Exuberance in House Prices and the Role of Monetary Policy: The Case of the UK

Abstract

In this paper, we examine the presence of episodes of exuberance in three widely used housing market indicators (real house prices, price-to-income ratio, and price-to-rent ratio) in the UK, by employing the state-of-the-art testing methodology proposed by Phillips and Yu (2011) and Phillips et al (2015). Dating such periods of exuberance in the housing market provides a timeline as well as empirical content to the narrative analysis connecting house price exuberance to the global 2008 recession and other documented episodes of bubbles in asset prices. Several episodes of exuberance are uncovered for the period from January 1991 to December 2015. While the phenomenon of exuberance in house prices in well-established as a driving force of housing bubbles, the role of credit supply and monetary policy stance is less well understood. We attempt to shed light on this role by examining the evidence of exuberance in several monetary aggregates, building on the argument that comparing the timeline of these exuberance episodes with that recorded in the housing market may provide insights on potential leading indicators of house price bubbles and on the "lean versus clean" debate on the role of monetary policy.

Keywords: house price bubbles, mildly explosive time series, supremum ADF test, generalized supremum ADF test

1. Introduction

The bursting of the US house price bubble sparked a global recession in 2008. Between 2008 and 2013, the UK, like many other countries, has been exposed to the global financial crisis and witnessed the slowest recovery on record in its history. House prices in the UK declined by around 15% between January 2008 and March 2009, and the number of property sales dropped from a peak value of 1.67 million in 2006 to 0.86 million in 2009[1].

Given the scale of these developments, the long-standing debate regarding the stance monetary policy should adopt in response to asset price fluctuations has been rekindled in macroeconomic policy circles. This debate is labeled as "*the Clean-Lean debate*", where 'Clean' stands for "*cleaning up the mess*", which involves waiting until the asset price bubble bursts and then taking measures to offset the aftermath (Greenspan, 2002, 2004, 2010; Gruen et al., 2005), while 'Lean' is the short form for "*leaning against the wind*", which entails taking precautionary actions in the hope of preventing bubbles

[1] Trends in the United Kingdom Housing Market, ONS. http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/dcp171766_373513.pdf

from taking shape or at least mitigating the expected cost of pricking the bubble (Cecchetti et al., 2000, 2002; Borio and Lowe, 2002, 2004; White, 2006).

Since the 1990s, the world's major central banks have implemented inflation targeting strategies. Advocates of this strategy argue that policy clarity in communicating the inflation targets *"facilitates well-informed decision making by households and businesses, reduces economic and financial uncertainty, increases the effectiveness of monetary policy, and enhances transparency and accountability, which are essential in a democratic society"* (FRB, 2015, preface). In the US, inflation targeting successfully kept the inflation rate at around 2%, creating a satisfactory environment for long-term economic growth before the 2008 global financial crisis. On the contrary, critics of inflation targeting argue that *"price and output stability do not ensure financial stability"* (Mishkin, 2010a, p.31), i.e., a low inflation climate does not guarantee financial stability mainly because it ignores asset prices. Furthermore, it propagates strong linkages between global economies, credit expansion, and rising leverage, which contributed to the Great Financial Crisis, the first global downturn in GDP in the post-war era (Bloxham et al., 2010; Krueger, 2010). This Crisis taught us an important lesson that asset price increases combined with high leverage and less prudent risk management can be dangerous (Taylor, 2009; Bloxham et al., 2010; Reinhart and Reinhart, 2010; Mishkin, 2011; Brunnermeier and Schnabel, 2015). Risk accumulates in the moderate period and materializes when the bubble bursts.

Castro (2008) points out that the lack of attention to asset price fluctuations might be the reason why the Great Financial Crisis initially emerged in the US housing market and quickly spread to the UK, while the asset markets in the Eurozone showed more stability at the beginning. The evidence suggests that before this crisis, the European Central Bank paid close attention to information about financial instability while the Bank of England and the Fed did not.

However, two main opposing views about leaning against the wind are prevalent (ECB, 2005 and 2010; Detken and Smets, 2004; White, 2009; Mishkin, 2010a). The first one revolves around the argument that it is difficult to identify asset price bubbles. Several basic questions about assets price bubbles like how to detect a bubble, what is the origination of the bubble, whether it is a bubble deriving from rational expectation, etc. are still open (Phillips et al., 2011b). A bubble might be detected under one specification of (asset price) fundamentals, but may vanish under another one for the same sample (Gürkaynak, 2008). The second view claims that monetary policy instruments are not only too blunt to contain a bubble in a specific market, but also require a long time to become effective. It is difficult to tell ex-ante whether the timing and scope of monetary interventions are appropriate, adding to the uncertainty of policy effects. As Brunnermeier and Schnabel (2015) argue, a leaning interest rate policy might be ineffective when it is too weak or too late and be harmful if it is too strong.

As houses are the largest assets held in majority of households' asset portfolios, the stability of the housing market is crucial to wealth allocation (Kohn, 2003; Boivin, 2010). A number of methodologies are proposed and applied to detect bubbles. Some of them attempt to amend the present value model which is the underlying model of rational bubbles, like the time-varying model (Froot and Obstfeld, 1991) and regime-switching model (Driffill and Sola, 1998) for the fundamentals. Black et al. (2006) use time-varying model to test UK housing price and preclude bubbles. Roche (2000) sets a regime-switching model and supports a speculative bubble in the Dublin house prices. Phillips et al. (2011b, 2015) methods which are related with Markov switching model are adopted by Chen and Funke (2014), Pavlidis et al. (2015), Lourenço and Rodrigues (2015). They all report that there are bubbles in UK housing market.

This paper tests whether bubbles exist in the UK's housing market and if they do, whether those bubbles are accompanied by the expansion of monetary aggregates and the overgrowth of credit. Based on empirical results for the period from January 1991 to December 2015 and a chronological comparison of the timelines of price exuberances and monetary policies, we discuss the role of monetary policy in maintaining financial stability, especially in house prices surveillance.

The remainder of the paper is organized as follows: Section 2 provides a selective review of the literature on bubble categories, bubbles tests, and relevant monetary theories to specialize the discussion scope. Section 3 defines rational bubbles from a mathematical perspective and the methodologies of bubble test and date stamping. Section 4 describes the data sources used in the empirical test and analyze the results of econometric tests. Section 5 offers some political recommendation and section 6 provides some concluding remarks.

2. A selective review of the literature
2.1 Bubbles and their detection methods

The earliest record of asset price bubbles is the Dutch *Tulipmania* (1634-1637). Other famous exuberances include the "*Mississippi bubble*" (1719-1720), the "*Lost decade*" in Japan (1985-2003), the "*Dot-com bubble*" (1995-2001), the Subprime Housing Bubble (2003-2010) originating from mortgage defaults in the US, etc. A complete list of bubble episodes throughout history is provided by Aliber and Kindleberger (2015).

2.1.1 Bubble definition and categorisation

There are many different definitions of bubbles. A general idea is that a bubble is associated with a continuous and notable deviation of an asset price from its long-term trend, which usually is followed by a market crash. Theoretical studies categorize asset price bubbles into two types, rational and irrational, depending on the difference in the behaviour of market players (Meltzer, 2002).

Rational bubbles and intrinsic rational bubbles

A rational bubble occurs if the asset holders believe that someone else will take over the asset at a higher price so that they can release themselves from the investment before the bubble bursts (Shiller, 1981; Blanchard and Watson, 1982; Canterbery, 1999; Abreu et al., 2003; Filardo, 2004). Specially, Case and Shiller (2003) define that a rational house bubble is aroused by the house buyers who realize the existence of bubble but still believe a further increase in housing price.

The rational bubble model is based on the asset pricing model which regards the fundamental value of the asset as the present value of expected future income streams in infinity horizon (Campbell and Shiller, 1987, 1988a, b; Craine, 1992). In the so-called "*bubble solution*" to rational expectations equilibria, prices conform to expectations on both the future fundamental stream and the future bubble values (Meltzer, 2002)[2]. A strict definition of rational bubbles requires that the bubbles must be independent of fundamentals. A broader definition of rational bubbles allows for correlation between bubbles and fundamentals. This is the intrinsic bubble (Froot and Obstfeld, 1991). The rational bubble is the premise of most bubble models which could be divided more elaborately according to the extent of information asymmetry.

Irrational bubbles

Irrational bubbles are driven by over-optimism and refer to behavioral models of irrational pricing (Canterbery, 1999; Shiller, 2000). The assumption of perfect rational agents is relaxed, allowing the irrational bubble model to be able to answer questions *"why arbitrage forces may fail to ensure that prices reflect fundamentals at all times"* (Scherbina, 2013, Page 3). Greenspan (1996) uses the term, "*irrational exuberance*", to describe the herd behaviour in the US stock market in the late 1990s[3]. However, the

[2] "Strictly speaking, the horizon must be infinite but, much of the literature discusses bubbles that collapse within a finite period." -- Meltzer, 2002,Page 2

[3] "Clearly, sustained low inflation implies less uncertainty about the future, and lower risk premiums imply higher prices of stocks and other earning assets. We can see that in the inverse relationship exhibited by price/earnings ratios and the rate of inflation in the past. But how do we know when irrational exuberance has unduly escalated asset values, which then become subject to unexpected and prolonged contractions as they have in Japan over the past decade?" -- Alan Greenspan, 1996-12-05

current understanding of behavioral biases and belief distortions is limited and the mechanisms triggering irrational bubbles are not so closed related with my thesis, so that they will not be covered except a quick glance when to test for price exuberance. Vissing-Jorgensen (2004) conducts a survey of irrational bubbles.

Credit-driven bubbles

A most recent proposal is a "*credit-driven bubble*" (Mishkin, 2010a). What we learned from financial history and the financial crisis of 2007-2009 is that the collapse in asset prices will be correlated with severe shocks to the financial system, especially if the bubbles are backed by high leverage and bank credit expansion. A famous case of a closed supervision on credit market abnormality is the "*Australian real estate bubble*" at the beginning of the 2000s (Brunnermeier and Schnabel, 2015; Ji and Otto, 2015). The Reserve Bank of Australia had been tightening credit conditions in several steps since mid-2000, long before the bubble could reach a dangerous level. It is the policies for credit-driven bubbles that represent the central argument now.

2.1.2 Development of rational bubble detection

According to Diakoumi's (2015, Page 17) summary, there are eight different econometric methodologies and a mathematical one for bubble identification. These are: the Variance-bound tests, West's Two-Step tests, the intrinsic bubbles concept, cointegration based tests, the MTAR[4] based model, the concept of a bubble as an unobserved variable, regime switching models tests, a mathematical definition-based model and recursive unit root tests. I review the first four and the late one of them.

The Variance Bounds tests and West's two-step approach

The first econometric model aiming at bubble test is "*West's two-step*" approach (1987, 1988) with the null hypothesis of no bubble. The basic idea is to observe the difference of coefficients which are estimated respectively from the two methods, the actual approach, and the constructed approach. The former one directly regresses stock prices on dividends to get the actual estimates, while the latter one consists of a no-arbitrage asset pricing model formed by the Euler equation and an autoregressive (AR) process of dividends. In the absence of bubbles, estimates obtained from the two approaches should be close enough to reject the null.[5]

Diba and Grossman's bubble detections

Both tests so far try to test the unobservable fundamental value but ignore that a typical characteristic of a bubble is the dramatic price increase. Blanchard and Watson (1982) state that, theoretically, the rational bubble is explosive process and can not be stationary by limited differencing, while the fundamental sequence is empirically proved to be stationary or unit-root processes. It implies that price will not be stationary or difference-stationary process in the presence of the bubble. In light of this finding, Diba and Grossman (1988a, b) use standard unit-root and cointegration tests to detect the non-stationary component in price. Their paper supports the consistence of stock prices with long-term fundamental (dividends) and therefore prove the absence of bubbles in the S&P 500 stock index.

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[4] The momentum threshold unit root test

[5] The possibility about model misspecification has been ruled through a number of specification tests on the Euler equation and the dividends process, including structural break test.

Periodically collapsing bubbles

Evans (1991) demonstrates that cointegration based methodologies are open to periodically collapsing bubbles. This bubble pops and restarts repeatedly, making the observed trajectory more like stationary series in first-order difference or even in level. It grows at different speeds in different stages: at first, it increases slowly at a mean rate; after crossing a threshold value, it enters an eruption channel which develops according to an exogenous i.i.d.[6] Bernoulli process of growing further or collapsing; when the bubble bursts finally, its increase rate falls back to the previous mean rate and the bubble evolution process restarts. Using the parameters estimated by Diba and Grossman (1988), Evans generates the dividend stream and then the fundamental prices. In the presence of periodically collapsing bubbles, a high percentage of the simulated price sequences do not reject the null hypothesis of no bubbles in unit-root tests and cointegration tests. Meanwhile, the percentage increases as the probability of bubble collapsing raises.

Intrinsic bubble model

Although economists have been advancing our understanding of why present rational bubbles models are unable to identify fundamentals and bubbles, we still have limited ideas about where the price deviation actually comes from. One assumption for the foregoing models is the independence of fundamentals and bubbles. But what if they are correlated? The "*intrinsic bubble model*" (Froot and Obstfeld, 1991) suggests connecting bubbles with dividends so to improve the testing power of discounted dividends model. Consequentially, noises in the random walk process of dividends make more profound influences on prices. When the intrinsic bubbles are absent (the null hypothesis), the price/dividend ratios should be a constant. But such linear relationship breaks in the presence of intrinsic bubbles. Their tests on the S&P 500 stock index reject the null hypothesis.

Skepticism mainly targets at the log-normal distribution of dividends. Both the fundamentals and bubbles are obtained from the simulation of dividends. Actually, if Markov switching is allowed in dividends formulas, Driffill and Sola (1998) find that bubbles explain rarely of prices, in other words, bubbles absent.

Evans's critique (1991)

A still open question about the rational bubble tests is the explicit sources of price exuberance. Kindleberger and Aliber (2015) argues that the Dutch "*Tulip-mania*" (1634-1637), the "*Mississippi bubble*" (1719-1720), "*US stock bubble*" (1928-1929), etc. are examples of bubbles, whereas Garber (2000) provides market-fundamental explanations for these episodes. As Evans's famous criticism stated, "*apparent evidence for bubbles can be reinterpreted in terms of market fundamentals that are unobserved by the researcher*" (Evans, 1991, Page 922). One recent research thinking turns to detect the exuberance phenomena of market prices rather than distinguishing which one is the explicit source of price deviation, the fundamentals or the bubbles. Phillips et al. (2011b, 2015) propose "*supremum Augmented Dickey-Fuller test*" and

[6] Independently and identically distributed

"*generalized supremum ADF test*"[7] through the combination of "*the forward recursive regression*" and "*the right-tailed ADF test*". I elaborate those methods in next subhead and their methodologies in section VI.

2.1.3 Phillips's models for exuberance detection

Taylor (2005) first puts forward the use of rolling and recursive methods when applying ADF test. Then Taipalus (2006) applies those methods on rolling subsamples to detect bubbles. She tests log rent to price ratio on real estate markets for Finland, USA, UK, Spain and Germany and draws a bubble conclusion on all markets (assume the rent growth rate are stationary).

Phillips et al. (2011b, 2015) introduce forward recursive regression and right-tailed supremum ADF tests to detect explosive characteristics in time series data, and construct valid asymptotic confidence intervals for the growth parameter in pricing equation. SADF test and GSADF test could be applied to all dramatic price increases triggered by "*either rational bubbles, herd behaviours, or explosive effects on economic fundamentals arising from time variation in discount rates*" (Phillips, 2011b, Page 222). Moreover, their mechanisms are able to empirically identify the origination and termination of the explosive behaviour.

The principle idea is straightforward: do recursive and rolling ADF tests in a right-tailed variation. There are two strategies: one for bubble detection wherein the null hypothesis is a unit root process and the alternative is an explosive one, and the other to locate dates of the emergence and collapse of exuberance. The SADF approach calculates ADF statistic series for each subsample which fixes the starting point at the first observation and extends the ending point one by one (subject to the minimum window size). Then they compare the supremum value of ADF statistic series with the right-tailed credit value which is obtained from simulated unit root process based on the full sample. Finally, they match the ADF statistic sequence with the right-tailed critical values for every chronological subsample. When the SADF statistic first time exceed its correspondingly right-tailed critical value, the exuberance begins; and the ending point is the observation where the statistic is just lower than the critical value.

As for the GSADF approach, it allows the supremum test statistic to be obtained from more flexible windows of subsamples, i.e., the starting point of subsamples also could vary. Then, the bubble detection is same while the date stamping is slightly different. Particularly, the right-tailed critical value is estimated from the asymptotic distribution of the supremum ADF t-statistic.

The SADF and GSADF tests have two obvious advantages. At first, the test procedures have discriminatory power for explosive processes and Evans's periodically collapsing bubbles, thereby making it possible to apply right-tailed unit root tests in bubble detection. Secondly, they deliver a consistent estimation strategy for dating the origination and collapse of bubbles in infinite samples. Even if in finite samples, the tests still have good test power. This point breaks the conventional views that bubbles only can be tested ex-post, indicating an important meaning in policy making. Even if

[7] Augmented Dickey-Fuller test are shortened for ADF test below; supremum Augmented Dickey-Fuller test, SADF test; generalized supremum ADF test, GSADF test.

the powers of both the SADF and GSADF tests become worse with the probability of bubble survival decreasing, their performance is clearly better than conventional tests.

2.1.4 Disagreement about the empirical results of the UK housing bubbles (needs some polishing)

There is no consensus about whether bubbles appear in the UK housing market especially when various models are used to describe the fundamentals. For example, Garino and Sarno (2004) provide evidence of UK house bubble during two periods, the late 1980s and the late 1990s to the early 2000s; Cameron, Muellbauer and Murphy (2006) claim no evidence for a bubble based on their models about fundamental factors, against to the estimation from Barrell et al. (2004) and the IMF (2005) that UK house price is about 30% or higher than its fundamental value in 2003; Black et al. (2006) construct VAR model in regard to price-income ratio to estimate the fundamental value and suggest that UK housing price contains bubbles.

In this paper, we mainly adopt Phillips et al. (2011b, 2015) methodologies, the SADF test, and GSADF test. A similar calculation is also used by a lot of papers, but they mainly focus on the US stock and housing market. Applications towards UK housing market are limited. Chen and Funke (2014) test OECD countries' house markets and find two peaks of tested statistics in UK real house price between 2003 and 2008, showing that there are bubbles. Moreover, they claim that the GSADF bubbles are able to early warn price slump. Pavlidis et al. (2015) tests on real house prices, real price-rent ratio and real price-income ratio while Diakoumi (2015) tests on real house prices and nominal price to fundamental ratios. Diakoumi summaries the differences of those three papers[8] and concludes bubble is a common phenomenon among OECD countries. Generally, the results imply that main bubble happens during the period before the Subprime Crisis.

Other papers also find bubbles, like Lourenço and Rodrigues (2015) report bubbles in log house price index of UK at the ending of the 1980s and from 2000 to 2005; Engsted et al. (2015) also approve the existence of housing bubbles in the UK.

2.2 Monetary policy and asset price bubbles

In this section, we review relevant literature about the role of monetary policies in the supervision of asset markets with a view to setting the scene for the empirical analysis carried out later.

2.2.1 Low inflation rate and financial stability

The central banks of majority economies almost adopt a neoclassicism monetary policy, "*inflation targeting*"[9], to guarantee the stability of aggregate price level. Central banks set base rates to meet targeted inflation rate and to amend the output gap, with no

[8] Diakoumi's comparison of those three papers' results could be found in Appendix Figure 19 to Figure 21.
[9] The precise name of this policy is "flexible inflation targeting". "It involves a strong, credible commitment by the central bank to stabilize inflation in the long run, often at an explicit numerical level, but also allows for the central bank to pursue policies to stabilize output around its natural rate level in the short run." -- Mishkin (2011, Page 66)

additional effort to supervise asset prices. A general consensus is that a moderate and stable inflation rate, around 2% per annual, has created a favorable climate to support domestic economic growth (Mishkin, 2010a; Schularick and Taylor, 2009). They owe the moderate growth before the Great Financial Crisis to the low and less variable inflation rate and a relative peaceful international environment after the Cold War.

Story had begun changing since the beginning of the new millennium. The burst of internet bubble in NASDAQ exposed the shortcomings of inflation targeting. Some attentive economists did make alert at that time (Cecchetti et al., 2000; Borio and Lowe 2002; Borio, English and Filardo, 2003; Borio and White, 2004; White, 2004; Dupor, 2005). With the increasing market scale and financial innovation, financial stability played more crucial role in economy so that the slumps of financial asset markets would lead to the shrink of growth more often than before (Dupor, 2005). However, as the internet bubble did not cause a serious recession, the voice from opponents did not evoke a common reflection about monetary policies.

The Subprime Crisis in 2007-2009, which was dubbed an "*once-in-a-century credit tsunami*", resulted in the most severe global economic recession since the 1930s Great Depression and ruined the credibility of monetary policies (Mishkin, 2010a). Its aftermath, finally, draws the public's attention back to the relationship between monetary policies and asset market stability. The current methodology of inflation measurer, CPI or analogous indicators, is blamed for its underestimation on majority asset prices, which pins down a relatively low bank rate. Moreover, the low inflation rate creates a loosen macro climate and actually encourages the banks' and the agents' risk-taking behaviours (Detken and Smets, 2004; Gambacorta, 2009). Such situation becomes disastrous when the asset markets are controlled by a prevalent overheating, which precisely the US faced before the plunge of housing price.

A more meaningful perspective is that financial crises are "*credit boom gone wrong*" (Schularick and Taylor, 2009), which is not a new story but just gets back to the macro discussion again. Overextended credit flows into financial market breaking the equilibria of asset supply and demand and blowing the asset bubbles. Brunnermeier and Schnabel (2015) checks 23 bubble episodes[10] that are related to an asset price boom and provides considerable support of the perspective that the financial system per se may generate economic instability with credit expansion and crunch and market mania and anxiety. A bubble accompanied by high leverage ratio and rapid credit expansion during its shaping period is the most fatal type (Bordo, 2008; Dokko et al., 2011). Keeping a closed eye on credit market development is the new thoughts and how to execute the leaning policies is the central of debate.

2.2.2 The Lean versus Clean debate

The opinions towards the monetary policies and asset-price bubbles can be roughly split into two sides (Mishkin, 2011). One of the camps is "*Leaning against the wind*". Timing and discretional policies should respond to bubble signals, like the departure of asset prices from their long-term trend, to hinder the momentum of asset prices or at least to mitigate the sweep-away power after bubble collapses (Cecchetti et al., 2000;

[10] Kindleberger (1978) looks over more than 23 bubbles. Brunnermeier and Schnabel (2015) select 20 of them. They then add 3 more bubbles, the Chicago real estate boom (1881-1883), the Norwegian crisis (1899) and the Australian real-estate bubble (the early 2000s). Those bubbles are asset related bubbles.

Borio and Lowe, 2002; White, 2006). A proactive increase of the interest rate during the winding phase leaves more policy chances for the central bank to decline it after the price fall, avoiding the zero lower bound situation (White, 2009).

On the contrary, "*cleaning up the mess*" supports to save costs on bubble detection and precautions and just compensate negative influence once bubble bursts (Greenspan, 1999, 2002). An essential argument from the "*Cleaning*" camps is that the expected costs arising from cleaning post-bubble mess are much less than those required by the "*Leaning*" actions. Moreover, a policy trying to mitigate bubbles might lead to the political distortion and even an early prick of bubbles which might trigger a more serious consequence (Bernanke et al., 1999; Greenspan, 2002; Gruen et al., 2003; Mishkin, 2007). Mishkin (2011) lists more than seven reasons argued by the "*Cleaning*" side, while I prefer to sum up them to three aspects: the challenge of bubble detection, the ineffectiveness of traditional instruments, and the better of alternative policies.

1) The challenge of bubble detection. The difficulty of bubble definition and examination has been clearly displayed in section 2.1. This point is cited hereon to support the "*Cleaning*" side. However, if the detection is effectual and forceful, it is still worth to identify bubbles even at the high cost. Therefore, a further logic is the virtual impossibility to detect bubbles. This is because the central banks in fact do not have information advantages in the asset prices. If a bubble could be perceived by central banks, no arbitrage principle guarantees the disappearance of bubble (Gruen et al., 2003; Giavazzi and Mishkin, 2006; Mishkin, 2010a, 2011). The stock price "bubbles" of Germany in 1927 is an example that the monetary authority wrongly assessed the stock market and pricked an nonexistent bubble (Brunnermeier and Schnabel, 2015).

2) The ineffectiveness of traditional instruments. In view of the "*Leaning*", benchmark interest rate is expected to lower so as to slow down the swell of asset-price bubbles. However, the "*Cleaning*" totally disagrees with it. Firstly, monetary policies, especially the base rate, are too blunt to pinpoint a certain asset market[11] (Dale, 2009; Boivin et al., 2010; ECB, 2010). A tighten monetary policy might help to stop the price increasing in a market, say, the housing market, but the cost is the contraction of other asset markets, and to a certain extent, the disruptions in the economy.

Secondly, even if the asset price explosion occurs widely in the economy, a more vital determinant is timing (Chen and Funke, 2013). An improper policy adjustment would weaken its own effect, and worse, aggravate the consequence of bubble burst (Bean, 2009; Mishkin, 2010, 2011). Over-reactive monetary policies cause the bubble burst earlier and possibly drag the economy into stagnant. It implies that monetary policy cannot be carried out without a rigorous assessment of its scope, degree, and span. This point is in line with the high cost of bubble detection, which is also the argument from the "*Cleaning*" to against the "*Leaning*".

A famous example to support this view is the "*Lost decade*" in Japan. According to Brunnermeier and Schnabel's survey (2015), Japanese monetary policies came too late and too strong, which directly pricked bubbles in stock and housing markets and pulled Japan into a protracted depression.

[11] Monetary policy is expected to make functions if the prices soaring is a common phenomenon in economy. (Boivin, Lane and Meh, 2010)

3) The better of alternative policies. As the monetary policy does not work in asset price intervention, substituted approaches should be considered. Nonconventional monetary policies, like liquidity and capital requirements, expectation management, securities purchasing programme, and exchange rate intervention could be adopted to clean up the post-bubble disorder with low expenditure if the central bank is competent and creditable (Kohn, 2008; Mishkin, 2010a). This point will return in section 2.2.4.

2.2.3 Credit-driven bubbles

The lesson from the Subprime Crisis is the necessity to rethink the current monetary system. Does a new supervision exist to avoid the shortcomings of current monetary practices? The most updated view on the relationship of money and credit is the "*credit view*" (Schularick and Taylor, 2009). Its characteristic is the divergence of credit aggregation and broad money aggregation. Hence, the bubble studies under this stage tending to link asset bubbles with credit booms rather than a sole price phenomenon.

Actually, early economists, like Kindleberger (1978), think about the relationship of monetary policies and asset bubbles from the point of credit expansion. On the one side, exogenous factors, such as technical advance, positive polity, financial innovation, market deregulation, etc., bring investment hotspots; one the other side, fierce competition among banking industry motivates more credit issues. Sequentially, speculative bubbles arise with high probability (Minsky 1977 cited by Filardo, 2004).

The global Subprime Crisis is a firm evidence for the "*Leaning*" to oppose previous attitudes of monetary authority toward the asset price abnormality (Bernanke, 2010). Brunnermeier and Schnabel (2015) compare the Subprime Crisis in the United States with the real estate bubble in Australia from 2002 to 2004 to confirm their arguments. Both bubbles were induced by the rapid developments in their domestic financial sectors, like the financial deregulation, assets securitization, and credit expansion. However, Reserve Bank of Australia watched carefully on the credit quality and banks' capital ratio when the housing prices ascended quickly. They tightened monetary policy step by step and took an "*open mouth*" operation to calm down the market. Those measures ensured a smooth transition in the de-bubbling process of the Australian housing market. On the contrary, the United States faces a substantial fall in output, a government austerity, and huge potential costs for the Fed to quit Quantitative Easing policy (Reinhart and Reinhart, 2010). Actually, US spent more than 6 years to step back from the brink due to the time-consuming deleveraging in the financial market.

From the stance of "*credit view*", a crucial premise of Australia's success is fitting the credit supervision into the larger framework of monetary policy (Taylor, 2009). When the bankers take the credit element into their introspection of the current monetary mechanism and look seriously into the factors fueling the price acceleration, they figure out that the "*credit-driven bubbles*" accompanied by extreme leverage are more dangerous than other bubble types, and that monetary policies are highly possible to make functions to credit market and sequentially to asset prices.

Credit expansion generates the "*credit-driven bubbles*" through a feedback loop whose inverse process is one of the roots of financial disruptions (Mishkin, 2007, 2009, 2010abc, 2011; Boivin et al., 2010; Dokko et al., 2011). In detail, for certain reasons[12], there is a credit expansion, and coincidently the public has an optimistic expectation on asset markets, say the housing market. The redundant money which cannot be absorbed by the real economy flows into the financial markets. In the housing market, investors snap up houses spurring the price. Because of the wealth effect, the price increase in turn stimulates people to buy more even if they will bear heavier mortgage. Thereafter, generate more demands for houses and further push the price up. However, such process is not endless. Price will give back much of the previous rise and bubble will pop, causing loans go sour. When the house value evaporates, more and more mortgagers tend to default with very low credit costs, leaving the mess to banks. Thereby, banks cut down credit issues to prevent further losses, aggravating price falling. Finally, market confidence is damaged and the economy gets into recession.

2.2.4 Macroprudential policies

The interaction between credit market and financial market justifies the "*Leaning*" policy. Thereupon, the political objective also changes from asset prices to credit expansion, a lightly but crucial shift. It is easier for the central banks to pay close attention to the credit market than to identify bubbles from market prices. Because of the information advantage, central banks have more policy space to intervene credit market. By now, the argument concentrates on how to prevent the credit-driven bubble or at least limit its destruction (White, 2009; Mishkin, 2010a, 2011).

Monetary approach is an old idea. Monetary policies are expected to make influence on credit creation process through changing the capital costs and investment incentives at the micro level, and influencing market expectation at the macro level. The Fed is still blamed for the excessively low interest rate before the Subprime Crisis. Gambacorta (2009) claims that a peaceful climate in fact might encourage the public's confidence on the economy and further their risk chasings on asset markets. Borio and Zhu (2008) state that low benchmark interest rate encourages the funds to search higher yield investment since the implication of risk free rate from base rate[13]; reduces the financing cost of companies so that increases their capability to leveraging and collateral; and brings more low-quality borrows (Ioannidou et al., 2009), a result of profit shrinking and increasing interbank competition.

However, the problem of monetary approach towards credit expansion is that it is still subjected to the critiques I mentioned in section 2.2.2. The underlying logic is the dilemma of policy goals (Mishkin, 2011)[14]. That is, monetary policies were required to keep the stability of economy and finance simultaneously. If monetary policies served such dual-task, the public would feel confused about which one is the indeed purpose of central banks, blocking the political communication. Mishkin deems that because financial market is more fluctuant than the real economy and monetary policies usually exhibit lags of its transmission mechanism, financial stability should be regarded as an independent policy objective (Bean, 2004).

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[12] A more dangerous characteristic of credit-driven bubbles is that their occurrence does not require for preempted price or output increases (Mishkin, 2011). A peaceful climate in fact might encourage the public's confidence on the economy and further their chasing on bubble assets (Gambacorta 2009).

[13] Central bank backstops and government bailouts, which have been proved lead the moral hazards of financial intermediaries, lead the fund managers underestimate risks they were taking.

[14] "There is a monetary policy trade-off between having the inflation forecast at the target and the pursuit of financial stability." -- Mishkin 2011

Recently, macroprudential policy has become a top trend in macroeconomic cycle (Dokko et al., 2011). The interbank accord *Basel III* is the best representation of the key principles of macroprudence. Basically, it argues that prudence of individual intermediations would harm the economy systematically. For example, when the prices decline, a simultaneous fire sale of assets by banks in order to meet fixed capital ratio leads a further fall of asset prices, eroding the banks' balance sheet more and infecting the whole economy finally. New liquidity requirements, a leverage cap and a countercyclical capital buffer are proposed by *Basel III* aiming at reducing systematic risk. The biggest challenge for macroprudential policy when it comes into implementation is the lobby from financial institutions whose activities are directly restrained, weakening policy effectiveness.

3. Methodology[15]

3.1 Econometric definitions of rational bubble

Rational bubble is the basic assumption of most methodologies for bubble detection today. According to the relationship of bubbles and asset fundamentals, rational bubbles could be divided into the standard model and the intrinsic model. Also, they could be ranged based on the behaviour of the fundamentals: the standard rational model and the explosive fundamental model.

3.1.1 Rational bubbles deriving from utility optimization

Assume personal utility, u, is solely determined by consumption, c_t, i.e., $u = u(c_t)$. A rational agent has y_t units endowment and x_t units certain asset at time t (y_t and x_t are independent). The consumption in day t is determined by the endowment, and the net capital inflow. i.e.,

$$c_t = y_t + (P_t + F_t)x_t - P_t x_{t+1}, \text{ (eq.1)}$$

where P_t is the asset price, and F_t is payoff from the asset (in standard rational bubble model, F_t is stationary). By allocating consumptions throughout all states (from $i = 0$ to infinity), the agent's total utility reaches an optimal level, U.

$$U = Max\ E_t\{\sum_{i=0}^{\infty} \beta^i u(c_{t+i})\} \text{ (eq.2)}$$

herein β is the personal time preference (the reciprocal of discount factor) and E_t represents the expectation of future utility at day t. If marginal utility is constant and risk preference is neutral, the first order condition of (eq.2) is

$$\beta E_t(P_{t+1} + F_{t+1}) = E_t(P_t) \text{ (eq.3)}$$

No arbitrage principle is a premise assumption for the rational bubble detection. Then, different people's βs converge to $\frac{1}{(1+r)}$[16], where r is a risk-free interest rate. Therefore, (eq.3) is transformed to

$$E_t(P_t) = \frac{1}{1+r} E_t(P_{t+1} + F_{t+1}) \text{ (eq.4)}$$

If the market is efficient, i.e., $E_t(P_t) = P_t$, then we obtain the universal equation for most rational bubble models,

$$P_t = \frac{1}{1+r} E_t(P_{t+1} + F_{t+1}) \text{ (eq.5)}$$

Recursive substitution yields

$$P_t = \sum_{i=0}^{\infty} (\frac{1}{1+r})^i E_t(F_{t+i}) + \lim_{i\to\infty} (\frac{1}{1+r})^i P_{t+i} \text{ (eq.6)}$$

According to the transversality condition, $\lim_{i\to\infty} (\frac{1}{1+r})^i P_{t+i}$ would converge to zero when i goes to infinity[17].

If bubble is not present, the market price equals its fundamental value,

$$P_t = P_t^f \text{ (eq.7)}$$

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[15] This section is based on my previous coursework essay for Econ 420 Time series course. A literature review of asset bubbles in theories and econometric implementation.

[16] Here, r is constant while researches also relax this condition to allow a time-varying discount factor.

[17] "If there is a positive bubble and this term is not zero, the infinitely lived agent could sell the asset and the lost utility, which is the discounted value of the dividend stream, will be lower than the sale value. This cannot be an equilibrium price as all agents will want to sell the asset and the price will fall to the fundamental level." -- Gurkaynak, R.S. (2008, Page 170)

hereon P_t^f is the fundamental value and is the unique solution of (eq.6) in the absence of bubbles,

$$P_t^f = \sum_{i=0}^{\infty}(\frac{1}{1+r})^i E_t(F_{t+i}) \text{ (eq.8)}$$

However, when the price has the bubble element, B_t, the solution of (eq.6) is

$$P_t = P_t^f + B_t \text{ (eq.9)}$$

If B_t is a rational bubble, it need to satisfy the restriction

$$E_t(B_{t+1}) = (1+r)B_t \text{ (eq.10)}$$

Thereby, (eq.5) is transformed to

$$P_t = \frac{1}{1+r}E_t(P_{t+1} + F_{t+1}) + B_t \text{ (eq.11)}$$

where the transversality condition still holds when B_t satisfies (eq.10).

3.1.2 The explosive fundamental model

A variant of (eq.5) is the explosive fundamental model (Pavlidis et al., 2015). In the presence of bubbles,

$$P_t = \frac{1}{1+r}F_t + \frac{1+r}{r}\sum_{i=0}^{\infty}(\frac{1}{1+r})^i E_t(\Delta F_{t+i}) + B_t \text{ (eq.12)}$$

where

$$F_t = \emptyset F_{t-1} + \epsilon_t, \epsilon_t \sim white\ noise(0, \sigma_\epsilon^2). \text{ (eq.13)}$$

F_t is stationary when $|\emptyset| < 1$, has unit root when $|\emptyset| = 1$, and is explosive when $|\emptyset| > 1$. When bubble disappears, (eq.12) can be transformed to

$$\frac{P_t}{F_t} = (1 + (1-\emptyset)\left(\frac{1+r}{1+r-\emptyset}\right))\frac{1}{r} \text{ (eq.14)}$$

That is, the ratio of price and its fundamental is non-explosive if bubble absences. Oppositely, if a bubble is present, the relationship of P_t and F_t cannot be re-written into linearity like (eq.14). In practical application, the ratio of P_t and F_t will be explosive when a bubble is present.

3.1.3 Intrinsic bubbles

Intrinsic bubble is a special example of the rational bubble. In this case, the bubble is correlated with the fundamental rather than grows exogenously at risk-free interest rate. Froot and Obstfeld (1991) suggest an AR(1) process to describe the random walk feature of fundamentals,

$$f_t = \mu + f_{t-1} + \xi_t \text{ (eq.15)}$$

where f_t is the log fundamental, $\xi_t \sim N(0, \sigma^2)$. So that once given the initial value of the fundamental, (eq.8) converges to

$$P_t^f = \kappa F_t \text{ (eq.16)}$$

where $\kappa = \frac{e^{(\mu + \frac{\sigma^2}{2} - \ln(1+r))}}{(1+r) - e^{(\mu + \frac{\sigma^2}{2})}}$. It implies that when the bubble part is excluded, the asset price should be linear with its dividend. That is,

$$\frac{P_t}{F_t} = \kappa \text{ (eq.17)}$$

On the other side, the intrinsic bubble can be formularized as

$$B(F_t) = cF_t^\lambda \text{ (eq.18)}$$

where λ is the positive root of $\frac{\lambda^2\sigma^2}{2} + \lambda\mu - \ln(1+r) = 0$, and c is an arbitrary positive constant. Obviously, (eq.18) meets the rational bubble condition, (eq.10).

Thereby, in the presence of intrinsic bubble, price/dividend ratio can not be expressed as a linear function of dividend.

$$\frac{P_t}{F_t} = \kappa + cF_t^{\lambda-1} + \iota_t \quad \text{(eq.19)}$$ [18]

Bubble represents the non-linearity in the price-dividend relationship.

3.2 Bubble detections and date-stamping strategies

The development of bubble detection saw transformations of research focus. First, econometricians try to imitate patterns of unobservable departure portion in price, like the "*Variance Bounds test*" and "*West's two-step*" approach which are not introduced in this thesis. Then, since Diba and Grossman (1988), they attempt to test the fundamentals. However, they are all subjected to Evans critique (1991): *any apparent evidence for bubbles can be reinterpreted in terms of market fundamentals that are unobserved by the researcher*[19]. Therefore, Phillips's methodologies (2011b, 2015) pay attention to the explosive behaviour of the market price per se.

3.2.1 Standard unit-root and cointegration tests

Diba and Grossman (1988) put forward those methods to test rational bubbles. They introduce an unobserved fundamental Λ_t into (eq.8), i.e.,

$$P_t^f = \sum_{i=0}^{\infty}(\frac{1}{1+r})^i E_t(F_{t+i} + \Lambda_{t+i}) \quad \text{(eq.20)}$$

where Λ_t is a variable that is unobservable by researchers or some times even the market participants but indeed exists in the market. In order to ensure the stationarity of P_t^f, $(F_t + \Lambda_t)$ is required to grow at a geometric rate smaller than $(1+r)$ [20]. Since in the absence of bubbles, $P_t = P_t^f$ (eq.7), then P_t is as stationary as P_t^f and sequentially, as F_t.

When turning to the bubble case, they state that the actual bubble solution of (eq.10) satisfies the stochastic difference equation,

$$B_{t+1} - (1+r)B_t = z_{t+1} \quad \text{(eq.21)}$$ [21]

where $E_t(z_{t+1}) = 0, \forall i \geq 1$. Thereby, after being differenced n times, the bubble procedure has following formula:

$$(1-L)^n[(1-(1+r)L]B_t = (1-L)^n z_t \quad \text{(eq. 22)}$$

where L is the lag operator. It is clear that B_t sequence is non-stationary[22]. Therefore, they conclude that P_t will be as stationary as F_t in the absence of bubbles.

---

[18] The existence of this error term, ι_t, is not well motivated. Froot and Obstfeld suggest it may arise because of within-period predictable excess returns.

[19] Similar explanation from Gurkaynak (2008): in general, having a less restrictive fundamentals model - for example by allowing for time-varying discount rates, risk aversion, or structural breaks - allows the fundamentals part of the model to fit the data better, leaving less room for a bubble.

[20] Alternatively, Λ_t is not more non-stationary than F_t. For example, if F_t are second order differenced stationary, Λ_t could be stationary at most in second order differenced difference, that is, stationary or first order differenced stationary.

[21] Diba and Grossman (1988) say that if a rational bubble exists, it must exist at the beginning of trading period, i.e., $t = 0$. Because if there is no bubble at time t, $(t > 0)$, a rational bubble cannot appear at time $t+1$ and all subsequent date.

[22] The existence of this error term is not well motivated. Froot and Obstfeld suggest it may arise because of within-period predictable excess returns.

This conclusion indicates that standard unit-root test has detective power in the bubble study. See (eq.7) and (eq.20), if P_t and F_t reject the null hypothesis of unit-root, or their differencing forms reject the null (as long as the differencing times of P_t is no more than those of F_t), the conclusion is no bubble. On the contrary, if bubbles are present, see (eq.9), (eq.20), and (eq.22), P_t will never be stationary within limited times of difference.

In the cointegration method, assume Λ_t is stationary in level and F_t is first differencing stationary, they rearrange (eq.20) and get

$$P_t - ar^{-1}F_t = B_t + ar^{-1}\left[\sum_{i=0}^{\infty}(\frac{1}{1+r})^i E_t(\Delta F_{t+i})\right] + \sum_{i=0}^{\infty}(\frac{1}{1+r})^i E_t(\Lambda_{t+i}) \quad \text{(eq.23)}$$

Obviously, if $B_t = 0$, the right side of the equation ensures the linear combination of P_t and F_t to be stationary. In other words, P_t and F_t are cointegrated. In the presence of bubbles, P_t and F_t are non-cointegrated since bubble inserts an explosive element in the right side of the equation.

In summary, Diba and Grossman's approaches refer to standard unit root test and cointegration test to discover the non-stationary behaviour in asset price. Under the null hypothesis of no bubble, the price is expected to be as stationary as the fundamental and at least one linear relationship between them is also expected.

3.2.2 Evans's (1991) periodically collapsing bubbles

Evans (1991) criticizes that several aspects can explain no cointegration between the price and the fundamental: 1) the presence of bubble; 2) F_t is stationary while P_t is non-stationary, due to the more non-stationary unobservable factors, Λ_t; 3) even if P_t is as stationary as F_t, it is still possible that there is no long-run equilibrium relationship between P_t and F_t. In a word, "*something non-stationary*" rather than an exclusive bubble leads the result that P_t is non-cointegrated with F_t (Gurkaynak, 2008).

Moreover, the standard unit root and cointegration tests lose effectiveness when faces periodically collapsing bubble. This type of bubbles booms and bursts repeatedly, making its trajectory more closed to an AR(1) process or even a stationary procedure. Meanwhile, it still follows Diba and Grossman's specification, (eq.21), during its explosive stage. Integration and cointegration methods are only applicable for monotonously explosive bubble with non-zero initial value, and thereby, are incapable in periodically collapsing bubbles.

The periodically collapsing bubble is specified as following:

$$B_{t+1} = (1+r)B_t v_{t+1}, \ \ if\ B_t \le \alpha \quad \text{(eq.24a)}$$
$$= [\delta + \pi^{-1}(1+r)\theta_{t+1} * (B_t - (1+r)^{-1}\delta]v_{t+1}, \ \ if B_t > \alpha \quad \text{(eq.24b)}$$

herein δ is a positive value smaller than $(1+r)\alpha$, $E_t(v_{t+1}) = 1$, and θ_{t+1} is an exogenous i.i.d. Bernoulli process equal to 1 with a probability π ($\pi > 0$) and equal to 0 with a probability $(1-\pi)$. Initially, bubble follows a mild explosion with the growth rate, $(1+r)$. Once its scale exceeds a threshold value, α, the evolution path diverges into two directions according to the Bernoulli process: keep exploding with the probability π or fall back to a small restarting value with the probability $(1-\pi)$.

Evans's critique (1991) disproves a lot of bubble detection methods at that time. Alternative ideas are put forward to overcome the weakness. For example, the regime-switching model deals with the mild explosion, the monotonous explosion, and the collapsing processes under different regimes. Another instance is to focus on the market price per se rather than the fundamental wealth.

3.2.3 Right-tailed Augmented Dickey-Fuller tests

The basic idea of right-tailed ADF tests is simple. They change the tested objective to the market price of asset, the most accessible sequence, to detect its departure from long-term trend. Generally, the steps are: 1) ADF t-statistic based on flexible subsamples is calculated repeatedly; 2) compare the supremum value with the right-tailed critical value based on full sample to determine whether reject the null hypothesis of no bubble; 3) compare the ADF t-statistic sequence with the critical value sequence to date the origination and termination of price exuberance.

Phillips's bubble models

Phillips et al. (2015) commence deduction from the original model with a mild drift in the price process:

$$x_t = dT^{-\eta} + \phi x_{t-1} + \varepsilon_t \quad \text{(eq.25)}$$

where d is a constant parameter, T is the sample size, $\eta > \frac{1}{2}$ to fit the magnitude order of x_t as that of a pure random walk, $\phi = 1$, and ε_t is the error term following a normal independent and identical distribution with zero mean and constant variance, σ^2. The empirical model of tested time series thereby can be expressed as an autoregressive equation, i.e.,

$$x_t = \mu_{r_1,r_2} + \phi_{r_1,r_2} x_{t-1} + \left[\sum_{j=1}^{J} \psi_{r_1,r_2}{}^{j} \Delta x_{t-j}\right] + \varepsilon_t,\ \ \varepsilon_t \sim iid.N(0, \sigma^2_{r_1,r_2}) \quad \text{(eq.26)}$$

where r_1 and r_2 are the beginning and the ending points of subperiod respectively[23] satisfying $r_2 = r_1 + r_w$. r_w is the fractional window size ($r_w > 0$) subjected to a minimum window size, r_0. And $r_1 \in [0, r_2 - r_0]$, $r_2 \in [r_0, 1]$, where r_0 also is the initial subsample window width fraction. Phillips et al (2015) recommend $r_0 = 0.01 + \frac{1.8}{\sqrt{T}}$. The full sample is the case when $r_1 = 0$ and $r_2 = 1$.

The authors propose a single-bubble model for the asset price which is a regime-switching model allowing the appearance of a martingale mechanism ($t < \tau_e$), a single mildly explosive episode following AR(1) process ($\tau_e \le t < \tau_f$), a collapsing ($t = \tau_f$), and a subsequent renewal of martingale behaviour ($t > \tau_f$):

$$\begin{aligned} x_t &= x_{t-1} + \varepsilon_t,\ \ if\ t < \tau_e && \text{(eq.27a)} \\ &= \delta_T x_{t-1} + \varepsilon_t,\ \ if\ \tau_e \le t \le \tau_f && \text{(eq.27b)} \\ &= \textstyle\sum_{k=\tau_f+1}^{t} \varepsilon_k + x^*_{\tau_f},\ \ if\ t > \tau_f && \text{(eq.27c)} \end{aligned}$$

where $\varepsilon_t \sim iid.N(0, \sigma^2_\varepsilon)$, $\tau_e = Tr_e$ ($\tau_f = Tr_f$) dates the commencement (termination) of the explosive episode, $\delta_T = 1 + cT^{-\alpha}$ ($c > 0$, and $\alpha \in (0,1)$), and $x^*_{\tau_f} = x_{\tau_e} + x^*$ ($x^* = O_p(1)$).

The multiple bubble model is similar:

$$\begin{aligned} x_t &= x_{t-1} + \varepsilon_t,\ \ if\ t \in N_0 && \text{(eq.28a)} \\ &= \delta_T x_{t-1} + \varepsilon_t,\ \ if\ t \in B_1 \cup B_2 \cup \ldots \cup B_i, i = 1,2,3, \ldots && \text{(eq.28b)} \end{aligned}$$

[23] i.e., the t_1th observation locals at $r_1 T$, and the t_2th at $r_2 T$.

$$= \sum_{k=\tau_{i,f}+1}^{t} \varepsilon_k + x_{\tau_{i,f}}^*, \quad if\ t \in N_i, i = 1,2,3, \ldots \qquad \text{(eq.28c)}$$

here, $N_0 = [1, \tau_e)$ is the pre-bubble period, $B_i = [\tau_{e,i}, \tau_{f,i}]$ is the expansion process, and N_i=$(\tau_{f,i}, \tau_{e,i+1})$ is the period between the price peak and the resurgence of next exuberance.

Rolling window tests for bubbles

Phillips et al. (2011b, 2015) notice the explosive behaviour in the asset price, p_t, and the nonexplosive behaviour in the fundamental, f_t, where p_t and f_t are the logarithmic forms of asset price and fundamental. To detect the temporary explosive behaviour in a periodically collapsing bubble, they use a right-tailed unit root test with the null hypothesis of a unit root ($\phi = 1$) against the alternative of an explosive root ($\phi > 1$). Repeatedly estimate (eq.26) in forward recursive regressions where the tested intervals are incremented successively by one observation at each estimation. The t-statistic of estimated coefficient under window (r_1, r_2) is denoted as ADF_{r_1,r_2},

$$ADF_{r_1,r_2} = \frac{\hat{\phi}_{r_1,r_2} - 1}{se(\hat{\phi}_{r_1,r_2})} \quad \text{(eq.29)}$$

where $\hat{\phi}_{r_1,r_2}$ is the least square estimate of ϕ_{r_1,r_2}, and $se(\hat{\phi}_{r_1,r_2})$ is the standard error of $\hat{\phi}_{r_1,r_2}$. So that their right-tailed test statistic is

$$\sup_{\substack{r_2 \in [r_0,1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1,r_2} = \sup_{\substack{r_2 \in [r_0,1] \\ r_1 \in [0, r_2 - r_0]}} \frac{\hat{\phi}_{r_1,r_2} - 1}{se(\hat{\phi}_{r_1,r_2})} \quad \text{(eq.30)}$$

When $\phi = 1$ (the null hypothesis),

$$\sup_{\substack{r_2 \in [r_0,1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1,r_2} \Rightarrow \sup_{\substack{r_2 \in [r_0,1] \\ r_1 \in [0, r_2 - r_0]}} \frac{\frac{1}{2} r_w [W(r_2)^2 - W(r_2)^2 - r_w] - \int_{r_1}^{r_2} W(r) dr [W(r_2) - W(r_1)]}{r_w^{1/2} \{ r_w \int_{r_1}^{r_2} W(r)^2 dr - [\int_{r_1}^{r_2} W(r) dr]^2 \}^{1/2}} \quad \text{(eq.31)}$$

where W is the standard Brownian motion (Wiener process), $\widetilde{W}(r) = W(r) - \frac{1}{r} \int_0^1 W$ is demeaned Brownian motion. This is the mechanism of generalized supremum ADF test and Diba and Grossman (1988) denote it as GSADF test:

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0,1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1,r_2} \quad \text{(eq.32)}$$

Supremum ADF (SADF) test is a special case of GSADF test where r_1 equals 0. That is fixing the beginning of window at the first observation.

$$ADF_{0,r_2} = \frac{\hat{\phi}_{0,r_2} - 1}{se(\hat{\phi}_{0,r_2})} \quad \text{(eq.33)}$$

$$SADF(r_0) = \sup_{r_2 \in [r_0,1]} ADF_{0,r_2} \quad \text{(eq.34)}$$

where, under the null hypothesis ($\phi = 1$),

$$\sup_{r_2 \in [r_0,1]} ADF_{0,r_2} \Longrightarrow \sup_{r_2 \in [r_0,1]} \frac{\int_0^{r_2} [W(r) - \frac{1}{r} \int_0^1 W] dW}{\{ \int_0^{r_2} [W(r) - \frac{1}{r} \int_0^1 W]^2 \}^{1/2}} \quad \text{(eq.35)}$$

The essential thought is showed in Figure 1.

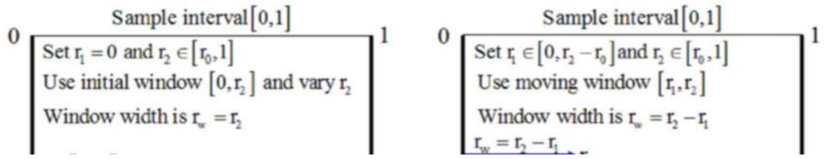
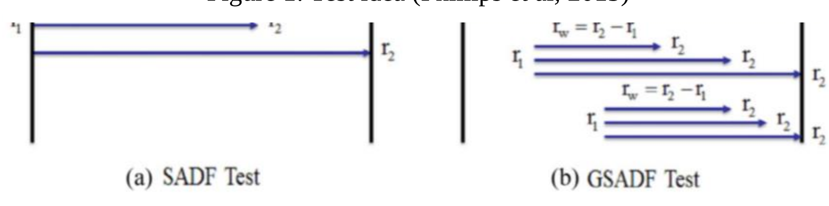


Figure 1: Test idea (Phillips et al, 2015)



Phillips et al. (2011b, 2015) get asymptotic critical values from numerical simulations with 2000 replications. The Wiener process is approximated by partial sums of 2000 independent $N(0,1)$ varieties. The finite sample critical values are obtained from Monte Carlo simulation with 2000 replications. When the test statistic exceeds the corresponding credit value, reject the null hypothesis of unit root, and there are explosive subperiods[24] in asset prices.

Date-stamping strategies

The basis of date-stamping strategies is a double recursive procedure, "*backward supremum ADF test*". Denote the test statistic of the backward supremum ADF (BSADF) test as

$$BSADF_{r_2^*}(r_0) = \sup_{r_1 \in [0, r_2^* - r_0]} ADF_{r_1, r_2^*} \quad \text{(eq.36)}$$

where the ending point r_2 is fixed at r_2^*, opposite to SADF test which fixes the beginning point. In other words, BADF test is "*a sup ADF test on a backward expanding sample sequence where the endpoint of each sample is fixed at r_2^* and the start point varies from 0 to $r_2^* - r_0$*" (Phillips et al., 2015, Page 1051).

Specifically, for the SADF strategy, the test statistic is the backward ADF statistic which is the inverse form of the ADF statistic; as for the GSADF strategy, the test statistic is BSADF statistic which performs each sample with fixed ending point, r_2, and backward expanding start point, r_1, varying from 0 to $r_2 - r_0$. See the Figure 2

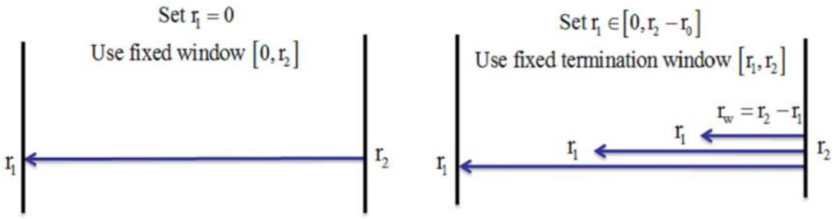


Figure 2: Test idea for backward method

If there is only one suspected bubble in the sample period, the SADF strategy is enough to determine the origin and ending dates of price exuberance. The operation process is comparing the first backward ADF statistic, ADF_{0,r_0},[25] with the corresponding right-tailed critical value, $cv_{r_0}^{\beta_T}$, which is approximated by the asymptotic distribution of the standard ADF t-statistic. Move r_2 to add one more observation. Then repeat the comparison again. The infimum of r_2 where ADF_{0,r_2} just exceeds $cv_{r_2}^{\beta_T}$ is the start point of exuberance whereas the endpoint is where ADF_{0,r_2} is just smaller than $cv_{r_2}^{\beta_T}$. Formulas are as following:

$$\hat{r}_e = \inf_{r_2 \in [r_0, 1]} \{r_2 : ADF_{0,r_2} > cv_{r_2}^{\beta_T}\} \quad \text{(eq.37a)}$$

---

[24] Prudently, the conclusion avoids to use word bubble since the reject of unit root hypothesis did not indicate any information about the source of price exuberance.

[25] The notation should be $BADF_{0,r_0}$, to be precise. But since there is no difference in the numeral results of ADF_{0,r_0} and $BADF_{0,r_0}$, here I use ADF_{0,r_0} to represent $BADF_{0,r_0}$.

$$\hat{r}_f = \inf_{r_2 \in [\hat{r}_e + L_T, 1]} \{r_2 : ADF_{0,r_2} < cv_{r_2}^{\beta_T}\} \quad \text{(eq.37b)}$$

where $\hat{r}_e$ ($\hat{r}_f$) is the fraction of the estimated beginning (ending) date of the exuberance.

In the multiple bubble case, similarly, the origination and termination are obtained from below comparisons:

$$\hat{r}_e = \inf_{r_2^* \in [r_0, 1]} \{r_2 : BSADF_{r_2^*}(r_0) > scv_{r_2^*}^{\beta_T}\} \quad \text{(eq.38a)}$$

$$\hat{r}_f = \inf_{r_2^* \in [\hat{r}_e + L_T, 1]} \{r_2 : BSADF_{r_2^*}(r_0) < scv_{r_2^*}^{\beta_T}\} \quad \text{(eq.38b)}$$

where $scv_{r_2^*}^{\beta_T}$ is the $100(1-\beta_T)\%$ critical value of the supremum ADF statistic based on $[Tr_2^*]$ observations. In order to limit the type I error, the value of $cv_{r_2}^{\beta_T}$ ($scv_{r_2^*}^{\beta_T}$) should diverge to infinity when the number of sample intervals T goes to infinity. Therefore, the significant level β_T, in theory, must be as closed as to zero. However, in practice, β_T could be set between 1-5%, or just let $cv_{r_2}^{\beta_T} = \log(\log(\mathrm{T}r_2))/100$ (same for $scv_{r_2^*}^{\beta_T}$). Phillips suggests that such setting is enough to get consistent estimates for $\hat{r}_e$ and $\hat{r}_f$. $L_T > 0$. So that "*short lived blips*" could be ruled out. Usually, it equals $\varpi\log(T)/T$, where ϖ depends on the expected minimal duration of explosive behaviour.

The strategies perform satisfactorily according to the 5000 times assessments of simulated bubble process. Specially, the SADF test shows more test power when the bubble is sole, while GSADF test is more reliable if there are more than one bubbles. Moreover, in sight of the date stamping function of SADF and GSADF tests, Phillips et al. (2011a) also apply them to determine the financial migration mechanism among different assets. They claim that the US subprime crisis starts from US house market, then spread to commodity markets and bond markets.

4. Results

This section reports and discusses the results of our empirical analysis. First, we employ the testing method proposed by Phillips et al. (2011b, 2013, 2015) to detect the presence of exuberance in UK house prices. Second, if evidence of explosive behavior is detected, we examine the relationship between episodes of exuberance in house prices and credit expansion.

Recent statistics of the UK housing market indicated that house prices soared to a new peak, £214,115 on average, in March, 2016, having reached an even higher than that level before the Great Financial Crisis of 2008-2009, alarming investors again (see Figure 3 below). Given these developments, which can be regarded as suggestive of exuberance in the UK housing market, we conduct a detailed empirical analysis whose aim is twofold: first, we examine the presence of explosive behaviour by applying a state-of-the-art testing methodology and second, we attempt to explain the exuberance phenomenon from a monetary perspective in order to identify potential leading indicators of house price bubbles.

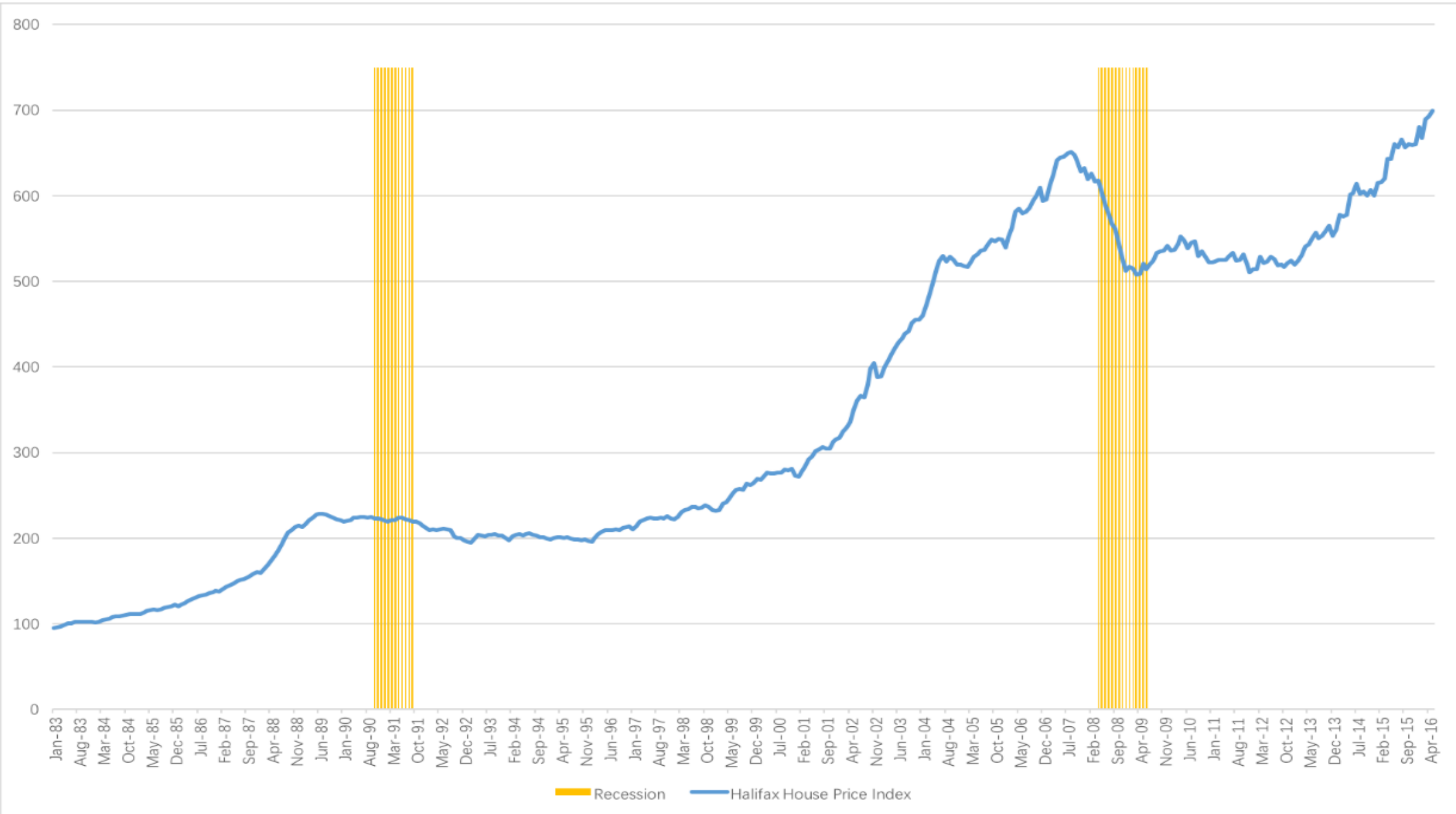


Figure 3: Nominal UK Halifax House Price Index

4.1 Data

The period under scrutiny in this paper spans from January 1991 to December 2015[26]. Two datasets are used in the empirical assessment conducted here: one for the UK house prices and the other for the UK monetary aggregate. The first dataset consists of three series: 1) The national Halifax House Price Index- this data is reported monthly based on a sample of mortgage data covering around 15,000 house purchases; since it is released in nominal values, we use the Consumer Price Index (CPI) to convert it into real values; 2 and 3) The UK real rental index and the UK real personal disposable income per capita, which are reported quarterly by the OECD-as house prices are available at a monthly frequency, we estimate the monthly values of the UK real rental index and the UK real personal disposable income per capita by interpolation. In line with the studies by Phillips et al. (2011b) and Pavlidis et al. (2015), we employ three series to capture the dynamics of the UK house market. These are: the real house price index (UKPND), the ratio of the real house price index to the real per personal disposable income (UKPNDI)[27], and the ratio of the real house price index to the real rent index (UKPNDR). These are depicted in

Figure 4, where the shaded areas in the graphs indicate recessions.

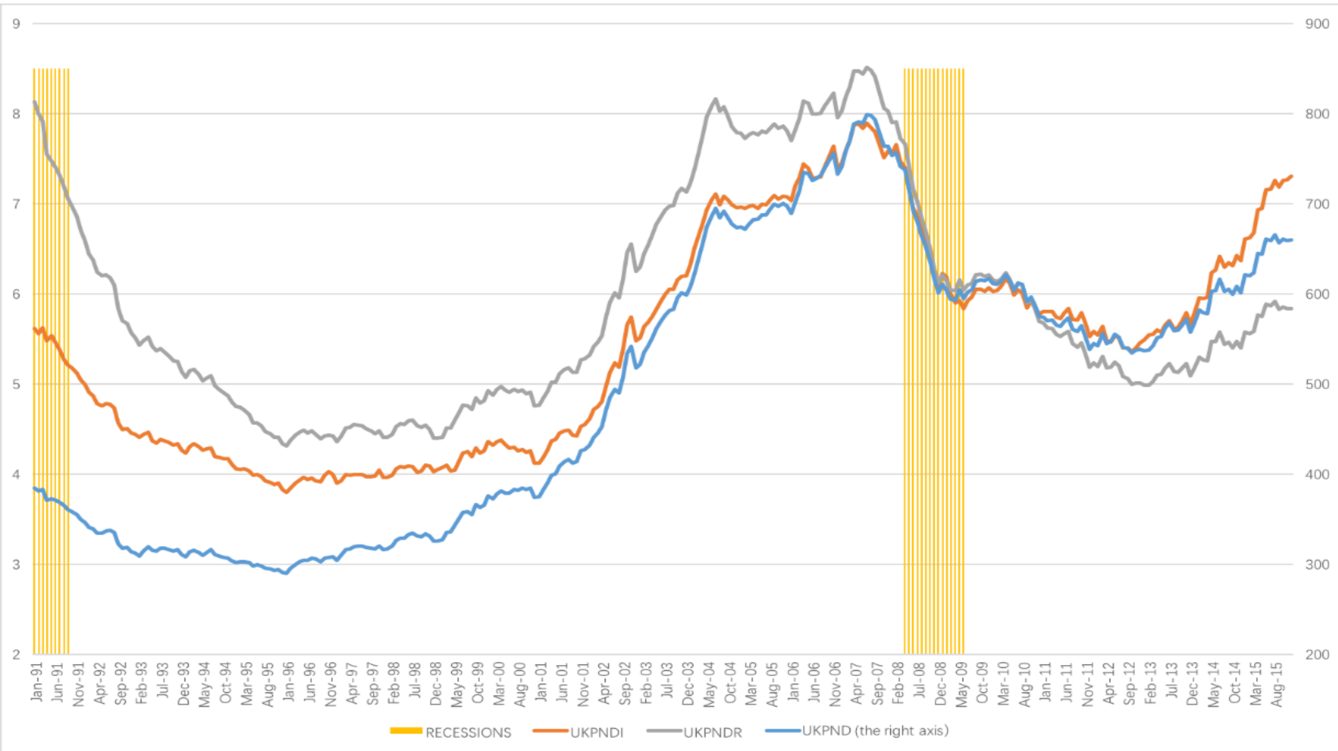


Figure 4: Indicators of the UK housing market

[26]This amounts to 300 observations. The main sources of data are: Halifax, OECD, the Office of National Statistics (ONS), and the Bank of England (BoE). More details on the data are provided in Table A in Appendix.

[27] This ratio is also called as the affordability index for housing in some studies.

The second dataset consists of monetary aggregates, in order to capture the stance of monetary policy. These are: M4 lending (M4L): (monetary financial institutions' sterling net lending to private sector, where M4 is a broad money aggregate measuring the quantity UK money supply), and secured lending (henceforth SL, which corresponds to lending secured on dwellings (i.e. mortgages) representing the value of total sterling approvals for secured lending to individuals, according to the definition provided by the Bank of England). All series are reported at monthly frequency and denominated in sterling millions after seasonal adjustment. The sample period for this second dataset (with the component series depicted in Figure 5 below) is in accordance with that for the housing market variables, while lending secured on dwellings is only available from April 1993.

Since the growth rates of the monetary aggregates described above are more informative than their total outstanding value, these two series (plotted in Figure 6) are transformed into year-on-year growth rates when empirical tests are carried out. Note them as M4L and SL.

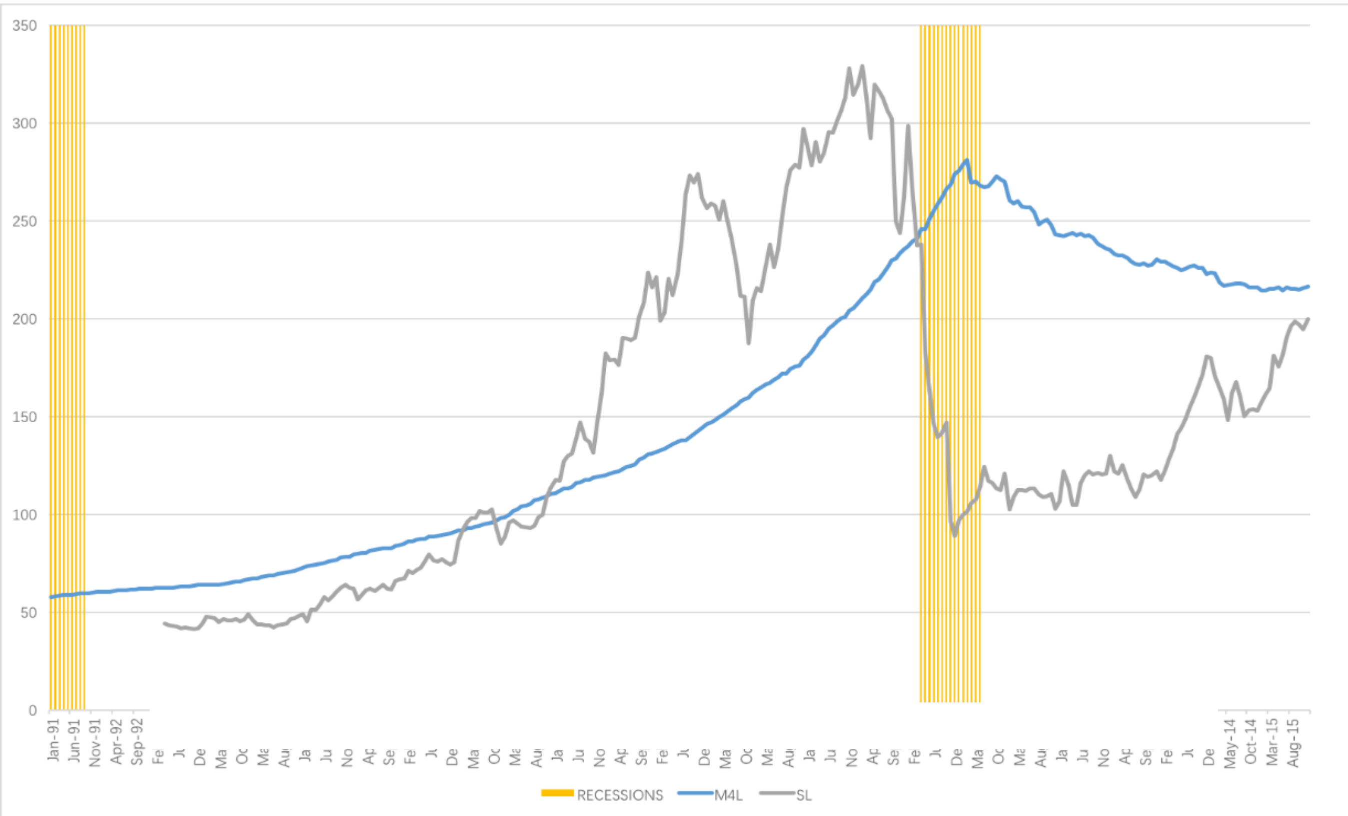


Figure 5: UK monetary aggregates

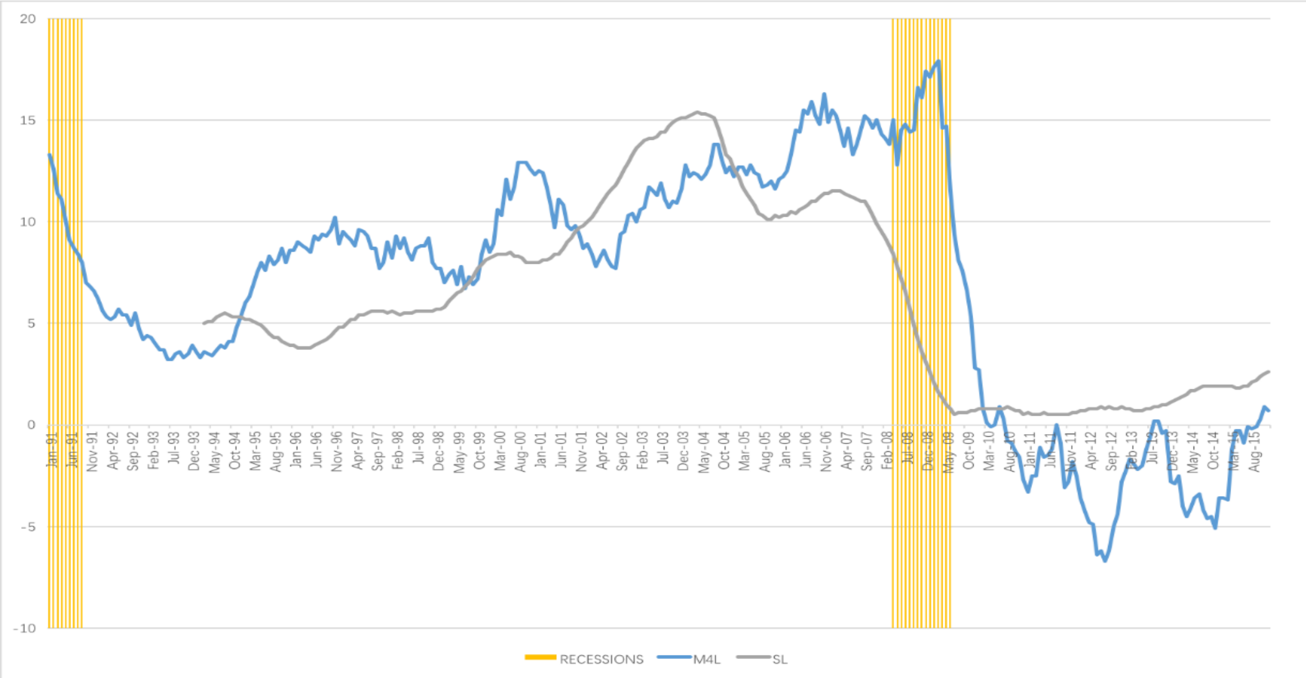


Figure 6: UK lending growth rates

4.2 Descriptive analysis of the UK house price movements

Before reporting the results of the tests for explosiveness in house prices and monetary aggregates, we set the scene by providing a shirt narrative analysis of the series under scrutiny in this study.

Figure 4 indicates that, for the period considered here, the real house price index started from around 380 points and slowly declined to 300 points during the first 5 years. After a period of stable increase in late 1990s, the UK housing market entered an upward trend, experiencing a remarkable boom from 2001 to 2004, and subsequently displaying less momentum and more volatility between 2004 and 2007, and collapsing as the US housing bubble burst. This was followed by a new rise.

The movements in the real price-to-income and real price-to-rent ratios are basically similar to those of the real price index. However, these series started at very high values at the beginning of the sample period, falling quickly afterwards, and subsequently taking more time to revert back to the initial level, showing a recovery shape close to a U-shape.

As for the monetary aggregates considered here (see Figure 6), although M4 lending is more volatile than secured lending, they share the same trends throughout the sample period: a slow increase with some small up-and-down cycles at first, then a considerable slump in the middle, and finally a sluggish recovery. The peak of secured lending appeared about 4 years earlier than that of M4 lending. Despite a short resurgence from 2006 to 2007, the unwinding of secured lending could not be held back until 2009. Several months later, M4 lending also dropped, entering a lengthy period of negative values. The UK economy witnessed two recessions during this period: the Lawson legacy in 1990-92 (GDP fell 1.4% in 8 months) and the Double Dip recession in 2007-09 (GDP fell 5.1% in 1 year and a half).

Table 1 shows the correlations between the house market indicators and the monetary aggregates considered in this study. As expected, the UK house market is more correlated with secured lending than with M4 lending, and among the three housing market series, the ratio of the real house price index to real rental index has the highest correlation with secured lending. This suggests that the growth of mortgage lending might be one of the reasons for the housing bubble.

Table 1: Correlations of variables

	M4L	SL
UKPND	0.082231	0.194282
UKPNDI	0.107829	0.227101
UKPNDR	0.454165	0.576688

4.3 Detection of the periods of exuberance in the UK housing market

In this section we present and discuss the results of the right-tailed unit root tests proposed by Phillips et al. (2011b, 2015). This is preceded by a standard analysis featuring unit root and cointegration tests, along the lines of the methodology proposed by Diba and Grossman's (1988a), who discuss the link between rational bubbles and the nonstationarity properties of a time series. The standard Augmented Dickey-Fuller (ADF) test is used to examine the univariate properties of the series. The results of the ADF test (conducted for the series transformed to their logarithmic form) are displayed in Table 2. All the logarithmic series do not reject the null hypothesis of unit root in level while rejecting this null in their first-difference form, hence being difference-stationary. Although Evans (1991) questions Diba and Grossman's (op. cit) approach, showing that simple unit root tests may not detect periodically collapsing bubbles, we can obviously argue that since rational bubbles describe a divergent path, evidence that house price changes exhibit stationarity excludes the possibility of rational bubbles.

Table 2: Standard ADF test results[28]

		Log UKPND	Log UKPNDI	Log UKPNDR	D(Log UKPND)	D(Log UKPNDI)	D(Log UKPNDR)
ADF test statistic		-0.7295	-2.06787	-2.39524	-5.07158***	-3.38308**	-3.82440***
Critical values:	1% level	-3.45237	-3.45307	-3.45260	-3.45237	-3.99047	-3.45260
	5% level	-2.87113	-2.87144	-2.87123	-2.87113	-3.42562	-2.87123
	10% level	-2.57195	-2.57212	-2.57200	-2.57195	-3.13596	-2.57200

[28]Henceforth, * denotes rejection of the null hypothesis at the 10% level of significance, ** at the 5% and *** at the 1%.

The basic idea of the cointegration-based approach to bubble detection is that the asset price and its fundamental (characterized by the order of integration) will not be linearly combined if bubbles are present. The results of the ADF test show that all the log series have a unit root in level but are stationary in first-difference form. Therefore the series are I(1) and hence can be tested for cointegration. The results of the Johansen (1988) test for cointegration (reported in Table 3) indicate that for the relationship between log log UNPND and UKPNDI there are 2 cointegrating vectors according to the Trace test and no cointegration according to the Max-eigenvalue test while for the log UKPNDR and log UKPND, both approaches indicates 1 cointegrating relationship. This finding that the real house price index is cointegrated with its fundamentals (house rentals and personal disposable income) suggests that no bubble is present in the UK house price index, a conclusion similar to that drawn from the standard ADF test.

Table 3: Results of Johansen's cointegration test for UK house market

	Trace test	Max-eigenvalue test
Series: Log UKPND, LogUKPNDI,	2 cointegrating vectors at the 5% level	no cointegration at the 5% level
Series: Log UKPND, LogUKPNDR	1 cointegratingvector at the 5% level level	1 cointegrating vector at the 5% level

In what follows, we present and discuss the results of the SADF and GSADF tests proposed by Phillips et al. (2011b and 2015). Phillips et al. (2011b, p. 203) state that their approaches can "*detect the presence of exuberance in the data and date stamp the origination and collapse of periods of exuberance*". Moreover, Evans's (1991) critique about periodically collapsing bubbles is also overcome.

In the specification of the auxiliary regressions of the tests, the parameter values are set according to Phillips et al. (2011b, 2015)[29]. We include a constant in the test equation with no linear time trend, and since the sample size is 300 observations[30], assign 34 observations as the initial window size r_0[31], and fix the lag to 0 to minimize distortion given the scale of sample size[32]. The 1%, 5% and 10% finite sample critical values of the test are generated via Monte Carlo simulations, using a number of replications set to 2000. All series are tested in their levels.[33]. When the right-tailed ADF test statistic exceeds its corresponding critical value, the null hypothesis of no explosiveness is rejected.

[29] To conduct the tests, we used an amended version of the Matlab computer codes available on Shuping Shi's personal website, https://sites.google.com/site/shupingshi/PrgGSADF.zip?attredirects=0.
[30] According to Phillips et al. (2015, Tables 2 and 3), the sample size is better to be limited about 200 to 400 observations to minimize size distortion.
[31] Based on the formula $r_0 = 0.01 + 1.8/\sqrt{T} = 0.1139$), where T is the sample size, as recommended by Phillips et al (2015),
[32] "Overall, size is reasonably well controlled when a small fixed lag length is used in the recursive tests. This approach is therefore recommended for empirical use of the SADF and GSADF test procedures as well as the dating algorithms that are implemented in the application later in the article". -- Phillips et al. (2015, Page 1058) We also test the series when the optimal lag number is determined by the Bayesian Information Criterion (BIC) with the maximum lag is 12. The results are similar to these obtained for a lag of zero.
[33] This point is controversial. Some papers recommend to use logarithmic equation and specify the lag order, e.g., Caspi (2016), whereas others promote to deal with raw series, e.g., Phillips et al (2011ab, 2015).

The results (reported in Table 4) suggest that the price-to-income ratio does not display any evidence of explosiveness, which implies that: 1) there is no exuberance in the price-income ratio; 2) if there is no unobservable fundamental, the house price index contains no bubble; 3) even if unobservable fundamental is present, as long as it is stationary in level or in its first difference, the house price index still does not contain bubbles. The practical meaning of this result is that if the price/income ratio is in favour of the explosive alternative, the reasons could be that: 1) a rational bubble appears in the house market; 2) there are unobservable fundamentals which are more nonstationary than income series; 3) there are irrational behaviours that encourage price departures. Pavlidis et al. (2015, page 6) state a similar conclusion: "*we do not generally observe all fundamentals… even if there is evidence of explosive behaviour in such observable ratios, we cannot truly rule out the possibility that explosiveness is inherited from the unobserved component of fundamentals*".

Table 4: The results of the SADF and GSADF tests for UK house market ($T = 300,\ r_0 = 34$)

	SADF test critical values:			GSADF test critical values:		
	90% level	95% level	99% level	90% level	95% level	99% level
	1.11892	1.38252	1.87751	1.91168	2.14505	2.67529
UKPND		7.35049***			7.494729888***	
UKPNDI		3.500672582***			5.576842236***	
UKPNDR		0.058192219			5.415565667***	

In the case of the UK real house price index, both SADF and GSADF test statistics support the existence of exuberance, contrary to the results from the standard ADF test. In the case of the price to disposable income ratio, the null hypothesis of a unit root is also rejected in favour of the alternative of explosiveness. This outcome illustrates that bubbles emerge in the housing market or, as previously stated, the unobservable variables dominate the price fundamental rather than the present value of future personal disposable incomes.

For the price to rent ratio, the GSADF test rejects the null hypothesis of no bubble whereas the SADF test does not reject the same null. It is worth to point out that both test statistics become relatively smaller than in the results for the UKPND and UKPNDI. The SADF statistic is only 0.058, considerably smaller than the 10% critical value. This suggests that the explosive behaviour of the house price index can be explained by contemporaneous exuberance of the house rent index, and that the rent index explains the explosive behaviour of the house price better than other measures if fundamentals like the personal disposable income.

More information on the origination and termination of the exuberance periods can be obtained from the detailed trajectories of the backward ADF sequence for the SADF test and the backward supremum ADF test for GSADF test. The sample period considered in this paper covers two intervals of exuberance, the Dot-com bubble and the subprime housing bubble[34]. These can be regarded as candidates for episodes of

[34] SADF and GSADF tests *per se* are designed to test price exuberance episodes rather than a bubble in the strict definition of the concept.

exuberance detected by the GSADF tests conducted over the period examined in this study. Moreover, when considering the noticeable price increase in the UK house market in the more recent period (see

Figure 4), a third episode of exuberance might be supported by the empirical evidence. Furthermore, Phillips et al. (2015) state that rapid changes in the data might lead to the the identification of crashes as bubbles. Therefore, the Lawson's legacy and the Double in Dip recession are expected to be detected by the UK house market. However, since I have set the initial window size equal to 34 months (from Jan., 1991 to Oct., 1993), which cuts off the period of the Lawson's legacy. Hence, this recession might not be identified by date stamping process.

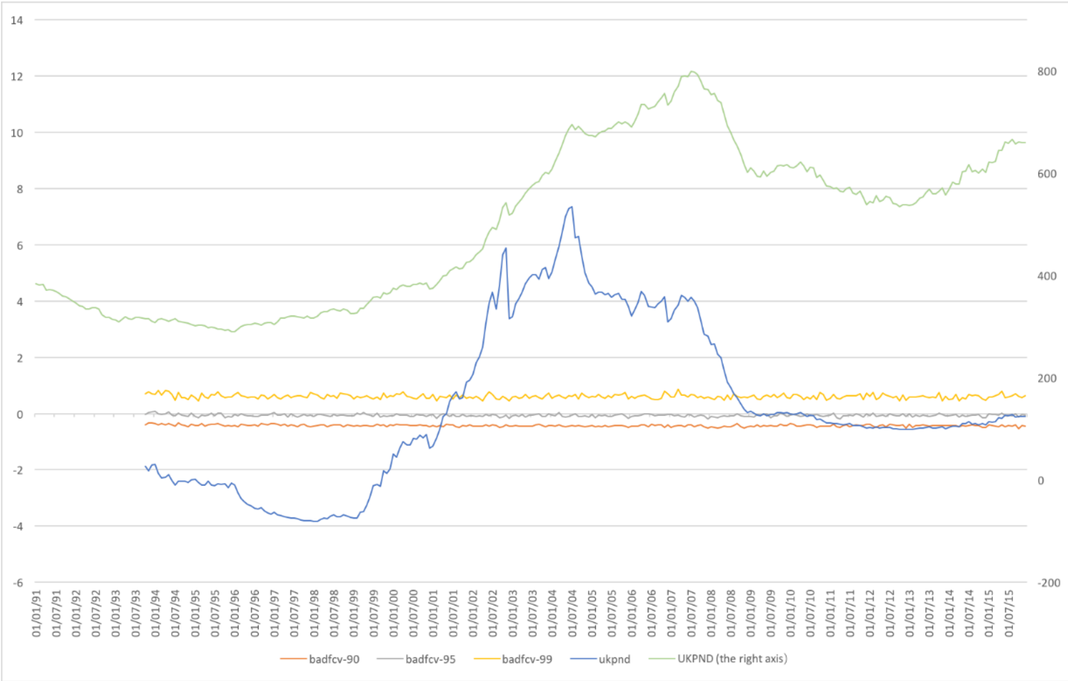


Figure 7: SADF test for UK real price index (UKPND)

Notes: 1) badfcv-90/95/99: 90%/95%/99% SADF critical value sequence (left axis, red, light blue and yellow lines); 2) ukpnd: backward ADF sequence (left axis, blue line); 3) UKPND UK real house price index (green line, right axis).

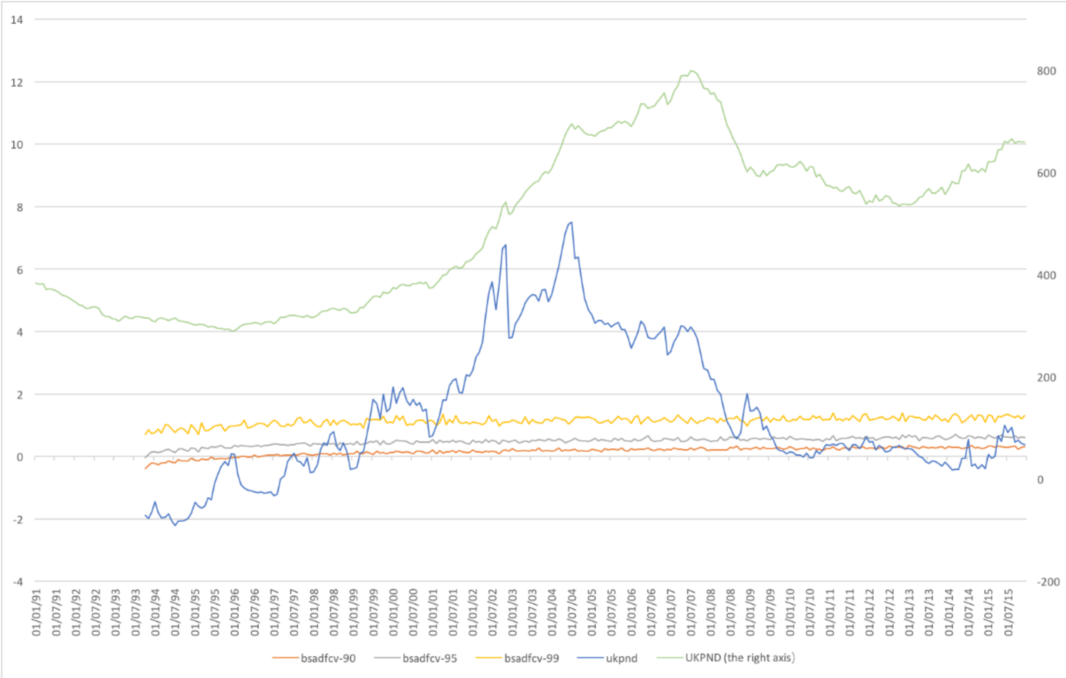


Figure 8: GSADF test for UK real price index (UKPND)

Notes: 1) badfcv-90/95/99: 90%/95%/99% GSADF critical value sequence (left axis, red, light blue and yellow lines); 2) ukpnd: backward SADF sequence (left axis, blue line); 3) UKPND (the right axis): UK real house price index (green line, right axis).

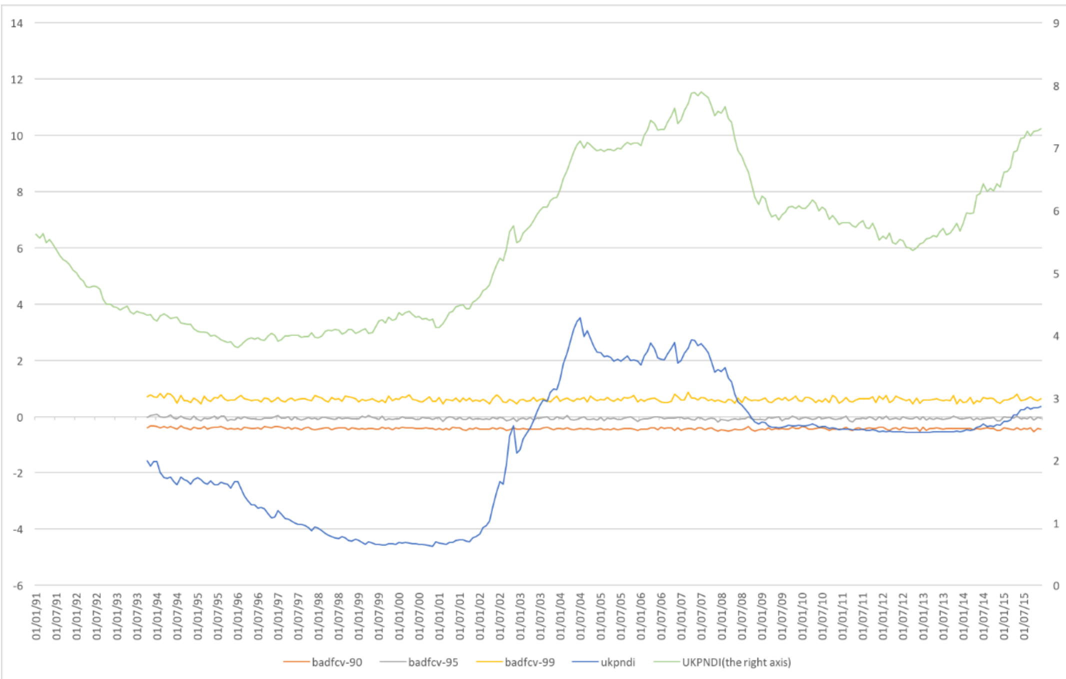


Figure 9: SADF test for the UK price to income ratio (UKPNDI)

Notes: 1) badfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) ukpndi: backward ADF sequence (left axis, blue line); 3) UKPNDI, the ratio of UK real house price index to real personal disposable income per capita (green line, right axis).

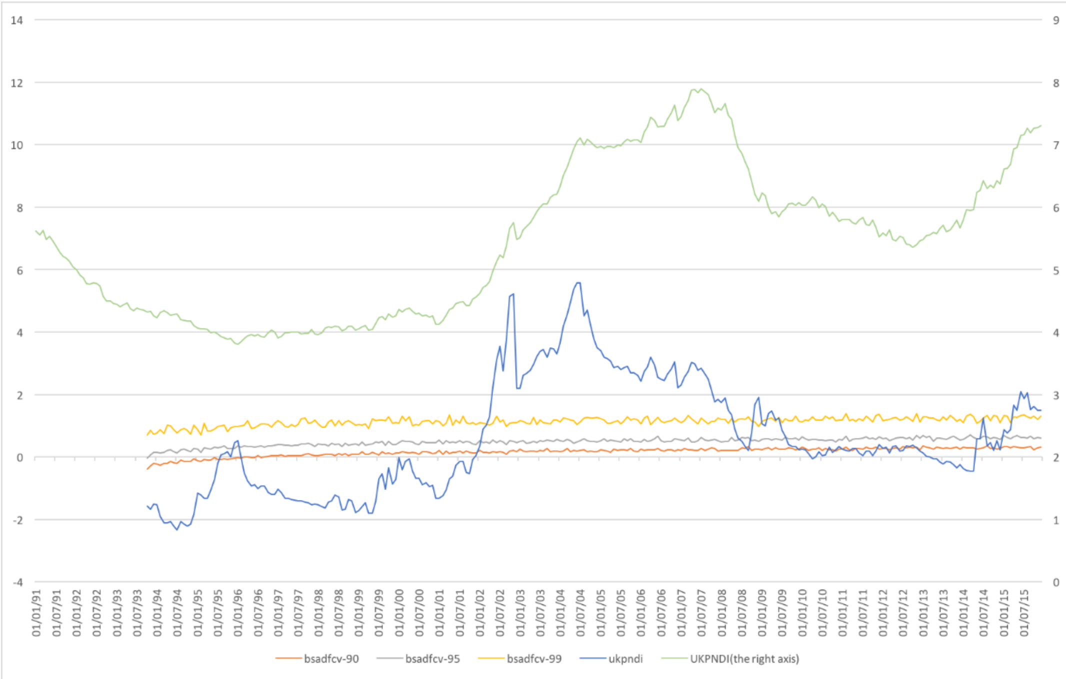


Figure 10: GSADF test for the UK price to income ratio (UKPNDI)

Notes: 1) bsadfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) ukpndi: backward SADF sequence (left axis, blue line); 3) UKPNDI, the ratio of UK real house price index to personal disposable income per capita (green line, right axis).

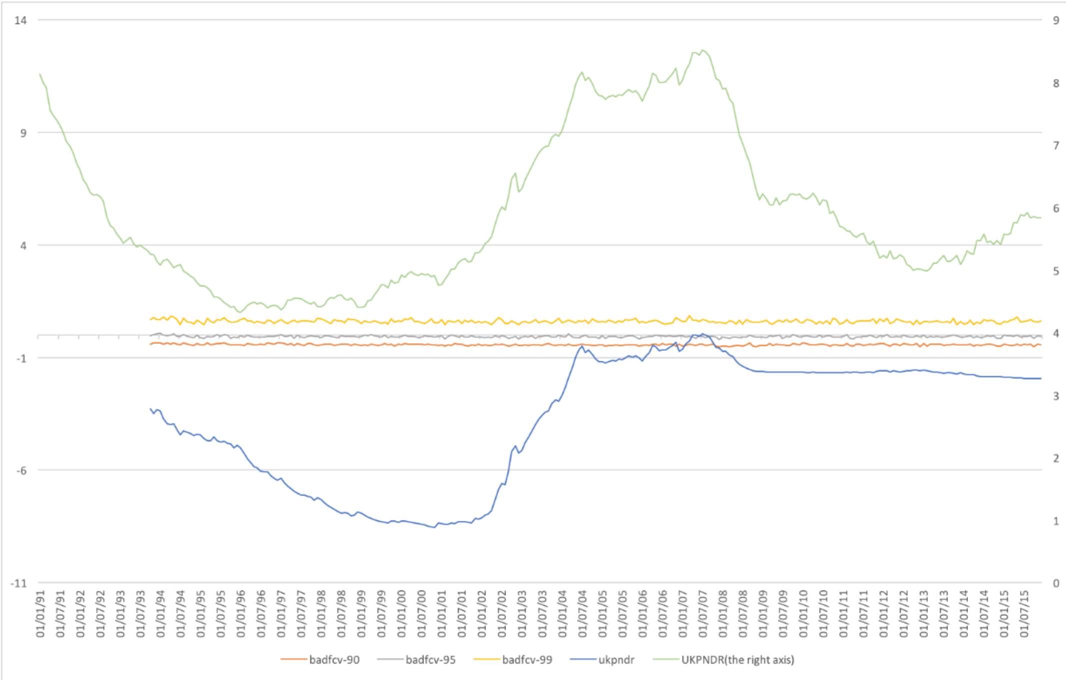


Figure 11: SADF test for the UK price to rent ratio (UKPNDR)

Notes: 1) badfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) ukpndr: backward ADF sequence (left axis, blue line); 3) UKPNDR: the ratio of UK real house price index to real rental index (right axis, green line).

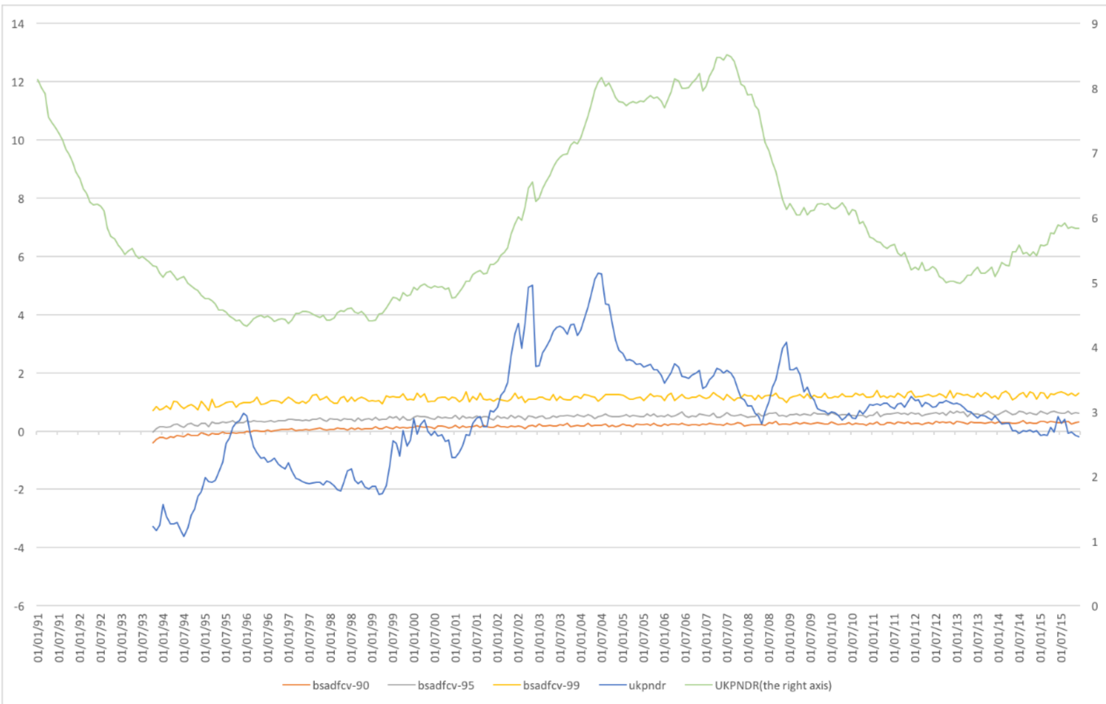


Figure 12: GSADF test for the UK price to rent ratio (UKPNDR)

Notes: 1) bsadfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) ukpndr: backward SADF sequence (left axis, blue line); 3) UKPNDR, the ratio of UK real house price index to real rent (green line, right axis).

The date-stamping strategy provided by the GSADF highlights the following episodes of exuberance:

1) The first episode in late 1995. This small episode is not indicated by other extant studies. Although as previously mentioned, the initial (subsample) window cuts off the actual range of Lawson's legacy, this period seems to keep influencing the UK house market. The real house price index and the price/fundamental ratios fall in the first-half of the 1990s. Then possibly due to the good news from the labor market[35] and the emerging internet technologies, the public became optimistic about the future. The long-lived downward trend finally decelerates and the house market seems to bounce back. The date-stamping procedure implies that the main interval of the downward episode corresponds to the fourth quarter of 1995, although its signal is too weak to be captured by the SADF tests and to last for more than two quarters in the GSADF tests (2 months in house price index, 7 months in price/income ratio and 5 months in price/rent ratio at the 10% significant level).

2) The Dot-com bubble. This was a mania in the US stock market that spread to the UK house market. The bubble in the house market shows the earliest signal in 1998 (March to November), and experiences a boom in 1999. The results from three GSADF tests provide convincing evidence for the view that when the Dot-com bubble spills onto the housing market, the rise in the house price is mainly driven by fundamental factors, herein, personal disposable income and house rent. In other words, this explosive behaviour of house price index can be explained by market fundamentals. The reason is that an exuberance episode is detected in the real price index sequence between January 1999 and November 2000 at the 99% critical level, while there is no signal in the price to income and price to rent ratios[36]. That is, if the influence of fundamentals was removed from house price, the house price would become non-explosive. In fact, the Dot-com bubble is stimulated by the introduction of new technologies and internet developments, therefore, the public has positive expectations about the economy and thereby about their future incomes or house rents. Therefore, the house price does not depart from its fundamentals and the following bubble burst does not trigger a recession.

3)The subprime house bubble. The burst of the Dot-com bubble is followed immediately by the subprime house bubble. This certifies that the 2001 recession almost has no impact on the UK housing market. Since February 2001, the house price index had been experiencing a sustained and accelerating growth over 7 years[37], although the duration is shorter in the cases of the price to fundamental ratios[38]. Since exuberances are detected in all three time series, the personal disposable income and house rent do not provide the whole 'fuel' to the price explosion. Therefore, it would be bubbles or other unobservable explosive fundamentals generating this exuberance.

[35] The unemployment in Oct., 1995, was at less than 2,300,000 - its lowest level for more than four years.
[36] Precisely, two flash blips in UKPNDR at Jan. and Mar. to Apr., 2000 when the significance level is taken to be 10%.
[37] From February 2001 to May 2008.
[38] The span of the episode in UKPNDI (UKPNDR) sequence is 14 (12) months later to the start and 1 (7) month(s) earlier to the end compared to the period detected for the price index at the 1% significance level.

It is worth pointing out that the peaks of the three backward supremum ADF sequences appear in January 2014 (UKPNDR) and July 2014 (UKPND and UKPNDI). After that, the bubble weakens. However, the highest values of UKPND, UKPNDI, and UKPNDR themselves are recorded in July, 2007. This provides us with an insight that the GSADF test is able to alert the market about the price collapsing, which has important policy implications for asset markets supervision.

4) The subprime crisis. Starting with the US mortgage market defaults, followed by the bankruptcy of Lehman Brothers, the tumbling house market induced a long lasting negative bubble[39] in the last part of the 2000s. A noticeable feature of exuberance displayed in the three tests sequences is that even with some recovery blips later, the exuberance almost disappears from the house price index and the price-to-income ratio in around one year, but it lasts throughout the overall recession when turning to the price-to-rent ratio. This scenario implies that the huge loss in the personal disposable income can explain the house price contraction; on the contrary, the other fundamental, the house rent, is more explosive than the house price itself, becoming less correlated with the house price and leading to the deviation of the price-rent ratio from long-term trend. The underlying reason is simple. AS shown in
Figure 13, the real house rent in UK keeps increasing just ignoring the huge slump in the house price index, while real personal disposable income shrinks remarkably due to the losses in real estate and financial assets. This suggests that a monetary perspective (offered in the next section) might help to explain the subprime bubble and crisis.

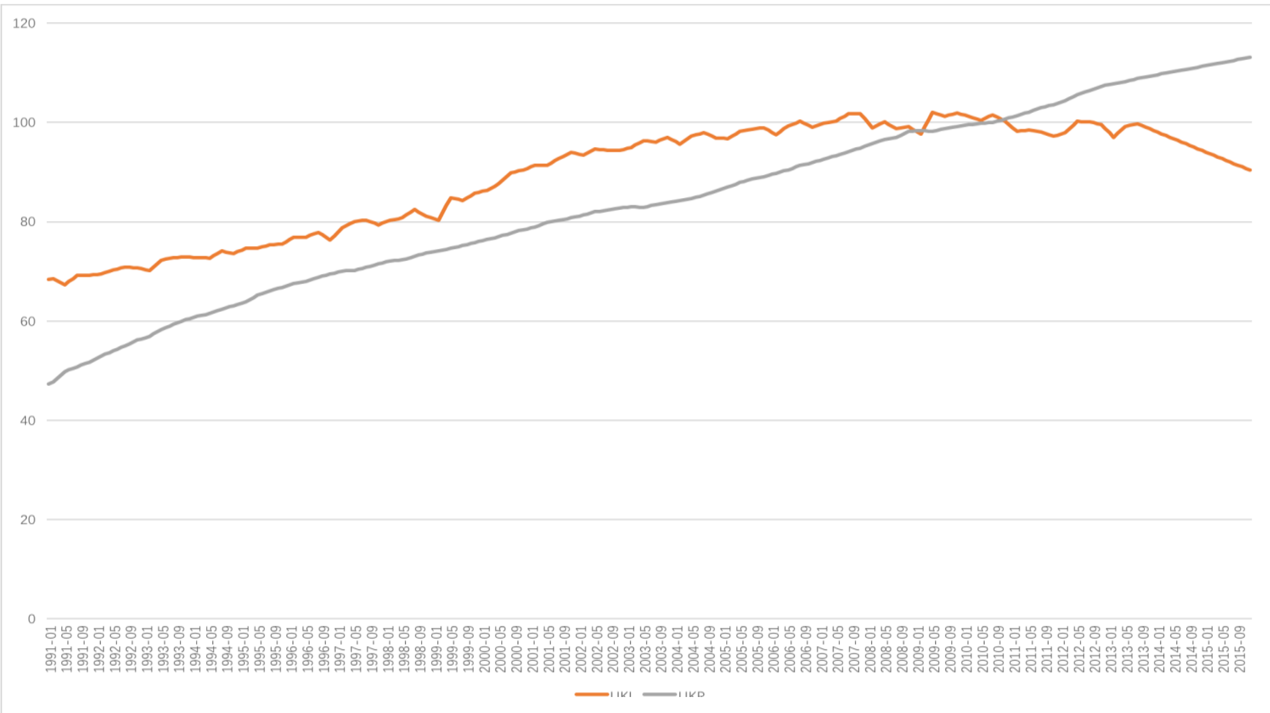


Figure 13: The trajectories of UK real personal disposable income and real house rent

[39] "More generally, a bubble is a situation in which the price of the asset deviates from its fundamental value, be it because the price exceeds the fundamental value or falls short of it. The latter case is sometimes referred to as a negative bubble." (Emery, 2014).

5) A shaping bubble. This bubble, in 2014-2015, is detected by the GSADF test in all series at the 10%significance level. In the UKPNDR series, there are only two short-lived signs, whereas in UKPNDI, the extent of explosion is even more noticeable than that in UKPND. The underlying logic is that the exuberance in the house price index is mainly due to the fluctuation in rent rather than the presence of bubbles. More underlying reasons can also be found in money supply developments, especially with respect to mortgage lending.

4.4 Monetary policy, credit booms and house price bubbles

Mishkin (2011) argues that monitoring and supervising credit conditions is vital to maintain financial market stability due to the causal relationship between credit expansion and financial crisis, and also because of the informational advantages for the central banks in the credit market. However, whether credit indicators represent efficient and effective substitutes for asset market indicators remains a matter of debate and requires a careful analysis.

The main purpose of the SADF and GSADF tests is to detect episodes of explosiveness in time series. When these tests are applied to asset prices for the purpose of bubble detection, the exuberance periods they indicate may suggest potential bubbles. If they are employed in the case of monetary policy aggregates, a result that lends empirical support to the presence of explosiveness result may suggest an oversupply of money. Furthermore, if the results with respect to the presence of explosiveness and date-stamping (the commencement and termination) of explosiveness periods are similar to those obtained by applying these tests to asset prices, then it may be argued that credit market measurers (in particular, measures of credit expansion) have the potential to play the role of leading indicators (or sentiment indicators) of asset price bubbles. Table 5 summarizes the results of applying the SADF and GSADF tests to the monetary policy stance indicators considered in this study (M4 lending and secured lending), while Figure 14 to 17 illustrate the date-stamping results.

Table 5: Results of SADF and GSADF tests for UK monetary supply measurers

Panel A (T=300, r_0 = 34)

	SADF test critical values:			GSADF test critical values:		
	90% level	95% level	99% level	90% level	95% level	99% level
	1.11892	1.38252	1.87751	1.911685	2.14505	2.67529
M4L	0.39518			1.67432		

Panel B (T=262, r_0 = 31)

	1.09045	1.40736	1.92170	1.89724	2.13104	2.77578
SL	6.93960***			8.53969***		

The results suggest that in the case of the M4L aggregate, the null hypothesis of unit root is lent empirical support, that is, the growth rate of broad money lending follows a random walk process throughout the period. The opposite result is uncovered for SL, with the evidence suggesting that the growth rate of secured lending displays some episodes of exuberance.

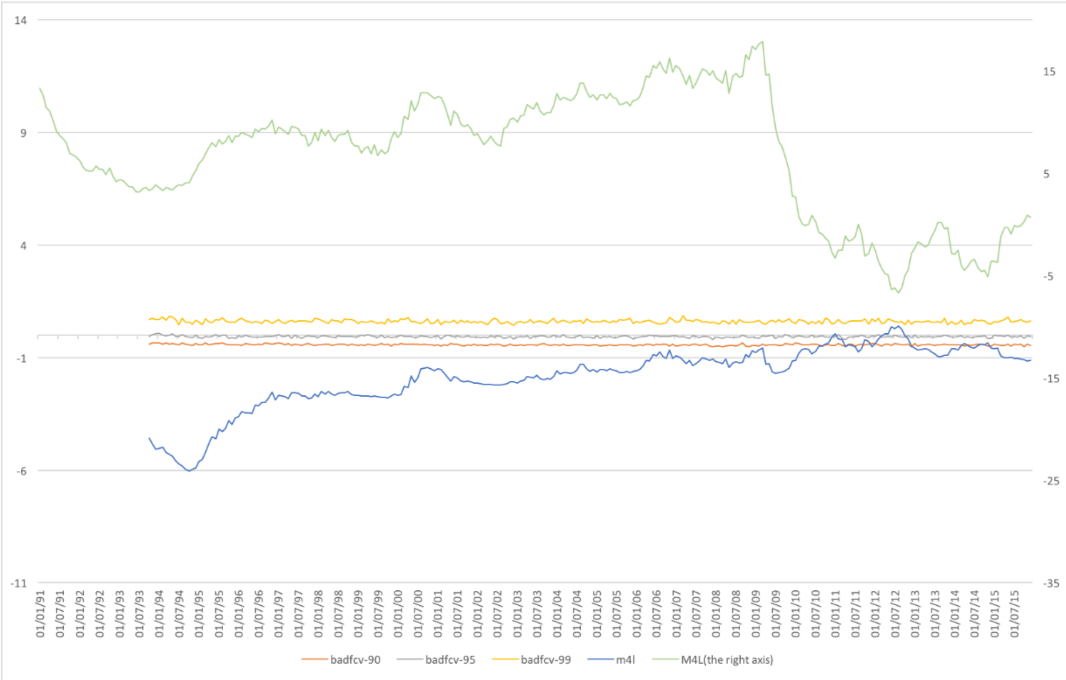


Figure 14: SADF test for M4L

Notes: 1) badfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) M4L: backward ADF sequence (left axis, blue line); 3) M4L: the 12- month growth rate of UK broad money lending (right axis, green line)

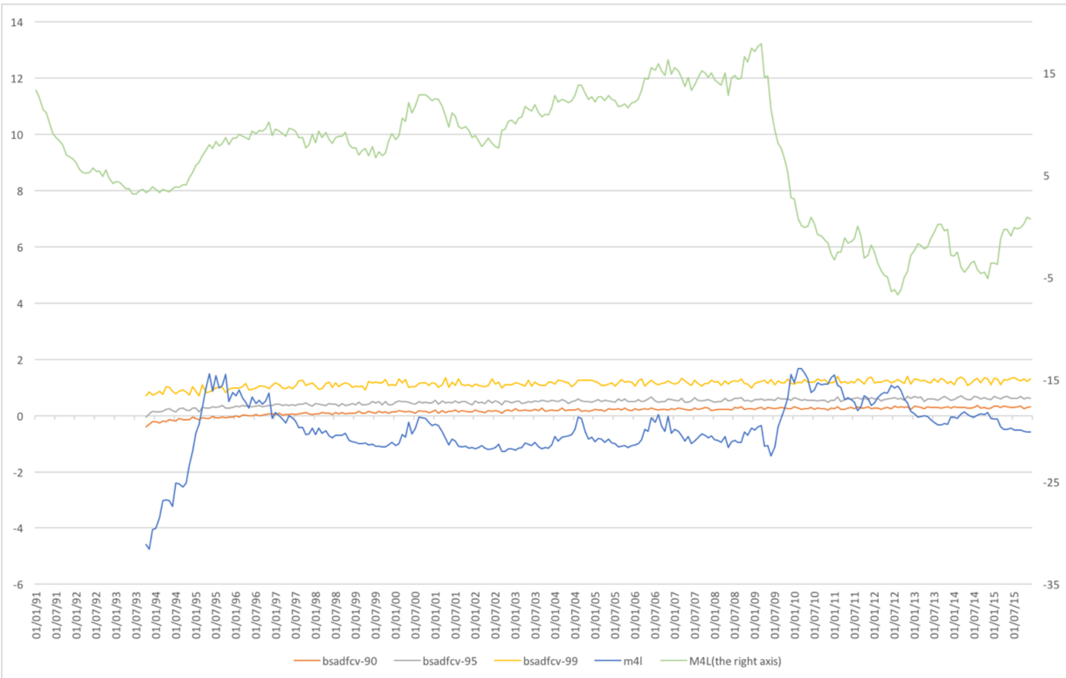


Figure 15: GSADF test for M4L

Notes: 1) badfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) M4L: backward SADF sequence (left axis, blue line); 3) M4L: the 12- month growth rate of UK broad money lending (right axis, green line)

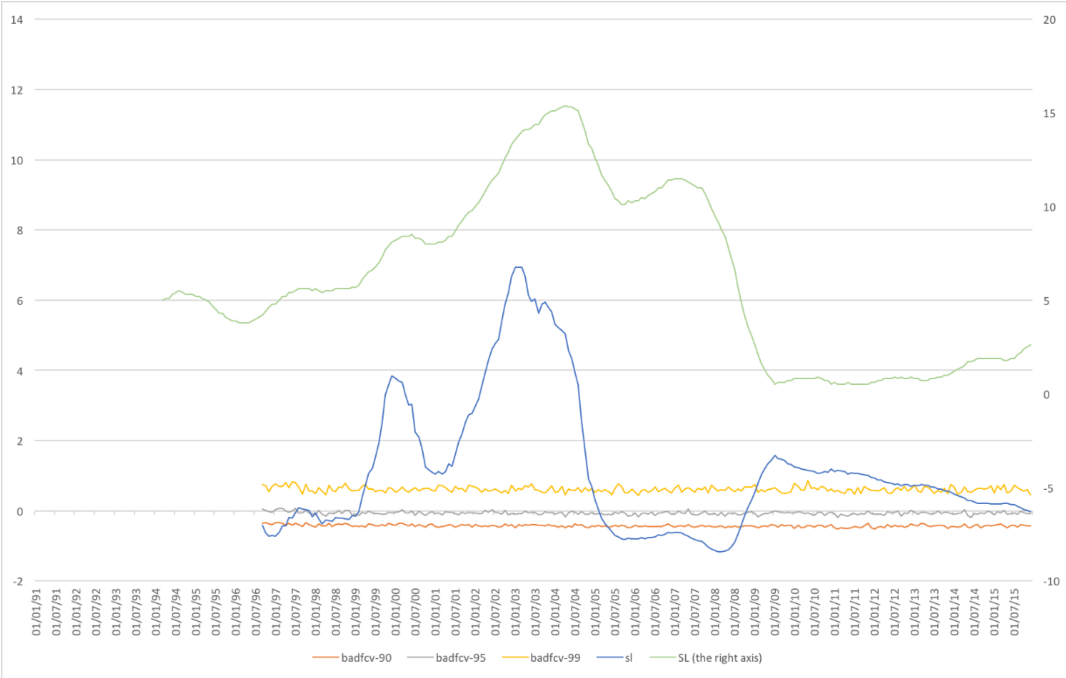


Figure 16: SADF test for SL

Notes: 1) badfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) SL: backward ADF sequence (left axis, blue line); 3) SL: the 12- month growth rate of UK broad money lending (right axis, green line)

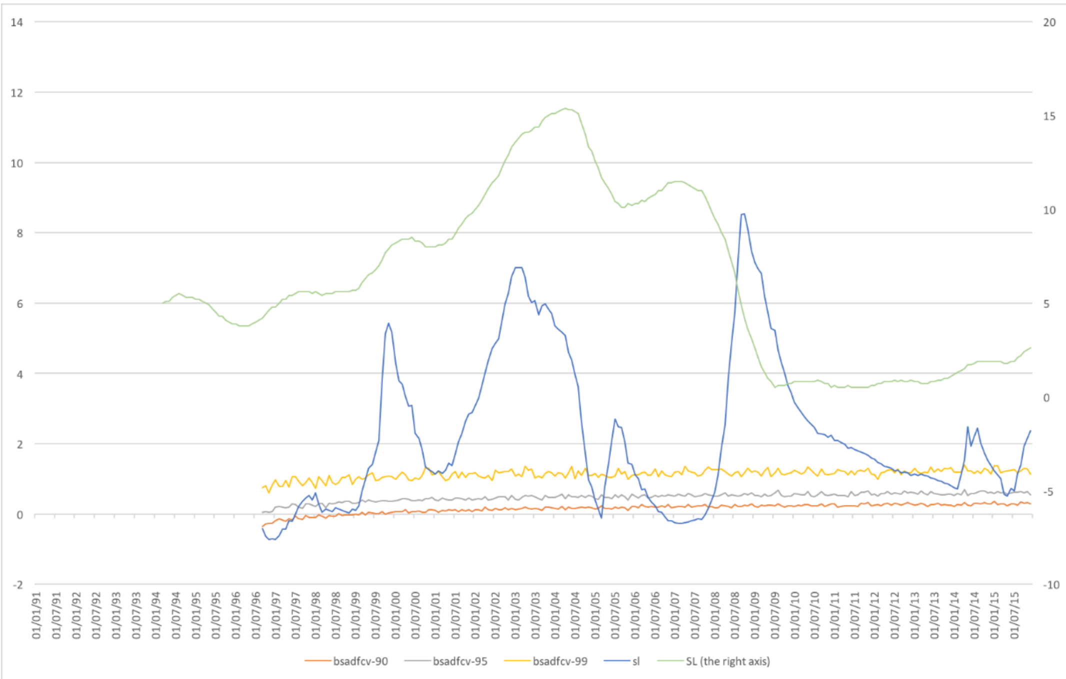


Figure 17: GSADF test for SL

Notes: 1) badfcv-90/95/99: 90%/95%/99% critical value sequence (left axis, red, light blue and yellow lines); 2) SL: backward SADF sequence (left axis, blue line); 3) SL: the 12- month growth rate of UK broad money lending (right axis, green line)

The output of the date-stamping for the SADF test applied to M4L indicates almost no bubble, except for two transient moments at the beginning of the 2010s. In the case of the GSADF test, there are only two minor up-and-down cycles, one in 1995-1996, the other in 2010-2012. The first episode may be regarded as an early indicator for the following Dot-com exuberance. In the housing market, evidence of explosiveness emerges later and fades away quickly while in the credit market it lasts for about 2 years covering a wider span. The second one happened during the Great Financial Crisis when the whole UK economy suffered huge losses.

The biggest problem is that it fails in detecting the dot-com bubble and the subprime bubble. It implies that from the overall aspect of the economy, the total money supply in those periods are consistent with its long-term trend. The following recessions of those two bubbles are both fired by price collapsing in certain asset market. So that the misallocation of capital among different markets is a possible reason.

Our purpose to test bubbles is to get some precautious signals for the market downturns. Since the broad money supply is a too blunt indicator and provides almost no information about the asset market, it is not a good substitution for the asset price.

As for SL sequence, the trajectory of SL seems match with true stories more satisfyingly. Except "the first episode in 1995" which is cut off by the initial window, all other episodes mentioned before are confirmed in its GSADF test output. [40] Although Table 1 has displayed the correlation of SL and house market indicators, the Vector Error Correct Model could offer a more refined answer about if SL is a suitable alternative for the house market indicators. First, the standard unit root test indicates all Log UKPND, Log UKPNDI, Log UKPNDR, and Log SL are first order integrated[41]. Then, the Johansen cointegration test finds that there are 1 cointegration equation at the 0.05 level in three groups: Log SL and Log UKPND, Log SL and Log UKPNDI, Log SL and Log UKPNDR.[42] Thereby, the series have long-term relationship to allow the Vector Error Correct Model.

Table 2: The information criteria for estimated VECMs[43]

	Akaike information criterion	Schwarz criterion
Series: Log SL, Log UKPND	-8.483522	-8.123465
Series: Log SL, Log UKPNDI	-8.458479	-8.098422
Series: Log SL, Log UKPNDR	-8.452469	-8.092412

Table 2 indicates that the VECM for Log SL-Log UKPND has better fitness extent than the Log SL-Log UKPNDI and Log SL-Log UKPNDR models, although such advantage is so tiny[44]. It confirms from another angle that besides the house rent and

[40] Mishkin (2011) and Brunnermeier (2015) state the US dot-com bubble is not driven by credit expansion. However, the tests indicate that there is a credit expansion during that time in UK house market.
[41] See Appendix **Error! Reference source not found.** to **Error! Reference source not found.**
[42] All the Eviews outputs are attached in Appendix **Error! Reference source not found.** to **Error! Reference source not found.**
[43] See Appendix
[44] Usually, the information criterions are not used to compare the fitness of different models. But since here, these three models with 5 lags have the same numbers of coefficients, information criterions can be cited as a standard for the fitness extent. The lag order, 5, is determined by Vector Autoregressive model.

the personal disposable income, there are other factors influencing the house price, which may be the bubbles or the unobservable fundamentals.

In Figure 18, I rearrange the date stamping results of UKPND, UKPNDI, UKPNDR and SL estimated by the GSADF tests. No valuable point can be obtained from the comparison of SL and UKPND. But comparing SL with the price to fundamental ratios, I find that SL shows a forward shift of starting and ending points of price exuberance. That is, at 90%, 95%, 99% critical level, SL dates the origination of the subprime bubble at Feb., 2001 and the termination at Oct., 2004, moreover, a following bubble during Mar., 2005 to Jan., 2006. The whole process is about one year ahead. This phenomenon proves that the growth rate of secured lending might be a leading indicator of exuberances in term of explosive fundamental model.

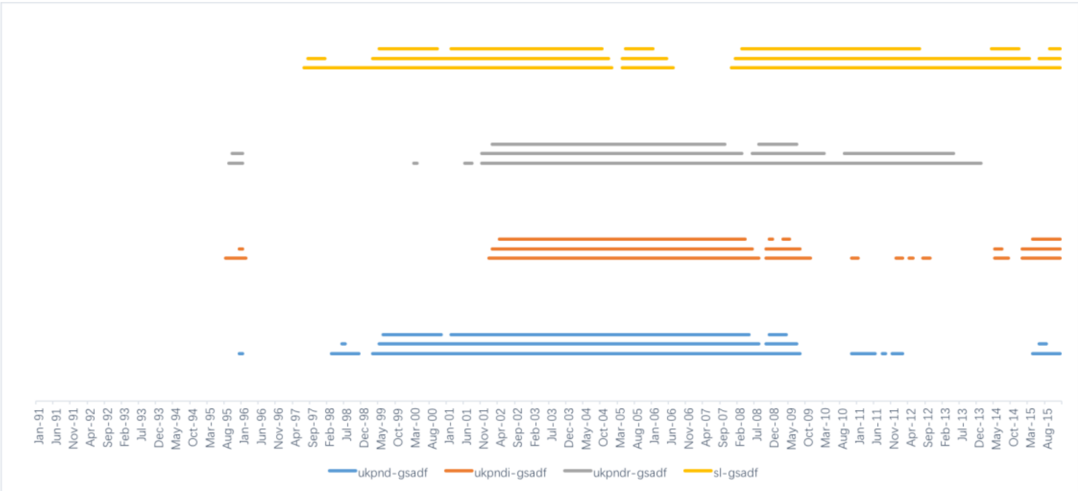


Figure 18: Comparison of date stamping results

However, from the limited empirical analysis in this thesis, I still cannot verify the proposition in Mishkin's (2011) paper that policy makers could watch out the credit market condition as a replacement for the asset market supervision. At least, the growth rate of secured lending is not a good substitution. It is because SL treats the dot-com bubble the same as the subprime bubble. In fact, the former did not bring on a recession while the latter promoted a deep financial crisis. Therefore, if the secured lending were the sole only monitor, the signal in the late 1990s would convince the central bank to lean against the wind which, in hindsight, might impair the economic achievement during that period.

A possible explanation of this scenario is that the availability of the secured lending might also be the simulation for the house market. The mechanism is that when the mortgage is issued loosely, the public would be encouraged to buy or change properties. Since the house has a long production process, its supply on the market in the short term is rigid. Hence house price appreciates. The increased house value changes people's estimation about their wealth, encouraging people rearrange their asset portfolios. It is the spillover effect of portfolio rearrangement rather than the secured lending that determines the risk level of the house bubble.

Therefore, a signal of credit boom does not always forecast a following recession after bubble prick. A more important signal comes from the measure of the spillover effect. That is to decide if the soaring prices have become a typical symptom in the whole economy. Separate detection for price deviation in different asset markets would be a method to carry out this idea.

Actually, in UK house market, the house price index to personal disposable income ratios is the best indicator among the four sequences I test. Not only does it early alert the subprime bubble burst, but also it successfully distinguishes the risk of the dot-com bubble and the subprime bubble, i.e., only the subprime bubble which induces a recession is detected by its backward supremum ADF statistics. The reason might be related to the explosive behaviour of house rent itself which has been regarded as the fundamental of the house price for a long time.

4.5 Some thoughts on monetary policy role

At the end of the literature review presented in Section 2, we summarized recent developments in the "*Cleaning*" versus "*Leaning*" debate about asset price bubble and concluded that the Leaning policy has the upper hand. Leaning against wind policy is recommended even in moderate market condition to prevent risk accumulation. The discussion focus has moved to whether the monetary policy is able to prevent or mitigate the credit-driven bubbles and if it could not, whether the macroprudential policy is an effective and efficient alternative method. Mishkin (2011) advises that the macroprudential policy is able to control the systematic risk carried by financial institutions, leaving the monetary policy mainly target at the stability of the overall economic inflation. As for the monitor of asset market bubbles, he suggests that it is easier and more cost-saving for central banks to stare at credit markets than asset markets considering their information advantages in credit markets.

Inspired by above analysis in empirical section, my argument here is that the credit expansion indeed has closed relationship with asset price bubble, but the credit market measurers, at least the broad money lending and the secured lending, are not suited for as alternatives for house bubble detection. Because the empirical results imply that secured lending cannot distinguish the dot-com bubble[45] (without following recession) and the subprime housing bubble (with following recession). On the other side, the price to fundamental ratios are better indictors to identify risk bubbles. Particularly, the ratio of house price index to personal disposable income shows a dramatical performance during the time of the subprime bubble and sequence crisis. Therefore, the supervision on the housing market should still focus on house price and its fundamental elements, like house rent and disposable income.

As for the policy choice, the practice that Australian central bank took during its 2002-2004 real estate bubble is a good example for authority intervention. Phillips's (2011b, 2015) methodology for bubble date stamping provides an admirable estimation of origination and termination dates. More importantly, the empirical tests suggest that the estimated dates are earlier than the real dates. Therefore, referring to the results from bubble detection, central banks are offered a feasible and reliable method to decide if the asset market has a mania and to predict if the price arrives peak, and then to take proper political actions.

On the monetary policy side, even if the secured lending is not a good indicator for the house bubble, policies to adjust mortgage approvals are still expected to make functions through the portfolio rearrangement mechanism. If the price bubble indeed emerges in the market, central bank could tighten its monetary policies, like increasing benchmark interest rate to add the cost of capital, rising the requirements of collaterals in repo to reduce the outstanding money, and opening mouth to talk down the expectation on high interest rate in long-term. However, those instruments aim to adjust the whole economy. Critiques on their bluntness and effect-lag are still true. Therefore, for the house market, more specific policies could be set the bottom line for retail mortgage rate, ask commercial banks check creditability of borrowers, increase the requirement on the loan to capital ratio, etc..

[45] As maintained in Footnote ?, the dot-com bubble here is the house price bubble induced by the internet boom.

On the marcoprudence side, the essential purpose is to reduce systematic risk. A lesson the Great Financial Crisis had taught us is the conflict between the sustainable of the individual institution and the stability of the whole financial system. Basel Accords III frames a specific supervision system from marcoprudence aspect. However, the marcoprudential policies faces a biggest hindrance from the lobbying of all kinds of syndicates, like all other regulations. The present Basel framework is already a compromise result.

In order to keep the independence of central bank, other policies are also put forward for the financial stability also on a macro level as auxiliaries, like regulating the behaviour of market participants to create a favorable environment, and educating the investors with hope to obtain a better communication about central banks' political purposes. All these policies imply more intervention which is strongly opposed by marketism but more commonly adopted in update central banks' practices.

An important point in political practice is timing. It requires central banks to carry out policies discretionally. That is, no matter what policies are carried out, central banks should assess the whole economic background and the possible outcomes comprehensively and completely and if necessary, use a package of policy rather than a single one to neutralize the undersides of policies.

5. Concluding Remarks

The world economy takes more than 7 years to walk out the aftermath of the subprime crisis and its sequel, the great global financial crisis. Some economies are still struggling with the dreadful messes in real economy and finance. It all started from a price bubble collapsing in the house market. When economists look back to the history, they find that housing mania ends because of the increasing defaults of low-quality mortgages. Thereby, an old Clean-lean debate about monetary policy stance in asset price supervision comes back to the public's spotlight, although the discussion focus has been concentrating on "how to" rather than previous "whether or not".

In this thesis, I first retrospect relevant literature on the theories of asset price bubbles and the evolving history of responsive policies, then introduce the methodologies of bubble detection, thereafter use the models from Diba and Grossman (1988) and Phillips et al. (2011b, 2015) combined with other econometric tests to do empirical research based UK's case of national house price and credit supply from 1991 to 2015. The test results support that there are significant bubbles and recessions in the UK house price and that the credit market measures are not satisfying alternatives for indicators which are based on house price itself, like the price to fundamental ratio. I recommend to detect house market bubbles using the statistics about housing price and its fundamentals. If central banks sense bubble in the market, use monetary and marcoprudential policies accompanied by other supplements discretionarily and synthetically. Finally, I argue that the policy objectives could target at a certain asset market, or the credit market, or the whole financial and economic systems, depending on if the price raises in certain market has spilled to other markets and if the bubbles are driven by the credit expansion. A bubble answering Yes to both standards has the highest suspicion of triggering a recession after burst.

Recently, the house price index of the United Kingdom has achieved an unprecedented level, even higher than that before the Subprime Crisis. And the empirical analysis in this dissertation supports that a housing bubble is taking shaping especially when the personal disposable income is regarded as the determination of house value. Considering that the public's confidence in the economy is still are not completely restored from the severe results of the Great Financial Crisis, latest economic recovery is faint and fragile. Moreover, the Brixit escalates the uncertainty of the UK economy, a potential bubble in the housing market will sow the seeds of a deep recession, dragging UK's economy into a longer and more struggling path toward recovery. Therefore, more closed attention on the house market is required. The analyses and conclusion in this dissertation are limited. Further detailed researches on asset price bubble detection would help the authorities to stabilize the financial and economic system.

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Appendix

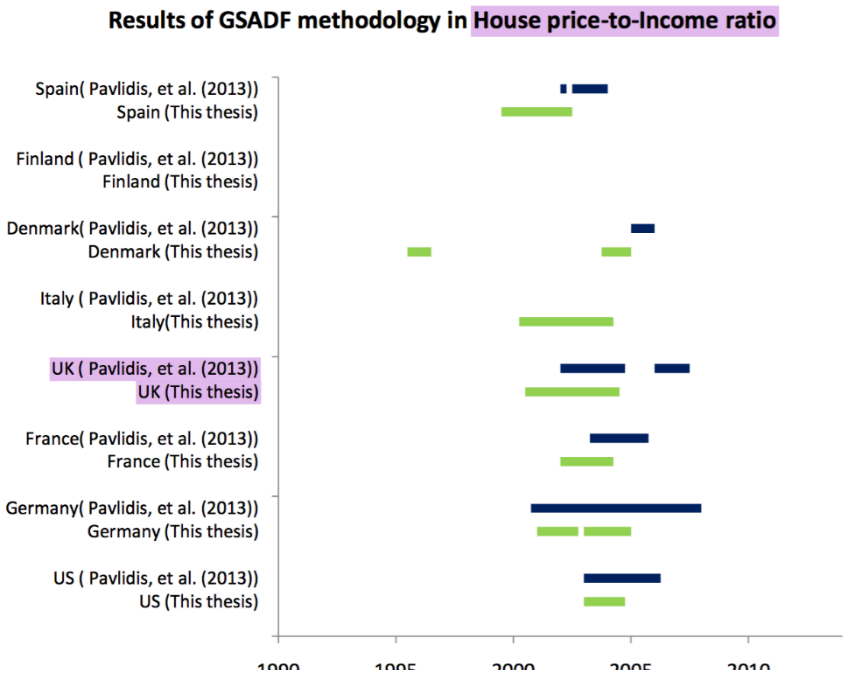

Figure 19: Diakoumi's (2015) comparison (1)

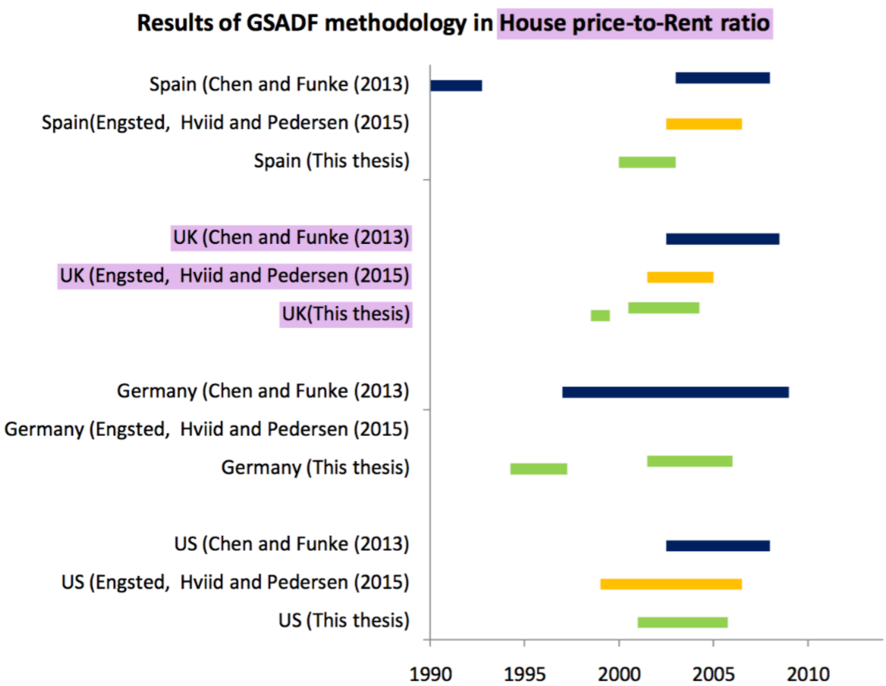

Figure 20: Diakoumi's (2015) comparison (2)

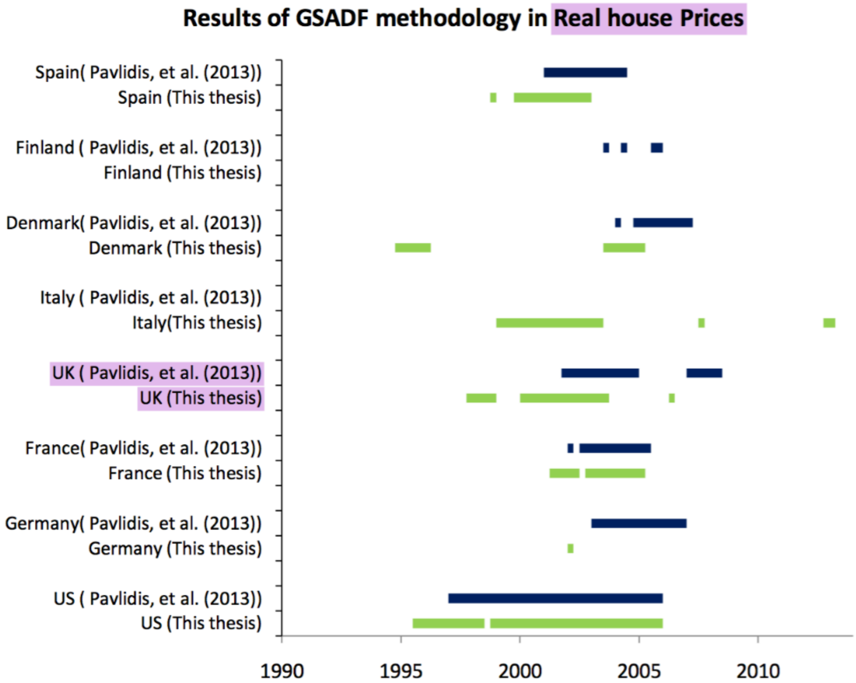

Figure 21: Diakoumi's (2015) comparison (3)

Table A1: Data sources

Name	Source
House Price Index	Halifax national House Price Index (monthly)
	http://www.halifax.co.uk/house-price-index/?wt.ac=HOME_PP_HPI&srnum=1
Real Rent Index	OECD Analytical House Prices Indicators (quarterly)
	http://stats.oecd.org
Real Personal Disposable Income (per capita)	The Office for National Statistics (quarterly) http://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/ihxz/ukea
Consumer Price Index	The Office for National Statistics (monthly)
	http://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7bt/mm23
M4 lending	Bank of England (series code: LPMVWVP)
	http://www.bankofengland.co.uk/boeapps/iadb/index.asp?first=yes&SectionRequired=A&HideNums=-1&ExtraInfo=false&Travel=NIxSTx
Secured lending	Bank of England (series code: LPMVTYI)
	http://www.bankofengland.co.uk/boeapps/iadb/index.asp?first=yes&SectionRequired=A&HideNums=-1&ExtraInfo=false&Travel=NIxSTx