Received: 7 December 2020 | Revised: 10 August 2022 | Accepted: 13 August 2022
DOI: 10.1002/ijfe.2696

RESEARCH ARTICLE

WILEY

Monetary policy shock and impact asymmetry in bank lending channel: Evidence from the UK housing sector

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Abstract
Banks play a defining role in translating monetary policy shocks to pull or push-effects in the housing market. The literature is ambiguous on the exact role of bank lending channel (BLC) in translating such effects into either moderation or acceleration of dynamics in the housing market. This paper argues that monetary policy shocks, of the same magnitude, can have asymmetric implications for a housing market via a state dependent BLC, particularly during expansion and recessionary phases of the business cycle. We test this hypothesis for the UK housing sector using a long quarterly data (1973Q1-2015Q4) and employing Markov Switching Vector Auto Regression (MSVAR) models. Our results show that the magnitude of the bank lending channel is contingent upon the state of the economy, with a one standard deviation expansionary monetary policy shock producing a significant effect only in normal economic times. Further study on whether large cuts in policy rates could stimulate mortgage lending and whether there is impact asymmetry to dissimilar expansionary monetary policy shocks during financial crisis, we show that a sharp cut in policy rate indeed stimulates the BLC greater compared to smaller expansionary money policy shocks during recessions.

KEYWORDS
bank lending channel, Markov, monetary transmission, real estate economics, switching VAR

1 | INTRODUCTION

The financial innovations during the great moderation years, followed by the housing crisis in 2008, have germinated a renewed interest towards understanding the complex interplay between the real economy, the financial sector, and the housing market. During both recession and good times, monetary mechanism is often used as the main vehicle of transmission medium that translates impulses from policy into effective response of the real economy, particularly, the housing sector. Despite a robust body of work, significant ambiguity persists on the relative (in)effectiveness of policy in this sector because there is a visible mismatch of the expected heat of policy intervention with that of the actual responses (Bekiros et al., 2019; Duan et al., 2019). Duan et al. (2019) exploits spatial interdependent dynamics and show that macroeconomic policy interventions have somewhat subdued effect on housing sector when spatial contiguity with respect to knowledge spillover is accounted for. The authors claim that bank lending channel (BLC) and its structural changes over various states of intervention would have considerable effects on housing sector. Bekiros et al. (2019) employing quantile regression, examine the role of monetary policy, among other important variables, on international housing price variations. The empirically quantified effects in the extant literature, however, appear to suffer measurably from the lack of modelling and non-distinction of state-dependent variable/asymmetric responses of monetary policy shocks on the housing prices. This paper aims to fill the gap in the literature in this direction.

Conditioning impulse-responses of a monetary policy shock to the state-specific BLC is important because a shift in the state of an economic system conserves bounded dynamics following measured changes in macroeconomic indicators, for instance. Each state is identified with a specific data generation mechanism and an elevation of a system to the next level or some regressive changes within can depict varied effects of a specific policy, such as monetary policy on a housing market. When channelized via BLC, the translated effects of the same policy with similar magnitudes may exhibit heterogeneous magnitudes of responses. If impact heterogeneity is disregarded in favour of a uniform pattern of effects, an under- or over-estimation bias may influence our inferences of the impact of a monetary policy shock on housing market via a BLC. This paper examines this state-dependent nature of BLC while channelizing the impact of monetary policy to desired effectiveness in housing market responses.

Our empirical context is the United Kingdom (UK), where housing sector is an integral component of the economy. The volatile nature of the housing sector makes it a crucial contributor to the UK business cycle fluctuations.[1] Extensive work has been carried out underpinning the theoretical and empirical linkage between monetary transmission mechanism and house prices fluctuations, asserting the role of both non-neoclassical and traditional neoclassical channel (see for instance, MacLennan et al., 1998). Among these the BLC, given its strong presence both at the source (at depository institutions) and at the destination level (households), is thought to play a vital role in the UK housing market (see Iacoviello & Minetti, 2008 for further details).

Considering this and in view of the observed sharp appreciation of UK house prices during the great moderation years followed by contraction throughout the recession[2] motivates us to examine whether the BLC is state-dependent in the UK housing sector. Furthermore, compared to previous recessions, during the 2008–2010, the BoE reduced policy rates sharply and hence giving us the impetus to examine whether mortgage supply is amplified by large expansionary monetary policy shocks during periods of economic uncertainty. Therefore, this paper addresses two non-linearity. First, quantifying, and distinguishing similar size expansionary monetary policy shock on the BLC during expansion and recessionary phases of the UK business cycle. And second, response of mortgage loan supply is examined to various degrees of expansionary monetary policy shocks during the 2008–2010 recessionary period.

Early empirical work on the BLC such as the one conducted by Bernanke and Blinder (1988) suffer from simultaneity problem, which are unable to identify the balance sheet channel (BSC) from the BLC and opt for a broad credit channel. The credit channel is the amalgamation of the BLC and the BSC (see more in Mishkin, 1995). To mitigate the identification problem, later work have relied on two separate methodologies. The first strand uses aggregate time series data and employ a *mix* variable, a ratio of bank credit to the sum of bank and non-bank credit in VAR/VECM setting to identify loan supply changes arising from monetary policy shocks. The significant response of the *mix* to monetary policy change indicates an operational BLC (Kashyap & Stein, 1995). Employing this methodology, Iacoviello and Minette (2008) and Halvorsen and Jacobsen (2016) find an operational BLC in the United Kingdom. The second strand of empirical work on BLC utilizes bank specific cross-sectional heterogeneities (such as size, capitalization, liquidity and securitization activity) to capture loan supply shifts arising from monetary policy changes.[3] There are two major drawbacks of using bank level microeconomic data: first, they do not ascertain whether the shifts in loan supply affects aggregate economic activity and second, as Generalized Method of Moments (GMM) estimators are mainly employed, biased results are produced when there are unaccounted structural breaks in the data (Chowdhury & Russell, 2018).

The explicit recognition of the impact of non-linear behaviour of economic agents on the macro economy were formally incorporated in theoretical models proposed by Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). By incorporating agency costs, these models demonstrate when information asymmetry is high in financial markets agents behave as if they are financially constrained, a situation which is likely to be binding in recessions rather than in expansionary phases. As financial friction varies over the business cycles, it is typical to expect channels of monetary transmission mechanism that are based on asymmetric information, such as the credit channel to also fluctuate over the business cycle.

Although substantial amount of work has examined the impact of monetary policy on output over the business cycle, research examining a specific monetary transmission channel is sparse (for further work, see Zheng, 2013; Chen, 2007). In the BLC literature most research assume the magnitude of the channel is identical over the business cycle and employ linear framework. Additionally, studies that look at this nonlinearity (e.g., Salachas et al., 2017) use bank level data and hence are fraught with the above-mentioned problems of the second strand. Furthermore, these studies classify recession dates exogenously, which may not be efficient when compared to endogenous procedures. Also, due to the unavailability of historical bank level data they only focus on recent episodes.

By utilizing a *mix* variable from the first strand, our work identifies and concurrently compares the magnitude of the BLC in the UK housing market to analogous expansionary monetary policy shocks, during boom and recessionary periods, over the period of 1973 quarter 1 to 2015 quarter 4. The work is carried out exploits MSVAR model and regime dependent impulse response functions (IRF) to help us understand asymmetric effects of shocks. The benefit of using MSVAR is that, if modelled accurately, the latent Markov process is able to identify the UK business cycle endogenously. Our results indicate that the magnitude of the BLC is dependent on the state of the economy; a one standard deviation expansionary monetary policy shock produces a significant BLC only in normal economic times. Given this finding and the fact that major central banks including the BoE reduced policy rates sharply in the 2008–2010 crisis (relative to previous recessions), persuades us to examine whether larger cuts in policy rates stimulated mortgage lending and by doing so the impact of dissimilar expansionary monetary policy shocks on mortgage lending during crisis period is explored. Results from this part suggest sharp cuts in policy rate do indeed stimulate the BLC more compared to smaller expansionary money policy shocks during recessions.

The rest of the paper is organized as follows. An overview and factors that create impact asymmetry in the magnitude of the BLC over the business cycle is discussed in Section 2, followed by the associated econometric methodology and data characteristics in Section 3. Section 4 presents the main results and the robustness tests. In Section 5, a small experiment is undertaken to examine the response of mortgage supply by depository institutions to dissimilar expansionary monetary policy shocks. Finally, Section 6 concludes with the main implications.

2 | BANK LENDING CHANNEL AND BUSINESS CYCLE

Bernanke and Blinder (1988) illustrate changes in monetary policy affect banks' reserves and insured deposits, thus impacting banks' ability to generate loan, which finally affects economic activity. This proposition is based on two assumptions; first, banks' deposits and non-reservable liabilities are imperfect substitutes and second, bank loans and internal sources of funds are imperfect substitutes for firms. With the advent of wholesale funding, dependence on retail deposits has become less in the banking sector, thus making the Bernanke and Blinder (1988) view obsolete to a great extent (e.g., Halvorsen & Jacobsen, 2016). Disyatat (2011), reformulates the Bernanke and Blinder (1988) view by emphasizing the greater dependence of market-based funding and contends that BLC operates through the impact of monetary policy on banks' external finance premium which is determined by its balance sheet strength and risk perception. Besides demand, supply of bank loans is influenced by funding conditions in the market. The impact of monetary policy changes is then transmitted through changes in required rate of returns rather than changes in quantity of deposits. Thus, according to the two views a contraction in monetary policy can lead either to a decrease in quantity of liquidity or a disproportionate rise in the price of liquidity. If banks cannot compensate this reduction in balance sheet strength by changing the composition of their portfolio or by increasing debt, they ultimately reduce loan supply.

The existence of the BLC depends on the assumption that asymmetric information exists between borrowers and lenders, is reflected in banks external finance premium. With asymmetric information varying over the business cycle, it becomes imperative external premium will vary also, increasing during periods of financial stress and less during expansion. During recession in the presence of additional funding cost an expansionary monetary policy becomes less effective in generating liquidity and loans compared to similar sized shock in expansion. With more dependence on market-based funding banks have become prone to market perceptions and the business cycle, hence contributing further towards making the magnitude of the BLC asymmetric over the business cycle. To identify why magnitude of the BLC may vary over the business cycle we focus on three factors: (1) bank capital, (2) market funding and securitization, and (3) the link between monetary policy and risk taking.

Compared to other form of funds bank capital is more expensive. Furthermore, due to imperfect equity markets, banks cannot easily issue new equity, especially in recessions due to high agency costs and adverse selection problem. Empirical work by Kishan and Opiela (2000) and Altunbus et al. (2009) illustrate bank capital become a crucial driver of banks' incentive structure during recessions, as in such periods increasing capital becomes expensive and hence unfeasible. During recession, confronted with an excessive cost of issuing new capital and faced with fulfilling a minimum capital requirement, banks tend to issue less loans compared to expansions when the cost is less. As a result of this excessive cost of capital, an expansionary monetary policy becomes less effective in increasing loan supply during recession compared to a similar size shock during normal period.

Innovations in securitization process, traditionally covered bond markets and in non-interest earning activity have not only provided banks with additional market-based funding but also significantly reduced dependence on retail deposits. However, these funding sources depend on the state of the economy. Estrella (2002) illustrates securitization have pro-cyclical effects on loan supply. During periods of expansion when asset prices are high securitization works smoothly, providing banks with liquid funds. During expansions asset prices tend to be high and an expansionary monetary policy during this period further increases asset prices, facilitating securitization activity and amplifying liquidity generation, hence magnifying the BLC (Loutskina, 2011). On the contrary, during recession with low-house prices and due to presence of loss aversion behaviour, expansionary monetary policy becomes ineffective in increasing market activity, and house price (Tsai, 2013). As a result, securitization process stagnates, curtailing banks from liquid funds. Gambacorta and Marques (2011) illustrate, banks that are more dependent on securitization are most affected and reduce loan supply more during crisis periods (even in the presence of expansionary policy). Furthermore, in times of recession as asset prices fall bank balance sheet become weak leading to a decrease in their net worth. The impact of lower net worth increases asymmetric information & moral hazard problem in the wholesale funds market. Consequently, in such states the effectiveness of expansionary monetary policy in reducing external finance premium becomes less, compared to a similar sized monetary shock in normal times, when banks' balance sheets are in better shape.

BLC can also be influenced by the impact of monetary policy on banks' perception of risk/or willingness to bear risk (Adrian & Shin, 2009; Borio & Zhu, 2008). In expansions if monetary policy is kept low for long periods, bank's perception and attitude towards risk changes; primarily due to fact that low interest rate scenarios reduce borrowers default probability which in turn increases bank's cash flow, profits, and hence strengthens bank's net worth. This consequently diminishes asymmetric information problem between investors and the bank, resulting in reduced funding cost and enhancing the BLC. Rao and Mishra (2020) argue for an asymmetric effects in this situation. However, during recessions increased default frequency among borrowers tend to reduce bank's net worth and increase bank's risk perception (see Gambacorta, 2009). Given the heightened risk perception a similar magnitude expansionary monetary policy is expected to be less effective in increasing loan supply during this period, thus resulting in a weak BLC.

3 | METHODOLOGY AND ESTIMATION

3.1 | Methodological setting

This section discusses the associated econometric methodology needed to examine the magnitude of the BLC at different stages of the UK business cycle. To apprehend the impact of the BLC over the business cycle we face two main difficulties; first, to separate the BLC from the other monetary transmission mechanism channels and second, to use an appropriate econometric methodology to capture the non-linear effects over the business cycle. The first problem is confronted by using a methodology analogous to Iacoviello and Minetti (2008) where a 'mix' variable is used in a succession of simultaneous equation frameworks, is explained in Section 3.1.2. We confront the second problem by using MSVARs in combination with regime dependent IRFs proposed by Ehrmann et al. (2003) which allows us to capture and examine the state dependence of the BLC during expansion and recessions, is explained in Section 3.1.1.[4]

3.1.1 | MSVAR, identification and regime dependent IRF

MSVAR

While it is atypical to use Markov Switching models in the BLC literature, the MSVAR has a great advantage over other non-linear econometric framework, in terms of the switching of all components (viz., intercept, variance and the coefficients). This way, the MSVAR allows one to capture complex dynamic patterns within the data, such as business cycles. Accordingly, we use MSVARs proposed by Krolzig (1997), which is a multivariate generalization of Hamilton's (1989) work:

$$X_t = \begin{cases} \mu_1 + B_{11}X_{t-1} + \dots + B_{p1}X_{t-p} + A_1\varepsilon_t, \mathit{if}\ S_t = 1 \\ \mu_2 + B_{22}X_{t-1} + \dots + B_{p1}X_{t-p} + A_2\varepsilon_t, \mathit{if}\ S_t = 2 \end{cases}, \varepsilon_t \sim N(0; I_K) \tag{1}$$

where X_t is the set of endogenous variables, ε_t is a K dimensional vector of fundamental residuals with the latter being uncorrelated at all leads and lags.

The variance of each fundamental disturbance is normalized to unity. Each fundamental disturbance is premultiplied by a switching matrix A_i. Equation (2) illustrates the regime dependent variance–covariance matrix, $\sum_i$ of the residuals, $A_i\epsilon_t$ will also be regime dependent:

$$\sum\nolimits_i = E\left(A_i\epsilon_t\epsilon_t' A_i'\right) = A_i E\left(\epsilon_t\epsilon_t'\right)A_i' = A_i I_K A_i' = A_i A_i' \quad (2)$$

In Equation (1) the latent variable, S_t indicates either expansionary or recessionary regime. S_t, is governed by a discrete state of a Markov stochastic process, which is defined by the following transition probabilities:

$$p_{ij} = \Pr(s_{t+1} = j | s_t = i)\ \widehat{P} = \begin{vmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{vmatrix}$$

where transition probability, P_{ij} states, the probability of state '*i*' at period t will be followed by state '*j*' at period $t+1$. Estimation of the model is carried out using Expectation–Maximization (EM) algorithm.

A typical characteristic of MSVAR is the way nonlinearity is naturally embedded within the model setting. A switch (typically in the slope) introduces non-linear interdependence within the system. Terasvirta and Anderson (1992) for instance use smoothed transition autoregressive (STAR) model whereas latter research has used self-exciting STAR (SETAR) model to embed features of nonlinearity. MSVAR is another mechanism where a switch in the mean, variance, intercept, and slope typically introduces nonlinearity in the relationship within the VAR systems (lags of all variables). One simple example is that if we have a slope, say *S1* in regime 1 and a slope, *S2* in regime 2, the change in the slope from *S1* to *S2* introduces changes in the response mechanism (the rate of change of the curvature). The regime dependent effects thus become naturally non-linear in character. Of course, regime dependency is not the only mechanism to generate non-linearity (an example we have provided is Terasvirta & Anderson, 1992).

Identification

A key challenge in any VAR is to identify the shocks. Here the challenge extends to identification of the relationship between the fundamental shocks and endogenous variables within each regime. The EM algorithm does not provide estimates of matrix A_1 and A_2.To identify these matrices restrictions are imposed on the estimated unrestricted model parameters. For each A_i to be identified K^2 restrictions are imposed. From equation (2) the identity $A_i A_i' = \Sigma_i$ inherently imposes $K(K+1)/2$, due to the symmetry of the variance–covariance matrix Σ_i. The remaining $K(K-1)/2$ restrictions are imposed following a recursive identification scheme. Under this identification scheme the matrix A_i is lower triangular and exactly identified, is recovered from a Choleski decomposition of the matrix $\Sigma_{i.}$

Regime dependent IRF

Regime-dependent IRFs depict the relationship between the endogenous variables and fundamental disturbances within a regime, which is a convenient way to track down the magnitude and the persistence of each variable's response to a shock over time. Regime dependent IRFs are conditional on a given regime prevailing at the time of the disturbance and throughout the duration of the response. According to the model presented by equation (1) there are $2K^2$ regime dependent IRFs, corresponding to the reaction of K variables to K disturbances in two regimes. Equation (3) provides the mathematical definition of the response of regime-dependent impulse. It traces the expected path of endogenous variables at time $t+h$ following a one standard deviation shock to the k-th initial disturbance at time t, conditional on regime i.

$$\theta_{k,i,h} = \left.\frac{\partial E_t X_{t+h}}{\partial \epsilon_{k,t}}\right|_{S_t = S_{t+h=i}} \mathit{for}\ h \geq 0 \quad (3)$$

Estimates of the response vectors are derived by combining the parameters from the unrestricted MSVAR with the estimates of the matrix $\widehat{A}_i$. The first response vector measures the impact effect on endogenous variables of the k-th fundamental disturbance. A one standard deviation shock to the k-th fundamental disturbance implies that the initial disturbance vector is $\varepsilon_0 = (0,..,0,1,0...0)$, that is, a vector of zeros except for k-th fundamental disturbance which is one. Multiplying this vector by the regime dependent matrix $\widehat{A}_i$ provides the impact responses. By solving forward for the endogenous variables in Equation (1) the remaining response vectors are obtained. Equations (4) and (5) illustrate connecting the estimated vectors with the estimated parameters $\widehat{A}$.

$$\widehat{\theta}_{k,i,0} = \widehat{A}_i \varepsilon_0 \quad (4)$$

$$\widehat{\theta}_{k,i,h} = \sum_{j=1}^{\min(h,p)} \widehat{\theta}_{ji}^{h-j+1} \widehat{A}_i \varepsilon_0 \quad (5)$$

The confidence bands of the impulse response functions are obtained by Markov Chain Monte Carlo (MCMC) simulation with Gibbs sampling of 5000 draws with a burn-in of 2000.

TABLE 1 Summary of the MSVARs

	Objectives	Shocks	Ordering of variable
First MSVAR	Overall impact of monetary policy	Expansionary monetary policy shock	Inflation, Δgdp, ΔUK policy rate, Δhouse prices, Δtotal mortgage loans
Second MSVAR	Credit Channel (BLC + BSC)	Expansionary monetary policy shock	Inflation, Δgdp, ΔUK policy rate, Δhouse prices, Δmortgage spread
Third MSVAR	Bank liquidity cost	Expansionary monetary policy shock	Inflation, Δgdp, ΔUK policy rate, Δhouse prices, Δmoney market spread
Fourth MSVAR	BLC (Step1)	Expansionary monetary policy shock	Inflation, Δgdp, ΔUK policy rate, Δhouse prices, mix
Fifth MSVAR	BLC (Step 2)	Positive Mix shock (Exogenous credit shock) (sshpshock)	Inflation, Δgdp, Δhouse prices, mix

Note: Ordering of the variables is done following Milcheva (2013) and Musso et al. (2011). Alternative ordering is also used (and we have not observed any substantial change in the IRFs).
Abbreviations: BLC, bank lending channel; BSC, balance sheet channel.

3.1.2 | Identification of the BLC

Monetary shocks tend to have simultaneous effects on loan supply and loan demand, creating a simultaneity problem. To isolate loan supply from loan demand shocks we use the '*mix*' variable which is the ratio between mortgage holding by depository institutions and the sum of mortgage holding by depository institutions and market-based financial intermediaries.[5] Given the assumption that managed liabilities are imperfect substitute of retail deposits, a contractionary monetary policy tend to reduce depository institutions mortgage lending. If the decline in mortgage supply is not compensated by alternative sources of funding then the '*mix*' variable will decrease, hence advocating an effective BLC.[6] One of the benefits of using the '*mix*' is that it remains unaltered by mortgage demand shocks since such shocks typically effect both depository and non-depository market based institutions in the same magnitude.[7] In Iacoviello and Minetti (2008) the *mix* is used in a succession of linear VAR's first to see the overall impact of monetary policy, then identify the credit channel and finally disentangle the credit channel; separate the BLC from the BSC. Instead of linear VARs we employ MSVARs and regime dependent IRFs as our objective is to identify the magnitude of the BLC during expansion and recessions. Recursive identification scheme analogous to Milcheva (2013) and Musso et al. (2011) are employed in the MSVARs (see Table 1). For robustness alternate ordering has also been used. Furthermore, special attention is provided to monetary policy shocks on output and inflation responses. The MSVARs that we estimate are as follow.

First MSVAR

The first MSVAR includes Δ*gdp*, *inflation*, Δ*total mortgage loans*, Δ*house prices* and Δ*UK policy rate*. As changes in total mortgage after a monetary policy change can be explained either by Keynesian interest rate channel, credit channel or by both, this MSVAR is uninformative in identifying the credit channel or the BLC. Nevertheless, this model enables one to capture the overall nonlinear effects of monetary policy on house prices, GDP and mortgages during expansion and recessions.

Second MSVAR

The second MSVAR includes Δ*gdp*, *inflation*, *mortgage spread*, Δ*house price index* and *the* Δ*UK policy rate*. A rise (*decrease*) in mortgage spread after a contractionary (*expansionary*) monetary policy can capture the increase (*decrease*) in the external finance premium which is associated with the credit channel. However, due to lack of detailed data on the mortgage rates, charged by different type of lenders prevents us from further using the model to disentangle the BLC from the BSC. Therefore, the model enables, only to identify the magnitude of the credit channel during boom and recession.

Third MSVAR

The third MSVAR incorporating Δ*gdp*, *inflation*, Δ*money market spread*, Δ*house prices index* and Δ*UK policy rate* illustrate how banks' funding costs respond to monetary policy changes during recession and expansions. A significant rise (*decrease*) in money market spread after an increase (*decrease*) in short term policy rate can capture the change in banks' external finance premium, can be

TABLE 2 Hansen stability test

	Δgdp	*ΔHouse price*	*Δtbill*	*mix*	*inf*	*mortgage spread*	*Wholesale spread*
Joint	2.112***	1.462***	3.045***	1.451***	12.71***	3.646***	1.524***
Variance	0.700**	0.160	2.957***	0.563**	3.35***	1.532***	0.898*
Mean	1.219***	1.318***	0.059	0.876***	9.98***	2.367***	0.4129*

Note: ***, **, * represents significance at 1%, 5% and at 10% level, respectively.

viewed as the new BLC theory, proposed by Disyatat (2011).[8]

Fourth MSVAR

The fourth MSVAR includes, Δ*gdp*, *inflation*, Δ*house prices*, Δ*UK policy rate* and the *mix*. If the BLC is operational, then after a contractionary (*expansionary*) monetary policy there will be a significant decrease (*increase*) in the *mix* and by comparing the response of the *mix* during boom and recession one can validate the magnitude of the BLC in the two regimes. Nonetheless, one might argue even if there is a significant decrease (*increase)* in the *mix* after a contractionary (*expansionary)* monetary policy, then that only demonstrates a relative change in the mortgages provided by depository institutions over non-depository ones. Henceforth, to accentuate the effect of a significant change in the *mix* on housing demand the analysis entail two steps; first, to analyse whether monetary policy affects the *mix* (fourth MSVAR) and if so then analyse whether changes in the *mix* affect house prices (fifth MSVAR).

Fifth MSVAR

If monetary policy has significant effect on the *mix*, we run the fifth MSVAR which includes, Δ*gdp*, *inflation*, Δ*house prices* and *the mix*. This model examines the effects of an exogenous increase in *mix* (external finance shock) on house prices, during boom and recessions. If the *mix* has any explanatory power on house price in a reduced form regression containing Δ*gdp* and inflation, its incremental explanatory power underpins the existence of an independent BLC.[9]

3.2 | Data characteristics and empirical analyses

Our data are quarterly and cover the period: 1973q4–2015q4.[10] Hansen (1992) stability test reported in Table 2 shows variables have breaks in the mean, variance or in both components jointly, hence validating our rational of using a MSIAH-VAR type of MSVAR. Note that in a MSAIH-VAR the intercepts, mean, autoregressive parameters and the variances switch. Linearity tests represented in Table 3 further illustrates linear VARs are rejected in favour of the MSIAH-VARs in all five models.

TABLE 3 Linearity test

Model	LR linearity test	Davis approximate upper bound
1st MSVAR	$\chi^2(47) = 4018.7$ [0.000]***	[0.000]***
2nd MSVAR	$\chi^2(47) = 2610.4$ [0.000]***	[0.000]***
3rd MSVAR	$\chi^2(47) = 2655.4$ [0.000]***	[0.000]***
4th MSVAR	$\chi^2(47) = 2198.2$ [0.000]***	[0.000]***
5th MSVAR	$\chi^2(32) = 1916.5$[0.000]***	[0.000]***

Note: ***, **, * represents significance at 1%, 5% and at 10% level, respectively.

Figure 1 represents the smoothed transition probability of regime 1 obtained from the MSIAH-VARs. The transition probability of the models tend to exhibit high similarities. They all tend to capture the late 70s and early 80s recession, Lawson boom and the volatile period during the ERM crisis. More recent events such as the 2008 financial crisis and the great moderation era are also well captured. Observing the transition probabilities, it is evident regime 1 represents expansionary phase of the UK business cycle in all models. Table 4 represents the transition probability and average duration of the regimes, illustrating average duration of the expansionary phase (regime 1) is about 9.5–11 years which is comparable to the recent findings by Drehmann et al. (2012).

4 | EMPIRICAL RESULTS AND DISCUSSIONS

4.1 | Main results

We discuss in some details the main results with respect to estimation of various stages of MSVAR (first to fifth). Figure 2a–e summarizes these results.

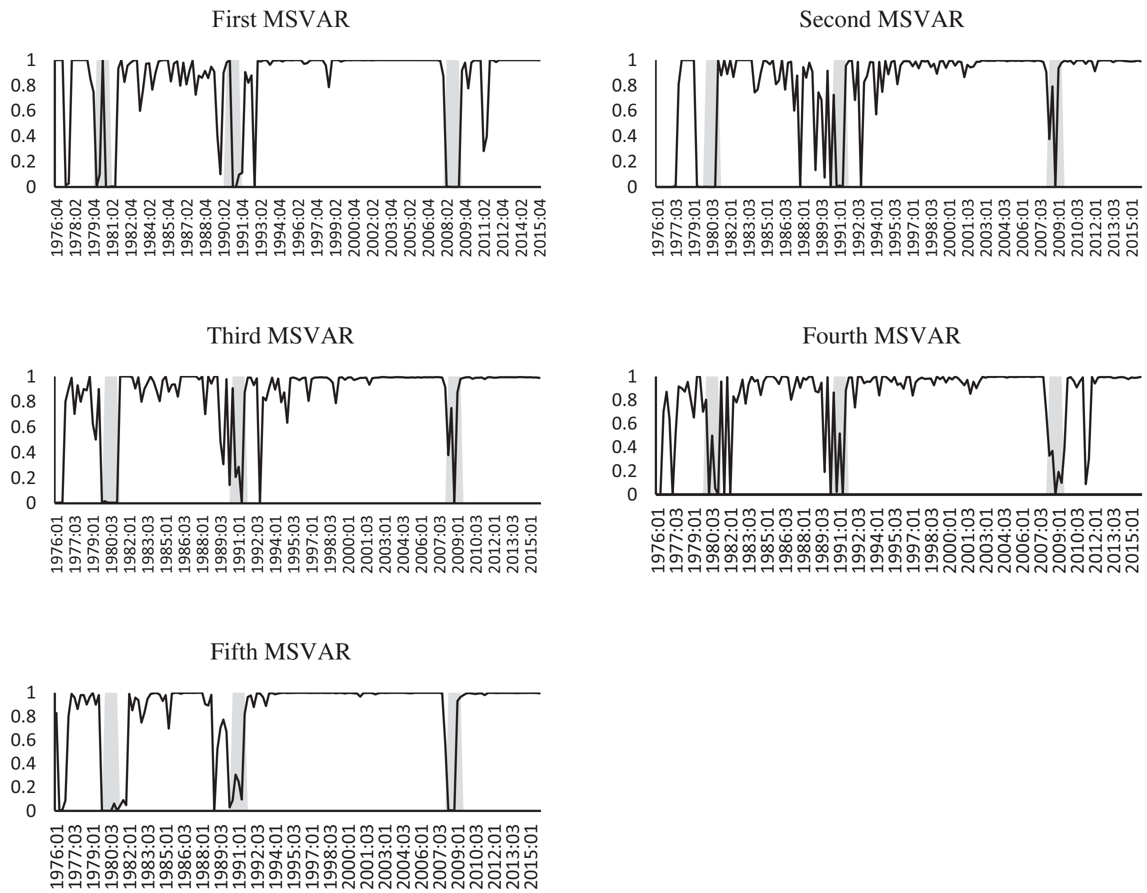

FIGURE 1 Smooth transition probability (Regime1). Shaded area represents recessionary periods

TABLE 4 Transition probabilities

	Transition probabilities		
Model	***P*(1|1)**	***P*(1|2)**	**Duration of regime 1**
1st MSVAR	0.975	0.025	40
2nd MSVAR	0.974	0.025	38.5
3rd MSVAR	0.977	0.022	43.5
4th MSVAR	0.976	0.023	43.5
5th MSVAR	0.974	0.026	38.5

Note: $P(1|1)$ is the probability of staying in regime 1. $P(1|2)$ is the probability of moving to regime.

4.1.1 | First MSVAR

Regime dependent IRFs from model one is reported in Figure 2a. It describes the magnitude of an expansionary monetary policy shock on Δ*house price*, Δ*gdp* and on Δ*mortgage credit*, showing the impact magnitudes are larger and more persistent during expansion than compared to a similar magnitude shock during recessions. Although, unable to separately identify the transmission channels, the impulse responses from the model clearly exhibit the state dependent nature of the expansionary monetary policy shock over the business cycle. Relatively lesser impact of expansionary monetary policy during recessions can be contributed to higher level of financial friction, uncertainty and binding financial constraints caused by lower net worth (both borrowers and lenders).[11] Recent studies have used loss aversion theory to explain the reduced effectiveness of monetary policy during recessions.[12]

4.1.2 | Second MSVAR

Regime dependent IRFs from the second MSVAR presented in Figure 2b illustrates after an expansionary monetary policy shock the increase in Δ*gdp* and Δ*house price*

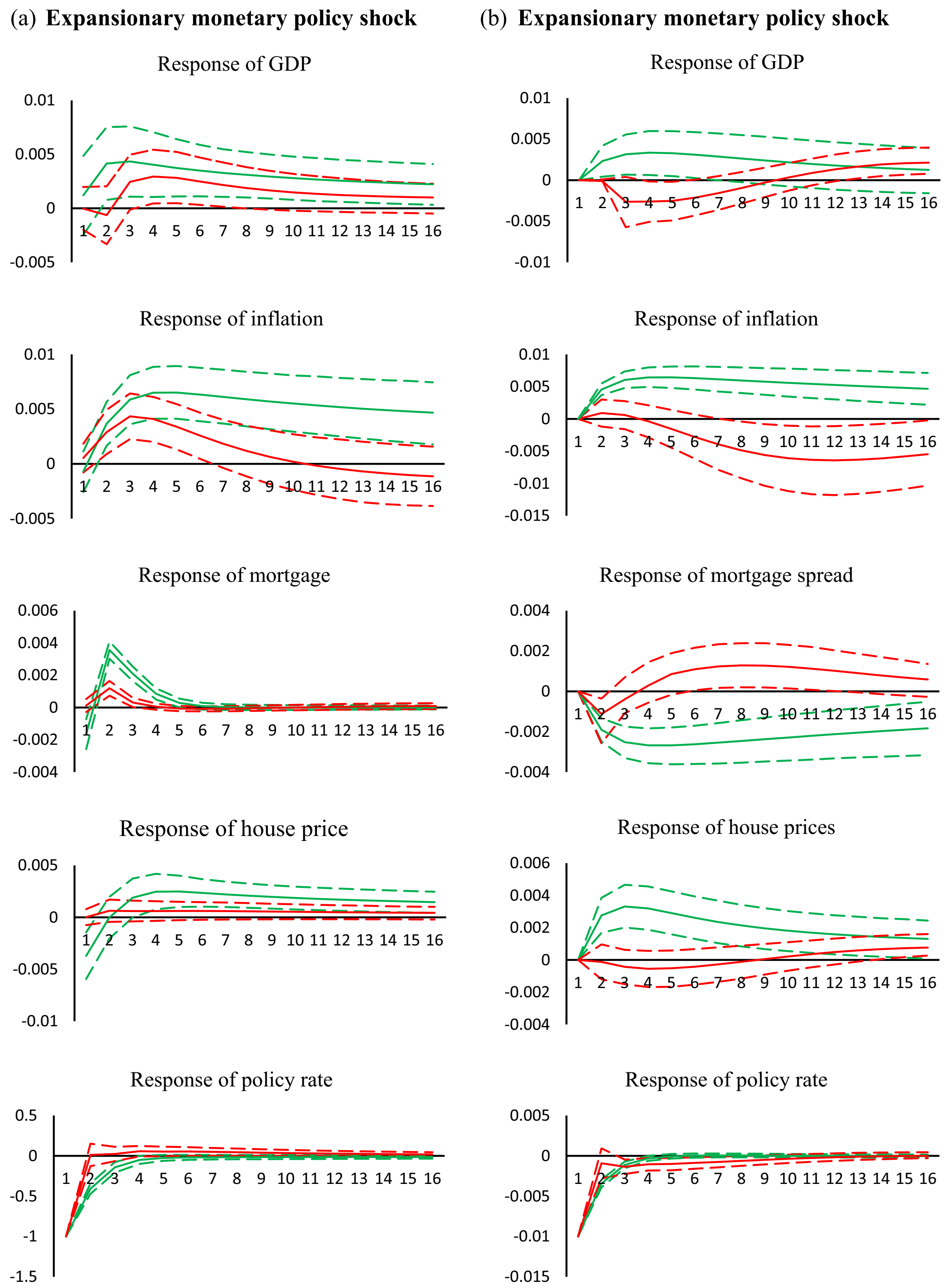

FIGURE 2 (a) First MSVAR. (b) Second MSVAR. (c) Third MSVAR. (d) Fourth MSVAR. (e) Fifth MSVAR. Broken red and green lines represent 95 percent confidence interval during recession and boom respectively. Unbroken red and green line represent response functions during recession and boom, respectively [Colour figure can be viewed at wileyonlinelibrary.com]

is larger and more persistent during expansionary periods, compared to a similar size shock during recession. Moreover, after a decrease in policy rate mortgage spread significantly decreases only in the expansionary phase, therefore, indicating an operational credit channel during this period. During recession asymmetric information between agents and mortgage lenders tend to rise as net worth of household and firms decline. This increases the overall external finance premium. Subject to the presence of this higher level of asymmetric information, the impact of an expansionary monetary policy shock becomes less effective in reducing

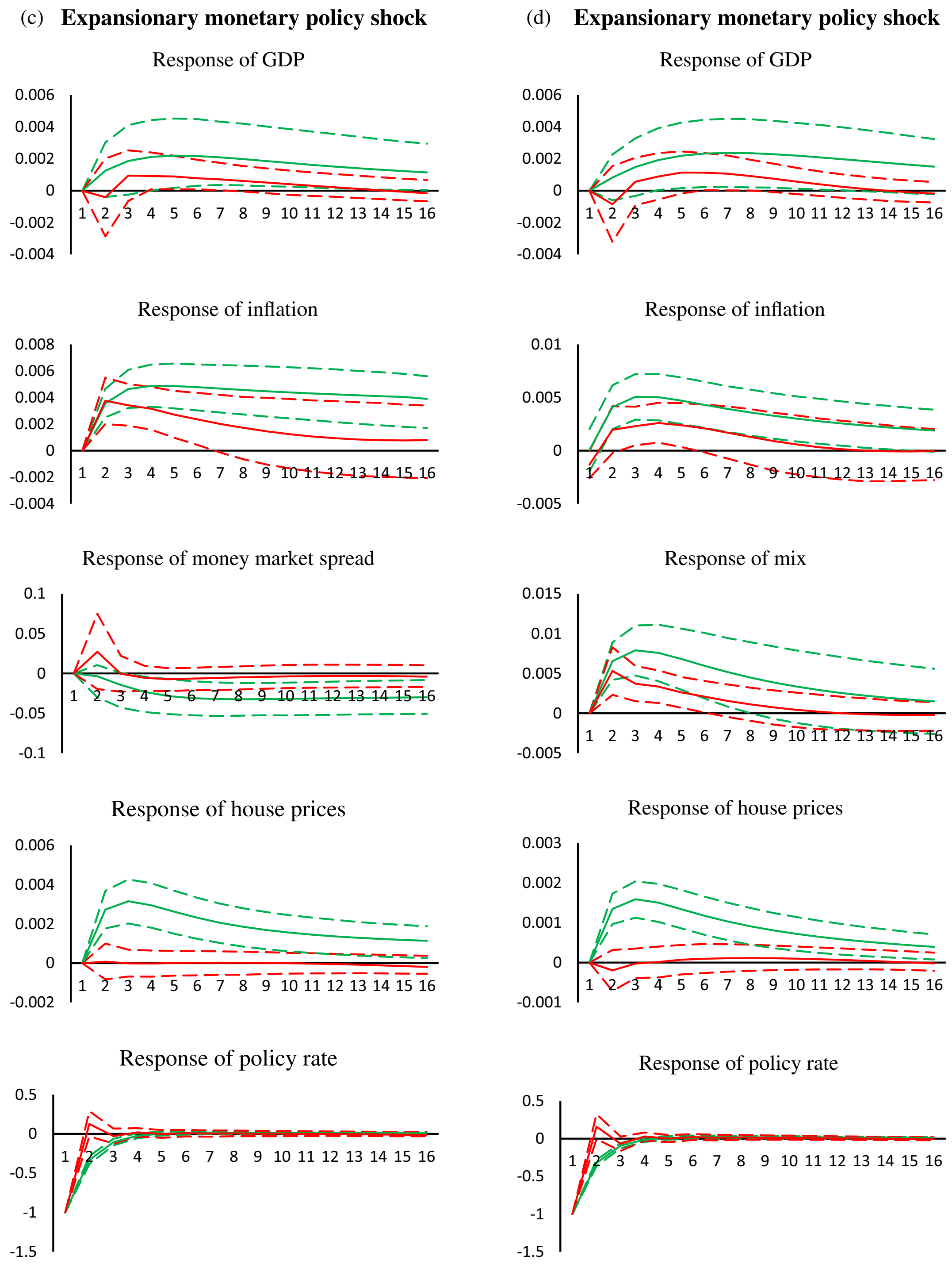

FIGURE 2 (Continued)

mortgage spread during recessions (compared to similar size shocks during expansions).

4.1.3 | Third MSVAR

Figure 2c represents regime dependent IRFs from the third MSVAR. The responses of Δ*gdp* and Δ*house price* to expansionary monetary policy shocks are analogues to the earlier models, larger and more persistent during expansions than in recessions. Inspection of monetary policy shock on the money market spread evidently illustrates that the decrease in the spread is only significant in the expansionary phase, hence, indicating a Disyatat (2011) type BLC in normal economic times. During periods of expansion mortgage default frequency is

FIGURE 2 (Continued)

typically low. An expansionary monetary policy shock during this period increases house prices and borrowers cash flow. This further reduces default probability, surges up banks' net worth and subsequently assists in reducing asymmetric information in the money market. Therefore, resulting in external finance premium to fall significantly. On the contrary, in recession due to the higher default rates among borrowers tend to make banks' balance sheet weak. This intensifies asymmetric information problem between money market participants and raises the external finance premium. Subject to the high levels of asymmetric information an expansionary monetary policy shock of similar magnitude tends to be less effective in reducing external finance premium during this period. The findings tend to corroborate with that of Bouis et al. (2014) and Scanlon et al. (2011) who find traditional monetary policy was ineffective in reducing the money market spread during the 2008 financial crisis.

4.1.4 | Fourth MSVAR

Responses of expansionary monetary policy shocks from the fourth MSVAR are presented in Figure 2d. Like the earlier models the impact of expansionary monetary policy shock on Δgdp and $\Delta house\ price$ is larger and persistent during periods of economic expansion. Examining the response of the *mix* to expansionary monetary policy shock illustrates in both phases the response is significant. However, the magnitude of shock is much larger and more persistent during expansionary period. The significant increase of this *mix* illustrates the relative increase in the mortgage supply by depository institutions over non-depository market-based institution, after an expansionary monetary policy shock. The larger magnitude of the shock during the expansionary phase of the business cycle can be attributed to better access of liquid funds (either from retail deposits, wholesale funds or via securitization process) by the depository institutions enabling them to generate more mortgages. Given the results from the third MSVAR and our explanation in Section 3.1, a significant response of the *mix* to an expansionary monetary policy shock gives the indication of an operational BLC and initiates us to run the fifth MSVAR, which tests the explanatory power of the *mix* variable on house prices.

4.1.5 | Fifth MSVAR

The regime dependent IRFs from the fifth MSVAR presented in Figure 2e, exhibits after a one standard deviation positive *mix* shock, house prices tend to increase in both phases of the business cycle. However, the response is only significant in expansions. Thus, in our case the impulse response functions tend to support the hypothesis that subject to similar size expansionary monetary policy shocks, BLC is only effective during expansionary phase. One positive thing in the first four MSVAR is that price puzzle is not observed, suggesting monetary policy shocks have been identified accurately.[13]

Our findings of an operational BLC, effective only in expansions can be explained by certain factors. First, during expansions when financial uncertainty is low, after an expansionary monetary policy access of retail deposit increase in the banking sector facilitating mortgage supply. However, during recessions due to increased financial uncertainty depository institutions tend not to increase mortgage supply even when sufficient funds are available (Baum et al., 2013; Talavera et al., 2012). Second, pro-cyclical impact of securitization on liquidity generation tends to amplify the BLC in the presence of expansionary monetary policy during normal economic times (Altunbas et al., 2009; Loutskina, 2011). Third, IRFs from the third MSVAR illustrate among two comparable sized expansionary monetary policy shock, policy is only effective in significantly reducing money market spread in normal economic times. This enables access of cheap non-reservable labilities to depository institutions which in turn facilitates to increase mortgage supply (see Milcheva, 2013). Finally, banks' perception of risk increases during recessions compared to normal economic times. Given the higher risk perception an expansionary monetary policy becomes less effective in stimulating loan supply, hence resulting in a weaker BLC, compared to normal times when perception of risk is low.

4.2 | Robustness

We conduct two robustness tests to support our baseline findings. First, we re-estimate the model by using an alternate measure of monetary policy, viz., a shadow policy rate which takes account of both conventional and unconventional policy. The second test is undertaken to neutralize the existence of the 'flight to quality hypothesis' to further validate the existence of the BLC.

Since 2008, beside using conventional policy, the BoE has been employing unconventional policy, such as quantitative easing (QE) and forward guidance. Recent findings by Buttz et al. (2015) illustrate QE created 'flighty deposits' in the UK banking system, leading to reduced effectiveness of the BLC during the 2008–2010 crisis. Contrary to this, Bowman et al. (2011) illustrate QE increased lending in Japanese banks during 2008–2009, by improving their liquidity position. Furthermore, Salachas et al. (2017) illustrate during 2008–2010 crisis, despite traditional monetary policy being ineffective in stimulating the BLC, QE had significant impact on the BLC. Thus, the impact of QE on the BLC is time and location specific. However, rather than assessing the cumulative effect of both conventional and unconventional monetary policy the above stated studies mainly examine the impact of unconventional monetary policy on the BLC. Thus, the use of shadow policy rate not just works as a robustness test, but it allows one to examine the aggregate impact of monetary policy on the BLC. We use the shadow policy rate proposed by Wu and Xia (2016) in the methodology proposed in Section 3.

4.2.1 | Alternative measure of monetary policy

The smooth transition probabilities obtained from the MSVARs using the shadow policy, presented in

Figure 3, are analogous to the earlier models (presented in Figure 1). The regime dependent IRFs obtained from these models presented in Figure 4, are also similar in magnitude and persistence to the earlier ones (presented in Figure 2). After a one standard deviation cut in shadow policy rate response of Δgdp and Δhp are significant and larger in expansion in all the MSVARs. Also, the magnitude of the decrease in both mortgage and money market spread is more and only significant in the expansionary regime. Finally, response of the *mix* to a standard deviation cut in the shadow policy rate is larger in the expansionary phase. This validates our prior finding that after an expansionary monetary policy shock magnitude of the BLC is larger in the expansionary phase of the business cycle. The magnitude of the *mix* response to the shadow policy rate shock is very similar to that of traditional policy rate shock, thus indicating QE may not have any additional effects on the BLC.

4.2.2 | Flight to quality hypothesis

One criticism of using the *mix* variable in the BLC identification process is that some might argue it does not completely solve the endogeneity problem because a change in the *mix* can capture a change in the quality composition of borrowers (Oliner & Rudebusch, 1996). Given the traditional belief that banks specialize in funding households with relatively weaker balance sheet, a decrease in the *mix* after a contraction in monetary policy may reflect a 'flight to quality' from risky households to households with stronger balance sheet strength, thus indicating a BSC rather than a BLC. In order to test whether non-depository institutions fund less riskier households than depository ones we ran Equation (6) where we regress the number of repossessions as a fraction of total mortgages on the *mix* and on the cyclical indicators of the housing market which include Δ*house prices*, Δgdp and *inflation*.

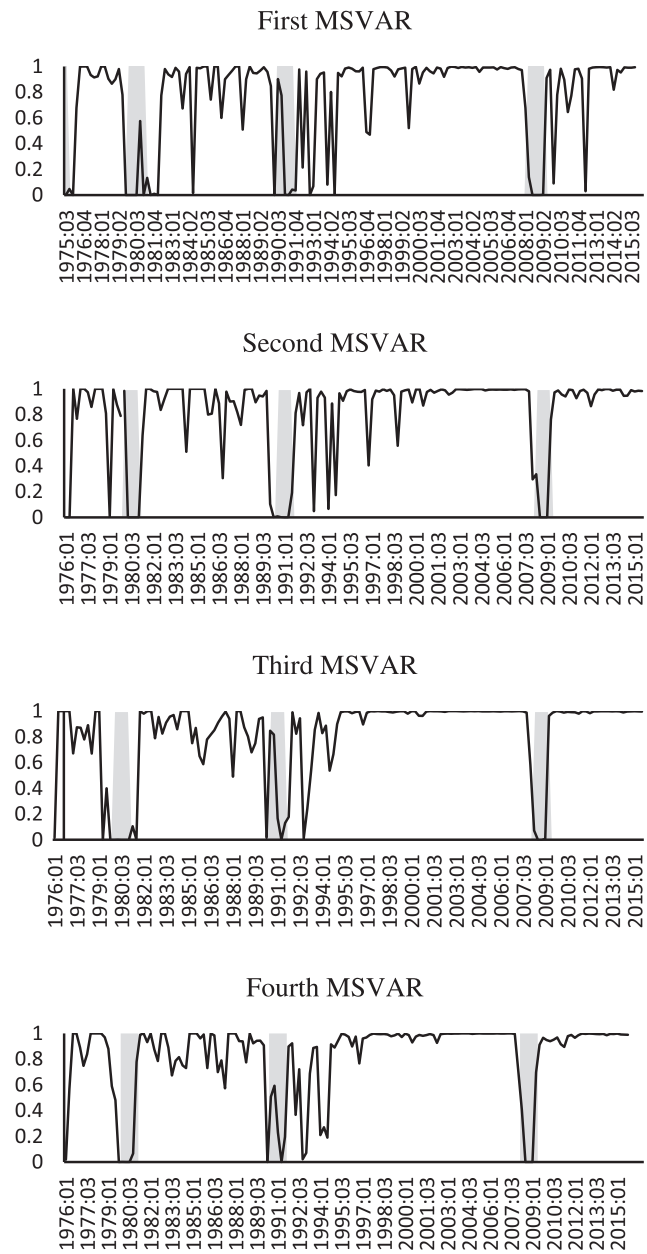

FIGURE 3 Smooth transition probability (Regime1). Models using shadow policy rate. Shaded area represents recessionary periods

$$\left(\frac{\text{rep}}{\text{tot mort}}\right)_t = \begin{cases} \mu_1 + B_{11}\, inf_{t-1} + B_{12}\Delta gdp_{t-2} + B_{13}\Delta hp_{t-2} + B_{14} mix_{t-1} + A_1\varepsilon_t, S_t = 1 \\ \mu_2 + B_{21}\, inf_{t-1} + B_{22}\Delta gdp_{t-2} + B_{23}\Delta hp_{t-2} + B_{24} mix_{t-1} + A_2\varepsilon_t, S_t = 2 \end{cases} \quad (6)$$

Under the hypothesis that non-depository institutions fund less risky assets, number of mortgage repressions and arrays as a fraction of total mortgages will fall (*increase*) if the *mix* decreases (*increase*).

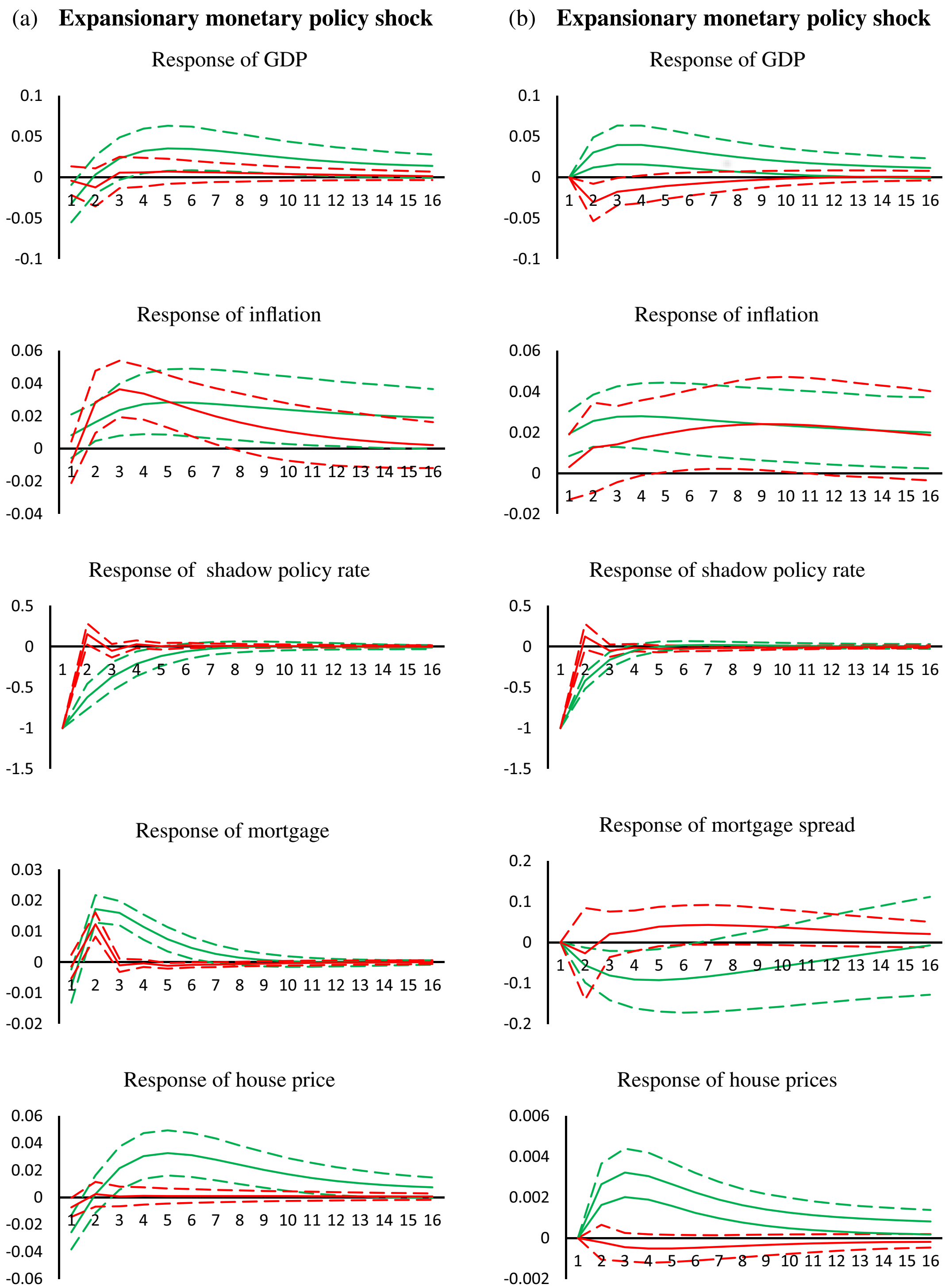

FIGURE 4 (a) First MSVAR (model with shadow policy rate). (b) Second MSVAR (model with shadow policy rate). (c) Third MSVAR (model with shadow policy rate). (d) Fourth MSVAR (model with shadow policy rate model). Broken red and green lines represent 95 percent confidence interval during recession and boom respectively. Unbroken red and green lines represent response functions during recession and boom respectively. [Colour figure can be viewed at wileyonlinelibrary.com]

Results presented in Table 5 (and Figure 5) show during expansions the *mix* is insignificant and in recessionary period it has negative sign, hence nullifying the 'flight to quality' hypothesis and strengthening our earlier finding about the operational validity of the BLC.

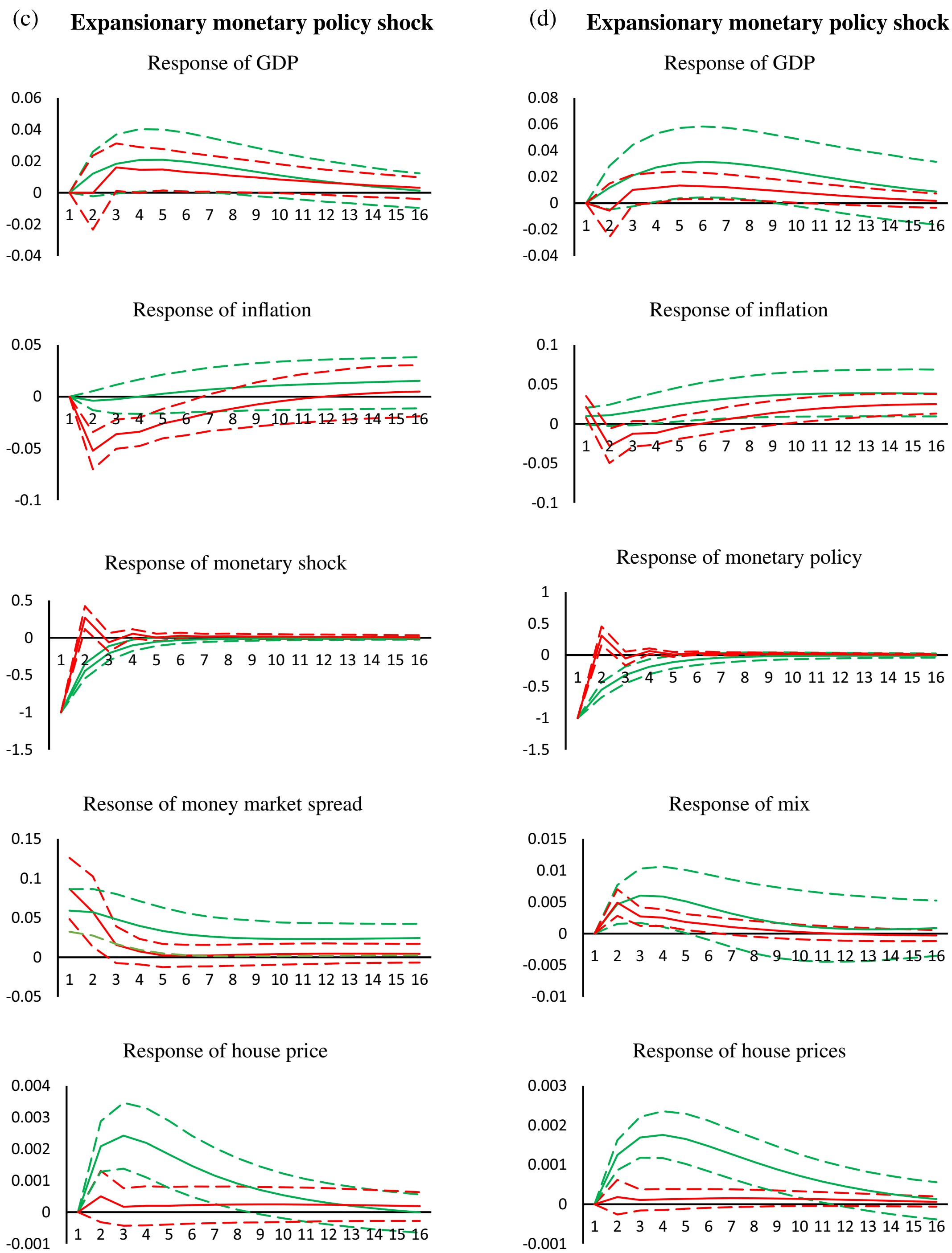

FIGURE 4 (Continued)

5 | MORTGAGE SUPPLY AND DISSIMILAR EXPANSIONARY MONETARY SHOCKS DURING RECESSION

Here we focus on nonlinearity, comparing small versus large expansionary monetary policy shocks on mortgage supply by depository institutions during periods of uncertainty. Although, studies have compared the impact of large and small expansionary monetary policy shocks on output, none have focused on the mortgage supply (see Barnichon & Matthes 2018; Zheng, 2013). Additionally, compared to earlier recessions, during the 2008–2010 crisis BoE reduced policy rate more sharply (see Figure 6), motivating us to examine whether the large cuts in policy rate amplified mortgage lending by depository institutions during this

TABLE 5 Flight to quality test

	Boom	Recession
$\frac{\text{Repossion}}{\text{Total mortgages}}$		
$inflation_{t-1}$	0.010*	0.001
$\Delta house\ price_{t-2}$	−0.092***	−0.152***
Δgdp_{t-2}	0001.	−0.01**
mix_{t-1}	0.005	−0.056**
constant	0.010	0.100**
variance	0.003	0.004
Transitory probability		
$\begin{vmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{vmatrix} = \begin{vmatrix} 0.966 & 0.031 \\ 0.033 & 0.843 \end{vmatrix}$		
Linearity test		
LR-test $\lambda^2(8) = 33.189[0.001]^{***}$, approximated uperbound : $[0.000]^{***}$		

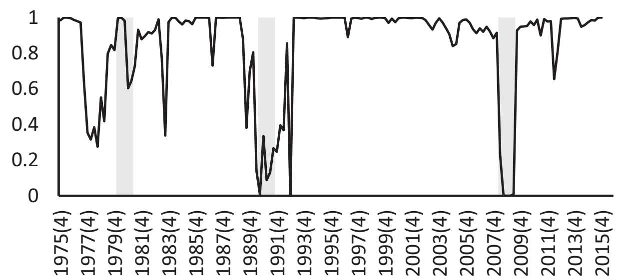

FIGURE 5 Smooth transition probability of model demonstrating "*flight to quality*" test

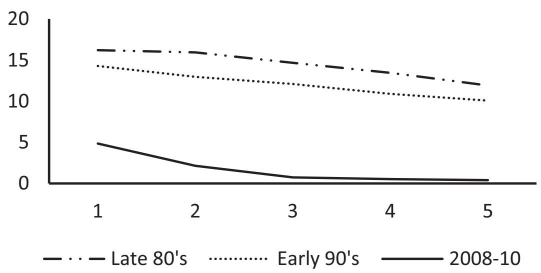

FIGURE 6 BoE policy rate during recessions

period. To properly capture the amplification of mortgage supply to expansionary monetary policy shocks we employ the methodology proposed by Kilian and Vigfusson (2011).[14] The advantage of the procedure is that it produces consistent and valid impulses response when censored variables are used to capture asymmetries in a VAR as it takes account of both the history of the series in question and the magnitude of the shocks. We estimate the following model:

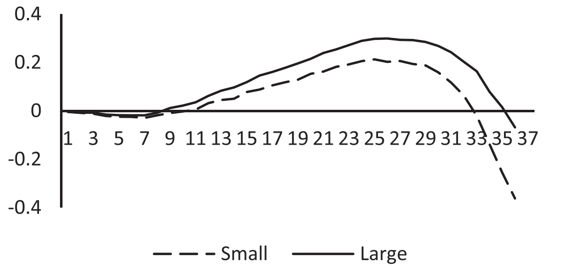

FIGURE 7 Small (−1 SD) and large (−2 SD) expansionary shocks. Broken and unbroken lines represent responses of mix from one and two standard deviation expansionary monetary shock respectively.

$$\Delta r_t = \alpha_{10} + \sum_{i=1}^{p=10} \alpha_{11,i} \Delta y_{t-i} + \sum_{i=1}^{p=10} \alpha_{12,i} \Delta r_{t-i} + \sum_{i=1}^{p=10} \alpha_{13,i}\, inf_{\,t-i} + \sum_{i=0}^{p=10} \alpha_{14,i} \Delta mix_{t-i} + \varepsilon_{1,t}$$

$$\Delta y_t = \alpha_{20} + \sum_{i=1}^{p=10} \alpha_{21,i} \Delta y_{t-i} + \sum_{i=1}^{p=10} \alpha_{22,i} \Delta r_{t-i} + \sum_{i=1}^{p=10} \alpha_{23,i}\, inf_{\,t-i} + \sum_{i=1}^{p=10} \alpha_{24,i} \Delta mix_{t-i} + \sum_{i=0}^{P=10} \alpha_{25,i} \Delta r^{\#}_{t-i} + \varepsilon_{2,t}$$

$$\Delta\, inf_{\,t} = \alpha_{30} + \sum_{i=1}^{p=10} \alpha_{31,i} \Delta y_{t-i} + \sum_{i=1}^{p=10} \alpha_{32,i} \Delta r_{t-i} + \sum_{i=1}^{p=10} \alpha_{33,i}\, inf_{\,t-i} + \sum_{i=1}^{p=10} \alpha_{34,i} \Delta mix_{t-i} + \sum_{i=0}^{P=10} \alpha_{35,i} \Delta r^{\#}_{t-i} + \varepsilon_{3,t}$$

$$\Delta mix_t = \alpha_{40} + \sum_{i=1}^{p=10} \alpha_{41,i} \Delta y_{t-i} + \sum_{i=1}^{p=10} \alpha_{42,i} \Delta r_{t-i} + \sum_{i=1}^{p=10} \alpha_{43,i}\, inf_{\,t-i} + \sum_{i=1}^{p=10} \alpha_{44,i} \Delta mix_{t-i} + \sum_{i=0}^{P=10} \alpha_{45,i} \Delta r^{\#}_{t-i} + \varepsilon_{4,t}$$

where Δr_t, Δmix_t and $\Delta r^{\#}_t$ is the change in policy rate, change in the mix variable and the nonlinear transformation of policy rate proposed by Mork (1989), respectively. In the above model changes in policy rate is assumed to be predetermined with respect to the 'mix' variable. While the official UK recessionary period is from 2008q2 to 2009q2, we choose our sample from Sept. 2007 to the end of 2012. Due to the "Northern Rock crisis" Sept. 2007 is selected as the start date, while the last negative growth in this volatile period occurred in the 4th quarter of 2012. In accordance with similar studies, we use one and two standard deviation expansionary monetary policy shocks. The non-linear impulse responses presented in Figure 7 illustrates large expansionary monetary policy shocks do indeed have larger and more persistence effect on the *mix*, when compared with smaller expansionary shocks. The cumulative impact of large expansionary monetary shock on the *mix* after 36 months is twice as large when compared with the small expansionary monetary shock (4.651 compared to 1.954).

6 | CONCLUSIONS

Capturing heterogeneity in the impact magnitudes of policy changes across regimes is challenging both theoretically and empirically. Questions arise on the theoretical foundation justifying that monetary policy shocks of the same magnitude can exert asymmetric effects on a housing market. The BLC is our proposed theoretical identification mechanism that can create and sustain impact heterogeneity across various regimes. This paper has examined the effect of monetary policy on a state-dependent BLC in the UK housing sector. Employing MSVARs and regime-dependent IRFs we have shown that a similar sized expansionary monetary policy shock in the BLC produces responses which are greater during normal times than during recessionary periods. This may be primarily due to the amalgamated effects of increased risk perception (by the depository institutions), increased cost of liquid funds and the breakdown of the securitization process. Further, we have examined the response of mortgage supply by depository institutions to various degrees of expansionary monetary policy shocks during periods of economic uncertainty and for this 2007–08 financial crisis period is chosen. The main reason is that the policy rate was reduced sharply during this period compared to earlier recessions. Our results suggest sharp cuts in policy rates do indeed stimulate mortgage lending more compared to minor reductions. Policy makers can take advantage of this impact heterogeneity across regimes to maximize on the differential outcomes of an intervention policy in the real economy.

Our findings further suggest policy implications, especially concerning whether central banks should continue with an orthodox policy or peruse a more Leaning Against the Wind (LATW) strategy. While studies by Dokko et al. (2011) and Bean et al. (2010) using counterfactual simulations illustrate a LATW policy is not feasible, as the magnitude of policy rate increase needed to stabilize a housing bubble may eviscerate the rest of the economy; these studies have been criticized for their methodology (see Cobham, 2013). Furthermore, proponents of the LATW strategy argue the main objective of a LATW policy is not to “prick bubbles” but to reduce output and inflation volatility (see Cecchetti et al., 2002; Wadhwani, 2008). Our findings tend to support the need for perusing a LATW policy on two grounds. First, since the magnitude of the monetary transmission channels including the BLC is relatively weak during the recessionary phase, makes it difficult for central bankers to stimulate economic activity, hence the logical conjecture will be to peruse a LATW tilt, reducing the probability of such scenarios in the very first place. Second, we find aggressive expansionary monetary policy do indeed stimulate mortgage lending by depository institutions during recessions, which we recommend should be the ideal strategy during recession. However, the existing low level of policy rate curtails the leverage for the Bank to undertake such policy. In addition, studies have shown that if the policy rate is kept too low for too long it may exacerbate risk taking behaviour among banks, hence jeopardizing future financial stability. Therefore, an optimal strategy will be a LATW tilt with a stringent macro prudential policy.

ACKNOWLEDGEMENTS

We are immensely thankful to two anonymous referees for helpful comments, which provided the backbone for a thoughtful and reliable quantitative narrative of our paper. We remain very grateful to an associate editor and the editor-in-chief, Professor Keith Pilbeam for excellent editorial handling of the paper. We are solely responsible for any errors and omissions.

DATA AVAILABILITY STATEMENT

Data derived from public domain resources: The data that support the findings of this study are available in: (i) https://fred.stlouisfed.org/, (ii) www.cml.org.uk, (iii) https://sites.google.com/view/jingcynthiawu/shadow-rates. All macroeconomic data which includes United Kingdome's 3-month t-bill rate, real gdp, inflation, libor rate and mortgage rate have been collected from Federal Reserve Bank of St. Louis (https://fred.stlouisfed.org/). Mortgage lending data for both depository institutions and non-depository institutions have been collected from BoE's website (MM8 data set) and is also available from Council of Mortgage Lenders (www.cml.org.uk) on request. United Kingdom's shadow policy rate data has been obtained from Jing Cynthia Wu's personal webpage (https://sites.google.com/view/jingcynthiawu/shadow-rates).

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ENDNOTES

[1] Many countries around the world have adopted heterogeneous monetary and fiscal policy approaches to tackle slackening demand and supply in the housing market. UK, for instance, adopted a zero-interest policy and sliced stamp duty to significantly boost housing demand and supply. According to the New York Times, in the face of depressing (housing) demand conditions following COVID-19, the Federal reserve left the target range for federal funds rate unchanged at 0%–0.25% and signalled it would be held at least until 2023 (Data source: https://www.nytimes.com/live/2020/09/16/business/stock-market-today-coronavirus).

[2] Even when the UK monetary policy rate was at historical low.

[3] See Altunbas et al. (2009), Kashyap and Stein (2000), Kishan and Opiela (2000), Van Heuvel (2002).

[4] Huang (2019), in related research, introduces regime switches and permanent changes in housing risk factor on housing returns and provides strong evidence of the role of time-varying exposure of housing excess returns to risk factors.

[5] In our study depository institutions include both banks and building societies.

[6] Conversely, during periods of expansionary monetary policy if depository institutions increase lending more compared to non-depository market-based institutions then the mix variable will increase.

[7] See Iacoviello and Minetti (2008) and Milcheva (2013).

[8] Since both depository and non-depository market based financial institutions depend on the wholesale funds one might argue changes in the external finance premium can be contributed to the balance sheet strength of both type of institutions. However, since market share of non-depository institutions in the United Kingdom is relatively small, their contribution towards the change in the spread is likely to be negligible (Scanlon et al., 2011).

[9] Following Ludvigson (1998), short term interest rate is not included as it indicates monetary policy. Including it would mean changes in the *mix* marginally reflect non-monetary effects. If the BLC is operative, then monetary policy should affect the *mix*, and the *mix* should affect house prices, but there should be no reason to expect that the *mix* affects house prices when some variable that captures monetary policy stance is present in the VAR.

[10] All macro-economic data which includes United Kingdom's 3-month T-bill rate, real gdp, inflation, LIBOR rate and mortgage rate have been collected from Federal Reserve Bank of St. Louis (https://fred.stlouisfed.org/). Mortgage lending data for both depository institutions and non-depository institutions have been collected from BoE's website (MM8 data set), is also available from Council of Mortgage Lenders (www.cml.org.uk) on request. United Kingdom's shadow policy rate data has been obtained from Jing Cynthia Wu's personal webpage (https://sites.google.com/view/jingcynthiawu/shadow-rates).

[11] See Kiyotaki and Moore (1997).

[12] See more in Santoro et al. (2014).

[13] Champagne and Sekkel (2018) show unaccounted breaks in linear VARs can be one of the reasons behind price puzzles.

[14] The Killian and Vigfusson (2011) methodology is explained in detail in the Appendix A.

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How to cite this article: Chowdhury, R. A., Jahan, D., Mishra, T., & Parhi, M. (2022). Monetary policy shock and impact asymmetry in bank lending channel: Evidence from the UK housing sector. *International Journal of Finance & Economics*, 1–20. https://doi.org/10.1002/ijfe.2696

APPENDIX A

Killian and vigfusson (2011) methodology

To examine the responses of variable y to innovations in variable x we estimate the following simultaneous equation model via OLS, equation-by-equation.

$$x_t = a_{10} + \sum_{j=1}^{j=p} a_{11,j} x_{t-j} + \sum_{j=1}^{j=p} a_{12,j} y_{i,t-j} + \epsilon_{1t}$$

$$y_t = a_{20} + \sum_{j=0}^{j=p} a_{21,j} x_{t-j} + \sum_{j=1}^{j=p} a_{22,j} y_{t-j} + \sum_{j=0}^{j=p} g_{21,j} x^{\#}_{t-j} + \epsilon_{2t}$$

Since the corresponding impulse response functions are nonlinear functions of the parameters $g_{21,0}, g_{21,1}, \ldots g_{21,p}$ as well the other parameters of the model the impulse response functions are computed by Monte Carlo integration. In the first step the impulse response functions are calculated to an innovation of the size δ in ϵ_{1t} for a given horizon h conditional on the history Ω^t. The conditional impulse response function, $I_y(h, \delta, \Omega^t)$ is then averaged over all the histories to obtain the unconditional IRF, $I_y(h, \delta)$. In a similar manner for a negative shock of the size $-\delta$, the condition impulse response function, $I_y(h, -\delta, \Omega^t)$ is first computed and then average over all histories to obtain the unconditional impulse response function, $I_y(h, -\delta)$.