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Price Bubbles in Private Real Estate

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CEA@Bayes Working Paper Series

WP-CEA-02-2023

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February 16, 2023

Abstract

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Keywords: Bubbles, Commercial Real Estate, Explosive behavior, Real estate price index.

J.E.L. Classification: C58, E30, E44, R30.

*This research started when Peter Cincinelli was visiting the Centre for Econometric Analysis (CEA) of Bayes Business School during July-August 2022.

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1 Introduction

In this paper, we study the presence of bubble episodes in the United Kingdom (UK) private real estate sectors (Retail, Offices, Industrial), using the backward supremum Augmented Dickey Fuller (BSADF) approach (Phillips et al., 2015a, 2015b) during December 1986 to April 2022 time period. We also investigate how economic, financial and real estate indicators are related to such explosiveness.

The real estate market plays an important role in financial and banking crises either precipitating or aggravating adverse developments, as in the economic slump and banking troubles in the UK in the early 1990s (Gentle et al., 1994), the Asian financial crisis in 1997 (Quigley, 2001; Collyns & Senhadji, 2002), and the global financial crisis in 2008-09 (Bullard et al., 2009; Stanton & Wallace, 2010; Mishkin, 2011). During these crises, lenders and investors (particularly the latter in the global financial crisis) have heavy exposure to the property market. A significant and sudden fall in property values accompanied by a reduction in the disposable income generated by real estate proves damaging for the banking sector, construction companies, and for general investors exposed to real estate.

Episodes of overvaluations in the real estate sector and the potential destabilizing effects of price bubbles bursting are flagged up as a source of risk to the broader financial system and the economy (European Systemic Risk Board (ESRB), 2015; Mallbauer, 2022), and may lead Government interventions, across the globe, in order to reduce the probability of a housing market failure (Floro, 2019; Akbari & Krystyniak, 2021). Significant falls in property values and deficient cash flows from underlying real estate assets most likely leads to a credit crunch and cause stress to lenders not only through a breach of underwriting criteria but also through a rise in nonperforming loans. Investment portfolios of pension funds and sovereign funds (with allocations that can exceed 15%), insurance companies and property funds face large reductions in their portfolio valuations. Property funds may even be forced to cease trading as the case was in summer 2016 in the UK. Further, the impact on the construction industry is severe

too as values may not cover replacement costs bringing construction activity to a halt with apparent repercussions on fixed capital investment and employment. Even if overvaluations in real estate are not per se the trigger for a financial crisis, they increase the vulnerability of the financial system to exogenous or internal shocks.

The potential destabilizing effect of overvaluations in the real estate market, with prices not supported by fundamentals creating conditions for price bubble formation, has long been acknowledged by scholars. Relevant research on price bubble in real estate is ongoing and follows the tradition of the broader literature on the subject. In line with this literature, real estate studies are concerned with: (i) generating sustainable or equilibrium values for real estate that reflect fundamentals and (ii) applying alternative methods to detect deviations of actual values from their fundamental path and hence establish the formation of price bubbles and their size. The pursuit of these objectives in empirical research informs the decision making of lenders, investors and developers.

There are two broad streams in price bubble work in real estate. The first stream focuses on the securitised segment of the market primarily represented by listed Real Estate Investment Trusts (REITs) and related corporations such as real estate operating companies. The second stream examines price bubbles in the private sector, underlying, or direct market (representing the actual real estate assets). This distinction is important to be made as the causes for price bubble formation and the triggers for the potential burst of the bubble in the two segments can be diverse. There is plenty of research on real estate bubbles especially for US REITs reflecting the greater availability of data (Brooks et al., 2001; Jirasakuldech et al., 2006; Anderson et al., 2011; Nneji et al., 2013; Escobari & Jafarinejad, 2016; Xie & Chen, 2015; Huerta-Sanchez et al., 2020).

The private or underlying real estate market deserves attention as it is the segment that backs values and performance across the property sector. REITs valuations reflect (and expected to reflect) the real assets REITs are invested in (Waters & Payne, 2007; Hoesli & Oikarinen, 2021). On the debt side of the market, conditions in the private market under-

lie the underwriting of debt products. The global financial crisis demonstrates how complex derivatives such as collateralized debt obligation became worthless when the underlying market (primarily residential) run into trouble.

Within the private element of the real estate sector it is appropriate to make a further distinction between work on the residential and commercial sectors. Most of the work is on the residential sector (Goodman & Thibodeau, 2008; Baur & Heaney, 2017; Bourassa et al., 2019; Pavlidis et al., 2019). These studies develop fundamental models of the housing market and apply alternative methods to detect and quantify the size house price bubbles. In contrast, there is a dearth of studies on the private commercial sector the main components of which are offices, retail and warehouses. The commercial component in institutional portfolios is large. In the UK, based on Morgan Stanley Capital International (MSCI) data for 2021, the office component was 20.5%, the retail component 25% and the industrial/distribution warehouse allocation 32.6%, with residential representing a much smaller proportion of 8.3%. With a 78% allocation to the commercial sector, a collapse in commercial property prices will have significant repercussions on investor portfolio valuations and renders the early detection of price bubble incidents in commercial real estate a valuable exercise.

A small number of early studies addressed the topic of commercial price bubbles (Hendershott, 2000; Hendershott et al., 2003) but it is only recently that the topic is examined more systematically. An example is the work on price bubbles in the private commercial market by Deghi et al. (2021) and Investment Property Forum Research Report (IPF, 2020). The present study focuses on price bubbles in the private commercial real estate market and furthers recent work on the topic. The aim is to detect bubbles in UK commercial real estate and identify indicators responsible for their formation. The empirical findings form part of an early warning system that key participants in this market -lenders, investors and developers- can use to detect the creation of bubbles on a continuing basis. For example, the findings are informative to property investors (property funds, pension funds, sovereign wealth funds, private equity, other), for possible portfolio rebalancing as the formation of a price bubble is detected. Similarly, lenders

can adjust underwriting criteria and review risk assessments.

This study makes a number of further empirical contributions. A well-known feature of real estate markets is that they are diverse, there is much heterogeneity among geographical markets and sectors alike. Countries have different levels of liquidity and display varied degrees of transparency, as documented in the surveys by JLL (2022). Hence, this factual geographical heterogeneity of real estate markets warrants the study of real estate price bubbles at country specific level. It should be noted that the degree of market transparency and information efficiency determine the quality of appraisals and market pricing. Similarly pricing is affected by different levels of liquidity (that is the volume of real estate assets transacted). In less transparent, less informationally efficient markets price bubble formation can be concealed or exuberance about real estate prices not assessed properly. In thin markets (lack of transactions) price evidence from market trades is sparse. In this paper we acknowledge that the study of bubbles is more appropriate to be country specific controlling for such non-cyclical factors that can distort pricing. Our focus is the UK market which is considered one of the most transparent real estate markets globally.

A further contribution we make is the study of bubbles at sector level. Deghi et al. (2021) refer to the relevance of e-commerce in the study of bubbles in the retail sector. Indeed, the dynamics of price developments in retail differ from those in the office sector. The latter for example, as result of the COVID-19 pandemic and technology facilitating remote/smart working, faces a new occupation paradigm that is likely to shock demand for office space, rents and prices. In contrast, the business of logistics drives pricing in the distribution warehouse sector. A study that has made this distinction is Xiao & Tan (2007) for Hong Kong real estate: authors break down the real estate market into three commercial parts (offices, retail, flatted factories) and residential, and deploy a state space model to spot bubbles. In conclusion these authors claim that the results do not clearly establish the bubble proportion in each sector. Still though, there is evidence to suggest that prices are not explained by fundamentals across the board and tentatively retail and flatted factories exhibit greater bubble proportions. Clearly,

work at sector level brings additional information and improves our understanding of real estate price bubble dynamics. Another notable feature of the present investigation, is the monthly frequency of the data we use for the underlying market, as per the study of Xiao & Tan (2007), that allows the study of price bubbles by sector monthly. Monitoring bubble formation at monthly intervals is particularly valuable at times of uncertainty.

There are several approaches to test for the presence of bubbles. In this paper we apply the Backward Supremum Augmented Dickey Fuller (BSADF) approach, introduced by Phillips et al. (2015a,b), to find evidence of a bubble. This method detects bubbles in all sectors but the date of occurrence of bubble episodes do not coincide. This supports the argument that a more aggregated analysis of price bubbles in the private market conceals sector specific dynamics. We subsequently investigate how key indicators relate to the explosiveness of prices. We examine the role of a number of indicators the choice of which is guided both by existing studies and also time series that are closely monitored by real estate professionals in the UK when assessing property market trends. The results show that the relevance of the indicators differs by sector. Sector risk premia, UK Consumer Price Index (CPI) inflation and the composite leading indicator are relevant to the explosiveness of prices across all sectors. The significance of employment, rents and consumer confidence varies by sector.

The paper is organized as follows. Section 2 provides a review of studies with focus on the commercial property market. This review contains methods to spot bubbles in real estate and methods to produce fundamental values. Section 3 outlines the data and the methodology. The empirical results are reported in Section 4. Section 5 reports sensitivity analyses. Section 6 concludes.

2 Literature Review

In this section, we review some selected studies to illustrate how the price bubble research has evolved in real estate and how it should progress to assess risks to lenders, the economy

and property investors. A workable distinction of this research area can be made between securitised and private real estate.

Most of the papers on bubbles in securitised real estate, specifically on REITs, focuses on the United States (US). This is the result of readily available REITs data, spanning back to the early 1970s, and the straightforward application of methods deployed in similar studies in the stock market. The production of fundamental REITs share prices is broadly common across studies. The dividend growth model and the Gordon growth model are mostly used. Based on pertinent studies in the stock market, a range of tests is used to establish the presence of bubbles in REITs prices.

Brooks et al. (2001) and Brooks & Katsaris (2003) examine whether actual and fundamental REITs prices cointegrate. The presence of cointegration is indicative of bubbles (originally suggested by Diba & Grossman (1988a; 1988b)). Jirasakuldech et al. (2006) apply several tests to detect price bubbles. They consider the consumer price index, industrial production, the federal funds rate and the default risk premium (spread of Aaa and Baa bonds) as the fundamental variables determining equity REITs returns. The simple approach to detect bubbles is checking the integration order of the fundamental variables and actual prices. If the integration order of the latter is higher than that of the former it is a sign of a bubble. The second method comprises cointegration tests to study the presence of a bubbles in prices. A third approach is based on the duration dependence principle that underpins relevant work in the stock market (Cochran & Defina, 1995). This method utilises the relationship between the length of a positive run and the probability of the positive run ending.

Waters & Payne (2007) apply a momentum threshold autoregressive process to the residuals of the cointegrating relationship between REITs prices and dividends. The objective is to pick up possible asymmetric adjustments in the case of positive or negative bubbles. This method is appropriate to establish periodically collapsing bubbles.

Anderson et al. (2011) apply the van Norden-Schaller model (Van Norden & Schaller, 1993) to detect periodically collapsing bubbles and calculate the probability of a bubble collapsing.

This methodology examines the different behaviour of returns in two regimes – a bubble surviving and a bubble collapsing regime. The probability of a bubble collapsing depends on the size of the bubble. A measure of the size of the bubble is used to determine the regime and regime switching. The fundamental values in this study are generated from the dividend multiple measure. These authors develop and evaluate trading strategies to profit from early signals about a bubble collapsing. These strategies are based on forecasting the time varying probabilities of a bubble collapsing. Periodically collapsing bubbles represent one of the focal points of Phillips et al. (2011) and subsequent work by these authors.

2.1 Private Real Estate

Price bubble research in the private real estate market is sparse and yet this is the segment of the market that can be a source of major risks. In price bubble investigations, the situation in the direct market is opposite from that in the securitised market. There is dearth of studies on price bubbles much owing to the restricted availability of data unlike the REITs market. Still though there is data for such research in certain jurisdictions (UK, US). In other market the length and frequency of the available data is short of what scholars would desire. Another reason is the idiosyncrasies of the private market that must be considered when generating fundamental values. A factor than can complicate the outcome and interpretation of price bubble research in the private market is the range of models constructed to explain prices in the real estate market. There is much work on price determination in commercial real estate and the range of models estimated can result in different fundamental values. Nevertheless, the reality remains, that there is a notable gap in price bubble research in real to estate to be filled.

Two recent studies have addressed the deficiency of bubble research in real estate. The overall objective of the paper by Deghi et al. (2021) is to study the impact of commercial price bubbles on the economy and the banking system. Following the conventional structure in such

research, these authors estimate fundamental (or fair) values. The deviation of fair values from the actual values determine the size of "misalignment" in prices. A structural VAR represents a general equilibrium framework to obtain fair commercial property values. The variables entering this VAR are net operating income growth, the spread between the capitalization rate (cap rate) and government bond yields, the output gap, yearly CPI inflation, non-financial corporate credit-to-output gap, broad money to output, the 3-month short-term interest rate and capital flow to output. The impact of price misalignment on future (commercial real estate) CRE prices is quantified with the construction and use of a commercial real estate price at risk measure. They find that a ten-basis point rise in misalignment corresponds to a 2.5% increase in downside risk in advanced economies. This impact on prices can amount to 10% over a three-year period.

The study by IPF (2020) takes a different approach. The generation of fundamental values is based both on naïve methods and simple empirical models. The empirical models in this study are reduced type regression equations. A key differentiation from the study of Deghi et al. (2021) is that bubbles are studied in capital values (prices) not in total returns. In terms of cycles there is little difference between the two (see Figure 1). Defining capital value as rent over the capitalization rate, price bubbles in the IPF study are examined through: (i) direct tests on the capital value series and (ii) based on trends in sustainable rents and sustainable cap rates. Income or rent in the IPF study is explicitly modeled to get equilibrium rent values whereas Deghi et al. (2021) use the actual net operating income.

Similarly, in the IPF (2020), cap rates are modeled to establish equilibrium cap rates. Based on the definition earlier, equilibrium/sustainable capital values are produced from sustainable rents divided by sustainable cap rates.

A noteworthy feature of the IPF study is the use of different models for equilibrium rents and cap rates. The study then assesses whether implied price corrections (by all models/methodologies) accurately predict actual outturns and whether these results are sensitive to the different methodologies used. The evaluation is based on the conventional mean error,

mean absolute error, root mean squared error and Theil U1 metrics. The overall picture from this forecast evaluation suggests that the method to obtain sustainable values and consequently implied corrections does matter. Model predictions can have different biases, the size of the error can differ with some models performing better on the mean error and mean absolute error criteria but worse so on root mean squared error and Theil U1 metrics which penalize for large errors. A further implication of this study is that results seem to be conditional on the actual data series used. In the IPF study the analysis is performed with MSCI UK Real Estate Indexes data along with data from Rent and Yield Monitor (CBRE) and JLL UK Property Index (JLL) (that is three sources but the MSCI data are dominant in acceptance and usage).

Given the importance of the private real estate market to the wider system, in this paper we focus on the private real estate market, which has important policy implications and/or warning signals for lenders and investors. The aims can extend to assess whether corrections implied by the estimated bubbles materialise (as in the IPF study).

Further it is recommended that the geographical focus should be the UK. This reflects the availability and superior quality of real estate data in the UK. This enables a researcher to have choice of more methodologies to deploy. Within the UK it is appropriate to execute the analysis by main sector, that is office, retail and industrial. In this way the research will be able to address additional questions. For example are bubbles occurring simultaneously in every sector and are they of the same magnitude? This is important information for say lender to have as the industrial may experience lower price bubble risks compare to another sector. Collapsing all sectors into a general category masks different price bubble dynamics.

Our focus in bubbles is capital values. This is because the income return component of total returns is rather stable through time with the volatility of total returns mirroring that of capital values. Figure 1 below illustrates this point.

[INSERT SOMEWHERE HERE FIGURE 1]

All data in Figure 1 are in nominal terms and total return amounts to income return plus

capital growth. The sample period is December 1986 to April 2022 (monthly frequency). The green bar series shows that income return (mostly income from rents net of any costs and charges such as ground rent) has displayed a downward trend though time but it does not exhibit much of cyclical. Capital growth on the other hand is the main source of the observed oscillations in total return data.

3 Data

The sample is composed of commercial property price series obtained from MSCI. MSCI assembles the data to construct indices from real estate investment portfolio managers. The data series are generated from open market valuations of actively managed portfolios and track prices in each sector among a large number of property asset performance metrics measured. The MSCI database is used to monitor the different aspects of direct property market performance in the UK¹.

Our analyses relies on the combination of two MSCI's data sets over 1986:12-2022:4 time period. From December 1986 to December 2000, the data are obtained from MSCI's UK monthly property index. From January 2001 to April 2022 the data are taken from MSCI's UK quarterly property index. The quarter datapoint is the value of the third month of the quarter. As a robustness check for combining the two series, the following test was run for each of the three sectors (i.e., Retail, Offices, Industrial) over the period January 2001 to April 2022 when both the quarterly and monthly databases are available.

We first create quarterly series from the monthly database considering the value in the third month of the quarter as the quarter value. This series is correlated with the corresponding quarterly series from the quarterly database. The correlations of nominal growth rates in capital values across the sectors ranges between 0.96 and 0.98. The following figures present the data

¹The performance data compiled by MSCI exclude the impact of debt, hence they represent the true value of the underlying asset. The MSCI data series are considered the standard benchmark for investors (see MSCI, 2022).

for the proposed study with a brief discussion. Figure 2 shows that divergence in cyclical activity in the three sectors post 2009. Prior to that the three sectors broadly followed similar trends but of different severity. Figure 3 shows the log nominal capital values by sector and it is a further visual illustration of the diverge trends in prices post 2009. Of course both prior and post 2009, prices in the three sectors could or could not be fully supported by fundamentals. It does not mean that large oscillations necessarily constitute a bubble. Figure 4 presents the natural log of real capital values. The cyclical behavior of the three capital value series is now more distinctive. The downward trend in retail capital values since mid-2007 will certainly raise eyebrows. This is the impact of e-commerce that presents a challenge to obtain fundamental values in the retail sector.

[INSERT SOMEWHERE HERE FIGURES 2-4]

The above data are available for sub-sectors within retail (shopping centres, retail warehouses, standard unit shops) and for regions in the UK (e.g., London, Rest of South East, and so on). Table 1 shows the MSCI indexes composition.

[INSERT SOMEWHERE HERE TABLE 1]

4 Empirical application

4.1 *Measuring price bubbles*

Asset prices deviations from market fundamentals and the subsequent collapse are conventionally considered as financial bubbles (Blanchard, 1979; Diba & Grossman, 1988b; Evans, 1991; Vogel & Werner, 2015; Lee & Phillips, 2016; Roy & Kemme, 2020; Chen et al., 2022). In

financial markets, the bubble phenomena can be demonstrated using the present value theory of finance:

$$P_t = \sum_{i=0}^{\infty} \left(\frac{1}{1+r_f} \right)^i \mathbb{E}(D_{t+i} + U_{t+i}) + B_t \quad (1)$$

where P_t is the price (after-dividend) of the asset at time t ; D_t is the payoff received from the asset (i.e., dividend) at time t ; r_f is the risk-free interest rate; U_t represents the unobservable fundamentals at time t ; B_t is the bubble components at time t , which satisfies the following submartingale property:

$$\mathbb{E}_t(B_{t+1}) = (1+r_f)B_t \quad (2)$$

when $B_t = 0$, there is no presence of a bubble and the degree of nonstationarity of the asset price relies on the dividend series and unobservable fundamentals. For example, if D_t is an $I(1)$ process and U_t is either an $I(0)$ or an $I(1)$ process, then the asset price is at most an $I(1)$ process. Otherwise, given Equation (2), asset prices will be explosive in the presence of bubbles. When unobservable fundamentals are at most $I(1)$ and D_t is stationary after differencing, empirical evidence of explosive behavior in asset prices may be used to infer the existence of bubbles.

Explosive behavior in asset prices are a primary indicator of market exuberance during the phase of a bubble. These episodes may be subjected to econometric testing using recursive testing procedures, like the right-sided unit root tests in Phillips et al. (2011). Recursive right-sided unit root tests seem to be particularly effective as real-time detection mechanisms for slightly explosive behavior and market exuberance. We apply the Backward Supremum Augmented Dickey Fuller (BSADF) approach of Phillips et al. (2015a; 2015b) that allows to identify multiple bubble episodes within a data set (Homm & Breitung, 2012; Phillips et al., 2015a). Appendix A describes the estimation approach.

4.2 Bubbles in UK private real estate

The data set used in the regressions covers the time period 1986:12-2022:4 (monthly fre-

quency). As first step, we test whether the capital values series of the private real estate contain a unit root, against the alternative that they are explosive processes. Table 2 reports the right-tail Augmented Dickey Fuller (ADF), Supremum Augmented Dickey Fuller (SADF), and BSADF statistics for UK private real estate.

[INSERT SOMEWHERE HERE TABLE 2]

The ADF, SADF and BSADF tests provide evidence against the unit-root null hypothesis at the 1% significance level. For completeness, Table A1 in Appendix A reports the sequences of t -statistics and corresponding critical values (95%) to identify the time periods during which episodes of explosive behavior occurred. Figures 5, 6, and 7 reveal different episodes of explosive behavior in private real estate. Regarding private real estate retail, we identify two episodes of explosive behavior: (i) 2003:9 - 2007:8; and (ii) 2019:9-2021:3. For private real estate office, there are three episodes of explosive behavior: (i) 1999:11 - 2001:12; (ii) 2005:11 - 2007:8; and (iii) 2014:3 - 2016:2. As far as private real estate industrial is concerned, we identify four episodes of bubbles: (i) 1999:11 - 2001:4; (ii) 2003:11 - 2007:8; (iii) 2017:8 - 2019:12; and (iv) 2021:3 - 2022:4.

[INSERT SOMEWHERE HERE FIGURES 5, 6, AND 7]

4.3 Determinants of bubbles in private real estate

In this section, we study how UK economic, financial and real estate indicators are related to the explosiveness in the UK's private real estate sectors. We aim to generate evidence to address the question of what information is available to indicate the dawn of a price explosiveness and bubble formation. This price explosiveness may not eventually prove harmful but the possibility of a price bubble collapsing with adverse consequences for the financial system and the economy

is much greater. The analysis also alerts investors, lenders to real estate and policy makers about elevated risks from the detection of a bubble formation.

We expect that the nature and significance of indicators will differ in each of the three main sectors, office, retail and industrials. This is warranted by their distinct cyclical activity and more importantly by the different structural changes affecting these sectors. A prime example is the advent of e-commerce and online shopping affecting the retail sector. To assess the information content of indicators to signal a forthcoming bubble episode, we deploy a probit model as follows:

$$\begin{aligned}
Pr(\text{Price Bubble}_t = 1) = \Phi(\beta X_t) = & \Phi(\beta_1 RETRE_t + \beta_2 \Delta OFFRE_t + \beta_3 INDRE_t + \\
& + \beta_4 \Delta INDRE_t + \beta_5 PREM_t + \beta_6 \Delta IRS_t + \\
& + \beta_7 EMP_t + \beta_8 \Delta EMP_t + \beta_9 CCI_t + \beta_{10} CLI_t)
\end{aligned} \tag{3}$$

where Φ is the cumulative normal distribution function; y_t takes value 1 when a time series for office, retail and industrials shows price explosiveness and 0 otherwise; X_t is a vector of potential bubble indicators. We examine both for contemporaneous and lagged effects of these indicators on signaling price explosiveness. We restrict the maximum lag length to six lags as we consider a six-month period sufficient for the market to embrace the bubble signal from the bubble indicators.

The monthly indicators we consider in the vector X are: $RETRE_t$ is the nominal retail rent level at month t ; $\Delta OFFRE_t$ is the monthly percentage in nominal office rents; $INDRE_t$ is the nominal rent level at month t ; $\Delta INDRE_t$ is the monthly percentage growth in nominal industrial rents; $PREM_t$ is the risk premium defined as the retail yields minus the 10-year gilt yield; ΔIRS_t is the annual change in interest sales as a proportion of total retail sales; EMP_t is the level of employment at month t ; ΔEMP_t is the monthly percentage growth in employment; CCI_t is the consumer confidence index at month t ; CLI_t is the OECD's composite leading indicator for the UK economy. Lags of the variables are examined, restricting the maximum lag length to six months. It is assumed that if a variable causes a bubble this impact will

manifest itself in prices within six months.

We have used the following selection criteria for specifying the probit model by sector: (i) coefficients should have the expected sign; (ii) variables should be statistically significant on their own; (iii) maximize value of McFadden's R^2 (or the *Pseudo* R^2) if previous two conditions are satisfied. Tables 3, 4 and 5 report the result for retail, office and industrial sectors, respectively.

[INSERT SOMEWHERE HERE TABLES 3, 4 AND 5]

The first observation to make from the results presented in Tables 3, 4 and 5 is that the combination of bubble indicators differs by sector. A common variable is the rent series which reflects income growth in the respective sectors. A strong rent growth and high levels of rents can be a source of growing optimism in the market over and above what is justified by the improved income levels. The risk premium, or the spread between property yield and the risk free rate, a metric commonly used in practice in the UK real estate profession only appears in the retail price equation. The economic and sentiment indicators vary by sector. This supports the deduction that the study of real estate price bubble behavior is only country specific but also sector specific.

In the retail probit, data for IRS (online sales as a percent of total sales) are only available from November 2006 when the series began and online sales were around 2% of total sales. We have set IRS to zero for the prior years denoting negligible or no internet sales as a proportion of total sales. The fit of the above model increases significantly if the sample period starts in November 2006 and the dominant variable is $\Delta_{12}IRS_t$.

In the three sector probit models (Tables 3, 4 and 5), all variables are statistically significant on their own. An ex-post forecast assessment finds that all models outperform the selected naïve model although the margin of success varies by sector with offices exhibiting the greatest level of success. Although the retail probit outperforms the naïve there is an element of misspecification detected by the Hosmer-Lemeshow statistic. Retail is the sector that has seen

the most significant structural change of all sectors, a likely source of instability in the retail probit model.

5 Sensitivity analysis

In this section, we evaluate how the probit model fitted values can be seen as signaling the building up of an price overvaluation and potentially a bubble in the respective real estate sector. As the probit model is rolled forward on a monthly frequency, it provides a constant update of whether an episode of overvaluation is forthcoming in the corresponding sector.

In Figures 8-10, the shaded area represents the periods of overvaluations detected by the BSADF procedure. The solid line is the fitted values of the respective probit model and represent the probability of the sector moving into a bubble state. A threshold value is reported by sector above which the model signals the formation of a bubble. The higher the fitted line the strong the probability of a bubble (positive or negative) forming. In the retail sector the probit is successful indicating the short-lived bubble of the late 1990s. In the period 2000 to 2004 the probability of a forthcoming bubble is elevated (above the threshold value of 21%) up to 40% but it rises further when the bubble occurs (2004-2007). There is a short false signal in 2010 and another one in 2016-2017 but probabilities did not move above 50%. The probit is a little late to signal the "Covid-19" bubble but predicts correctly the end of it. With the exception of a strong false signal in the late 1990s the office probit signals the bubble in advance in 2000-2001 and 2014-2015 but with a few months delay in 2006-2007.

[INSERT SOMEWHERE HERE FIGURES 8-10]

Finally, in the industrial sector there are two short-lived incorrect signals in 1998 and in 2001 (when the market is in bubble state but the model points to continuing elevated risks). The episodes of bubbles are signaled accurately. Since 2015 this sector has exhibit three periods of bubbles with short breaks. The probit model has signaled all along mispricing in the sector,

it indicated lower risks at the end of 2019 but again the probabilities increased fast to point to a bubble at the end of the sample.

In practice this analysis is informative for investors having exposure to real estate. Investors process a host of information but the continuous updating of the probabilities for a bubble starting gives them an anchor to assess and interpret other qualitative information.

6 Conclusions

In this paper, we studied the existence of bubble episodes in the United Kingdom (UK) real estate sectors (Retail, Offices, Industrial), using the Backward Supremum Augmented Dickey Fuller approach, introduced by Phillips et al. (2015a,b) over the period December 1986 to April 2022. We also examined the role of a number of indicators the choice of which is guided both by existing studies and also time series that are closely monitored by real estate professionals in the UK when assessing property market trends. The results shown that the relevance of the indicators differs by sector. Sector *risk premia*, UK *consumer price index* inflation and the composite leading indicator are relevant to the explosiveness of prices across all sectors. The significance of *employment*, *rents* and *consumer confidence* varies by sector.

The main findings in this paper have a number of policy implications. For instance, in order to provide a better assessment of the risks posed by a rise-up in the real estate prices and a build-up in vulnerabilities in the real estate sector, there is the need to improve both availability and quality for some indicators such as leverage, price-income and price-rent ratios, capitalization rates, measures of credit growth. In addition, policymakers ought tightening some macroprudential policies to reduce downside risks to real estate price and to mitigate the negative effects of real estate price corrections on the real economy.

Future research developments could be the evaluation of alternatives policy tools such as the level of leverage of households, of construction sector and of financial sector (one of the main risks from real estate bubbles cycles), extra capital to sustain investors' confidence during

financial stress periods, the uncertainty surrounding the estimation of corporate credit losses, and the role of non-bank financial intermediaries in the real estate sector. Finally, it would be interesting to evaluate whether bubbles in real estate are likely to migrate (contagion) to other sectors. We leave these issues to future research.

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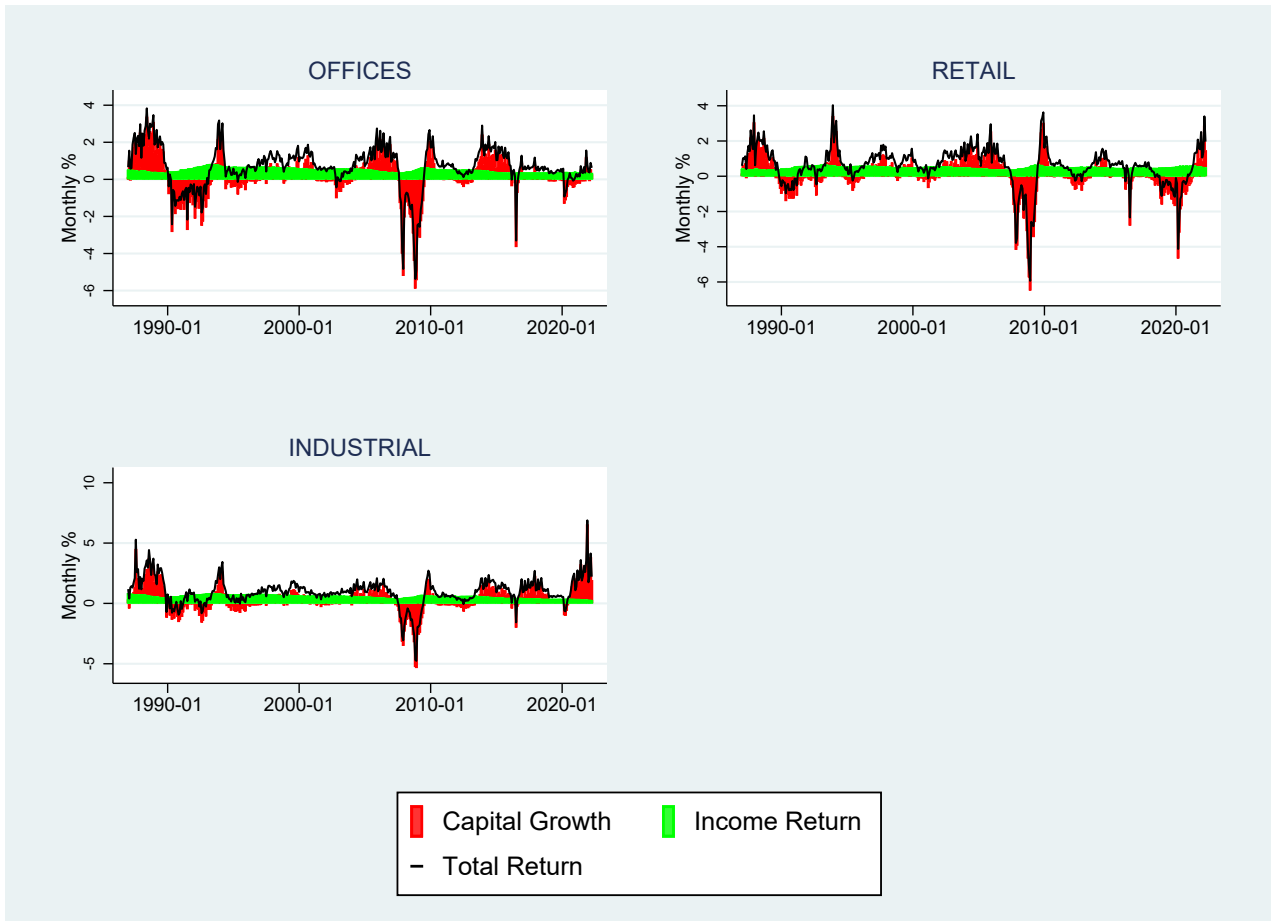
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Figure 1: Components of total returns for Offices, Retail and Industrial in the UK.



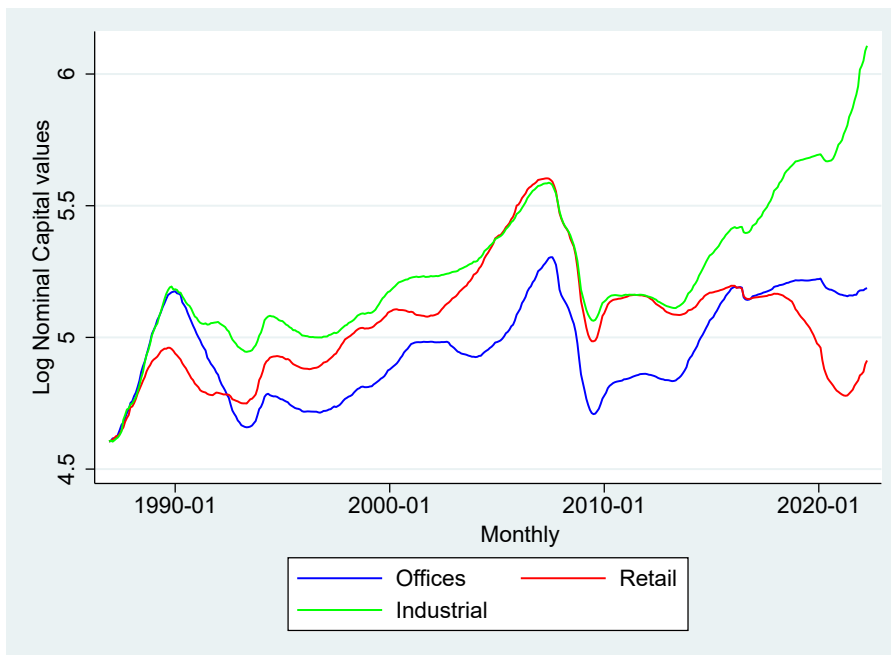
Source: MSCI, Authors.

Figure 2: Capital values (prices) by main sector.



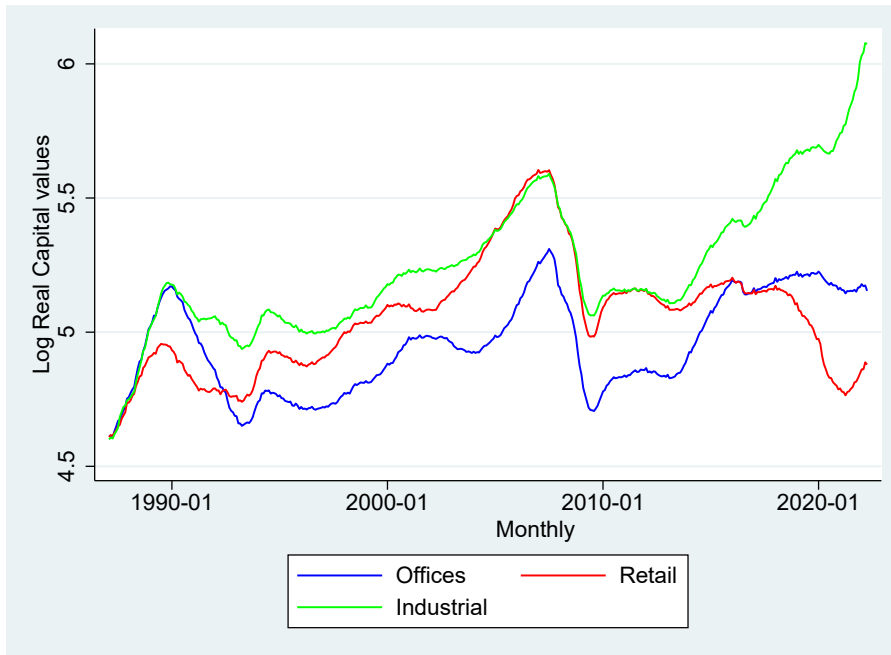
MSCI, Authors.

Figure 3: Log Nominal Capital values by sector.



MSCI, Authors.

Figure 4: Log Real Capital values by sector.



MSCI, Authors.

Figure 5: Detecting Bubbles periods for Real Estate Retail UK.

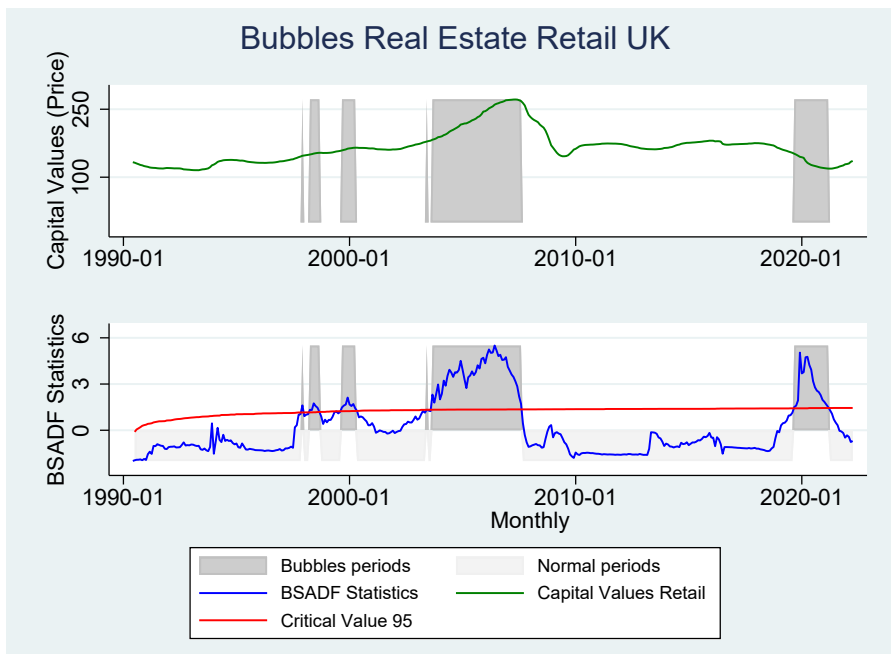


Figure 6: Detecting Bubbles periods for Real Estate Offices UK.

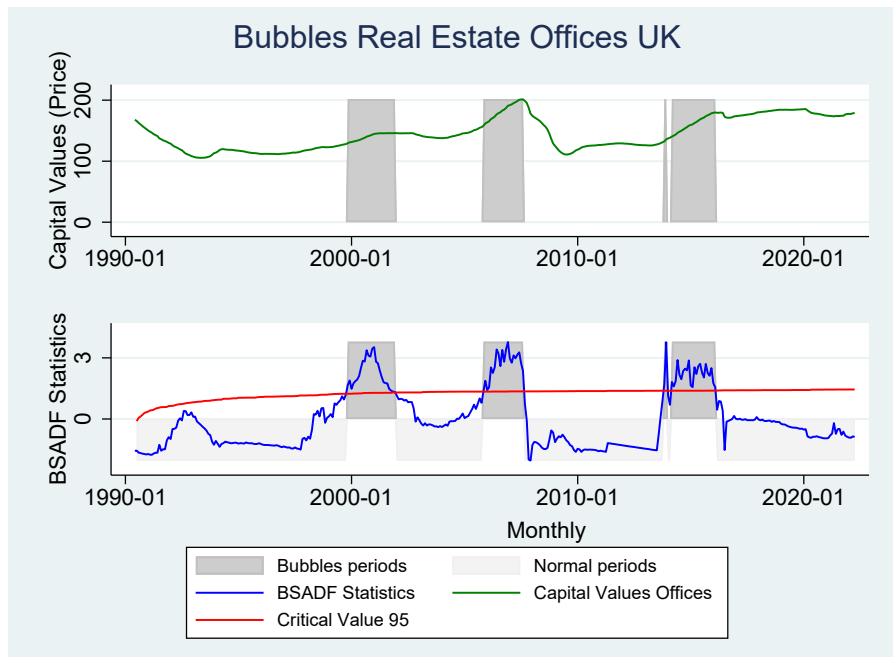


Figure 7: Detecting Bubbles periods for Real Estate Industrial UK.

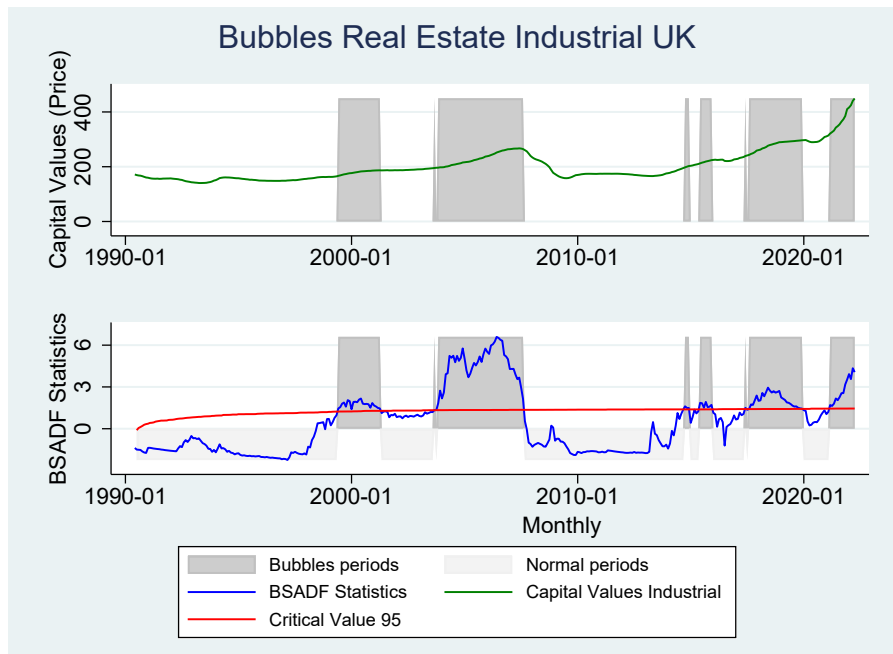


Figure 8: Probit model fitted values - Real Estate Offices UK.

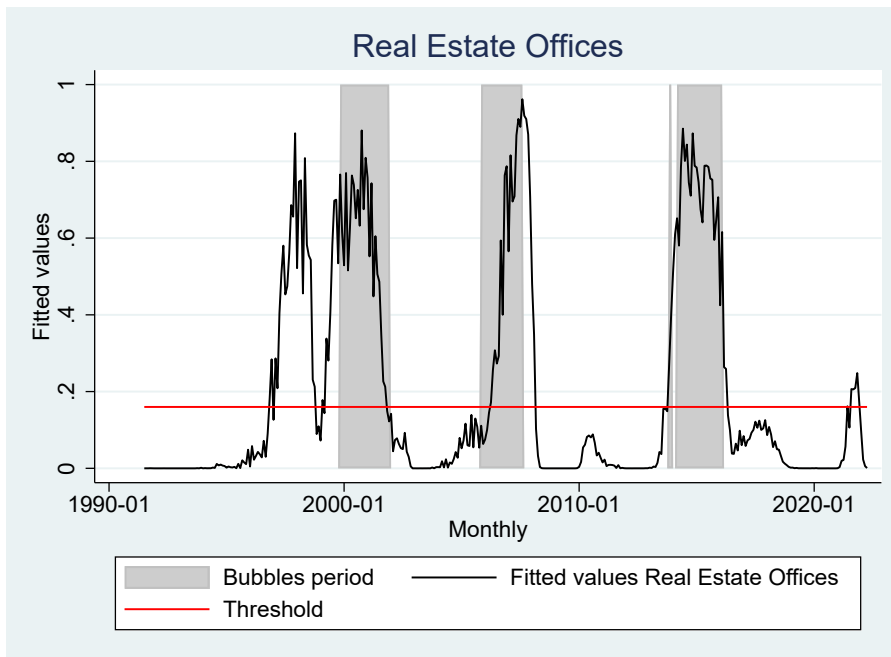


Figure 9: Probit model fitted values - Real Estate Retail UK.

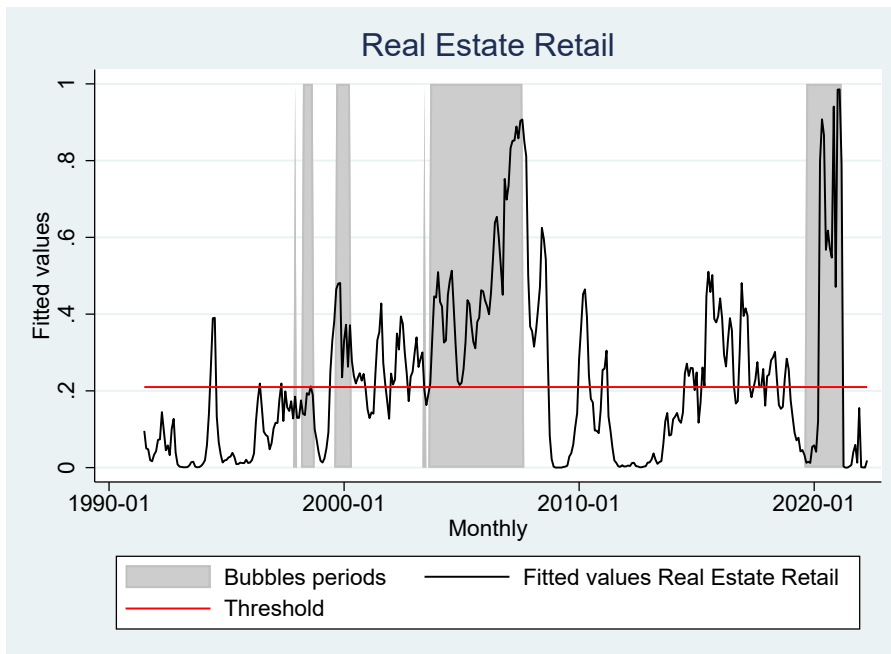
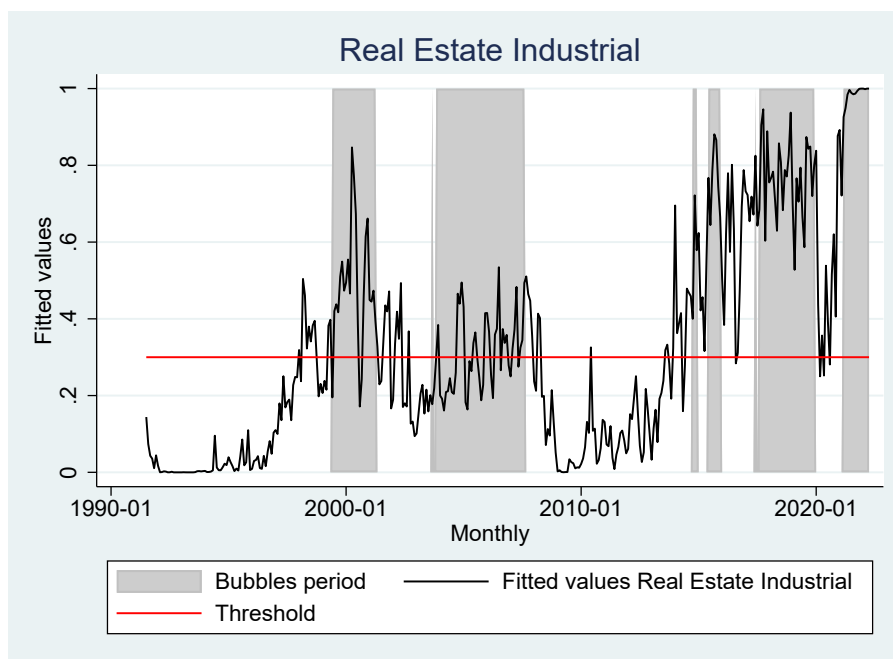


Figure 10: Probit model fitted values - Real Estate Industrial UK.



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Table 1: MSCI sub-indexes.

Current index	Components
UK Retail	- Standard retail in the South East (i.e., shop units, including high street); - Standard retail in the rest of UK; - Shopping centres (UK wide); - Retail warehouses (UK wide).
UK Office	- City of London offices; - Mid-Town & West End offices; - Rest of the South East offices; - Rest of the UK offices.
UK Industrial	- South East industrials; - Rest of UK industrials.

The Table reports the MSCI sub indices.

Table 2: Right-tail ADF, SADF, BSADF statistics for UK private real estate.

Test	Retail	Office	Industrial
ADF	-2.42	-2.48	2.28
SADF	2.73	-0.73	2.67
BSADF	5.49	3.77	6.59

The Table reports the right-tail Augmented Dickey Fuller (ADF), Supremum Augmented Dickey Fuller (SADF), and Backward Supremum Augmented Dickey Fuller (BSADF) test statistics for explosive behavior proposed by Phillips et al. (2011) and Phillips et al. (2015).

Table 3: Results for Real Estate Retail price bubble behavior.

(a) Probit results.

Indicator	Coefficient (p-value)
$RETRE_t$	0.01*** (0.00)
CCI_{t-6}	0.33*** (0.00)
$\Delta_{12}IRS_t$	0.30*** (0.00)
$PREM_{t-1}$	-0.93*** (0.00)
$PREM_{t-5}$	0.76*** (0.00)
N. Obs.	370
<i>Pseudo R</i> ²	0.30
<i>McFadden R</i> ²	0.27
Hosmer-Lemeshow (H-L) goodness of fit test p-value	0.00

The Table reports the results from probit model for Retail UK sector. An intercept is included in the probit model. $RETRE_t$ is the nominal retail rent level; CCI_{t-6} is the consumer confidence indicator; $\Delta_{12}IRS_t$ is the annual change in interest sales as a proportion of total retail sales; $PREM_{t-5}$ is the risk premium defined as the retail yield minus the 10-year gilt yield. Probit model shows evidence of lack of fit based on the H-L statistic.

(b) Prediction analysis of retail probit model.

Description	Total N. Obs.	N. Obs. in state 0	N. Obs. in state 1
Actual	370	287	83
Probit correct predictions at threshold of 50%		186	69
		% correct=64.8%	% correct=83.1%

Gain over naïve model (constant probability model): 41.5%. Threshold probability: 21% (threshold probability maximizing gain over naïve model). The naïve model is the constant probability model. it predicts all state 0 correctly and all state 1 wrongly.

Table 4: Probit results for Real Estate Offices price bubble behavior.

(a) Probit results.

Indicator	Coefficient (p-value)
CCI_t	0.28** (0.01)
CLI_t	0.32** (0.03)
CLI_{t-6}	0.35** (0.03)
$\Delta OFFRE_t$	1.10*** (0.00)
$\Delta OFFRE_{t-2}$	0.85** (0.02)
N. Obs.	376
<i>Pseudo R</i> ²	0.50
<i>McFadden R</i> ²	0.50
Hosmer-Lemeshow (H-L) goodness of fit test p-value	0.97

The Table reports the results from probit model for Offices UK sector. An intercept is included in the probit model. CCI_t is consumer confidence index; CLI_t is the OECD's composite leading indicator for the UK economy; $\Delta OFFRE_t$ is the monthly percentage growth in nominal office rents. Probit model shows no evidence of lack of fit based on the H-L statistic.

(b) Prediction analysis of office probit model.

Description	Total N. Obs.	N. Obs. in state 0	N. Obs. in state 1
Actual	376	302	74
Probit correct predictions of states 0 (normal state) and 1 (bubble state)		255	67
		% correct=84.4%	% correct=90.5%

Outperforms naïve. Gain over naïve is 66% at threshold probability of 16% (see Table 3).

Table 5: Probit results for Real Estate Industrial price bubble behavior.

(a) Probit results.

Indicator	Coefficient (p-value)
$\Delta INDRE_t$	1.73*** (0.00)
$\Delta INDRE_{t-1}$	1.61*** (0.00)
$INDRE_t$	0.06*** (0.00)
ΔEMP_t	2.97*** (0.00)
EMP_t	-0.32*** (0.00)
N. Obs.	376
<i>Pseudo R</i> ²	0.43
<i>McFadden R</i> ²	0.36
Hosmer-Lemeshow (H-L) goodness of fit test p-value	0.40

The Table reports the results from probit model for Industrial UK sector. An intercept is included in the probit model. $\Delta INDRE_t$ is the monthly percentage growth in nominal industrial rents; $INDRE_t$ is the nominal rent level; ΔEMP_t is the monthly percentage growth in employment; EMP_t is the level of employment. Probit model shows no evidence of lack of fit based on the H-L statistic.

(b) Prediction analysis of industrial probit model.

Description	Total N. Obs.	N. Obs. in state 0	N. Obs. in state 1
Actual	380	256	124
Probit correct predictions at threshold of 50%		194	101
		% correct=75.8%	% correct=81.5%

Outperforms naïve. Gain over naïve is 45% at threshold probability of 30% (see Table 3).

Price Bubbles in Private Real Estate.

INTERNET APPENDIX

Estimation of Bubble Episodes

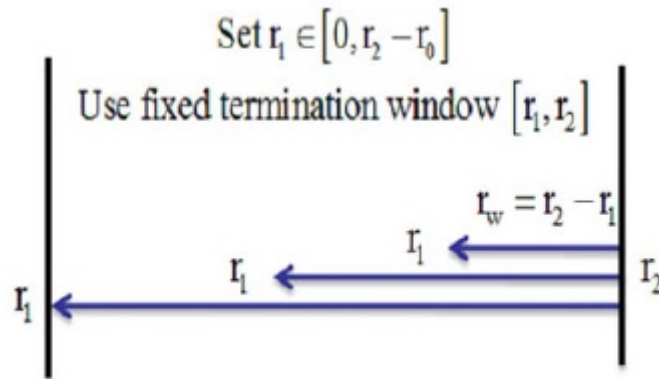
February 16, 2023

The Backward Supremum Augmented Dickey Fuller (BSADF) is defined as follows:

$$BSADF_{r_2}(r_0) = \sup_{r_1 \in [0, r_2 - r_0]} \{BADF_{r_1}^{r_2}\} \quad (A1)$$

where r_1 and r_2 denote the starting and the ending fraction of the sample, respectively, implying that $r_1 < r_2$; r_0 is the fractional threshold and it is chosen on a lower bound of 1% of the full sample with the following functional form: $r_0 = (0.01 + 1.8/\sqrt{T})$, where T refers to the number of observations in the sample. We denote r_w , the window size of the regression, as $r_1 - r_2$. Figure A1 shows the flexibility of BSADF test in the detection of multiple bubbles.

Figure A1: Recursive nature of the BSADF test.



Source: Phillips et al. (2015a, p. 1052).

Phillips et al. (2015a) suggest to implement the BSADF test on a sample sequence where the end point is fixed at r_2 , and expands backwards to the starting point, r_1 , which varies between 0 and $(r_2 - r_0)$. Let r_e the fraction of the sample at which the bubble starts, r_f the fraction of the sample at which it ends, and \hat{r}_e and \hat{r}_f the estimators of both. The origination and termination points of a bubble, i.e. r_e and r_f , are calculated according to the Equations (A2) and (A3):

$$\hat{r}_e = \inf_{r_2 \in [r_0, 1]} [r_2 : BSADF_{r_2}(r_0) > scv_{r_2}^\beta] \quad (\text{A2})$$

$$\text{and } \hat{r}_f = \inf_{r_2 \in [\hat{r}_e + \delta \log(T), 1]} [r_2 : BSADF_{r_2}(r_0) < scv_{r_2}^\beta] \quad (\text{A3})$$

where T is the number of observations, $scv_{r_2}^\beta$ is the critical value of the BSADF statistic based on $[Tr_2]$ observations and confidence level β . $[Tr_2]$ refers to the largest integer smaller than or equal to Tr_2 . Phillips et al. (2015a) impose a condition that for a bubble to exist its duration must exceed a slowly varying (at infinity) quantity such as $L_T = \log(T)$. This condition helps to exclude short lived blips in the fitted autoregressive coefficient and can be adjusted to consider the data frequency. Thus, $\delta \log(T)$ is a minimal bubble length, and δ is a frequency-dependent parameter chosen freely.

Table A1: BSADF Statistics and BSADF Statistics 95% critical values.

Time (monthly)	Offices			Private Real Estate UK			Industrial		
	BSADFt	BSADFt	Explosive behavior	BSADFt	BSADFt	Explosive behavior	BSADFt	BSADFt	Explosive behavior
		95% cv			95% cv			95% cv	
1990-06	-1.560			-1.993			-1.381		
1990-07	-1.555	-0.102	0	-1.947	-0.102	0	-1.498	-0.102	0
1990-08	-1.649	0.052	0	-1.916	0.052	0	-1.509	0.052	0
1990-09	-1.672	0.123	0	-1.913	0.123	0	-1.522	0.123	0
1990-10	-1.699	0.200	0	-1.890	0.200	0	-1.633	0.200	0
1990-11	-1.719	0.289	0	-1.943	0.289	0	-1.708	0.289	0
1990-12	-1.738	0.333	0	-1.859	0.333	0	-1.737	0.333	0
1991-01	-1.720	0.362	0	-1.927	0.362	0	-1.374	0.362	0
1991-02	-1.748	0.417	0	-1.550	0.417	0	-1.371	0.417	0
1991-03	-1.758	0.430	0	-1.391	0.430	0	-1.395	0.430	0
1991-04	-1.698	0.454	0	-1.535	0.454	0	-1.420	0.454	0
1991-05	-1.656	0.509	0	-1.018	0.509	0	-1.439	0.509	0
1991-06	-1.656	0.536	0	-1.031	0.536	0	-1.456	0.536	0
1991-07	-1.267	0.559	0	-0.903	0.559	0	-1.470	0.559	0
1991-08	-1.558	0.583	0	-0.958	0.583	0	-1.497	0.583	0
1991-09	-1.485	0.583	0	-1.005	0.583	0	-1.510	0.583	0
1991-10	-1.486	0.588	0	-1.019	0.588	0	-1.533	0.588	0
1991-11	-1.047	0.593	0	-1.204	0.593	0	-1.549	0.593	0
1991-12	-0.890	0.633	0	-1.220	0.633	0	-1.567	0.633	0
1992-01	-0.982	0.642	0	-1.094	0.642	0	-1.582	0.642	0
1992-02	-0.489	0.645	0	-1.070	0.645	0	-1.595	0.645	0
1992-03	-0.481	0.666	0	-1.066	0.666	0	-1.610	0.666	0
1992-04	-0.421	0.696	0	-1.047	0.696	0	-1.621	0.696	0
1992-05	-0.077	0.716	0	-1.115	0.716	0	-1.414	0.716	0
1992-06	0.035	0.729	0	-1.110	0.729	0	-1.248	0.729	0
1992-07	-0.070	0.734	0	-1.098	0.734	0	-1.319	0.734	0
1992-08	0.393	0.750	0	-0.955	0.750	0	-0.977	0.750	0
1992-09	0.387	0.771	0	-0.786	0.771	0	-0.817	0.771	0
1992-10	0.188	0.787	0	-0.988	0.787	0	-0.952	0.787	0
1992-11	0.199	0.794	0	-0.966	0.794	0	-0.789	0.794	0
1992-12	0.328	0.808	0	-0.977	0.808	0	-0.521	0.808	0
1993-01	0.107	0.821	0	-0.924	0.821	0	-0.690	0.821	0
1993-02	0.116	0.830	0	-0.936	0.830	0	-0.666	0.830	0
1993-03	-0.123	0.841	0	-0.990	0.841	0	-0.740	0.841	0
1993-04	-0.205	0.853	0	-1.021	0.853	0	-0.690	0.853	0
1993-05	-0.287	0.853	0	-1.009	0.853	0	-0.864	0.853	0
1993-06	-0.382	0.871	0	-1.235	0.871	0	-1.033	0.871	0
1993-07	-0.466	0.885	0	-1.272	0.885	0	-1.102	0.885	0
1993-08	-0.565	0.889	0	-1.185	0.889	0	-1.218	0.889	0
1993-09	-0.724	0.892	0	-1.298	0.892	0	-1.436	0.892	0
1993-10	-0.790	0.898	0	-1.357	0.898	0	-1.451	0.898	0
1993-11	-1.109	0.918	0	-1.088	0.918	0	-1.656	0.918	0
1993-12	-1.266	0.924	0	0.449	0.924	0	-1.523	0.924	0
1994-01	-1.077	0.939	0	-1.525	0.939	0	-1.695	0.939	0
1994-02	-1.216	0.945	0	-0.720	0.945	0	-1.418	0.945	0
1994-03	-1.365	0.950	0	0.158	0.950	0	-1.120	0.950	0
1994-04	-1.226	0.950	0	-0.612	0.950	0	-1.414	0.950	0
1994-05	-1.185	0.991	0	-0.767	0.991	0	-1.395	0.991	0
1994-06	-1.112	0.992	0	-0.291	0.992	0	-1.479	0.992	0
1994-07	-1.142	0.993	0	-0.692	0.993	0	-1.657	0.993	0
1994-08	-1.161	0.996	0	-0.620	0.996	0	-1.590	0.996	0
1994-09	-1.191	1.002	0	-0.695	1.002	0	-1.717	1.002	0
1994-10	-1.180	1.016	0	-0.655	1.016	0	-1.748	1.016	0
1994-11	-1.163	1.016	0	-0.826	1.016	0	-1.841	1.016	0
1994-12	-1.169	1.016	0	-0.913	1.016	0	-1.785	1.016	0

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(a) Table A1 (*continued*).

Time (monthly)	Private Real Estate UK								
	Offices			Retail			Industrial		
	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior
1995-01	-1.207	1.042	0	-0.862	1.042	0	-1.761	1.042	0
1995-02	-1.183	1.042	0	-1.106	1.042	0	-1.880	1.042	0
1995-03	-1.193	1.042	0	-1.137	1.042	0	-1.925	1.042	0
1995-04	-1.206	1.042	0	-0.856	1.042	0	-1.909	1.042	0
1995-05	-1.151	1.048	0	-1.054	1.048	0	-1.946	1.048	0
1995-06	-1.181	1.048	0	-1.248	1.048	0	-1.962	1.048	0
1995-07	-1.192	1.048	0	-1.256	1.048	0	-1.941	1.048	0
1995-08	-1.189	1.048	0	-1.206	1.048	0	-1.975	1.048	0
1995-09	-1.216	1.048	0	-1.229	1.048	0	-1.967	1.048	0
1995-10	-1.233	1.050	0	-1.251	1.050	0	-1.989	1.050	0
1995-11	-1.221	1.070	0	-1.288	1.070	0	-1.973	1.070	0
1995-12	-1.189	1.077	0	-1.293	1.077	0	-1.962	1.077	0
1996-01	-1.230	1.083	0	-1.296	1.083	0	-2.028	1.083	0
1996-02	-1.263	1.083	0	-1.299	1.083	0	-2.033	1.083	0
1996-03	-1.277	1.094	0	-1.312	1.094	0	-2.052	1.094	0
1996-04	-1.274	1.097	0	-1.346	1.097	0	-2.028	1.097	0
1996-05	-1.278	1.097	0	-1.321	1.097	0	-2.063	1.097	0
1996-06	-1.290	1.097	0	-1.313	1.097	0	-2.087	1.097	0
1996-07	-1.297	1.097	0	-1.333	1.097	0	-2.075	1.097	0
1996-08	-1.307	1.100	0	-1.350	1.100	0	-2.097	1.100	0
1996-09	-1.288	1.102	0	-1.332	1.102	0	-2.108	1.102	0
1996-10	-1.305	1.103	0	-1.296	1.103	0	-2.124	1.103	0
1996-11	-1.349	1.111	0	-1.276	1.111	0	-2.128	1.111	0
1996-12	-1.380	1.111	0	-1.217	1.111	0	-2.190	1.111	0
1997-01	-1.351	1.111	0	-1.317	1.111	0	-2.162	1.111	0
1997-02	-1.374	1.119	0	-1.291	1.119	0	-2.179	1.119	0
1997-03	-1.403	1.119	0	-1.178	1.119	0	-2.243	1.119	0
1997-04	-1.393	1.119	0	-1.178	1.119	0	-2.058	1.119	0
1997-05	-1.445	1.119	0	-1.141	1.119	0	-1.695	1.119	0
1997-06	-1.450	1.119	0	-1.060	1.119	0	-1.739	1.119	0
1997-07	-1.394	1.124	0	-1.139	1.124	0	-1.658	1.124	0
1997-08	-1.450	1.127	0	0.194	1.127	0	-1.736	1.127	0
1997-09	-1.466	1.144	0	0.328	1.144	0	-1.795	1.144	0
1997-10	-1.502	1.154	0	1.016	1.154	0	-1.823	1.154	0
1997-11	-0.971	1.155	0	1.042	1.155	0	-1.839	1.155	0
1997-12	-0.926	1.155	0	1.616	1.155	1	-1.770	1.155	0
1998-01	-1.051	1.155	0	0.913	1.155	0	-1.852	1.155	0
1998-02	-0.869	1.161	0	1.013	1.161	0	-1.288	1.161	0
1998-03	-0.968	1.161	0	1.039	1.161	0	-1.348	1.161	0
1998-04	-0.529	1.161	0	1.332	1.161	1	-0.818	1.161	0
1998-05	0.241	1.161	0	1.313	1.161	1	-0.575	1.161	0
1998-06	0.216	1.167	0	1.746	1.167	1	-0.172	1.167	0
1998-07	0.402	1.167	0	1.572	1.167	1	0.392	1.167	0
1998-08	0.124	1.184	0	1.464	1.184	1	0.406	1.184	0
1998-09	0.524	1.190	0	1.193	1.190	1	0.437	1.190	0
1998-10	0.540	1.192	0	0.889	1.192	0	0.470	1.192	0
1998-11	-0.186	1.192	0	0.411	1.192	0	-0.036	1.192	0
1998-12	0.054	1.192	0	0.687	1.192	0	0.696	1.192	0
1999-01	0.129	1.209	0	0.517	1.209	0	0.703	1.209	0
1999-02	0.242	1.209	0	0.676	1.209	0	0.245	1.209	0
1999-03	0.092	1.222	0	0.671	1.222	0	0.473	1.222	0
1999-04	0.766	1.228	0	0.876	1.228	0	0.786	1.228	0
1999-05	0.695	1.228	0	1.174	1.228	0	0.963	1.228	0
1999-06	0.822	1.233	0	1.227	1.233	0	1.457	1.233	1
1999-07	0.913	1.235	0	1.097	1.235	0	1.548	1.235	1
1999-08	1.115	1.235	0	1.189	1.235	0	1.799	1.235	1
1999-09	0.956	1.238	0	1.485	1.238	1	1.881	1.238	1
1999-10	1.204	1.238	0	1.604	1.238	1	1.584	1.238	1
1999-11	1.665	1.240	1	1.670	1.240	1	2.052	1.240	1
1999-12	1.889	1.240	1	2.121	1.240	1	1.981	1.240	1

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(b) Table A1 (*continued*).

Time (monthly)	Private Real Estate UK								
	Offices			Retail			Industrial		
	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior
2000-01	1.484	1.240	1	1.674	1.240	1	1.401	1.240	1
2000-02	1.745	1.248	1	1.573	1.248	1	1.920	1.248	1
2000-03	1.855	1.250	1	1.703	1.250	1	1.939	1.250	1
2000-04	1.934	1.250	1	1.430	1.250	1	1.902	1.250	1
2000-05	2.108	1.257	1	1.246	1.257	0	2.091	1.257	1
2000-06	2.502	1.257	1	0.838	1.257	0	2.167	1.257	1
2000-07	2.860	1.269	1	0.898	1.269	0	1.796	1.269	1
2000-08	2.822	1.277	1	0.842	1.277	0	1.769	1.277	1
2000-09	3.374	1.280	1	0.701	1.280	0	1.784	1.280	1
2000-10	3.116	1.280	1	0.579	1.280	0	1.758	1.280	1
2000-11	3.060	1.282	1	0.323	1.282	0	1.510	1.282	1
2000-12	3.450	1.284	1	0.329	1.284	0	1.845	1.284	1
2001-01	3.531	1.284	1	0.462	1.284	0	1.665	1.284	1
2001-02	2.818	1.284	1	0.239	1.284	0	1.595	1.284	1
2001-03	2.731	1.284	1	-0.163	1.284	0	1.492	1.284	1
2001-04	2.374	1.284	1	-0.095	1.284	0	1.461	1.284	1
2001-05	2.066	1.284	1	-0.007	1.284	0	1.120	1.284	0
2001-06	1.806	1.287	1	-0.049	1.287	0	1.236	1.287	0
2001-07	1.761	1.287	1	-0.105	1.287	0	1.246	1.287	0
2001-08	1.747	1.287	1	-0.110	1.287	0	1.235	1.287	0
2001-09	1.472	1.287	1	-0.216	1.287	0	0.821	1.287	0
2001-10	1.393	1.287	1	-0.193	1.287	0	0.991	1.287	0
2001-11	1.343	1.303	1	-0.119	1.303	0	0.962	1.303	0
2001-12	1.330	1.303	1	-0.029	1.303	0	1.072	1.303	0
2002-01	1.157	1.303	0	-0.181	1.303	0	0.835	1.303	0
2002-02	0.965	1.303	0	-0.108	1.303	0	0.881	1.303	0
2002-03	0.992	1.303	0	-0.054	1.303	0	0.887	1.303	0
2002-04	0.972	1.303	0	-0.033	1.303	0	0.749	1.303	0
2002-05	0.902	1.303	0	0.209	1.303	0	0.885	1.303	0
2002-06	0.940	1.304	0	0.384	1.304	0	0.942	1.304	0
2002-07	0.824	1.304	0	0.406	1.304	0	0.838	1.304	0
2002-08	0.833	1.304	0	0.559	1.304	0	0.915	1.304	0
2002-09	0.832	1.304	0	0.505	1.304	0	0.906	1.304	0
2002-10	0.510	1.304	0	0.503	1.304	0	0.868	1.304	0
2002-11	-0.126	1.304	0	0.679	1.304	0	0.945	1.304	0
2002-12	0.084	1.304	0	0.897	1.304	0	1.008	1.304	0
2003-01	-0.058	1.305	0	0.688	1.305	0	0.916	1.305	0
2003-02	-0.225	1.305	0	0.768	1.305	0	0.881	1.305	0
2003-03	-0.317	1.324	0	1.038	1.324	0	0.954	1.324	0
2003-04	-0.207	1.324	0	1.264	1.324	0	1.185	1.324	0
2003-05	-0.321	1.324	0	1.143	1.324	0	1.081	1.324	0
2003-06	-0.264	1.331	0	1.332	1.331	1	1.131	1.331	0
2003-07	-0.271	1.331	0	1.281	1.331	0	1.200	1.331	0
2003-08	-0.307	1.331	0	1.240	1.331	0	1.194	1.331	0
2003-09	-0.364	1.331	0	2.313	1.331	1	1.341	1.331	1
2003-10	-0.361	1.335	0	1.794	1.335	1	1.334	1.335	0
2003-11	-0.399	1.335	0	2.368	1.335	1	1.838	1.335	1
2003-12	-0.347	1.335	0	2.971	1.335	1	2.735	1.335	1
2004-01	-0.395	1.335	0	2.005	1.335	1	2.179	1.335	1
2004-02	-0.334	1.335	0	2.370	1.335	1	2.606	1.335	1
2004-03	-0.267	1.337	0	3.220	1.337	1	3.918	1.337	1
2004-04	-0.331	1.337	0	2.892	1.337	1	3.980	1.337	1
2004-05	-0.124	1.341	0	3.534	1.341	1	5.233	1.341	1
2004-06	-0.106	1.341	0	3.928	1.341	1	5.095	1.341	1
2004-07	-0.107	1.341	0	3.748	1.341	1	5.245	1.341	1
2004-08	-0.095	1.341	0	3.467	1.341	1	4.774	1.341	1
2004-09	0.016	1.341	0	3.767	1.341	1	5.228	1.341	1
2004-10	0.006	1.345	0	3.740	1.345	1	4.875	1.345	1
2004-11	0.127	1.345	0	3.915	1.345	1	5.091	1.345	1
2004-12	0.271	1.345	0	4.506	1.345	1	5.766	1.345	1

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(c) Table A1 (continued).

Time (monthly)	Private Real Estate UK								
	Offices			Retail			Industrial		
	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior
2005-01	0.044	1.345	0	3.929	1.345	1	5.034	1.345	1
2005-02	0.104	1.345	0	3.308	1.345	1	4.178	1.345	1
2005-03	0.150	1.345	0	2.739	1.345	1	3.698	1.345	1
2005-04	0.324	1.345	0	3.440	1.345	1	3.949	1.345	1
2005-05	0.490	1.345	0	3.554	1.345	1	4.367	1.345	1
2005-06	0.705	1.345	0	3.821	1.345	1	4.727	1.345	1
2005-07	0.494	1.345	0	3.577	1.345	1	4.541	1.345	1
2005-08	0.746	1.345	0	3.766	1.345	1	4.792	1.345	1
2005-09	1.010	1.345	0	4.218	1.345	1	5.187	1.345	1
2005-10	0.795	1.345	0	4.011	1.345	1	4.796	1.345	1
2005-11	1.363	1.345	1	4.630	1.345	1	5.351	1.345	1
2005-12	1.878	1.345	1	4.706	1.345	1	5.756	1.345	1
2006-01	1.425	1.345	1	4.347	1.345	1	5.526	1.345	1
2006-02	1.559	1.345	1	4.896	1.345	1	5.372	1.345	1
2006-03	2.533	1.345	1	5.246	1.345	1	5.982	1.345	1
2006-04	2.261	1.348	1	5.023	1.348	1	6.063	1.348	1
2006-05	2.539	1.348	1	5.045	1.348	1	6.253	1.348	1
2006-06	3.413	1.348	1	5.499	1.348	1	6.592	1.348	1
2006-07	3.205	1.348	1	5.181	1.348	1	6.521	1.348	1
2006-08	2.596	1.348	1	4.815	1.348	1	6.386	1.348	1
2006-09	3.390	1.348	1	4.899	1.348	1	6.317	1.348	1
2006-10	2.811	1.348	1	4.562	1.348	1	5.295	1.348	1
2006-11	3.416	1.348	1	4.581	1.348	1	5.192	1.348	1
2006-12	3.775	1.348	1	4.743	1.348	1	4.996	1.348	1
2007-01	2.972	1.356	1	4.114	1.356	1	4.285	1.356	1
2007-02	2.765	1.356	1	3.871	1.356	1	4.295	1.356	1
2007-03	3.121	1.356	1	3.619	1.356	1	4.299	1.356	1
2007-04	2.977	1.356	1	3.461	1.356	1	3.891	1.356	1
2007-05	3.159	1.356	1	3.182	1.356	1	3.561	1.356	1
2007-06	3.271	1.356	1	2.852	1.356	1	3.670	1.356	1
2007-07	2.728	1.356	1	2.194	1.356	1	2.948	1.356	1
2007-08	2.358	1.356	1	1.726	1.356	1	2.147	1.356	1
2007-09	0.738	1.356	0	0.453	1.356	0	0.542	1.356	0
2007-10	-0.086	1.356	0	-0.312	1.356	0	-0.057	1.356	0
2007-11	-1.988	1.356	0	-0.785	1.356	0	-0.999	1.356	0
2007-12	-2.040	1.356	0	-1.077	1.356	0	-1.100	1.356	0
2008-01	-1.268	1.356	0	-1.042	1.356	0	-1.295	1.356	0
2008-02	-1.122	1.356	0	-0.976	1.356	0	-1.160	1.356	0
2008-03	-1.148	1.356	0	-0.933	1.356	0	-1.088	1.356	0
2008-04	-1.202	1.356	0	-0.892	1.356	0	-1.019	1.356	0
2008-05	-1.289	1.359	0	-0.970	1.359	0	-1.089	1.359	0
2008-06	-1.404	1.359	0	-0.984	1.359	0	-1.152	1.359	0
2008-07	-1.469	1.359	0	-1.134	1.359	0	-1.274	1.359	0
2008-08	-1.477	1.359	0	-1.096	1.359	0	-1.291	1.359	0
2008-09	-1.414	1.360	0	-0.558	1.360	0	-1.041	1.360	0
2008-10	-1.017	1.360	0	-0.087	1.360	0	-0.773	1.360	0
2008-11	-0.561	1.360	0	0.232	1.360	0	0.219	1.360	0
2008-12	-0.668	1.360	0	0.339	1.360	0	0.089	1.360	0
2009-01	-1.136	1.362	0	-0.459	1.362	0	-0.859	1.362	0
2009-02	-0.965	1.362	0	-0.185	1.362	0	-0.716	1.362	0
2009-03	-0.849	1.362	0	-0.124	1.362	0	-0.718	1.362	0
2009-04	-0.894	1.362	0	-0.212	1.362	0	-0.925	1.362	0
2009-05	-0.770	1.362	0	-0.259	1.362	0	-0.932	1.362	0
2009-06	-0.897	1.362	0	-0.505	1.362	0	-1.041	1.362	0
2009-07	-1.046	1.362	0	-0.781	1.362	0	-1.272	1.362	0
2009-08	-1.132	1.367	0	-0.909	1.367	0	-1.475	1.367	0
2009-09	-1.286	1.367	0	-1.193	1.367	0	-1.745	1.367	0
2009-10	-1.334	1.367	0	-1.565	1.367	0	-1.820	1.367	0
2009-11	-1.520	1.367	0	-1.697	1.367	0	-1.885	1.367	0
2009-12	-1.615	1.367	0	-1.793	1.367	0	-1.887	1.367	0

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(d) Table A1 (*continued*).

Time (monthly)	Private Real Estate UK								
	Offices			Retail			Industrial		
	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior
2010-01	-1.460	1.370	0	-1.443	1.370	0	-1.660	1.370	0
2010-02	-1.496	1.370	0	-1.561	1.370	0	-1.688	1.370	0
2010-03	-1.616	1.370	0	-1.607	1.370	0	-1.749	1.370	0
2010-04	-1.520	1.370	0	-1.500	1.370	0	-1.680	1.370	0
2010-05	-1.494	1.370	0	-1.472	1.370	0	-1.673	1.370	0
2010-06	-1.512	1.370	0	-1.476	1.370	0	-1.622	1.370	0
2010-07	-1.503	1.370	0	-1.456	1.370	0	-1.629	1.370	0
2010-08	-1.504	1.370	0	-1.465	1.370	0	-1.608	1.370	0
2010-09	-1.510	1.370	0	-1.486	1.370	0	-1.607	1.370	0
2010-10	-1.520	1.370	0	-1.482	1.370	0	-1.619	1.370	0
2010-11	-1.536	1.370	0	-1.505	1.370	0	-1.632	1.370	0
2010-12	-1.582	1.370	0	-1.525	1.370	0	-1.693	1.370	0
2011-01	-1.556	1.370	0	-1.527	1.370	0	-1.687	1.370	0
2011-02	-1.578	1.370	0	-1.543	1.370	0	-1.649	1.370	0
2011-03	-1.593	1.370	0	-1.573	1.370	0	-1.694	1.370	0
2011-04	-1.612	1.370	0	-1.551	1.370	0	-1.682	1.370	0
2011-05	-1.182	1.381	0	-1.562	1.381	0	-1.555	1.381	0
2011-06	-1.197	1.382	0	-1.573	1.382	0	-1.575	1.382	0
2011-07	-1.210	1.382	0	-1.566	1.382	0	-1.593	1.382	0
2011-08	-1.225	1.382	0	-1.572	1.382	0	-1.617	1.382	0
2011-09	-1.235	1.382	0	-1.576	1.382	0	-1.637	1.382	0
2011-10	-1.253	1.382	0	-1.592	1.382	0	-1.655	1.382	0
2011-11	-1.267	1.382	0	-1.580	1.382	0	-1.672	1.382	0
2011-12	-1.280	1.382	0	-1.587	1.382	0	-1.689	1.382	0
2012-01	-1.297	1.382	0	-1.593	1.382	0	-1.700	1.382	0
2012-02	-1.311	1.382	0	-1.572	1.382	0	-1.724	1.382	0
2012-03	-1.325	1.382	0	-1.564	1.382	0	-1.734	1.382	0
2012-04	-1.339	1.382	0	-1.577	1.382	0	-1.730	1.382	0
2012-05	-1.352	1.382	0	-1.542	1.382	0	-1.714	1.382	0
2012-06	-1.365	1.382	0	-1.547	1.382	0	-1.728	1.382	0
2012-07	-1.375	1.382	0	-1.575	1.382	0	-1.672	1.382	0
2012-08	-1.391	1.382	0	-1.578	1.382	0	-1.728	1.382	0
2012-09	-1.404	1.382	0	-1.571	1.382	0	-1.708	1.382	0
2012-10	-1.420	1.382	0	-1.583	1.382	0	-1.717	1.382	0
2012-11	-1.429	1.382	0	-1.539	1.382	0	-1.712	1.382	0
2012-12	-1.448	1.382	0	-1.571	1.382	0	-1.726	1.382	0
2013-01	-1.460	1.386	0	-1.596	1.386	0	-1.750	1.386	0
2013-02	-1.470	1.386	0	-1.593	1.386	0	-1.746	1.386	0
2013-03	-1.483	1.386	0	-1.601	1.386	0	-1.657	1.386	0
2013-04	-1.501	1.386	0	-1.206	1.386	0	-0.253	1.386	0
2013-05	-1.516	1.386	0	-0.130	1.386	0	0.478	1.386	0
2013-06	-1.526	1.386	0	-0.137	1.386	0	-0.362	1.386	0
2013-07	-1.536	1.386	0	-0.158	1.386	0	-0.464	1.386	0
2013-08	-0.749	1.386	0	-0.229	1.386	0	-0.819	1.386	0
2013-09	0.097	1.389	0	-0.464	1.389	0	-1.043	1.389	0
2013-10	0.895	1.389	0	-0.528	1.389	0	-1.260	1.389	0
2013-11	1.739	1.389	1	-0.740	1.389	0	-1.263	1.389	0
2013-12	3.769	1.389	1	-1.021	1.389	0	-1.142	1.389	0
2014-01	1.133	1.389	0	-0.867	1.389	0	-1.427	1.389	0
2014-02	0.696	1.389	0	-0.921	1.389	0	-1.066	1.389	0
2014-03	1.819	1.389	1	-1.051	1.389	0	-0.152	1.389	0
2014-04	1.600	1.389	1	-1.064	1.389	0	-0.476	1.389	0
2014-05	1.860	1.389	1	-1.116	1.389	0	0.196	1.389	0
2014-06	2.893	1.389	1	-1.071	1.389	0	1.127	1.389	0
2014-07	2.178	1.389	1	-1.049	1.389	0	0.700	1.389	0
2014-08	1.953	1.389	1	-1.094	1.389	0	1.075	1.389	0
2014-09	2.353	1.389	1	-0.810	1.389	0	1.370	1.389	0
2014-10	2.471	1.389	1	-0.899	1.389	0	1.609	1.389	1
2014-11	2.388	1.389	1	-0.875	1.389	0	1.491	1.389	1
2014-12	2.875	1.389	1	-0.783	1.389	0	1.489	1.389	1

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(e) Table A1 (continued).

Time (monthly)	Private Real Estate UK								
	Offices			Retail			Industrial		
	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior	BSADFt	BSADFt 95% cv	Explosive behavior
2015-01	1.647	1.389	1	-0.965	1.389	0	0.424	1.389	0
2015-02	1.564	1.389	1	-0.878	1.389	0	0.840	1.389	0
2015-03	2.541	1.389	1	-0.787	1.389	0	1.372	1.389	0
2015-04	2.213	1.389	1	-0.794	1.389	0	1.101	1.389	0
2015-05	2.588	1.389	1	-0.741	1.389	0	1.246	1.389	0
2015-06	2.710	1.389	1	-0.643	1.389	0	1.859	1.389	1
2015-07	2.272	1.389	1	-0.660	1.389	0	1.831	1.389	1
2015-08	2.039	1.389	1	-0.563	1.389	0	1.509	1.389	1
2015-09	2.704	1.392	1	-0.412	1.392	0	1.926	1.392	1
2015-10	2.259	1.392	1	-0.450	1.392	0	1.550	1.392	1
2015-11	2.123	1.392	1	-0.373	1.392	0	1.583	1.392	1
2015-12	2.499	1.392	1	-0.171	1.392	0	1.716	1.392	1
2016-01	1.752	1.393	1	-0.469	1.393	0	1.146	1.393	0
2016-02	1.558	1.393	1	-0.485	1.393	0	1.035	1.393	0
2016-03	0.456	1.393	0	-1.033	1.393	0	0.143	1.393	0
2016-04	0.883	1.403	0	-0.450	1.403	0	0.688	1.403	0
2016-05	0.854	1.403	0	-0.592	1.403	0	0.771	1.403	0
2016-06	0.387	1.408	0	-0.907	1.408	0	0.470	1.408	0
2016-07	-1.523	1.408	0	-1.521	1.408	0	-1.209	1.408	0
2016-08	-0.138	1.408	0	-1.091	1.408	0	0.124	1.408	0
2016-09	-0.091	1.408	0	-1.090	1.408	0	0.251	1.408	0
2016-10	-0.049	1.408	0	-1.095	1.408	0	0.331	1.408	0
2016-11	0.001	1.408	0	-1.100	1.408	0	0.588	1.408	0
2016-12	0.150	1.408	0	-1.103	1.408	0	0.956	1.408	0
2017-01	0.008	1.408	0	-1.117	1.408	0	0.662	1.408	0
2017-02	-0.012	1.411	0	-1.128	1.411	0	0.702	1.411	0
2017-03	0.015	1.411	0	-1.139	1.411	0	1.158	1.411	0
2017-04	-0.034	1.411	0	-1.143	1.411	0	0.972	1.411	0
2017-05	-0.036	1.411	0	-1.156	1.411	0	1.058	1.411	0
2017-06	-0.008	1.411	0	-1.163	1.411	0	1.499	1.411	1
2017-07	-0.059	1.411	0	-1.170	1.411	0	1.360	1.411	0
2017-08	-0.057	1.411	0	-1.178	1.411	0	1.422	1.411	1
2017-09	-0.057	1.411	0	-1.153	1.411	0	1.745	1.411	1
2017-10	-0.060	1.411	0	-1.184	1.411	0	1.709	1.411	1
2017-11	-0.031	1.411	0	-1.168	1.411	0	2.040	1.411	1
2017-12	0.093	1.411	0	-1.143	1.411	0	2.382	1.411	1
2018-01	-0.022	1.414	0	-1.193	1.414	0	2.000	1.414	1
2018-02	-0.065	1.414	0	-1.192	1.414	0	2.036	1.414	1
2018-03	-0.026	1.418	0	-1.235	1.418	0	2.569	1.418	1
2018-04	-0.094	1.418	0	-1.258	1.418	0	2.328	1.418	1
2018-05	-0.101	1.418	0	-1.286	1.418	0	2.628	1.418	1
2018-06	-0.084	1.418	0	-1.336	1.418	0	2.952	1.418	1
2018-07	-0.078	1.418	0	-1.355	1.418	0	2.739	1.418	1
2018-08	-0.141	1.418	0	-1.328	1.418	0	2.598	1.418	1
2018-09	-0.097	1.418	0	-1.180	1.418	0	2.695	1.418	1
2018-10	-0.139	1.418	0	-1.084	1.418	0	2.591	1.418	1
2018-11	-0.146	1.418	0	-0.511	1.418	0	2.643	1.418	1
2018-12	-0.149	1.418	0	-0.045	1.418	0	2.714	1.418	1
2019-01	-0.238	1.418	0	-0.134	1.418	0	2.246	1.418	1
2019-02	-0.267	1.418	0	0.317	1.418	0	2.156	1.418	1
2019-03	-0.271	1.418	0	0.457	1.418	0	2.066	1.418	1
2019-04	-0.325	1.418	0	0.491	1.418	0	1.889	1.418	1
2019-05	-0.371	1.418	0	0.631	1.418	0	1.861	1.418	1
2019-06	-0.396	1.418	0	0.954	1.418	0	1.775	1.418	1
2019-07	-0.419	1.424	0	0.976	1.424	0	1.660	1.424	1
2019-08	-0.425	1.424	0	1.140	1.424	0	1.592	1.424	1
2019-09	-0.430	1.424	0	1.507	1.424	1	1.604	1.424	1
2019-10	-0.455	1.424	0	1.598	1.424	1	1.506	1.424	1
2019-11	-0.484	1.424	0	1.938	1.424	1	1.465	1.424	1
2019-12	-0.469	1.424	0	5.040	1.424	1	1.445	1.424	1

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(f) Table A1 (continued).

Time (monthly)	Private Real Estate UK								
	Offices			Retail			Industrial		
	BSADF _t	BSADF _t 95% cv	Explosive behavior	BSADF _t	BSADF _t 95% cv	Explosive behavior	BSADF _t	BSADF _t 95% cv	Explosive behavior
2020-01	-0.521	1.424	0	3.690	1.424	1	1.335	1.424	0
2020-02	-0.499	1.424	0	3.775	1.424	1	1.287	1.424	0
2020-03	-0.853	1.424	0	4.738	1.424	1	0.534	1.424	0
2020-04	-0.904	1.424	0	4.766	1.424	1	0.239	1.424	0
2020-05	-0.919	1.441	0	4.237	1.441	1	0.280	1.441	0
2020-06	-0.869	1.441	0	3.932	1.441	1	0.437	1.441	0
2020-07	-0.872	1.441	0	3.181	1.441	1	0.487	1.441	0
2020-08	-0.849	1.441	0	2.785	1.441	1	0.468	1.441	0
2020-09	-0.890	1.441	0	2.570	1.441	1	0.659	1.441	0
2020-10	-0.906	1.441	0	2.481	1.441	1	0.951	1.441	0
2020-11	-0.937	1.441	0	2.284	1.441	1	1.158	1.441	0
2020-12	-0.949	1.444	0	1.972	1.444	1	1.319	1.444	0
2021-01	-0.948	1.444	0	1.841	1.444	1	1.049	1.444	0
2021-02	-0.936	1.444	0	1.673	1.444	1	1.206	1.444	0
2021-03	-0.811	1.444	0	1.509	1.444	1	1.702	1.444	1
2021-04	-0.714	1.444	0	1.298	1.444	0	1.634	1.444	1
2021-05	-0.200	1.444	0	1.074	1.444	0	1.800	1.444	1
2021-06	-0.728	1.448	0	0.709	1.448	0	2.173	1.448	1
2021-07	-0.498	1.448	0	0.497	1.448	0	2.049	1.448	1
2021-08	-0.487	1.448	0	0.327	1.448	0	2.266	1.448	1
2021-09	-0.778	1.448	0	-0.038	1.448	0	2.554	1.448	1
2021-10	-0.620	1.448	0	-0.076	1.448	0	2.556	1.448	1
2021-11	-0.815	1.448	0	-0.179	1.448	0	3.180	1.448	1
2021-12	-0.872	1.448	0	-0.480	1.448	0	3.525	1.448	1
2022-01	-0.912	1.449	0	-0.329	1.449	0	3.920	1.449	1
2022-02	-0.921	1.449	0	-0.432	1.449	0	3.564	1.449	1
2022-03	-0.856	1.449	0	-0.760	1.449	0	4.342	1.449	1
2022-04	-0.877	1.449	0	-0.699	1.449	0	4.065	1.449	1

The Table reports $BSADF_t$ and $BSADF_t$ the 95% critical values (cv). The $BSADF_t$ 95% critical values are based on a window size given by $r_0 = (0.01 + 1.8/\sqrt{T})$, where T refers to the number of observations in the sample. Explosive behavior is an indicator variable equal to 1 when $BSADF_t$ is above its 95% critical value and 0 otherwise.