Author/s:
Lim, GC;Tsiaplias, S

Title:
Interest Rates, Local Housing Markets and House Price Over-reactions

Date:
2018-06-01

Citation:
Lim, G. C. & Tsiaplias, S. (2018). Interest Rates, Local Housing Markets and House Price Over-reactions. Economic Record, 94 (S1), pp.33-48. https://doi.org/10.1111/1475-4932.12402.

Interest Rates, Local Housing Markets and House Price Over-reactions

G.C. Lim and Sarantis Tsiaplias[1]

[1]Corresponding author: stsiaplias@unimelb.edu.au. This research was supported by ARC DP160102654. We thank the editor, two anonymous referees, Adrian Pagan and Efrem Castelnuovo for helpful comments and suggestions. All errors are our own.

Interest Rates, Local Housing Markets and House Price Over-reactions

G.C. Lim and Sarantis Tsiaplias[1]

[1]Corresponding author: stsiaplias@unimelb.edu.au. This research was supported by ARC DP160102654. We thank the editor, two anonymous referees, Adrian Pagan and Efrem Castelnuovo for helpful comments and suggestions. All errors are our own.

Abstract

Understanding the effects of interest rates on city-specific house price to household income ratios is important for managing local housing markets. In particular, there is concern that keeping interest rates at sufficiently low levels can distort the relationship between local house prices and fundamentals. We use house price to income ratios across capital cities in Australia to investigate this issue and show that there is a national interest rate 'transition' point below which housing dynamics can become unstable. This result lends support to the presence of a duration-dependent threshold effect (hitherto mainly explored in theoretical models).

Keywords: house prices, cities, financial stability, banks, interest rates

JEL classification: E40, G21, R10, R31

1 Introduction

The link between interest rates, mortgage borrowing, and house price appreciation has attracted extensive attention in recent years (Taylor 2007; Bernanke 2010; Leamer, 2015; Piazzesi and Schneider, 2016). This is largely unsurprising given widespread talk of pre- and post- 2007/08 housing booms and busts, and the current status quo of record low interest rates. There is considerable contention, however, regarding the broader relationship between house prices and interest rates. Numerous researchers find that the impact of monetary policy shocks on house prices is relatively small (Del Negro and Otrok, 2007; Goodhart and Hofmann, 2008; Glaeser, Gottlieb and Gyourko, 2010). Conversely, others contend that there is a clear relationship between house price booms and busts, and interest rates (Taylor, 2007 and 2009; Jordà, Schularick and Taylor, 2015). The latter authors, in particular, argue that loose monetary conditions are causal for house price booms. Although the relationship between aggregate house prices and interest rates is important for national policymakers, it is also important - particularly for local policymakers - to consider the impact of interest rates on local housing markets. Accordingly, this paper uses a cross-section of city-specific house price to income ratios to consider the impact of lending rates on housing markets.

There is little doubt that house price differences exist across cities and regions (Glaeser, Gyourko, and Saks, 2006; Saiz, 2010), raising the risk that aggregating these differences can mitigate the relationship between interest rates and house prices. If housing investors consider local economic differences in their investment decision then interest rate conditions may (either directly or indirectly) affect some cities more than others. Restricting examination to a single national housing market can therefore yield incorrect inferences about the effects of interest rates on local housing markets. In this respect, a key issue is the indivisibility of expensive housing assets with most households being heavily exposed to region-specific risks which are further magnified by the relatively illiquid nature of housing markets. In contrast, stockmarket investors can purchase small amounts of a diverse range of stocks thereby minimising idiosyncratic and regional risks.[1] More broadly, Beraja et al. (2015) highlight the importance of regional heterogeneity in collateral values for determining the impact of monetary policy, finding that the effectiveness of monetary policy declines when collateral values become depressed.

In order to account for these regional differences, we propose a non-linear approach that relates interest rates to a cross-section of city-specific house price to income ratios. The ratios are derived using Australian capital-city house prices based on hedonic indices that reflect inter-temporal changes in both compositional structure and housing quality. The dataset is particularly useful since a large proportion of total regional heterogeneity can be accounted for using a relatively small number of cities whose dynamics can therefore be jointly estimated. In turn, reliable city-specific hedonic indices are available for Australia which, similar to the US and other geographically dispersed economies, is also subject to significant regional economic differences that need to be considered when examining house price to income ratios.

In contrast to the above-mentioned papers, which focus primarily on the direct effects of interest rates on housing markets, this paper examines the indirect non-linear ramifications of interest rates. In particular, we consider whether it is possible to identify an interest rate threshold below which there is a significant change in the relationship between house price to income ratios and economic fundamentals. We also consider whether the disaggregation of house price data to the city level assists in the identification of such a threshold. Our empirical approach is underpinned by Himmelberg, Mayer and Sinai (2005) who suggest that house prices are theoretically more sensitive to fundamentals when rates are already low. Moreover, Kuttner (2012) describes a theoretical 'over-reaction' point where house prices tend to over-react to interest rates below this point, arguing that such a point is necessary in order to validate the hypothesis that expansionary monetary policy leads to housing market bubbles.[2]

[1] Labour market mobility may also be relevant, with differences in labour demand potentially resulting in city-specific house price dynamics that partially offset each other in the presence of interstate migration (thereby producing national house prices that can hide significant local instability).

[2] The estimated model also provides a basis for testing the predictions stemming from theoretical models that establish a link between asset price bubbles and fundamental drivers (such as interest

By allowing for non-linearities that depend on interest rates, we avoid the restrictive assumption of a solely linear relationship between interest rates and house prices which, at least in recent years, appears to be inconsistent with the house price behaviour of a large number of Western economies. In the absence of such non-linearities, the generality of the usual finding of a weak relationship between house prices and interest rates is in doubt, as is the capacity to fully examine how aggregate interest rates impact on city-specific housing markets. Accordingly, this paper proposes a model that allows for non-linearities in the relationship between city-specific house price to income ratios and housing market fundamentals, and in the housing market spillovers across cities, that depend on the lending rate level.

In so doing, we consider the suitability of a transition function that determines the time-varying nature of the relationship between a city's house price to income ratio and its economic fundamentals by reference to the deviation between the current housing lending rate and an unobserved interest rate threshold. The transition function is also used to examine whether there is an interest rate over-reaction point where the response of relative house prices to interest rates exhibits a significant change, and whether such a point is 'hard' or 'soft' (in other words, whether the transition from one set of dynamics to another upon breaching any over-reaction point occurs abruptly or smoothly). The presence of a 'soft' or 'hard' threshold is important since it provides information about the certainty with which the analyst can determine that the economy is in one regime or the other. When the threshold is 'hard', if interest rates fall below the threshold then the analyst knows with probability close to unity that a particular regime holds and can determine his or her response accordingly. On the other hand, if the threshold is 'soft' then there is uncertainty about the prevailing regime and this introduces an additional layer of complexity to the policymaker's problem.

Our results provide strong evidence of: 1) the presence of an interest rate threshold below which Australian housing markets become unstable; and 2) a significant change in the relationship between housing dynamics and fundamentals below this interest rate

rates), by essentially identifying the interest rate point (if it exists) at which bubble formation can occur (Froot and Obstfeld, 1991).

threshold. In this respect, we show that spillovers across cities change substantially around the threshold, reflecting a transition from stable to unstable housing conditions. These spillovers assist in identifying and estimating the financial stability threshold, which is shown to be both statistically significant and robust to alternative specifications. This is a key contribution of the paper given that the presence of a threshold effect provides empirical support for theoretical models which posit such a nonlinear effect (see Himmelberg, Mayer and Sinai, 2005; Piazzesi and Schneider, 2007). It also helps explain why it is difficult to identify a stability threshold using aggregated data.

The threshold is shown to be a 'soft' threshold such that the transition is not abrupt but is instead a function of city-specific economic conditions, the extent to which interest rates are below the threshold and the period of time that rates stay below the threshold. Consequently, there is almost always uncertainty about the prevailing regime at any given time period. Moreover, it is shown that the unstable regime encompasses local house price boom and bust conditions that justify interpretation of the threshold as a potential over-reaction point. The results are important for bank lending policies, monetary policy and local government since easing beyond a certain point creates significant risks of regional housing market instability.

The remainder of the paper is structured as follows. Section 2 presents the econometric model used to examine the effects of interest rates on housing dynamics. Section 3 describes the housing data utilised in this paper. Section 4 discusses the empirical results stemming from the model, with Section 5 examining the robustness of the results. Section 6 concludes.

2 An econometric model of housing dynamics

Numerous papers have investigated the relationship between interest rates and house prices in an attempt to deduce the direct impact of interest rate changes on house prices, and to determine the extent to which monetary policy can be used to diffuse house price instability (Del Negro and Otrok 2007; Goodhart and Hofmann, 2008; Jarocinski and

Smets 2008; Allen and Rogoff 2011; Glaeser, Gottlieb and Gyourko; 2010; Williams 2011; Kuttner 2012; Adam and Woodford 2013). Relying predominantly on structural VARs, the papers suggest that expansionary interest rates lead to a small but statistically significant increase in national house prices for both the U.S. and numerous other industrialized countries.

Himmelberg, Mayer and Sinai (2005), Piazzesi and Schneider (2007) and Kuttner (2012), however, also explain the potential for non-linearities in the relationship between house prices and fundamentals that depend on interest rates, in addition to the existence of a theoretical interest rate 'over-reaction' point for house price behaviour. The model proposed here investigates these non-linearities by providing empirical evidence on the indirect effects stemming from interest rate changes.

To undertake the analysis, we adopt a smooth transition VAR (Granger and Terasvirta, 1993) that relates city-specific house price to income ratios, house price fundamentals and interest rates to examine whether the sensitivity of house price dynamics to fundamentals changes below a certain interest rate.[3]

The proposed approach is useful as it allows for asymmetries in housing affordability dynamics that are induced by interest rate movements and provides a capacity for identifying interest rate points (if they exist) at which the dynamics may exhibit significant and potentially non-linear change. Our formal model specification, which accommodates (but does not enforce) such an over-reaction point, is:

$$\begin{aligned} h_t &= \beta_0 r_{t-1} + \lambda t + G\left(r_t;\gamma,c\right)\left[\Pi_1\left(L\right)h_t + X_t\beta_1\right] + \\ &\quad \left(1 - G\left(r_t;\gamma,c\right)\right)\left[\Pi_2\left(L\right)h_t + X_t\beta_2\right] + e_t \qquad (1) \\ G\left(r_t;\gamma,c\right) &= 1 - \left(1 + \exp\left\{-\gamma\left(r_t - c\right)\right\}\right)^{-1}, \quad \gamma > 0, c \geq 0 \qquad (2) \\ e_t &\sim MVN\left(0,\Sigma\right) \qquad (3) \end{aligned}$$

where $h_t = [h_{1t}, ..., h_{nt}]'$ is a vector of house price to income ratios for each of the n major

[3] See, also, Auerbach and Gorodnichenko (2012), Berger and Vavra (2014) and Caggiano, Castelnuovo and Groshenny (2014).

cities in Australia, X_t is a matrix of demographic and economic regressors for each city, t is a time trend and r_t is the lending rate for housing loans which is common to all cities.[4] The dynamics in the model are governed by the Π_1 and Π_2 matrices which determine the inter-temporal spillovers between cities. The β_0, β_1 and β_2 vectors specify each city's relationship with interest rates and the demographic and macroeconomic variables in X_t.

The framework allows for two possible regimes. The weights associated with the regimes (with (Π_1,β_1) reflecting the parameters in regime 1 and (Π_2,β_2) the parameters in regime 2) are determined by $G(r_t; \gamma, c)$ which is a logistic transition function of interest rates r_t. Our specification of $G(r_t; \gamma, c)$ captures the effects of interest rates on housing dynamics by reference to the threshold c and the scale (or smoothness) parameter γ. Unlike the standard approach, we estimate the threshold and scale parameters rather than calibrate them prior to estimation. This is important since it allows us to endogenously determine whether there is an interest rate point at which there is a change in housing dynamics. In addition to the nonlinear impact of interest rates on the house price to income ratio, interest rates also enter the model linearly. Accordingly, $G(r_t; \gamma, c)$ allows us to evaluate the non-linear impact of interest rates on housing dynamics after accounting for any linear impact. We also test for the presence of any further non-linearity associated with interest rates, in addition to examining the sensitivity of the model to alternative specifications, in Section 5 which details the range of robustness tests adopted in this paper.

The benefit of the adoption of a 'smooth transition' probability function G is that we avoid imposing the binary situation where any value of r_t less than or equal to c forces the regime dynamics (Π_1,β_1) to prevail with probability one, and any value of r_t exceeding c results in the dynamics (Π_2, β_2) with probability one. This restrictive scenario is, nevertheless, accommodated if the smoothness parameter γ is sufficiently large.

Instead, as r_t falls below c the probability function G rises above 0.5 (such that the

[4]We use the lending rate for housing loans rather than the cash rate target since the former is the rate actually paid by borrowers.

first regime is more probable than the second regime), with γ determining the speed at which G approaches unity. Accordingly, the model allows for non-linearities in the relationship between nominal lending rates and housing dynamics, with both cross-city spillovers and sensitivity to demographic and economic variables depending indirectly on lending rates through the potentially time-varying $G(r_t; \gamma, c)$.

We estimate the model parameters by solving the following non-linear least squares problem for γ and c

$$\min_{\gamma,c} \sum_{i=1}^{n} \sum_{t=p+1}^{T} \left(h_{it} - z'_{it}\psi\right)^2 \tag{4}$$

where $z_{it} = \left[r_{t-1}, t, Gh'_{t-1}, ..., Gh'_{t-p}, Gx'_{it}, (1-G)\,h'_{t-1}, ..., (1-G)\,h'_{t-p}, (1-G)\,x'_{it}\right]'$, $\psi = [\beta_0, \lambda, \Pi_{11}, ..., \Pi_{1p}, \beta_1, \Pi_{21}, ..., \Pi_{2p}, \beta_2]'$ and p is the number of lags L in the model's VAR component.[5]

Conditional on γ and c, it is straightforward to obtain ψ as the solution to an OLS problem by the appropriate vectorisation of h_{it} and z_{it} (Terasvirta, 1994). In the presence of normally distributed errors, (4) yields the maximum likelihood parameter estimates, whereas in the absence of normality the non-linear least squares estimates are effectively quasi maximum likelihood estimates (see, further, Potscher and Prucha, 1997; Leybourne, Newbold and Vougas, 1998).

3 Data

The house price measure h_{it} is constructed on a quarterly basis for Australia's five major capital cities, $i = 1$ to n, $n = 5$, corresponding to Sydney (Syd), Melbourne (Mel), Brisbane (Bne), Adelaide (Ade) and Perth (Per) respectively over the period December 1995 to June 2015, for a total of $nT = 395$ observations. The measure is created as the ratio of dwelling prices to household disposable income

$$h_{it} = \frac{p_{it}}{y_{it}}$$

[5]We adopt a lag length $p = 2$ which satisfies standard tests of residual autocorrelation and is consistent with the chosen lag length based on the AIC criterion (see, further, Section 5).

where p_{it} is the dwelling price and y_{it} is household disposable income.

To obtain p_{it} we adjust median dwelling prices as at 31 July 2015 based on the changes in the CoreLogic RP Data Daily Home Value Index.[6] Dwellings encompass both houses and units, the prices of which appear to be cointegrated (Valadkhani and Smyth, 2016). This city-specific hedonic index accounts for time-varying changes in the attributes of properties thereby better reflecting changes in the value of dwellings. In the absence of such an adjustment, a shift in housing structure (for example, smaller houses) will obfuscate the true value of dwellings over time.[7] In particular, changes in factors such as housing structure and land size may result in units of comparison that can be substantially different over time. In so far as quality adjustments take place during periods where the cost of borrowing is low and housing investment is high (for example, the sub-division of land), the failure to adjust prices for changes in these factors will influence the ability to accurately measure the impact of interest rates on house prices.

The denominator y_{it} is based on annual household disposable income per capita for each capital city. The per capita value is transformed to a household level value using the average number of household members for each city and converted to a quarterly basis by allocating the annual change in household disposable income by reference to the proportion of annual total wage compensation attributed to the relevant quarter.[8] The latter variable is chosen on the basis that wages have historically constituted about 80 per cent of total income for (non-retired) households across the five capital cities that we consider.[9] Given the smoothness of total wage compensation, this procedure

[6] Data supplied by Securities Industry Research Centre of Asia-Pacific (SIRCA) on behalf of CoreLogic. Technical details regarding index construction are available at: http://www.corelogic.com.au/resources/pdf/rismark/technical_method_paper.pdf

[7] Median or mix-adjusted measures are often used. Whilst the latter account for changes in compositional mix they do not account for changes in quality. Some articles use repeat-sales measures to account for quality adjustments, although these measures are inefficient (see, further, Ghysels et al., 2013).

[8] Average household members for each capital city are obtained from the Australian Bureau of Statistics' (ABS) Surveys of Income and Housing over the period 1994-95 to 2011-12. The average household size across the five capital cities exhibits a small decline over time, but has remained fairly flat since 2002-03 at about 2.5 persons per household.

[9] For example, according to the 2011-12 ABS Survey of Income and Housing, wages and salaries constituted 78 per cent of total income (for non-retired households) for Sydney, 75 per cent for Adelaide

produces a quarterly allocation of the annual change in household disposable income that is mostly equal for each quarter in the relevant fiscal year.

The indicators are presented in Figure 1. With the exception of Sydney, the indicators exhibit relatively normal growth until 2000 when affordability levels decline substantially across all capital cities. A general correction is observed in 2003 for all areas except Perth which appears to be related to a surge in prices associated with the commodities 'boom'. During this period, Perth overtakes Sydney as the least affordable of the major capital cities in Australia. Over the past ten years, affordability levels appear to be related to business cycle conditions, particularly for Melbourne and Sydney (see, further, Costello, Fraser and Groenewold, 2011). The latter two cities have exhibited a significant decline in affordability levels in the last few years, in contrast to the remaining cities.

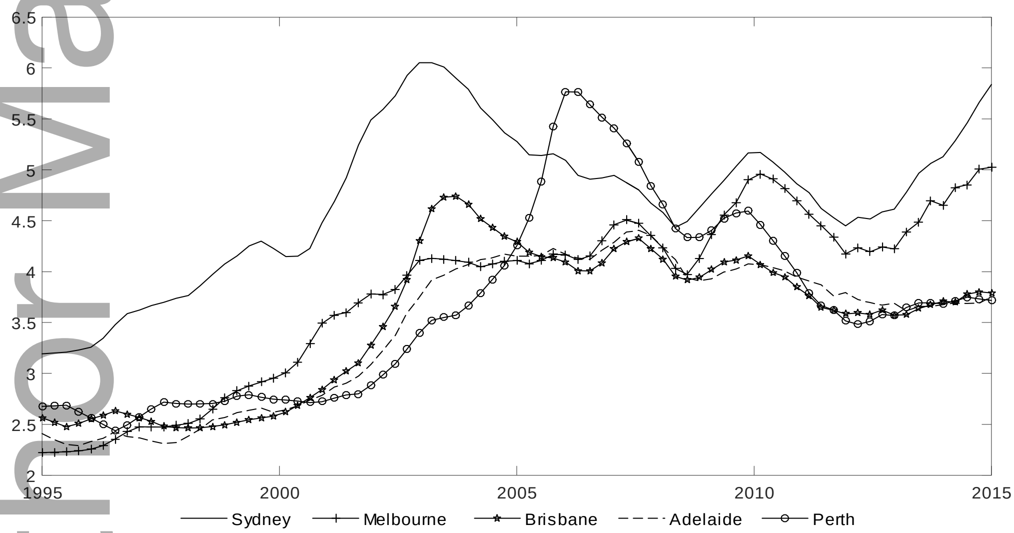


Fig. 1: House price to income levels h_{it} for Australia's five major capital cities over the period December 1995 to June 2015.

The lending rate r_t for housing loans is chosen as an alternative to the formal cash rate since it accounts for periods when banks increase or decrease their lending rates

and 79 per cent for Melbourne, Brisbane and Perth.

irrespective of any changes to the cash rate (see, further, Gambacorta, 2008).[10] In particular, we find that although lending rates typically follow the path of the official cash rate (which targets the Consumer Price Index), there are periods when bank lending rates do not co-move with changes in the cash rate (during which the cash rate does not reflect changes in borrowing costs). This occurs particularly during the periods that are of greatest interest (being crises periods).

We adopt the nominal lending rate since this is the actual interest rate payable by borrowers, and also to account for nominal rigidities and potential money illusion effects. In this respect, a possible reason for explaining any house price over-reaction to low interest rates is that the impact of money illusion on housing affordability is non-linear and greatest when rates are below the nominal threshold c. This explanation is supported by Brunnermeier and Julliard (2008) who find money illusion effects in the US, UK and Australian house price to rent ratios, and provide evidence that the ratios are affected by nominal rather than real interest rates (see, further, Piazzesi and Schneider, 2007). Iacoviello and Neri (2010) and Guerrieri and Iacoviello (2016) also discuss the importance of nominal rigidities, especially in terms of their impact on housing preferences and their capacity to amplify the housing impact of shocks.

The regressors $X_t = [x_{1t}, ..., x_{nt}]'$ are specified as

$$x_{it} = [1, g_{it}, u_{it-1}, s_{it-1}, q_{it-2}, \pi_{it-1}]', \quad i = 1, ..., n \tag{5}$$

where g_{it} is the log of the period t growth rate of the resident population in the relevant state, u_{it} represents the change in the quarterly state-specific unemployment rate, s_{it} is household sentiment data regarding whether it is a good time to buy a dwelling in the relevant state, q_{it} reflects state-specific changes in housing supply, and π_{it} is the quarterly percentage change in the city-specific CPI.[11] We focus on variables that exhibit regional

[10] We use the quarterly standard variable bank lending rate for housing loans computed by the Reserve Bank of Australia.

[11] Population, employment and supply data are obtained from the Australian Bureau of Statistics. Sentiment data is from the Melbourne Institute of Applied Economic and Social Research. The quarterly unemployment rate is calculated as the average of the monthly seasonally adjusted unemployment rates for the relevant quarter.

variation since they represent information that may be able to parsimoniously explain differences between the house price to income ratios in different cities. In any case, we have also considered the addition of alternative regressors (such as commodity prices) with little change to the results (see, further, the discussion in Section 5).

Pursuant to x_{it}, the house price to income ratio responds concurrently to population change and this is designed to capture the shift in housing demand associated with an increase in interstate and international migration (see, further, Poterba (1991) regarding the importance of population factors). The unemployment, sentiment and inflation variables are essentially proxies for wider economic conditions which may impact on the future bidding behaviour of economic agents, while the supply variable seeks to capture the impact of incoming housing stock on the housing market.

Quarterly population growth rates are always positive and the log of these rates is adopted to account for periods of particularly sharp population growth. Given the practical and procedural lags associated with interstate and international migration (and the importance of other factors, such as fertility and mortality rates), it is highly unlikely that a change in the house price to income ratio will result in a concurrent change in the population growth rate. It is therefore sensible to treat this variable as exogenous.

The sentiment data is from the 'Time to buy a Dwelling' index associated with the Melbourne Institute - Westpac Consumer Sentiment Survey. The latter index is constructed for each state and is based on household responses regarding whether it is a good time to buy a dwelling. Essentially, this data is used to provide information about economic expectations and user costs as they pertain to the housing market that is not adequately captured by historical population or employment conditions (see, further, Himmelberg, Mayer and Sinai, 2005).

The supply side variable is included in line with Glaeser, Gyourko and Saiz (2008) who provide evidence that the elasticity of housing supply has an impact on the frequency and magnitude of housing bubbles. This suggests that region-specific supply conditions are important in both normal or low interest rate conditions, and that rates should have little impact on prices in elastically supplied markets. We construct q_{it} by reference to residential dwelling commencement data for each state. Using national data on average dwelling construction periods, we calculate the residential supply variable as a weighted average of residential dwelling commencements lagged two and three quarters. The weights account for the typical time required to transition from the dwelling commencement stage to dwelling completion and therefore broadly capture actual new supply at a given time period.

Australian Bureau of Statistics' data on residential dwelling construction periods indicate that the majority of residential dwellings are built within two and three quarters (with the average being closer to two). This construction duration is similar to that observed for the US, where the duration from start to completion for typical single-family homes takes about 6 months (Oh and Yoon, 2016). Construction periods are similar across the major states, although Queensland times are somewhat smaller. In any case, adjusting the weights for Queensland produces little change in the results. We adopt the annual change in the resulting weighted average (and, without loss of generality, divide the annual change by 100 for estimation purposes) thereby capturing the additional new supply relative to the same period last year.

4 Empirical Results

The model described in Section 2 proposes understanding the dynamics of the relationship between city-specific house price to income ratios and national interest rates by reference to local economic and demographic variables (as measured by β_1, β_2) and cross-city spillovers (as reflected in the autoregressive matrices Π_1,Π_2), with the observed outcome determined by the time-varying weight G (which is a function of the lending rate r_t, the threshold c and the smoothness parameter γ). We discuss each of these in turn.

The β_0 coefficients reflect the linear relationship between the house price to income ratios and lending rates, while β_1 and β_2 provide information about the degree of asymmetry in the relationship between the house price measures and demographic or economic conditions as lending rates move across the threshold c. The first set of coefficients β_1 is more likely to prevail when $r < c$ and β_2 is more likely when $r > c$. The estimated parameters are

$$\widehat{\beta}_0 = \left[\underset{(0.0733)}{-0.3288^{***}} \quad \underset{(0.0740)}{-0.2835^{***}} \quad \underset{(0.0734)}{-0.2451^{***}} \quad \underset{(0.0748)}{-0.2556^{***}} \quad \underset{(0.0729)}{-0.2585^{***}} \right]$$

$$x'_{it}\widehat{\beta}_1 = \underset{(0.3145)}{-2.383^{***}} + \underset{(0.1251)}{0.0278} g_{it} + \underset{(0.3495)}{0.0953} u_{it-1} - \underset{(0.0010)}{0.0024^{**}} s_{it-1} - \underset{(0.0953)}{0.2137^{**}} q_{it-2} + \underset{(0.3411)}{0.7287^{**}} \pi_{it-1},$$

$$x'_{it}\widehat{\beta}_2 = \underset{(0.1365)}{-0.4958^{***}} + \underset{(0.0251)}{0.0109} g_{it} - \underset{(0.1245)}{0.0390} u_{it-1} + \underset{(0.0003)}{0.0008^{***}} s_{it-1} - \underset{(0.0323)}{0.0685^{**}} q_{it-2} - \underset{(0.0632)}{0.0123} \pi_{it-1}$$

where the values in parentheses are standard errors and the asterisks denote significance at the 1 (***) and 5 (**) per cent levels. As noted above, $g_{it}, u_{it}, s_{it}, q_{it}$ and π_{it} are respectively: log quarterly growth in estimated resident population for the relevant state (g_{it}), change in the quarterly unemployment rate (u_{it}), quarterly percentage change in dwelling purchase sentiment (s_{it}), annual change in new housing stock (divided by 100) (q_{it}), and quarterly percentage change in the city's CPI (π_{it}). It is noted that a likelihood ratio test of a common intercept cannot be rejected at the 0.05 level such that we present the model with a common intercept rather than an individual intercept for each capital city.

Firstly, it is clear that interest rates have a negative, linear impact on house price to income ratios, and that this impact is relatively similar across cities. A percentage point decline in the lending rate typically raises the house price to income ratio in each city by 0.3 and this is statistically significant albeit relatively small. The negative linear relationship between interest rates and house prices appears to be a general phenomenon for industrialised countries, particularly those with developed mortgage markets (Calza, Monacelli and Stracca, 2013). The result is also consistent with previous findings that expansionary monetary policy leads to a positive but relatively small (direct) increase in national house prices for both the U.S. and other industrialized countries (Del Negro and Otrok 2007; Goodhart and Hofmann, 2008; Jarocinski and Smets 2008; Glaeser, Gottlieb and Gyourko, 2010).

Noteably, however, there also appears to be a significant non-linear impact associated with interest rates, and this impact is predominantly reflected in the impact of local supply side housing conditions. The supply side variable is significantly different to zero in both regimes, with an increase in supply leading to a fall in the house price to income ratio irrespective of high or low interest rates (see, also, Fry, Martin and Voukelatos, 2010). Housing supply appears to be particularly important when rates are below c, however, and its impact on the house price to income ratio *triples* during periods of low interest rates.

Although declining supply will increase the house price to income ratio in either regime, the impact of a decline in supply on each city's housing affordability is particularly onerous when interest rates are below the threshold. This shift in the importance of supply conditions when moving from higher to lower interest rates also suggests that the observed rise in the house price to income ratio in recent years reflects the combined effects of low lending rates and housing under-supply.

Given the inclusion of the supply variable, factors such as unemployment and population do not appear to be statistically significant in terms of the house price to income ratio nor does their importance appear to depend on the presence of high or low lending rates. These factors (together with a range of other factors, including regulatory and geographic constraints) may, however, impact on long-run supply conditions and therefore indirectly influence the house price to income ratio. In this respect, Saiz (2010) examines the geographic and demographic determinants of housing supply, while Saks (2008) and Glaeser, Gyourko and Saks (2006) examine possible links between labour and housing supply.

In addition to supply, housing sentiment is also significant with the direction of its impact changing according to the prevailing regime. In absolute terms, however, the house price to income ratio is approximately three times more sensitive to sentiment in the lower interest rate regime than in the higher interest rate regime. This is consistent with Shiller (2007; 2008) who finds that sentiment is particularly important during periods of sharp price changes. In the low interest rate regime, sentiment appears to be linked to affordability with declining sentiment corresponding to a higher house price to income ratio and therefore a fall in affordability. In the higher interest rate regime, however, housing sentiment does not appear to be focused on affordability levels with sentiment and house prices moving in the same direction. Finally, inflation is significant but this is limited to the lower interest rate regime. When this regime prevails, however, rising inflation in a particular city is associated with a higher house price to income ratio for that city.[12]

The results appear sensible when considered in the context of previous findings. Himmelberg, Mayer and Sinai (2005), for example, argue that non-linearities in the discounting of rents can lead to over-reactions when interest rates change. In particular, the authors provide theoretical evidence that the sensitivity of house prices to interest rates changes when rates are low. The authors suggest, further, that the sensitivity of house prices to fundamentals increases with low interest rates. Shiller (2007; 2008), on the other hand, finds that boom-bust cycles have frequently had little to do with economic fundamentals, instead being driven by investor sentiment.

Our parameter estimates are consistent with both assessments, with the sensitivity of house prices to fundamentals such as supply and inflation - *and* non-fundamentals such as sentiment - increasing significantly when interest rates fall below a particular level.

Autoregressive dynamics

The autoregressive dynamics Π_1, Π_2 represent the inter-temporal relationships and spillovers (or cross-correlations) between the housing measures across capital cities. It is evident that, just as the impact of economic and demographic conditions vary, the

[12] Individual likelihood ratio tests indicate that the coefficients on housing supply, sentiment and inflation differ significantly (at the .01 level) across the two regimes.

autoregressive dynamics change noticeably as G increases. The estimated parameters in Table 1 indicate that housing dynamics are stable when Π_2 prevails (viz. $r > c$), with the roots of $\det(I_n - \Pi_2(1)z - \Pi_2(2)z^2) = 0$ all lying outside of the complex unit circle.

The dynamics change significantly, however, when Π_1 prevails (such that $r < c$) with the VAR system becoming unstable. The roots of $\det(I_n - \Pi_1(1)z - \Pi_1(2)z^2) = 0$ no longer always lie outside the unit circle and are, in fact, explosive (ie. some of the roots are less than unity). Given the importance of this result, we also re-estimate the model using second and third-order detrended house price to income ratios and find that the transformations do not have any substantive impact on the existence of either the threshold or the stability/instability dichotomy observed across the two regimes (see, further, Section 5).

Table 1: Cross-city parameter estimates. Estimates are based on the sum of the first and second order autoregressive matrices in each regime ($\Pi_1 = \Pi_1(1) + \Pi_1(2)$ corresponds to the parameters in the first regime and $\Pi_2 = \Pi_2(1) + \Pi_2(2)$ to the parameters in the second regime).

	$\Pi_{1,Syd}$	$\Pi_{1,Mel}$	$\Pi_{1,Bne}$	$\Pi_{1,Ade}$	$\Pi_{1,Per}$
$\Pi_{1,Syd}$	1.7862	0.4148	0.4854	0.5865	0.5675
$\Pi_{1,Mel}$	-0.5803	0.6733	-0.5098	-0.3684	-0.3590
$\Pi_{1,Bne}$	-1.2448	-0.4154	1.5640	0.0181	-0.7642
$\Pi_{1,Ade}$	1.5820	0.5983	0.4838	1.0891	0.7403
$\Pi_{1,Per}$	-0.2291	0.1239	-0.6057	-0.0134	1.1480
	$\Pi_{2,Syd}$	$\Pi_{2,Mel}$	$\Pi_{2,Bne}$	$\Pi_{2,Ade}$	$\Pi_{2,Per}$
$\Pi_{2,Syd}$	0.8691	-0.0323	-0.0007	-0.0305	-0.0674
$\Pi_{2,Mel}$	0.0539	0.9922	0.0091	0.0256	-0.1002
$\Pi_{2,Bne}$	0.0959	0.0068	0.8217	0.0481	-0.0366
$\Pi_{2,Ade}$	-0.1579	-0.0901	0.0511	0.8566	0.2823
$\Pi_{2,Per}$	0.0548	0.0553	0.0651	0.0531	0.9017

The resulting dynamics suggest that, in normal conditions, the ratio of house prices to disposable income is stationary across all cities and has a predictable long-run mean. Below a given interest rate, however, the relationship between a city's house price and household income can break down. At this point, the cost of borrowing is sufficiently low that household income levels are no longer an appropriate anchor for the dynamics of city-specific house prices. Technically, at below the threshold c, it is also not possible to identify a long-run mean in the ratio of house prices to household income nor is it possible to identify the inter-temporal impact of a housing shock.

Given that the roots of $\det\left(I_n - \Pi_1(1)z - \Pi_1(2)z^2\right) = 0$ are explosive, a large G results in dynamics that accommodate both house price bubbles and boom and bust cycles in house prices. In this respect, the relationship between the roots of an autoregressive process and the presence of bubbles is detailed in Evans (1991) and Phillips, Wu and Yu (2011), and is consistent with the treatment of c as a potential over-reaction point for city house prices.

Transition between regimes

Figure 2a shows the estimated transition function $G\left(r_t; \widehat{\gamma}, \widehat{c}\right)$ which includes four spikes that are associated with the Asian Financial Crisis in the late 1990s, the 2001 US recession, the Global Financial Crisis (GFC) and the 'zero-lower-bound' period resulting from the cumulative impact of the GFC and the European debt crisis, while Figure 2b shows how the bank lending rate has changed over each of these periods. The latter three periods, in particular, produce a greater than 50 per cent probability associated with the unstable (lower interest rate) regime.

The transition function's scale (or smoothness) parameter $\gamma = 2.4825$ ($p < 0.01$) indicates that transitions between the two states are fairly smooth (in contrast, large values of γ imply abrupt shifts between the regimes). The smoothness in the transition function suggests that there is no 'hard' threshold below and above which the unstable or stable regimes (as represented by the (Π_1,β_1) and (Π_2,β_2) parameters respectively) unambiguously prevail. Instead there is a 'soft' threshold with house price dynamics approaching the two extremes (Π_1,β_1) and (Π_2,β_2) as interest rates move away from the threshold. This is important since it indicates that there is almost always uncertainty about the prevailing regime.

The results indicate that house prices exhibit an asymmetric relationship with interest rates. As the transition function approaches unity, the system moves away from stable housing dynamics towards instability. However, since the threshold is soft, the hypothesis of an immediate or sudden price surge in response to lower interest rates is not supported. Instead, both γ and the spillover dynamics Π_1 imply that any housing instability due to interest rates is the result of interest rates being below the threshold c for a sufficiently long period of time (in other words, it is the duration of the breach rather than the breach itself that is of primary importance). The latter duration condition stems from the inter-temporal properties of the stability condition with house price to income ratios changing gradually over time.

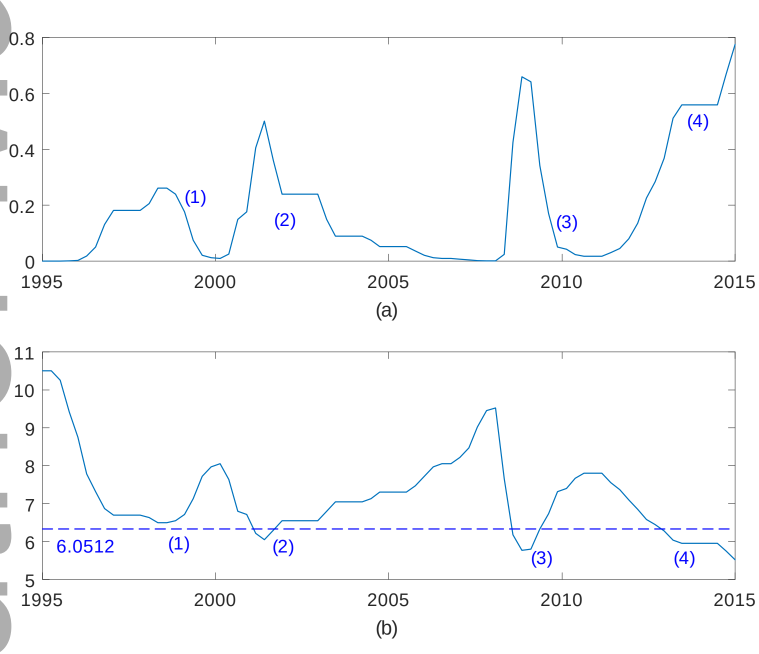


Fig. 2: (a) The time-varying transition function $G(r_t;\gamma,c)$ representing the probability associated with the unstable house price regime; (b) Bank lending rates (the dashed horizontal line is the estimated threshold c). The four numbered episodes are: (1) declining rates following the Asian Financial Crisis; (2) the 2001 US recession; (3) the Global Financial Crisis; and (4) the 'zero lower bound' period.

Figure 2b shows the threshold, which is significantly different to zero at $c = 6.0512$ ($p < 0.01$), in the context of the lending rate movements observed over the sample period (the actual rate r is below c for approximately 11.25 per cent of the sample period). This threshold is globally identified and robust to alternative transformations of the dependent variable (see Section 5 for further details). We suggest interpreting c as the threshold below which 'normal' housing spillovers and relationships with supply conditions are no longer likely to hold (instead, giving way to dynamics that are characterised by instability and an increased sensitivity to fundamental drivers and sentiment).

The literature suggests two possible reasons for the presence of threshold and overreaction behaviour. The first relates to subjective assessments made by households (and investors) such as non-linearities in the discounting of rents, money illusion effects or the presence of overly-optimistic expectations. When credit costs decline beyond a certain point, for example, households and investors may engage in a different type of discounting that can lead to excess demand and increase the probability of boom-bust type conditions (Himmelberg, Mayer and Sinai, 2005). Alternatively, Piazzesi and Schneider (2007) show that money illusion effects can generate interest rate thresholds and house price boom conditions when interest rates are particularly low or high, while Burnside, Eichenbaum and Rebelo (2016) develop a model where heterogeneity (and spillovers) in house price expectations (for example, households with overly-optimistic expectations) can induce boom-bust conditions.

The second school of thought relates to the presence of occasionally binding collateral constraints on housing wealth (see, for example, Guerrieri and Iacoviello, 2016). When these constraints bind, this can lead to nonlinear dynamics such as an amplified response to shocks during economic downturns. In this respect, Figure 2a shows that the probability in favour of unstable house price to income dynamics exceeds 50 per cent during the GFC (denoted as period 3 in the figure) and is also at 50 per cent during the 2001 US recession (period 2). During the former period, in particular, there was a significant increase in financial distress and a concomitant sharp fall in new credit approvals.[13] It is possible, therefore, that the threshold is identifying these occasionally binding constraints as they impact on each city's housing market (and on household wealth more generally, given the importance of housing in the typical household's balance sheet).

What happens if aggregate data are used?

To determine the impact of aggregation on the findings, we re-estimate the model using aggregate Australian data. The estimated threshold parameter for the aggregate Australian dataset is 7.02 per cent which is considerably higher than the 6.05 per cent estimated using city-specific data. The threshold for the aggregate dataset corresponds to the 45th percentile of the empirical distribution of Australian mortgage lending rates and does not appear to be meaningfully associated with periods of sharp changes in affordability. In particular, the associated transition probabilities fail to correspond with the periods of sharp capital appreciation observed in Figure 1, whereas the transition probabilities estimated using the city-based dataset correspond closely with the periods where affordability levels decline sharply.

Most importantly, the aggregate model's persistence parameters are less than unity in both regimes (0.63 and 0.51 for the first and second regimes respectively) indicating that the stability/instability dichotomy no longer continues to be applicable when using aggregate data. The use of aggregate data therefore appears to hide sharp city-specific house price changes, and overstates the level of stability in the house price to income ratio. Since the capacity to observe a threshold that defines periods of stable and unstable price to income ratios can no longer be observed when using aggregate data, house prices can *never* become unstable under the aggregate model.[14]

Using only a subset of the regressors or omitting the linear introduction of the interest rate has little impact on this finding. The results highlight the importance of

[13] See, for example, Reserve Bank of Australia new credit approval data (Bank Lending to Business – New Credit Approvals by Size and by Purpose – D7.4), which exhibited record annual declines of 27 and 33 per cent in 2008Q4 and 2009Q1 respectively.

[14] This property also appears to be inconsistent with the behaviour of Australian regulatory bodies such as the Australian Prudential Regulatory Authority (APRA). For example, in response to sharp house price changes in recent years, APRA initiated a number of restrictions on bank lending (focusing on investors) in order to forestall any potential instability.

spillovers across cities in identifying points of instability and in estimating the threshold at which stability breaks down - particularly since the adoption of aggregate data implies a zero probability of ever entering the unstable regime. Although it is conceptually and econometrically simpler to estimate the model with aggregate housing data, there also appears to be a significant cost in terms of the potentially severe understatement of housing market risks.

5 Robustness

Testing for misspecification and lag length

A range of papers have consider the potential for non-linearities in the relationship between house prices and interest rates (Himmelberg, Mayer and Sinai, 2005; Piazzesi and Schneider, 2007; Kuttner, 2012). To empirically motivate this reasoning, we test for the linearity of the specification (1) using the method proposed in Terasvirta and Yang (2014). The test of linearity is essentially a test of the equivalence of (Π_1,β_1) and (Π_2,β_2), but can alternatively be considered a test of $\gamma = 0$. The test rejects the null hypothesis of linearity at the 0.01 level rendering it clear that asymmetries are present in the behaviour of the house price to income ratio at different interest rates. In this respect, the Lagrange multiplier test statistic for the null hypothesis of (Π_l,β_l) =(Π_h,β_h) is 122.53 ($p < 0.01$). The strength of this rejection indicates that the inter-temporal dynamics of the housing measures, and their relationship with demographic and economic conditions, change markedly as interest rates move above or below some unknown threshold.

To estimate the model, we adopt a lag length of $p = 2$ with standard diagnostic tests indicating that little autocorrelation is observed in the residuals after accounting for the first two lags. The Ljung-Box Q statistic fails to reject the null hypothesis of no serial dependence in the residuals, with Engle's ARCH test not indicating any significant conditional heteroscedasticity in the squared residuals. In this respect, given the large number of parameters, we restrict the VAR matrices for lags greater than unity to be diagonal for both testing and estimation purposes. Furthermore, the choice of $p = 2$ is consistent with the preferred lag length indicated by the Akaike Information Criterion (AIC).

We also test for the presence of any further non-linearity associated with interest rates (for example, there being more than one transition function G with different threshold and smoothness parameters) by applying the Lagrange Multiplier test for additional additive non-linearity proposed in Terasvirta and Yang (2014). The test depends on both the functional form and parameterisation of the transition function and the associated test statistic of 82.00 ($p = 0.19$) provides little evidence of any additional additive non-linearity.

Transformations of the house price to income ratio

Although the estimated model allows for a trend, we also re-estimate the model using a detrended house price to income ratio h_t in order to examine whether the results are robust to alternative transformations. In particular, we replace the dependent variable with the residuals from both a second and third order time-polynomial detrending of h_t.

We find that the transformations mainly influence the smoothness of the transition function but do not have any substantive impact on the existence of a threshold or on the stability/instability dichotomy when lending rates are above or below the estimated threshold. In the second order case, γ rises by a relatively small amount ($\gamma = 2.984$), whilst in the third order case γ rises to 18.642. In other words, the smoothness of the transition function is (not unsurprisingly) influenced by knowledge about the future direction of the dependent variable (which is implicit in the detrending process).

It does not appear that c is particularly sensitive to reasonable transformations of h_t, with the threshold parameter increasing only slightly to just under 6.2 per cent for the second and third order detrended data (6.182 and 6.178 per cent respectively). These two thresholds correspond to an empirical probability for $r < c$ that is effectively identical to the 11.25 per cent obtained when estimating the model using untransformed data. The results, therefore, do not contradict the presence of a significant lending rate threshold lying a little above 6 per cent.

The interpretation of c as a point of instability also continues to hold, with the transformations not producing a change in the instability/stability dichotomy observed for Π_1 and Π_2 respectively. In all cases, when interest rates fall substantially below c the price dynamics in the model are unstable and contain explosive roots.

Sensitivity to other regressors and specifications

We have focused on variables for which city-specific information is available as these provide a basis for explaining cross-city differences in the house price to income ratio. However, we also consider the addition of lagged quarterly growth rates of stockmarket returns, exchange rates, commodity prices and state final demand as regressors. In this respect, the AUD/USD and TWI exchange rates are considered, in addition to commodity prices based on the RBA Commodity Price Index and stockmarket returns based on the ASX200.

Our findings do not change significantly following the inclusion of these variables. In particular, the additional regressors do not impact on the observed explosive nature of the parameters in the first regime, and the presence of stable parameters in the second regime, nor do they have a substantive impact on the threshold or smoothness parameters.

We also consider whether changes to the chosen specification impact significantly on the qualitative results. In particular, we re-estimate the model after removing the linear impact of the lending rate such that interest rates only enter the model non-linearly. This has little impact on either the threshold or the smoothness parameters and is consistent with previous research that highlights the relatively small linear impact of interest rates (nominal or real) on house prices (Muellbauer and Murphy, 1997; Brunnermeir and Julliard, 2007). Furthermore, the VAR parameters remain unstable in the first regime, with the impact of supply side conditions continuing to exhibit a jump when moving from the 'normal' interest rate regime to the 'low' interest rate regime.

Given that the omission of the linear impact of interest rates does not impact significantly on our results, it is not surprising that a range of papers that rely on the assumption of a linear relationship between the two variables have found that the impact of interest rates on house prices is statistically significant but small. The results in this paper indicate that it is the non-linear and indirect impact of interest rates that is primarily of importance in determining the overall effect of interest rates on house prices.

Uniqueness of the threshold and smoothness parameters

To ensure robustness of the transition function parameters, we consider the extent to which the threshold and the smoothness parameters are uniquely identified. Auerbach and Gorodnichenko (2012) point out that the advantage of using a smooth-transition VAR is that the regime dependent parameter estimates use *all* the data. Consequently, the problem of having relatively few observations above or below the threshold is accounted for. However, due to the non-linearities in the model it is also possible there may be a number of local optima that the optimisation function may converge to (see, also, Terasvirta and Yang, 2013).

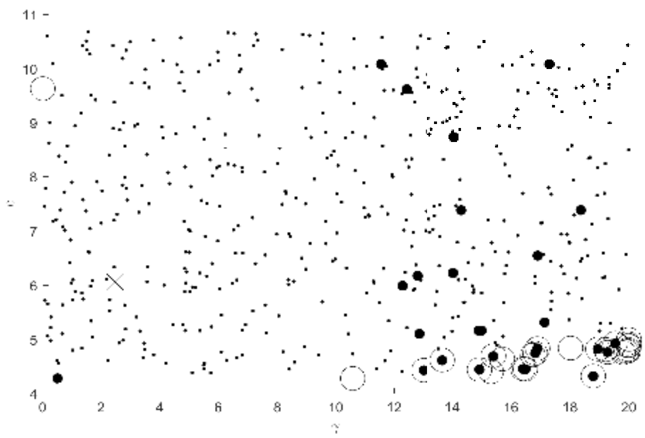


Fig. 3: Basins of attraction indicating convergence to the pair (γ, c) for 500 randomly selected starting points. The small solid dots converged to the point identified by the star (corresponding to a log-likelihood of 681), whereas the large solid dots converged to the space identified by the hollow circles (typically corresponding to logl $\sim$ 570, and in one case to logl $\sim$ 461).

To examine this possibility, we adopt the following approach to identify the basins of attraction for the γ, c parameters in the transition function. We randomly draw starting points for $\gamma^* \in (0, 20)$, $c^* \in (4, 11)$. Conditional on the draws, we obtain least squares estimates of the model's remaining parameters by solving (4) subject to $\gamma = \gamma^*$, $c = c^*$. The latter parameters coupled with the draws γ^*, c^* are used as starting values for the model's maximum likelihood problem. The procedure is repeated 500 times to ascertain the points of convergence.

The results, presented in Figure 3, indicate that for nearly every starting point γ^*, c^* (represented by the small solid dots in the figure) the model converges to the result $\gamma = 2.4825$, $c = 6.0512$ (represented by the star). In a small number of cases, the parameters converge to a flat portion of the likelihood function characterised by a substantially smaller likelihood value and a threshold c that is implausibly high or low. It is clear, therefore, that the smoothness and threshold parameters in the transition function are identified and do not stem from a local optimum.

6 Conclusion

Understanding the effects of changes in interest rates on house prices is important for managing house price bubbles and ensuring housing affordability. In particular, policymakers are often concerned that low interest rates may facilitate significantly higher house prices in some cities thereby impacting negatively on housing affordability and financial stability.

Our empirical analysis indicates that the structural dynamics between city-specific house price to income ratios and interest rates are likely to be non-linear, with economic and demographic differences across cities being important in terms of determining the impact of interest rates on house prices. Using city-specific house price data, we find that house price dynamics - and their sensitivity to both fundamental drivers and household sentiment - depend significantly on the level of interest rates.

In particular, we observe an interest rate threshold that represents a tipping point for changes in local house price dynamics. When interest rates fall below this level, house price to income ratios for some cities can become unstable and no longer exhibit 'normal' levels of sensitivity to fundamental drivers. Instead, house prices become particularly sensitive to both local housing supply and household sentiment. This change in sensitivity to fundamentals has substantial welfare ramifications, including potentially misdirecting the decision of households regarding where to live and whether or not to rent or purchase (Glaeser, Gyourko and Saiz, 2008).

The threshold is shown to act as a potential over-reaction point in the vein of Kuttner (2012), with local house prices being open to boom and bust type behaviour if the interest rate threshold is breached. The onset of housing market instability, however, does not appear to occur abruptly or uniformly across cities. Instead, house price dynamics depend on the extent to which rates fall below the threshold, the period of time that rates remain below the threshold, and on city-specific economic conditions (which may aggravate or mitigate the threshold effects).

The empirical analysis indicates that, when interest rates are below the threshold, there is a risk that stimulus stemming from expansionary monetary policy can be offset by local housing market instability. The results are therefore also important in terms of the housing market implications of macroprudential policies, particularly given recent evidence that house price booms and busts are predictive of financial crises (Jordà, Schularick and Taylor, 2015).

References

[1] Adam, K. and Woodford, M. (2013), "Housing Prices and Robustly Optimal Monetary Policy," Columbia University Academic Commons, http://dx.doi.org/10.7916/D8JS9NC4.

[2] Allen, F. and Rogoff, K. (2011), "Asset Prices, Financial Stability and Monetary Policy," Wharton Financial Institutions Center Working Papers #11-39, The University of Pennsylvania.

[3] Auerbach, A.J. and Gorodnichenko, Y. (2012), "Measuring the Output Responses to Fiscal Policy," American Economic Journal: Economic Policy, 4(2), 1-27.

[4] Berger, D. and Vavra, J. (2014), "Measuring How Fiscal Shocks Affect Durable Spending in Recessions and Expansions," American Economic Review, 104(5), 112-115.

[5] Beraja, M., Fuster, A., Hurst, E., and Vavra, J. (2015), "Regional Heterogeneity and Monetary Policy," Federal Reserve Bank of New York Staff Reports, no. 731.

[6] Bernanke, B.S. (2010), "Monetary Policy and the Housing Bubble," Speech at the Annual Meeting of the American Economic Association, Atlanta, Georgia.

[7] Brunnermeier, M.K. and Julliard, C. (2008), "Money Illusion and Housing Frenzies," Review of Financial Studies, 21, 135-180.

[8] Burnside, C., Eichenbaum, M., and Rebelo, S. (2016),."Understanding Booms and Busts in Housing Markets," Journal of Political Economy, 124(4), 1088–1147.

[9] Caggiano, G., Castelnuovo, E., and Groshenny, N. (2014), "Uncertainty Shocks and Unemployment Dynamics in U.S. Recessions," Journal of Monetary Economics, 67, 78-92.

[10] Calza, A., Monacelli, T., and Stracca, L. (2013), "Housing Finance and Monetary Policy," Journal of the European Economic Association, 11(1), 101-122.

[11] Costello G., Fraser, P., and Groenewold, N. (2011),"House Prices, Non-fundamental Components and Interstate Spillovers: The Australian Experience," Journal of Banking and Finance, 35(3), 653–669.

[12] Del Negro, M. and Otrok, C. (2007), "99 Luftballons: Monetary Policy and the House Price Boom across U.S. states," Journal of Monetary Economics, 54(7), 1962-1985.

[13] Evans, G. (1991), "Pitfalls in Testing for Explosive Bubbles in Asset Prices," American Economic Review, 81, 922-930.

[14] Froot, K.A. and Obstfeld, M. (1991), "Intrinsic Bubbles: The Case of Stock Prices," American Economic Review, 81(5), 1189-1214.

[15] Fry, R.A., Martin, V.L., and Voukelatos, N. (2010), "Overvaluation in Australian Housing and Equity Markets: Wealth Effects or Monetary Policy?" Economic Record, 86(275), 465–485.

[16] Gambacorta, L. (2008), "How Do Banks Set Interest Rates?" European Economic Review, 52, 792-819.

[17] Ghysels, E., Plazzi, A., Valkanov, R., and Torous, W. (2013), "Forecasting Real Estate Prices," in: Handbook of Economic Forecasting vol. 2a (eds. Elliott, G. and Timmermann, A.), Elsevier B.V., Amsterdam.

[18] Glaeser, E.L., Gottlieb, J.D., and Gyourko, J. (2010), "Can Cheap Credit Explain the Housing Bubble?" NBER Working Paper 16230.

[19] Glaeser, E.L., Gyourko, J., and Saks, R. (2006), "Urban Growth and Housing Supply," Journal of Economic Geography 6, 71–89.

[20] Glaeser, E., Gyourko, J. and Saiz, A. (2008), "Housing Supply and Housing Bubbles," Journal of Urban Economics, 64, 198-217.

[21] Goodhart, C. and Hofmann, B. (2008), "House Prices, Money, Credit, and the Macroeconomy," Oxford Review of Economic Policy, 24(1), 180–205.

[22] Granger, C.W.J. and Terasvirta, T. (1993), Modelling Nonlinear Economic Relationships, Oxford University Press, Oxford.

[23] Guerrieri, L. and Iacoviello, M. (2016), "Collateral Constraints and Macroeconomic Asymmetries," Working Paper, https://www2.bc.edu/matteo-iacoviello/research_files/ASYMMETRIES_PAPER.pdf.

[24] Himmelberg, C., Mayer, C., and Sinai, T. (2005), "Assessing High House Prices: Bubbles, Fundamentals, and Misperceptions," Journal of Economic Perspectives 19(4), 67-92.

[25] Iacoviello, M. and Neri, S. (2010), "Housing Market Spillovers: Evidence from an Estimated DSGE Model," American Economic Journal: Macroeconomics,2, 125-164.

[26] Jarocinski, M. and Smets, F. (2008), "House Prices and the Stance of Monetary Policy," Federal Reserve Bank of St. Louis Review, 90(4), 339–365.

[27] Jordà, Ò., Schularick, M., and Taylor, A.M. (2015), "Betting the House," Journal of International Economics, 96 (s1), S2–S18.

[28] Kuttner, K.N. (2012), "Low Interest Rates and Housing Bubbles: Still No Smoking Gun," Williams College Department of Economics Working Paper 2012-01.

[29] Leamer, E.E. (2014), "Housing Really is the Business Cycle: What Survives the Lessons of 2008-09?" Journal of Money, Credit and Banking, 47(S1), 43-50.

[30] Leybourne, S., Newbold, P., and Vougas, D. (1998), "Unit roots and Smooth Transitions," Journal of Time Series Analysis, 19, 83-97.

[31] Muellbauer, J. and Murphy, A. (1997), "Booms and Busts in the UK housing market," Economic Journal, 107, 1701-1727.

[32] Notarpietro, A. and Siviero, S. (2015), "Optimal Monetary Policy Rules and House Prices: The Role of Financial Frictions," Journal of Money, Credit and Banking, 47(S1), 383-410.

[33] Oh, H. and Yoon, C. (2016), "Residential Construction Lags across the US and their Implications for Housing Supply," Vanderbilt University Department of Economics Working Paper 16-00002.

[34] Phillips, P.C.B., Wu, Y., and Yu, J. (2011), "Explosive Behavior in the 1990s Nasdaq: When did Exuberance Escalate Asset Values?" International Economic Review, 52, 201-226.

[35] Piazzesi, M. and Schneider, M. (2007), "Inflation Illusion, Credit, and Asset Pricing," NBER Working Paper No. 12957.

[36] Piazzesi, M. and Schneider, M. (2016), "Housing and Macroeconomics," NBER Working Paper No. 22354.

[37] Poterba, J.M. (1991), "House Price Dynamics: The Role of Tax Policy and Demography," Brookings Papers on Economic Activity, 2, 143-203.

[38] Pötscher, B.M. and Prucha, I.R. (1997), Dynamic Nonlinear Econometric Models: Asymptotic Theory, Springer-Verlag, Berlin.

[39] Saiz, A. (2010), "The Geographic Determinants of Housing Supply," Quarterly Journal of Economics, 125(3), 1253-1296.

[40] Saks, R. (2008), "Job Creation and Housing Construction: Constraints on Metropolitan Area Employment Growth," Journal of Urban Economics, 64, 178-195.

[41] Shiller, R. (2007), "Understanding Recent Trends in House Prices and Home Ownership," Cowles Foundation Discussion Paper No. 1630, Yale University.

[42] Shiller, R. (2008), "Historical Turning Points in Real Estate," Eastern Economic Journal, 34, 1-13.

[43] Taylor, J.B. (2007), "Housing and Monetary Policy," Working Paper No. 13682, National Bureau of Economic Research.

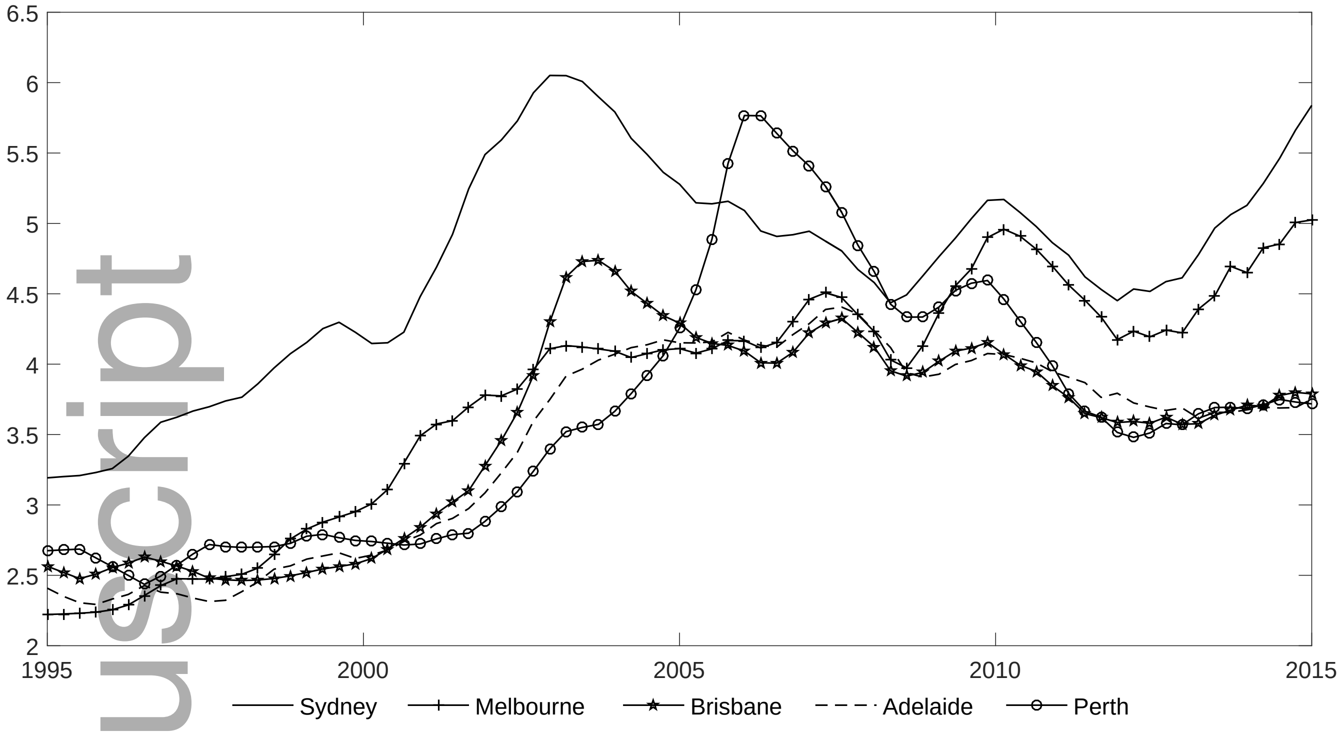
[44] Taylor, J.B. (2009), "The Financial Crisis and the Policy Responses: An Empirical Analysis of What Went Wrong," Working Paper 14631, National Bureau of Economic Research.

[45] Terasvirta, T. (1994), "Specification, Estimation, and Evaluation of Smooth Transition Autoregressive Models," Journal of the American Statistical Association 89, 208-218.

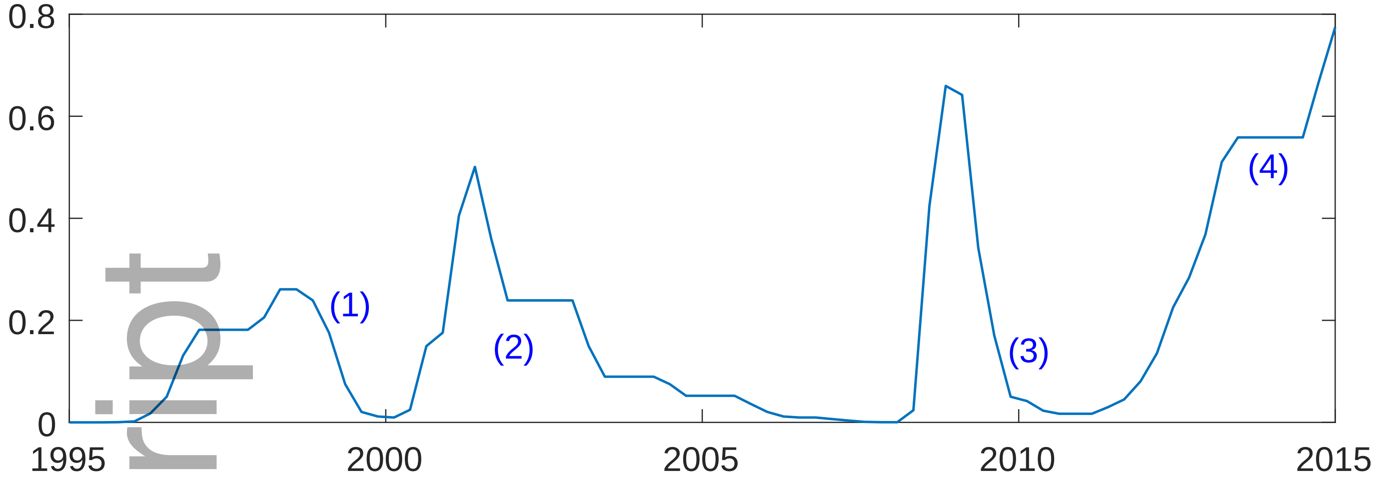
[46] Terasvirta, T. and Yang, Y. (2014), "Linearity and Misspecification Tests for Vector Smooth Transition Regression Models," CREATES Research Paper 2014-4, School of Economics and Management, University of Aarhus.

[47] Valadkhani, A. and Smyth, R. (2016), "Self-exciting Effects of House Prices on Unit Prices in Australian Capital Cities," Urban Studies, forthcoming.

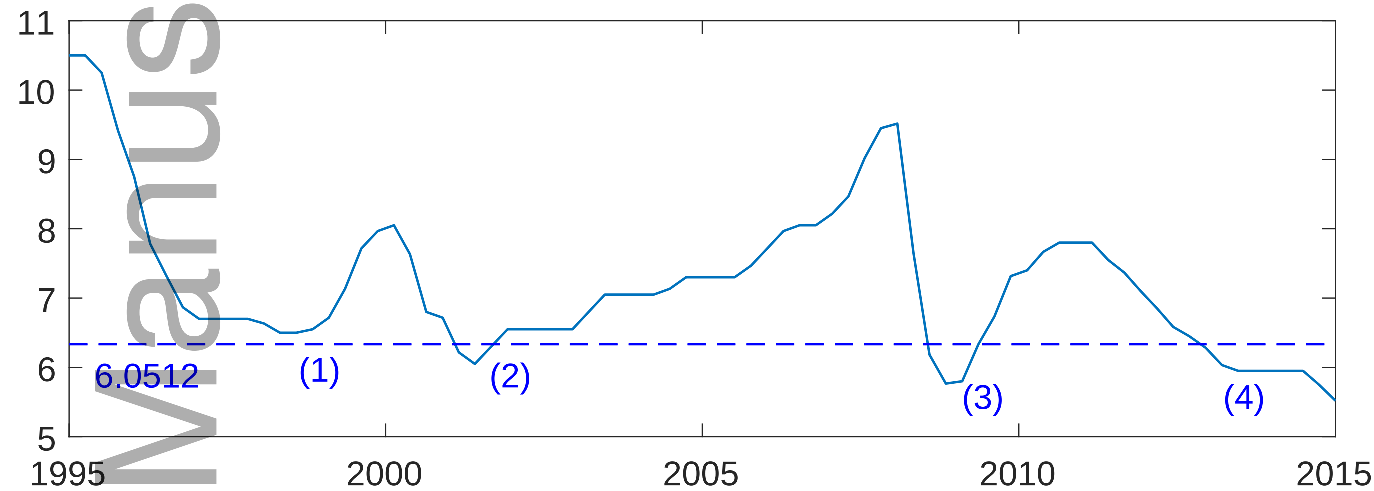
[48] Williams, J.C. (2011), "Monetary Policy and Housing Booms," International Journal of Central Banking, 7(1), 345–355.



ecor_12402_f1.eps

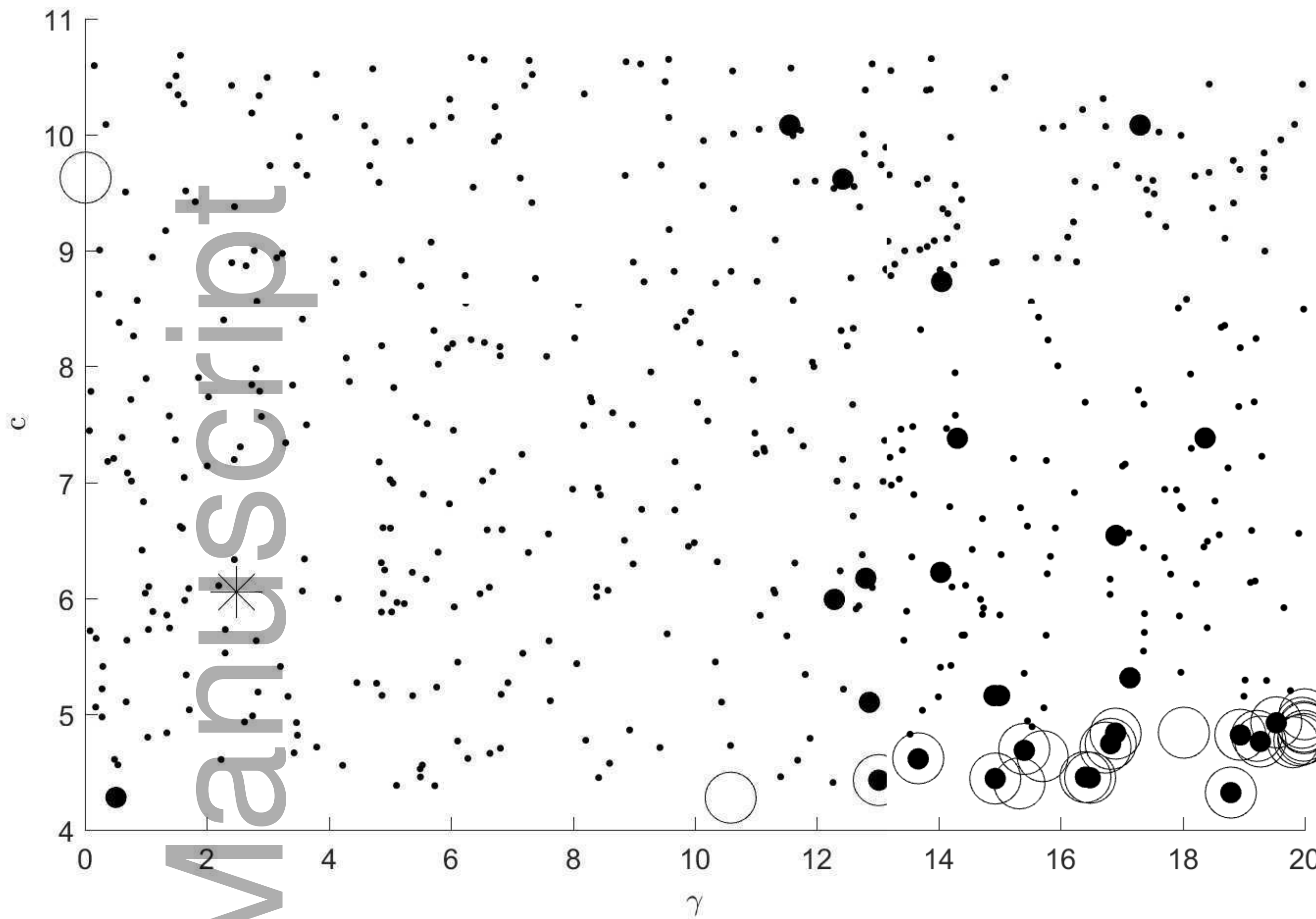


(a)



(b)

ecor_12402_f2.eps



ecor_12402_f3.eps