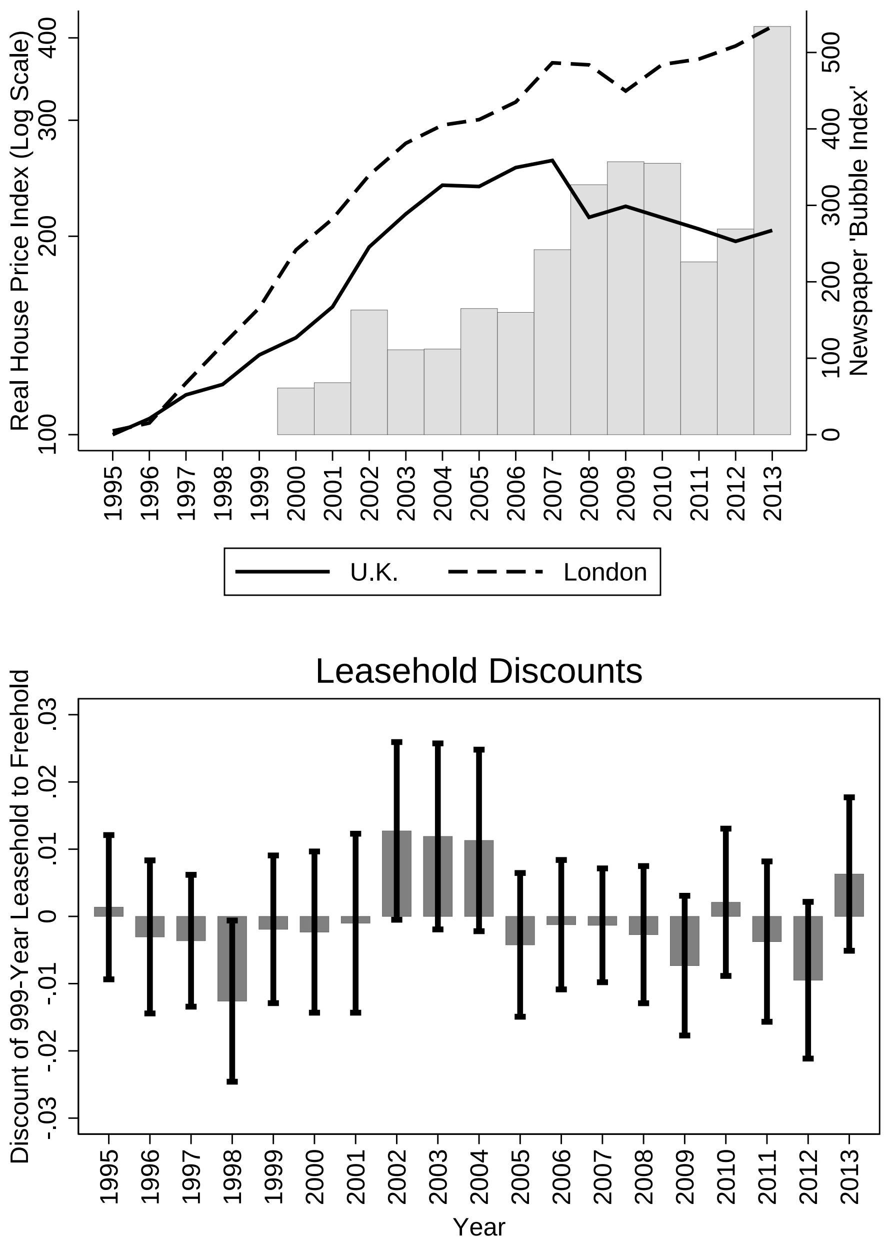
Note: The map shows for each 3-digit U.K. postcode the fraction of transactions of leaseholds with more than 700 years remaining. White indicates that the fraction was 0%. Black indicates that 2% or more of the transactions were of extremely long leaseholds, with gray indicating intermediate percentages.

Figure 2: U.K. Sample - Distribution of 700+ Year Leaseholds - London



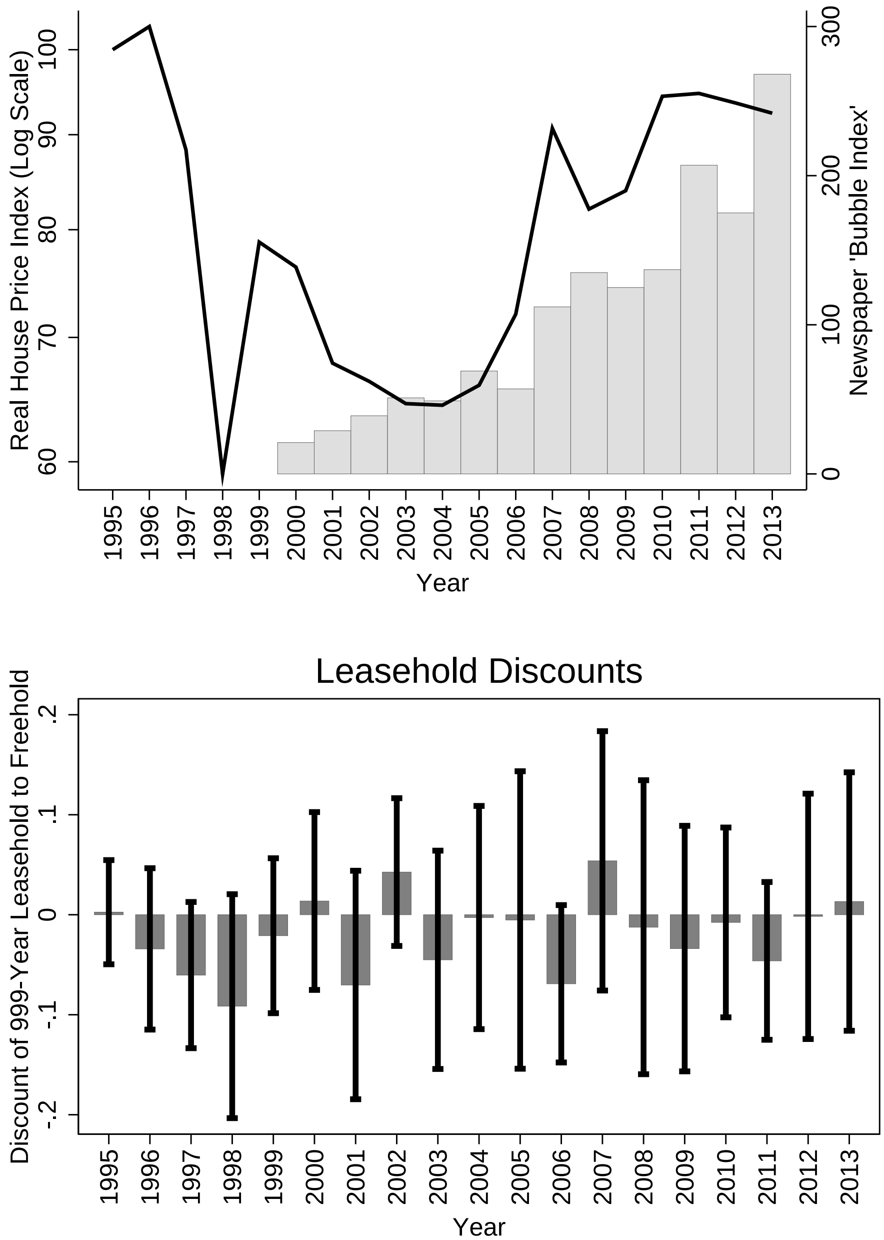
Note: The map shows for each 3-digit U.K. postcode the fraction of transactions of leaseholds with more than 700 years remaining. White indicates that the fraction was 0%. Black indicates that 2% or more of the transactions were of extremely long leaseholds, with gray indicating intermediate percentages. The figure zooms in on London.

Figure 3: U.K. - Time Series



Note: The top panel shows a time series of house prices in the U.K. (solid line) and for London (dashed line) on the left scale, and a "bubble index" constructed from newspaper articles on the right scale (bars). National nominal house price data are from the Nationwide House Price Index, London house prices are from the Land Registry. We divide the nominal index by the U.K. Office of National Statistics "long term indicator of prices of consumer goods and services" to obtain a real house price index. The "bubble index" counts the number of times the phrases "real estate bubble" and "U.K." jointly appear in the following newspapers: The Sun, The Daily Mail, The Daily Telegraph, The Times, The Sunday Times, The Guardian, The Financial Times, The Independent, The Observer, The Daily Mirror, The Sunday Mirror, as reported by ProQuest. The "bubble index" can only be constructed from 2000 onwards. The bottom panel shows year-by-year estimates of the discount between 700+ year leaseholds and freeholds from regression (3), constructed by interacting the indicator $ExtremelyLongLease_{i,t}$ with calendar year. The bars indicate the 95% confidence interval of the estimate using standard errors clustered at the 3-digit postcode level.

Figure 4: Singapore - Time Series



Note: The top panel shows a time series of house prices in the Singapore on the left scale (line), and a "bubble index" constructed from newspaper articles on the right scale (bars). The nominal annual house price index is from the Urban Redevelopment Authority. CPI is from Statistics Singapore. We obtain the real house price index by deflating the nominal index by CPI. The "bubble index" counts the number of times the phrases "real estate bubble" and "Singapore" jointly appear in the world's most widely-circulated English-language newspapers and periodicals, as reported by ProQuest. The "bubble index" can only be constructed from 2000 onwards. The bottom panel shows year-by-year estimates of the discount between 700+ year leaseholds and freeholds from regression 3, constructed by interacting the indicator $ExtremelyLongLease_{i,t}$ with calendar year. The bars indicate the 95% confidence interval of the estimate using standard errors clustered at the 5-digit postcode level.